Groovy Language Documentation

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Introduction

Groovy…

- is an agile and dynamic language for the Java Virtual Machine
- builds upon the strengths of Java but has additional power features inspired by languages like Python, Ruby and Smalltalk
- makes modern programming features available to Java developers with almost-zero learning curve
- provides the ability to statically type check and statically compile your code for robustness and performance
- supports Domain-Specific Languages and other compact syntax so your code becomes easy to read and maintain
- makes writing shell and build scripts easy with its powerful processing primitives, OO abilities and an Ant DSL
- increases developer productivity by reducing scaffolding code when developing web, GUI, database or console applications
- simplifies testing by supporting unit testing and mocking out-of-the-box
- seamlessly integrates with all existing Java classes and libraries
- compiles straight to Java bytecode so you can use it anywhere you can use Java

Groovy Language Specification

Syntax

This chapter covers the syntax of the Groovy programming language. The grammar of the language derives from the Java grammar, but enhances it with specific constructs for Groovy, and allows certain simplifications.

Comments

Single-line comment

Single-line comments start with // and can be found at any position in the line. The characters following //, until the end of the line, are considered part of the comment.

```
// a standalone single line comment
println "hello" // a comment till the end of the line
```

Multiline comment

A multiline comment starts with /* and can be found at any position in the line. The characters following /* will be considered part of the comment, including new line characters, up to the first */ closing the comment. Multiline comments can thus be put at the end of a statement, or even inside a statement.

```
/* a standalone multiline comment
   spanning two lines */
println "hello" /* a multiline comment starting
                   at the end of a statement */
println 1 /* one */ + 2 /* two */
```

Groovydoc comment

Similarly to multiline comments, Groovydoc comments are multiline, but start with /** and end with */. Lines following the first Groovydoc comment line can optionally start with a star *. Those comments are associated with:

- type definitions (classes, interfaces, enums, annotations),
- fields and properties definitions
- methods definitions

Although the compiler will not complain about Groovydoc comments not being associated with the above language elements, you should prepend those constructs with the comment right before it.

```
/**
```

```
 * A Class description
 */
class Person {
    /** the name of the person */
    String name

    /**
     * Creates a greeting method for a certain person.
     *
     * @param otherPerson the person to greet
     * @return a greeting message
     */
    String greet(String otherPerson) {
       "Hello ${otherPerson}"
    }
}
```

Groovydoc follows the same conventions as Java's own Javadoc. So you'll be able to use the same tags as with Javadoc.

In addition, Groovy supports **Runtime Groovydoc** since 3.0.0, i.e. Groovydoc can be retained at runtime.

NOTE	Runtime Groovydoc is disabled by default. It can be enabled by adding JVM option `-Dgroovy.attach.runtime.groovydoc=true`

The Runtime Groovydoc starts with `/**@` and ends with `*/`, for example:

```
/**@
 * Some class groovydoc for Foo
 */
class Foo {
    /**@
     * Some method groovydoc for bar
     */
    void bar() {
    }
}

assert Foo.class.groovydoc.content.contains('Some class groovydoc for Foo') ①
assert Foo.class.getMethod('bar', new Class[0]).groovydoc.content.contains('Some
method groovydoc for bar') ②
```

① Get the runtime groovydoc for class `Foo`

② Get the runtime groovydoc for method `bar`

Shebang line

Beside the single-line comment, there is a special line comment, often called the *shebang* line understood by UNIX systems which allows scripts to be run directly from the command-line, provided you have installed the Groovy distribution and the `groovy` command is available on the `PATH`.

```
#!/usr/bin/env groovy
println "Hello from the shebang line"
```

NOTE The `#` character must be the first character of the file. Any indentation would yield a compilation error.

Keywords

Groovy has the following reserved keywords:

Table 1. Reserved Keywords

abstract	assert	break	case
catch	class	const	continue
def	default	do	else
enum	extends	final	finally
for	goto	if	implements
import	instanceof	interface	native
new	null	non-sealed	package
public	protected	private	return
static	strictfp	super	switch
synchronized	this	threadsafe	throw
throws	transient	try	while

Of these, `const`, `goto`, `strictfp`, and `threadsafe` are not currently in use.

The reserved keywords can't in general be used for variable, field and method names.

A trick allows methods to be defined having the same name as a keyword by surrounding the name in quotes as shown in the following example:

```
// reserved keywords can be used for method names if quoted
def "abstract"() { true }
// when calling such methods, the name must be qualified using "this."
this.abstract()
```

Using such names might be confusing and is often best to avoid. The trick is primarily intended to enable certain Java integration scenarios and certain DSL scenarios where having "verbs" and "nouns" with the same name as keywords may be desirable.

In addition, Groovy has the following contextual keywords:

Table 2. Contextual Keywords

as	in	permits	record
sealed	trait	var	yields

These words are only keywords in certain contexts and can be more freely used in some places, in particular for variables, fields and method names.

This extra lenience allows using method or variable names that were not keywords in earlier versions of Groovy or are not keywords in Java. Examples are shown here:

```
// contextual keywords can be used for field and variable names
def as = true
assert as

// contextual keywords can be used for method names
def in() { true }
// when calling such methods, the name only needs to be qualified using "this."
in scenarios which would be ambiguous
this.in()
```

Groovy programmers familiar with these contextual keywords may still wish to avoid using those names unless there is a good reason to use such a name.

The restrictions on reserved keywords also apply for the primitive types, the boolean literals and the null literal (all of which are discussed later):

Table 3. Other reserved words

null	true	false	boolean
char	byte	short	int
long	float	double	

While not recommended, the same trick as for reserved keywords can be used:

```
def "null"() { true }  // not recommended; potentially confusing
assert this.null()     // must be qualified
```

Using such words as method names is potentially confusing and is often best to avoid, however, it might be useful for certain kinds of DSLs.

Identifiers

Normal identifiers

Identifiers start with a letter, a dollar or an underscore. They cannot start with a number.

A letter can be in the following ranges:

- 'a' to 'z' (lowercase ascii letter)
- 'A' to 'Z' (uppercase ascii letter)
- '\u00C0' to '\u00D6'
- '\u00D8' to '\u00F6'
- '\u00F8' to '\u00FF'
- '\u0100' to '\uFFFE'

Then following characters can contain letters and numbers.

Here are a few examples of valid identifiers (here, variable names):

```
def name
def item3
def with_underscore
def $dollarStart
```

But the following ones are invalid identifiers:

```
def 3tier
def a+b
def a#b
```

All keywords are also valid identifiers when following a dot:

```
foo.as
foo.assert
foo.break
foo.case
foo.catch
```

Quoted identifiers

Quoted identifiers appear after the dot of a dotted expression. For instance, the `name` part of the `person.name` expression can be quoted with `person."name"` or `person.'name'`. This is particularly interesting when certain identifiers contain illegal characters that are forbidden by the Java Language Specification, but which are allowed by Groovy when quoted. For example, characters like a dash, a space, an exclamation mark, etc.

```
def map = [:]

map."an identifier with a space and double quotes" = "ALLOWED"
map.'with-dash-signs-and-single-quotes' = "ALLOWED"

assert map."an identifier with a space and double quotes" == "ALLOWED"
assert map.'with-dash-signs-and-single-quotes' == "ALLOWED"
```

As we shall see in the following section on strings, Groovy provides different string literals. All kind of strings are actually allowed after the dot:

```
map.'single quote'
map."double quote"
map.'''triple single quote'''
map."""triple double quote"""
map./slashy string/
map.$/dollar slashy string/$
```

There's a difference between plain character strings and Groovy's GStrings (interpolated strings), as in that the latter case, the interpolated values are inserted in the final string for evaluating the whole identifier:

```
def firstname = "Homer"
map."Simpson-${firstname}" = "Homer Simpson"

assert map.'Simpson-Homer' == "Homer Simpson"
```

Strings

Text literals are represented in the form of chain of characters called strings. Groovy lets you instantiate `java.lang.String` objects, as well as GStrings (`groovy.lang.GString`) which are also called *interpolated strings* in other programming languages.

Single-quoted string

Single-quoted strings are a series of characters surrounded by single quotes:

```
'a single-quoted string'
```

NOTE Single-quoted strings are plain `java.lang.String` and don't support interpolation.

String concatenation

All the Groovy strings can be concatenated with the `+` operator:

```
assert 'ab' == 'a' + 'b'
```

Triple-single-quoted string

Triple-single-quoted strings are a series of characters surrounded by triplets of single quotes:

```
'''a triple-single-quoted string'''
```

NOTE Triple-single-quoted strings are plain `java.lang.String` and don't support interpolation.

Triple-single-quoted strings may span multiple lines. The content of the string can cross line boundaries without the need to split the string in several pieces and without concatenation or newline escape characters:

```
def aMultilineString = '''line one
line two
line three'''
```

If your code is indented, for example in the body of the method of a class, your string will contain the whitespace of the indentation. The Groovy Development Kit contains methods for stripping out the indentation with the `String#stripIndent()` method, and with the `String#stripMargin()` method that takes a delimiter character to identify the text to remove from the beginning of a string.

When creating a string as follows:

```
def startingAndEndingWithANewline = '''
line one
line two
line three
'''
```

You will notice that the resulting string contains a newline character as first character. It is possible to strip that character by escaping the newline with a backslash:

```
def strippedFirstNewline = '''\
line one
line two
line three
'''

assert !strippedFirstNewline.startsWith('\n')
```

Escaping special characters

You can escape single quotes with the backslash character to avoid terminating the string literal:

```
'an escaped single quote: \' needs a backslash'
```

And you can escape the escape character itself with a double backslash:

```
'an escaped escape character: \\ needs a double backslash'
```

Some special characters also use the backslash as escape character:

Escape sequence	Character
\b	backspace
\f	formfeed
\n	newline
\r	carriage return
\s	single space
\t	tabulation
\\	backslash
\'	single quote within a single-quoted string (and optional for triple-single-quoted and double-quoted strings)
\"	double quote within a double-quoted string (and optional for triple-double-quoted and single-quoted strings)

We'll see some more escaping details when it comes to other types of strings discussed later.

Unicode escape sequence

For characters that are not present on your keyboard, you can use unicode escape sequences: a backslash, followed by 'u', then 4 hexadecimal digits.

For example, the Euro currency symbol can be represented with:

```
'The Euro currency symbol: \u20AC'
```

Double-quoted string

Double-quoted strings are a series of characters surrounded by double quotes:

```
"a double-quoted string"
```

NOTE Double-quoted strings are plain `java.lang.String` if there's no interpolated expression, but are `groovy.lang.GString` instances if interpolation is present.

NOTE To escape a double quote, you can use the backslash character: "A double quote: \"".

String interpolation

Any Groovy expression can be interpolated in all string literals, apart from single and triple-single-quoted strings. Interpolation is the act of replacing a placeholder in the string with its value upon evaluation of the string. The placeholder expressions are surrounded by `${}`. The curly braces may be omitted for unambiguous dotted expressions, i.e. we can use just a $ prefix in those cases. If the GString is ever passed to a method taking a String, the expression value inside the placeholder is evaluated to its string representation (by calling `toString()` on that expression) and the resulting String is passed to the method.

Here, we have a string with a placeholder referencing a local variable:

```
def name = 'Guillaume' // a plain string
def greeting = "Hello ${name}"

assert greeting.toString() == 'Hello Guillaume'
```

Any Groovy expression is valid, as we can see in this example with an arithmetic expression:

```
def sum = "The sum of 2 and 3 equals ${2 + 3}"
assert sum.toString() == 'The sum of 2 and 3 equals 5'
```

NOTE Not only are expressions allowed in between the `${}` placeholder, but so are statements. However, a statement's value is just `null`. So if several statements are inserted in that placeholder, the last one should somehow return a meaningful value to be inserted. For instance, "The sum of 1 and 2 is equal to ${def a = 1; def b = 2; a + b}" is supported and works as expected but a good practice is usually to stick to simple expressions inside GString placeholders.

In addition to `${}` placeholders, we can also use a lone `$` sign prefixing a dotted expression:

```
def person = [name: 'Guillaume', age: 36]
assert "$person.name is $person.age years old" == 'Guillaume is 36 years old'
```

But only dotted expressions of the form `a.b`, `a.b.c`, etc, are valid. Expressions containing parentheses like method calls, curly braces for closures, dots which aren't part of a property expression or arithmetic operators would be invalid. Given the following variable definition of a number:

```
def number = 3.14
```

The following statement will throw a `groovy.lang.MissingPropertyException` because Groovy believes you're trying to access the `toString` property of that number, which doesn't exist:

```
shouldFail(MissingPropertyException) {
    println "$number.toString()"
}
```

NOTE You can think of `"$number.toString()"` as being interpreted by the parser as `"${number.toString}()"`.

Similarly, if the expression is ambiguous, you need to keep the curly braces:

```
String thing = 'treasure'
assert 'The x-coordinate of the treasure is represented by treasure.x' ==
    "The x-coordinate of the $thing is represented by $thing.x"   // <= Not allowed:
ambiguous!!
assert 'The x-coordinate of the treasure is represented by treasure.x' ==
        "The x-coordinate of the $thing is represented by ${thing}.x"  // <= Curly
braces required
```

If you need to escape the `$` or `${}` placeholders in a GString so they appear as is without interpolation, you just need to use a `\` backslash character to escape the dollar sign:

```
assert '$5' == "\$5"
assert '${name}' == "\${name}"
```

Special case of interpolating closure expressions

So far, we've seen we could interpolate arbitrary expressions inside the `${}` placeholder, but there is a special case and notation for closure expressions. When the placeholder contains an arrow, `${→}`, the expression is actually a closure expression — you can think of it as a closure with a dollar prepended in front of it:

```
def sParameterLessClosure = "1 + 2 == ${-> 3}" ①
assert sParameterLessClosure == '1 + 2 == 3'

def sOneParamClosure = "1 + 2 == ${ w -> w << 3}" ②
assert sOneParamClosure == '1 + 2 == 3'
```

① The closure is a parameterless closure which doesn't take arguments.

② Here, the closure takes a single `java.io.StringWriter` argument, to which you can append content with the `<<` leftShift operator. In either case, both placeholders are embedded closures.

In appearance, it looks like a more verbose way of defining expressions to be interpolated, but closures have an interesting advantage over mere expressions: lazy evaluation.

Let's consider the following sample:

```
def number = 1 ①
def eagerGString = "value == ${number}"
def lazyGString = "value == ${ -> number }"

assert eagerGString == "value == 1" ②
assert lazyGString ==  "value == 1" ③

number = 2 ④
assert eagerGString == "value == 1" ⑤
assert lazyGString ==  "value == 2" ⑥
```

① We define a `number` variable containing `1` that we then interpolate within two GStrings, as an expression in `eagerGString` and as a closure in `lazyGString`.

② We expect the resulting string to contain the same string value of 1 for `eagerGString`.

③ Similarly for `lazyGString`

④ Then we change the value of the variable to a new number

⑤ With a plain interpolated expression, the value was actually bound at the time of creation of the GString.

⑥ But with a closure expression, the closure is called upon each coercion of the GString into String, resulting in an updated string containing the new number value.

NOTE An embedded closure expression taking more than one parameter will generate an exception at runtime. Only closures with zero or one parameter are allowed.

Interoperability with Java

When a method (whether implemented in Java or Groovy) expects a `java.lang.String`, but we pass a `groovy.lang.GString` instance, the `toString()` method of the GString is automatically and transparently called.

```
String takeString(String message) {         ④
    assert message instanceof String        ⑤
    return message
}

def message = "The message is ${'hello'}"   ①
assert message instanceof GString           ②

def result = takeString(message)            ③
assert result instanceof String
assert result == 'The message is hello'
```

① We create a GString variable

② We double-check it's an instance of the GString

③ We then pass that GString to a method taking a String as parameter

④ The signature of the `takeString()` method explicitly says its sole parameter is a String

⑤ We also verify that the parameter is indeed a String and not a GString.

GString and String hashCodes

Although interpolated strings can be used in lieu of plain Java strings, they differ with strings in a particular way: their hashCodes are different. Plain Java strings are immutable, whereas the resulting String representation of a GString can vary, depending on its interpolated values. Even for the same resulting string, GStrings and Strings don't have the same hashCode.

```
assert "one: ${1}".hashCode() != "one: 1".hashCode()
```

GString and Strings having different hashCode values, using GString as Map keys should be avoided, especially if we try to retrieve an associated value with a String instead of a GString.

```
def key = "a"
def m = ["${key}": "letter ${key}"]     ①

assert m["a"] == null                   ②
```

① The map is created with an initial pair whose key is a GString

② When we try to fetch the value with a String key, we will not find it, as Strings and GString have different hashCode values

Triple-double-quoted string

Triple-double-quoted strings behave like double-quoted strings, with the addition that they are multiline, like the triple-single-quoted strings.

```
def name = 'Groovy'
def template = """
    Dear Mr ${name},

    You're the winner of the lottery!

    Yours sincerly,

    Dave
"""

assert template.toString().contains('Groovy')
```

NOTE Neither double quotes nor single quotes need be escaped in triple-double-quoted strings.

Slashy string

Beyond the usual quoted strings, Groovy offers slashy strings, which use / as the opening and closing delimiter. Slashy strings are particularly useful for defining regular expressions and patterns, as there is no need to escape backslashes.

Example of a slashy string:

```
def fooPattern = /.*foo.*/
assert fooPattern == '.*foo.*'
```

Only forward slashes need to be escaped with a backslash:

```
def escapeSlash = /The character \/ is a forward slash/
assert escapeSlash == 'The character / is a forward slash'
```

Slashy strings are multiline:

```
def multilineSlashy = /one
    two
    three/

assert multilineSlashy.contains('\n')
```

Slashy strings can be thought of as just another way to define a GString but with different escaping rules. They hence support interpolation:

```
def color = 'blue'
def interpolatedSlashy = /a ${color} car/

assert interpolatedSlashy == 'a blue car'
```

Special cases

An empty slashy string cannot be represented with a double forward slash, as it's understood by the Groovy parser as a line comment. That's why the following assert would actually not compile as it would look like a non-terminated statement:

```
assert '' == //
```

As slashy strings were mostly designed to make regexp easier so a few things that are errors in

GStrings like `$()` or `$5` will work with slashy strings.

Remember that escaping backslashes is not required. An alternative way of thinking of this is that in fact escaping is not supported. The slashy string `/\t/` won't contain a tab but instead a backslash followed by the character 't'. Escaping is only allowed for the slash character, i.e. `/\/folder/` will be a slashy string containing `'/folder'`. A consequence of slash escaping is that a slashy string can't end with a backslash. Otherwise that will escape the slashy string terminator. You can instead use a special trick, `/ends with slash ${'\\'}/`. But best just avoid using a slashy string in such a case.

Dollar slashy string

Dollar slashy strings are multiline GStrings delimited with an opening `$/` and a closing `/$`. The escaping character is the dollar sign, and it can escape another dollar, or a forward slash. Escaping for the dollar and forward slash characters is only needed where conflicts arise with the special use of those characters. The characters `$foo` would normally indicate a GString placeholder, so those four characters can be entered into a dollar slashy string by escaping the dollar, i.e. `$$foo`. Similarly, you will need to escape a dollar slashy closing delimiter if you want it to appear in your string.

Here are a few examples:

```
def name = "Guillaume"
def date = "April, 1st"

def dollarSlashy = $/
    Hello $name,
    today we're ${date}.

    $ dollar sign
    $$ escaped dollar sign
    \ backslash
    / forward slash
    $/ escaped forward slash
    $$$/ escaped opening dollar slashy
    $/$$ escaped closing dollar slashy
/$

assert [
    'Guillaume',
    'April, 1st',
    '$ dollar sign',
    '$ escaped dollar sign',
    '\\ backslash',
    '/ forward slash',
    '/ escaped forward slash',
    '$/ escaped opening dollar slashy',
    '/$ escaped closing dollar slashy'
].every { dollarSlashy.contains(it) }
```

It was created to overcome some of the limitations of the slashy string escaping rules. Use it when its escaping rules suit your string contents (typically if it has some slashes you don't want to escape).

String summary table

String name	String syntax	Interpolated	Multiline	Escape character
Single-quoted	`'…'`	[check empty]	[check empty]	`\`
Triple-single-quoted	`'''…'''`	[check empty]	[check]	`\`
Double-quoted	`"…"`	[check]	[check empty]	`\`
Triple-double-quoted	`"""…"""`	[check]	[check]	`\`
Slashy	`/…/`	[check]	[check]	`\`
Dollar slashy	`$/…/$`	[check]	[check]	`$`

Characters

Unlike Java, Groovy doesn't have an explicit character literal. However, you can be explicit about making a Groovy string an actual character, by three different means:

```
char c1 = 'A' ①
assert c1 instanceof Character

def c2 = 'B' as char ②
assert c2 instanceof Character

def c3 = (char)'C' ③
assert c3 instanceof Character
```

① by being explicit when declaring a variable holding the character by specifying the `char` type

② by using type coercion with the `as` operator

③ by using a cast to char operation

NOTE	The first option *1* is interesting when the character is held in a variable, while the other two (*2* and *3*) are more interesting when a char value must be passed as argument of a method call.

Numbers

Groovy supports different kinds of integral literals and decimal literals, backed by the usual `Number` types of Java.

Integral literals

The integral literal types are the same as in Java:

- byte
- char
- short
- int
- long
- java.math.BigInteger

You can create integral numbers of those types with the following declarations:

```
// primitive types
byte  b = 1
char  c = 2
short s = 3
int   i = 4
long  l = 5

// infinite precision
BigInteger bi =  6
```

If you use optional typing by using the def keyword, the type of the integral number will vary: it'll adapt to the capacity of the type that can hold that number.

For positive numbers:

```
def a = 1
assert a instanceof Integer

// Integer.MAX_VALUE
def b = 2147483647
assert b instanceof Integer

// Integer.MAX_VALUE + 1
def c = 2147483648
assert c instanceof Long

// Long.MAX_VALUE
def d = 9223372036854775807
assert d instanceof Long

// Long.MAX_VALUE + 1
def e = 9223372036854775808
assert e instanceof BigInteger
```

As well as for negative numbers:

```
def na = -1
```

```
assert na instanceof Integer

// Integer.MIN_VALUE
def nb = -2147483648
assert nb instanceof Integer

// Integer.MIN_VALUE - 1
def nc = -2147483649
assert nc instanceof Long

// Long.MIN_VALUE
def nd = -9223372036854775808
assert nd instanceof Long

// Long.MIN_VALUE - 1
def ne = -9223372036854775809
assert ne instanceof BigInteger
```

Alternative non-base 10 representations

Numbers can also be represented in binary, octal, hexadecimal and decimal bases.

Binary literal

Binary numbers start with a `0b` prefix:

```
int xInt = 0b10101111
assert xInt == 175

short xShort = 0b11001001
assert xShort == 201 as short

byte xByte = 0b11
assert xByte == 3 as byte

long xLong = 0b101101101101
assert xLong == 2925l

BigInteger xBigInteger = 0b111100100001
assert xBigInteger == 3873g

int xNegativeInt = -0b10101111
assert xNegativeInt == -175
```

Octal literal

Octal numbers are specified in the typical format of `0` followed by octal digits.

```
int xInt = 077
```

```
assert xInt == 63

short xShort = 011
assert xShort == 9 as short

byte xByte = 032
assert xByte == 26 as byte

long xLong = 0246
assert xLong == 166l

BigInteger xBigInteger = 01111
assert xBigInteger == 585g

int xNegativeInt = -077
assert xNegativeInt == -63
```

Hexadecimal literal

Hexadecimal numbers are specified in the typical format of `0x` followed by hex digits.

```
int xInt = 0x77
assert xInt == 119

short xShort = 0xaa
assert xShort == 170 as short

byte xByte = 0x3a
assert xByte == 58 as byte

long xLong = 0xffff
assert xLong == 65535l

BigInteger xBigInteger = 0xaaaa
assert xBigInteger == 43690g

Double xDouble = new Double('0x1.0p0')
assert xDouble == 1.0d

int xNegativeInt = -0x77
assert xNegativeInt == -119
```

Decimal literals

The decimal literal types are the same as in Java:

- `float`
- `double`

- `java.math.BigDecimal`

You can create decimal numbers of those types with the following declarations:

```
// primitive types
float  f = 1.234
double d = 2.345

// infinite precision
BigDecimal bd =  3.456
```

Decimals can use exponents, with the `e` or `E` exponent letter, followed by an optional sign, and an integral number representing the exponent:

```
assert 1e3  ==  1_000.0
assert 2E4  == 20_000.0
assert 3e+1 ==     30.0
assert 4E-2 ==      0.04
assert 5e-1 ==      0.5
```

Conveniently for exact decimal number calculations, Groovy chooses `java.math.BigDecimal` as its decimal number type. In addition, both `float` and `double` are supported, but require an explicit type declaration, type coercion or suffix. Even if `BigDecimal` is the default for decimal numbers, such literals are accepted in methods or closures taking `float` or `double` as parameter types.

NOTE	Decimal numbers can't be represented using a binary, octal or hexadecimal representation.

Underscore in literals

When writing long literal numbers, it's harder on the eye to figure out how some numbers are grouped together, for example with groups of thousands, of words, etc. By allowing you to place underscore in number literals, it's easier to spot those groups:

```
long creditCardNumber = 1234_5678_9012_3456L
long socialSecurityNumbers = 999_99_9999L
double monetaryAmount = 12_345_132.12
long hexBytes = 0xFF_EC_DE_5E
long hexWords = 0xFFEC_DE5E
long maxLong = 0x7fff_ffff_ffff_ffffL
long alsoMaxLong = 9_223_372_036_854_775_807L
long bytes = 0b11010010_01101001_10010100_10010010
```

Number type suffixes

We can force a number (including binary, octals and hexadecimals) to have a specific type by giving a suffix (see table below), either uppercase or lowercase.

Type	Suffix
BigInteger	`G` or `g`
Long	`L` or `l`
Integer	`I` or `i`
BigDecimal	`G` or `g`
Double	`D` or `d`
Float	`F` or `f`

Examples:

```
assert 42I == Integer.valueOf('42')
assert 42i == Integer.valueOf('42') // lowercase i more readable
assert 123L == Long.valueOf("123") // uppercase L more readable
assert 2147483648 == Long.valueOf('2147483648') // Long type used, value too large for
an Integer
assert 456G == new BigInteger('456')
assert 456g == new BigInteger('456')
assert 123.45 == new BigDecimal('123.45') // default BigDecimal type used
assert .321 == new BigDecimal('.321')
assert 1.200065D == Double.valueOf('1.200065')
assert 1.234F == Float.valueOf('1.234')
assert 1.23E23D == Double.valueOf('1.23E23')
assert 0b1111L.class == Long // binary
assert 0xFFi.class == Integer // hexadecimal
assert 034G.class == BigInteger // octal
```

Math operations

Although operators are covered in more detail elsewhere, it's important to discuss the behavior of math operations and what their resulting types are.

Division and power binary operations aside (covered below),

- binary operations between `byte`, `char`, `short` and `int` result in `int`
- binary operations involving `long` with `byte`, `char`, `short` and `int` result in `long`
- binary operations involving `BigInteger` and any other integral type result in `BigInteger`
- binary operations involving `BigDecimal` with `byte`, `char`, `short`, `int` and `BigInteger` result in `BigDecimal`
- binary operations between `float`, `double` and `BigDecimal` result in `double`
- binary operations between two `BigDecimal` result in `BigDecimal`

The following table summarizes those rules:

	byte	char	short	int	long	BigInteger	float	double	BigDecimal
byte	int	int	int	int	long	BigInteger	double	double	BigDecimal
char		int	int	int	long	BigInteger	double	double	BigDecimal
short			int	int	long	BigInteger	double	double	BigDecimal
int				int	long	BigInteger	double	double	BigDecimal
long					long	BigInteger	double	double	BigDecimal
BigInteger						BigInteger	double	double	BigDecimal
float							double	double	double
double								double	double
BigDecimal									BigDecimal

NOTE Thanks to Groovy's operator overloading, the usual arithmetic operators work as well with `BigInteger` and `BigDecimal`, unlike in Java where you have to use explicit methods for operating on those numbers.

The case of the division operator

The division operators `/` (and `/=` for division and assignment) produce a `double` result if either operand is a `float` or `double`, and a `BigDecimal` result otherwise (when both operands are any combination of an integral type `short`, `char`, `byte`, `int`, `long`, `BigInteger` or `BigDecimal`).

`BigDecimal` division is performed with the `divide()` method if the division is exact (i.e. yielding a result that can be represented within the bounds of the same precision and scale), or using a `MathContext` with a precision of the maximum of the two operands' precision plus an extra precision of 10, and a scale of the maximum of 10 and the maximum of the operands' scale.

NOTE For integer division like in Java, you should use the `intdiv()` method, as Groovy doesn't provide a dedicated integer division operator symbol.

The case of the power operator

The power operation is represented by the `**` operator, with two parameters: the base and the exponent. The result of the power operation depends on its operands, and the result of the operation (in particular if the result can be represented as an integral value).

The following rules are used by Groovy's power operation to determine the resulting type:

- If the exponent is a decimal value
    - if the result can be represented as an `Integer`, then return an `Integer`
    - else if the result can be represented as a `Long`, then return a `Long`
    - otherwise return a `Double`
- If the exponent is an integral value
    - if the exponent is strictly negative, then return an `Integer`, `Long` or `Double` if the result value fits in that type
    - if the exponent is positive or zero
        - if the base is a `BigDecimal`, then return a `BigDecimal` result value
        - if the base is a `BigInteger`, then return a `BigInteger` result value
        - if the base is an `Integer`, then return an `Integer` if the result value fits in it, otherwise a `BigInteger`
        - if the base is a `Long`, then return a `Long` if the result value fits in it, otherwise a `BigInteger`

We can illustrate those rules with a few examples:

```
// base and exponent are ints and the result can be represented by an Integer
assert    2    **   3    instanceof Integer    //  8
assert   10    **   9    instanceof Integer    //  1_000_000_000

// the base is a long, so fit the result in a Long
// (although it could have fit in an Integer)
assert    5L   **   2    instanceof Long       //  25

// the result can't be represented as an Integer or Long, so return a BigInteger
assert  100    **  10    instanceof BigInteger //  10e20
assert 1234    ** 123    instanceof BigInteger //  170515806212727042875...

// the base is a BigDecimal and the exponent a negative int
// but the result can be represented as an Integer
assert    0.5  **  -2    instanceof Integer    //  4

// the base is an int, and the exponent a negative float
// but again, the result can be represented as an Integer
assert    1    **  -0.3f instanceof Integer    //  1

// the base is an int, and the exponent a negative int
// but the result will be calculated as a Double
// (both base and exponent are actually converted to doubles)
assert   10    **  -1    instanceof Double     //  0.1

// the base is a BigDecimal, and the exponent is an int, so return a BigDecimal
assert    1.2  **  10    instanceof BigDecimal //  6.1917364224

// the base is a float or double, and the exponent is an int
// but the result can only be represented as a Double value
```

```
assert    3.4f **   5    instanceof Double     //  454.35430372146965
assert    5.6d **   2    instanceof Double     //  31.359999999999996

// the exponent is a decimal value
// and the result can only be represented as a Double value
assert    7.8  **   1.9  instanceof Double     //  49.542708423868476
assert    2    **   0.1f instanceof Double     //  1.0717734636432956
```

Booleans

Boolean is a special data type that is used to represent truth values: `true` and `false`. Use this data type for simple flags that track true/false conditions.

Boolean values can be stored in variables, assigned into fields, just like any other data type:

```
def myBooleanVariable = true
boolean untypedBooleanVar = false
booleanField = true
```

`true` and `false` are the only two primitive boolean values. But more complex boolean expressions can be represented using logical operators.

In addition, Groovy has special rules (often referred to as *Groovy Truth*) for coercing non-boolean objects to a boolean value.

Lists

Groovy uses a comma-separated list of values, surrounded by square brackets, to denote lists. Groovy lists are plain JDK `java.util.List`, as Groovy doesn't define its own collection classes. The concrete list implementation used when defining list literals are `java.util.ArrayList` by default, unless you decide to specify otherwise, as we shall see later on.

```
def numbers = [1, 2, 3]         ①

assert numbers instanceof List  ②
assert numbers.size() == 3      ③
```

① We define a list numbers delimited by commas and surrounded by square brackets, and we assign that list into a variable

② The list is an instance of Java's `java.util.List` interface

③ The size of the list can be queried with the `size()` method, and shows our list contains 3 elements

In the above example, we used a homogeneous list, but you can also create lists containing values of heterogeneous types:

```
def heterogeneous = [1, "a", true]  ①
```

① Our list here contains a number, a string and a boolean value

We mentioned that by default, list literals are actually instances of `java.util.ArrayList`, but it is possible to use a different backing type for our lists, thanks to using type coercion with the `as` operator, or with explicit type declaration for your variables:

```
def arrayList = [1, 2, 3]
assert arrayList instanceof java.util.ArrayList

def linkedList = [2, 3, 4] as LinkedList    ①
assert linkedList instanceof java.util.LinkedList

LinkedList otherLinked = [3, 4, 5]          ②
assert otherLinked instanceof java.util.LinkedList
```

① We use coercion with the `as` operator to explicitly request a `java.util.LinkedList` implementation

② We can say that the variable holding the list literal is of type `java.util.LinkedList`

You can access elements of the list with the `[]` subscript operator (both for reading and setting values) with positive indices or negative indices to access elements from the end of the list, as well as with ranges, and use the `<<` leftShift operator to append elements to a list:

```
def letters = ['a', 'b', 'c', 'd']

assert letters[0] == 'a'     ①
assert letters[1] == 'b'

assert letters[-1] == 'd'    ②
assert letters[-2] == 'c'

letters[2] = 'C'             ③
assert letters[2] == 'C'

letters << 'e'               ④
assert letters[ 4] == 'e'
assert letters[-1] == 'e'

assert letters[1, 3] == ['b', 'd']         ⑤
assert letters[2..4] == ['C', 'd', 'e']    ⑥
```

① Access the first element of the list (zero-based counting)

② Access the last element of the list with a negative index: -1 is the first element from the end of the list

③ Use an assignment to set a new value for the third element of the list

④ Use the << leftShift operator to append an element at the end of the list

⑤ Access two elements at once, returning a new list containing those two elements

⑥ Use a range to access a range of values from the list, from a start to an end element position

As lists can be heterogeneous in nature, lists can also contain other lists to create multidimensional lists:

```
def multi = [[0, 1], [2, 3]]     ①
assert multi[1][0] == 2          ②
```

① Define a list of numbers

② Access the second element of the top-most list, and the first element of the inner list

Arrays

Groovy reuses the list notation for arrays, but to make such literals arrays, you need to explicitly define the type of the array through coercion or type declaration.

```
String[] arrStr = ['Ananas', 'Banana', 'Kiwi']  ①

assert arrStr instanceof String[]    ②
assert !(arrStr instanceof List)

def numArr = [1, 2, 3] as int[]      ③

assert numArr instanceof int[]       ④
assert numArr.size() == 3
```

① Define an array of strings using explicit variable type declaration

② Assert that we created an array of strings

③ Create an array of ints with the as operator

④ Assert that we created an array of primitive ints

You can also create multi-dimensional arrays:

```
def matrix3 = new Integer[3][3]         ①
assert matrix3.size() == 3

Integer[][] matrix2                     ②
matrix2 = [[1, 2], [3, 4]]
assert matrix2 instanceof Integer[][]
```

① You can define the bounds of a new array

② Or declare an array without specifying its bounds

Access to elements of an array follows the same notation as for lists:

```
String[] names = ['Cédric', 'Guillaume', 'Jochen', 'Paul']
assert names[0] == 'Cédric'     ①

names[2] = 'Blackdrag'          ②
assert names[2] == 'Blackdrag'
```

① Retrieve the first element of the array

② Set the value of the third element of the array to a new value

Java-style array initialization

Groovy has always supported literal list/array definitions using square brackets and has avoided Java-style curly braces so as not to conflict with closure definitions. In the case where the curly braces come immediately after an array type declaration however, there is no ambiguity with closure definitions, so Groovy 3 and above support that variant of the Java array initialization expression.

Examples:

```
def primes = new int[] {2, 3, 5, 7, 11}
assert primes.size() == 5 && primes.sum() == 28
assert primes.class.name == '[I'

def pets = new String[] {'cat', 'dog'}
assert pets.size() == 2 && pets.sum() == 'catdog'
assert pets.class.name == '[Ljava.lang.String;'

// traditional Groovy alternative still supported
String[] groovyBooks = [ 'Groovy in Action', 'Making Java Groovy' ]
assert groovyBooks.every{ it.contains('Groovy') }
```

Maps

Sometimes called dictionaries or associative arrays in other languages, Groovy features maps. Maps associate keys to values, separating keys and values with colons, and each key/value pairs with commas, and the whole keys and values surrounded by square brackets.

```
def colors = [red: '#FF0000', green: '#00FF00', blue: '#0000FF']   ①

assert colors['red'] == '#FF0000'    ②
assert colors.green  == '#00FF00'    ③

colors['pink'] = '#FF00FF'           ④
colors.yellow  = '#FFFF00'           ⑤
```

```
assert colors.pink == '#FF00FF'
assert colors['yellow'] == '#FFFF00'

assert colors instanceof java.util.LinkedHashMap
```

① We define a map of string color names, associated with their hexadecimal-coded html colors

② We use the subscript notation to check the content associated with the `red` key

③ We can also use the property notation to assert the color green's hexadecimal representation

④ Similarly, we can use the subscript notation to add a new key/value pair

⑤ Or the property notation, to add the `yellow` color

NOTE When using names for the keys, we actually define string keys in the map.

NOTE Groovy creates maps that are actually instances of `java.util.LinkedHashMap`.

If you try to access a key which is not present in the map:

```
assert colors.unknown == null

def emptyMap = [:]
assert emptyMap.anyKey == null
```

You will retrieve a `null` result.

In the examples above, we used string keys, but you can also use values of other types as keys:

```
def numbers = [1: 'one', 2: 'two']

assert numbers[1] == 'one'
```

Here, we used numbers as keys, as numbers can unambiguously be recognized as numbers, so Groovy will not create a string key like in our previous examples. But consider the case you want to pass a variable in lieu of the key, to have the value of that variable become the key:

```
def key = 'name'
def person = [key: 'Guillaume']      ①

assert !person.containsKey('name')   ②
assert person.containsKey('key')     ③
```

① The `key` associated with the `'Guillaume'` name will actually be the `"key"` string, not the value associated with the `key` variable

② The map doesn't contain the `'name'` key

③ Instead, the map contains a `'key'` key

NOTE	You can also pass quoted strings as well as keys: ["name": "Guillaume"]. This is mandatory if your key string isn't a valid identifier, for example if you wanted to create a string key containing a dash like in: ["street-name": "Main street"].

When you need to pass variable values as keys in your map definitions, you must surround the variable or expression with parentheses:

```
person = [(key): 'Guillaume']        ①

assert person.containsKey('name')    ②
assert !person.containsKey('key')    ③
```

① This time, we surround the `key` variable with parentheses, to instruct the parser we are passing a variable rather than defining a string key

② The map does contain the `name` key

③ But the map doesn't contain the `key` key as before

Operators

This chapter covers the operators of the Groovy programming language.

Arithmetic operators

Groovy supports the usual familiar arithmetic operators you find in mathematics and in other programming languages like Java. All the Java arithmetic operators are supported. Let's go through them in the following examples.

Normal arithmetic operators

The following binary arithmetic operators are available in Groovy:

Operator	Purpose	Remarks
`+`	addition	
`-`	subtraction	
`*`	multiplication	
`/`	division	Use `intdiv()` for integer division, and see the section about integer division for more information on the return type of the division.
`%`	remainder	

Operator	Purpose	Remarks
**	power	See the section about the power operation for more information on the return type of the operation.

Here are a few examples of usage of those operators:

```
assert  1  + 2 == 3
assert  4  - 3 == 1
assert  3  * 5 == 15
assert  3  / 2 == 1.5
assert 10  % 3 == 1
assert  2 ** 3 == 8
```

Unary operators

The + and - operators are also available as unary operators:

```
assert +3 == 3
assert -4 == 0 - 4

assert -(-1) == 1  ①
```

① Note the usage of parentheses to surround an expression to apply the unary minus to that surrounded expression.

In terms of unary arithmetics operators, the ++ (increment) and -- (decrement) operators are available, both in prefix and postfix notation:

```
def a = 2
def b = a++ * 3             ①

assert a == 3 && b == 6

def c = 3
def d = c-- * 2             ②

assert c == 2 && d == 6

def e = 1
def f = ++e + 3             ③

assert e == 2 && f == 5

def g = 4
def h = --g + 1             ④
```

```
assert g == 3 && h == 4
```

① The postfix increment will increment a after the expression has been evaluated and assigned into b

② The postfix decrement will decrement c after the expression has been evaluated and assigned into d

③ The prefix increment will increment e before the expression is evaluated and assigned into f

④ The prefix decrement will decrement g before the expression is evaluated and assigned into h

For the unary not operator on Booleans, see Conditional operators.

Assignment arithmetic operators

The binary arithmetic operators we have seen above are also available in an assignment form:

- +=
- -=
- *=
- /=
- %=
- **=

Let's see them in action:

```
def a = 4
a += 3

assert a == 7

def b = 5
b -= 3

assert b == 2

def c = 5
c *= 3

assert c == 15

def d = 10
d /= 2

assert d == 5

def e = 10
e %= 3
```

```
assert e == 1

def f = 3
f **= 2

assert f == 9
```

Relational operators

Relational operators allow comparisons between objects, to know if two objects are the same or different, or if one is greater than, less than, or equal to the other.

The following operators are available:

Operator	Purpose
`==`	equal
`!=`	different
`<`	less than
`<=`	less than or equal
`>`	greater than
`>=`	greater than or equal
`===`	identical (Since Groovy 3.0.0)
`!==`	not identical (Since Groovy 3.0.0)

Here are some examples of simple number comparisons using these operators:

```
assert 1 + 2 == 3
assert 3 != 4

assert -2 < 3
assert 2 <= 2
assert 3 <= 4

assert 5 > 1
assert 5 >= -2
```

Both `===` and `!==` are supported which are the same as calling the `is()` method, and negating a call to the `is()` method respectively.

```
import groovy.transform.EqualsAndHashCode

@EqualsAndHashCode
class Creature { String type }
```

```
def cat = new Creature(type: 'cat')
def copyCat = cat
def lion = new Creature(type: 'cat')

assert cat.equals(lion) // Java logical equality
assert cat == lion      // Groovy shorthand operator

assert cat.is(copyCat)  // Groovy identity
assert cat === copyCat  // operator shorthand
assert cat !== lion     // negated operator shorthand
```

Logical operators

Groovy offers three logical operators for boolean expressions:

- `&&`: logical "and"
- `||`: logical "or"
- `!`: logical "not"

Let's illustrate them with the following examples:

```
assert !false           ①
assert true && true     ②
assert true || false    ③
```

① "not" false is true

② true "and" true is true

③ true "or" false is true

Precedence

The logical "not" has a higher priority than the logical "and".

```
assert (!false && false) == false   ①
```

① Here, the assertion is true (as the expression in parentheses is false), because "not" has a higher precedence than "and", so it only applies to the first "false" term; otherwise, it would have applied to the result of the "and", turned it into true, and the assertion would have failed

The logical "and" has a higher priority than the logical "or".

```
assert true || true && false        ①
```

① Here, the assertion is true, because "and" has a higher precedence than "or", therefore the "or" is executed last and returns true, having one true argument; otherwise, the "and" would have executed last and returned false, having one false argument, and the assertion would have failed

Short-circuiting

The logical || operator supports short-circuiting: if the left operand is true, it knows that the result will be true in any case, so it won't evaluate the right operand. The right operand will be evaluated only if the left operand is false.

Likewise for the logical && operator: if the left operand is false, it knows that the result will be false in any case, so it won't evaluate the right operand. The right operand will be evaluated only if the left operand is true.

```
boolean checkIfCalled() {   ①
    called = true
}

called = false
true || checkIfCalled()
assert !called              ②

called = false
false || checkIfCalled()
assert called               ③

called = false
false && checkIfCalled()
assert !called              ④

called = false
true && checkIfCalled()
assert called               ⑤
```

① We create a function that sets the called flag to true whenever it's called

② In the first case, after resetting the called flag, we confirm that if the left operand to || is true, the function is not called, as || short-circuits the evaluation of the right operand

③ In the second case, the left operand is false and so the function is called, as indicated by the fact our flag is now true

④ Likewise for &&, we confirm that the function is not called with a false left operand

⑤ But the function is called with a true left operand

Bitwise and bit shift operators

Bitwise operators

Groovy offers four bitwise operators:

- &: bitwise "and"

- |: bitwise "or"
- ^: bitwise "xor" (exclusive "or")
- ~: bitwise negation

Bitwise operators can be applied on arguments which are of type byte, short, int, long, or BigInteger. If one of the arguments is a BigInteger, the result will be of type BigInteger; otherwise, if one of the arguments is a long, the result will be of type long; otherwise, the result will be of type int:

```
int a = 0b00101010
assert a == 42
int b = 0b00001000
assert b == 8
assert (a & a) == a                  ①
assert (a & b) == b                  ②
assert (a | a) == a                  ③
assert (a | b) == a                  ④

int mask = 0b11111111                ⑤
assert ((a ^ a) & mask) == 0b00000000   ⑥
assert ((a ^ b) & mask) == 0b00100010   ⑦
assert ((~a) & mask)    == 0b11010101   ⑧
```

① bitwise and

② bitwise and returns common bits

③ bitwise or

④ bitwise or returns all '1' bits

⑤ setting a mask to check only the last 8 bits

⑥ bitwise exclusive or on self returns 0

⑦ bitwise exclusive or

⑧ bitwise negation

It's worth noting that the internal representation of primitive types follow the Java Language Specification. In particular, primitive types are signed, meaning that for a bitwise negation, it is always good to use a mask to retrieve only the necessary bits.

In Groovy, bitwise operators are overloadable, meaning that you can define the behavior of those operators for any kind of object.

Bit shift operators

Groovy offers three bit shift operators:

- <<: left shift
- >>: right shift

* `>>>`: right shift unsigned

All three operators are applicable where the left argument is of type `byte`, `short`, `int`, or `long`. The first two operators can also be applied where the left argument is of type `BigInteger`. If the left argument is a `BigInteger`, the result will be of type `BigInteger`; otherwise, if the left argument is a `long`, the result will be of type `long`; otherwise, the result will be of type `int`:

```
assert 12.equals(3 << 2)          ①
assert 24L.equals(3L << 3)        ①
assert 48G.equals(3G << 4)        ①

assert 4095 == -200 >>> 20
assert -1 == -200 >> 20
assert 2G == 5G >> 1
assert -3G == -5G >> 1
```

① `equals` method used instead of `==` to confirm result type

In Groovy, bit shift operators are overloadable, meaning that you can define the behavior of those operators for any kind of object.

Conditional operators

Not operator

The "not" operator is represented with an exclamation mark (`!`) and inverts the result of the underlying boolean expression. In particular, it is possible to combine the `not` operator with the Groovy truth:

```
assert (!true)    == false                      ①
assert (!'foo')   == false                      ②
assert (!'')      == true                       ③
```

① the negation of `true` is `false`

② 'foo' is a non-empty string, evaluating to `true`, so negation returns `false`

③ '' is an empty string, evaluating to `false`, so negation returns `true`

Ternary operator

The ternary operator is a shortcut expression that is equivalent to an if/else branch assigning some value to a variable.

Instead of:

```
if (string!=null && string.length()>0) {
    result = 'Found'
} else {
    result = 'Not found'
```

```
}
```

You can write:

```
result = (string!=null && string.length()>0) ? 'Found' : 'Not found'
```

The ternary operator is also compatible with the Groovy truth, so you can make it even simpler:

```
result = string ? 'Found' : 'Not found'
```

Elvis operator

The "Elvis operator" is a shortening of the ternary operator. One instance of where this is handy is for returning a 'sensible default' value if an expression resolves to `false`-ish (as in Groovy truth). A simple example might look like this:

```
displayName = user.name ? user.name : 'Anonymous'   ①
displayName = user.name ?: 'Anonymous'              ②
```

① with the ternary operator, you have to repeat the value you want to assign

② with the Elvis operator, the value, which is tested, is used if it is not `false`-ish

Usage of the Elvis operator reduces the verbosity of your code and reduces the risks of errors in case of refactorings, by removing the need to duplicate the expression which is tested in both the condition and the positive return value.

Elvis assignment operator

Groovy 3.0.0 introduces the Elvis operator, for example:

```
import groovy.transform.ToString

@ToString(includePackage = false)
class Element {
    String name
    int atomicNumber
}

def he = new Element(name: 'Helium')
he.with {
    name = name ?: 'Hydrogen'   // existing Elvis operator
    atomicNumber ?= 2           // new Elvis assignment shorthand
}
assert he.toString() == 'Element(Helium, 2)'
```

Object operators

Safe navigation operator

The Safe Navigation operator is used to avoid a `NullPointerException`. Typically when you have a reference to an object you might need to verify that it is not `null` before accessing methods or properties of the object. To avoid this, the safe navigation operator will simply return `null` instead of throwing an exception, like so:

```
def person = Person.find { it.id == 123 }     ①
def name = person?.name                        ②
assert name == null                            ③
```

① `find` will return a `null` instance

② use of the null-safe operator prevents from a `NullPointerException`

③ result is `null`

Direct field access operator

Normally in Groovy, when you write code like this:

```
class User {
    public final String name                   ①
    User(String name) { this.name = name}
    String getName() { "Name: $name" }         ②
}
def user = new User('Bob')
assert user.name == 'Name: Bob'                ③
```

① public field `name`

② a getter for `name` that returns a custom string

③ calls the getter

The `user.name` call triggers a call to the property of the same name, that is to say, here, to the getter for `name`. If you want to retrieve the field instead of calling the getter, you can use the direct field access operator:

```
assert user.@name == 'Bob'                     ①
```

① use of `.@` forces usage of the field instead of the getter

Method pointer operator

The method pointer operator (`.&`) can be used to store a reference to a method in a variable, in order to call it later:

```
def str = 'example of method reference'            ①
def fun = str.&toUpperCase                         ②
def upper = fun()                                  ③
assert upper == str.toUpperCase()                  ④
```

① the `str` variable contains a `String`

② we store a reference to the `toUpperCase` method on the `str` instance inside a variable named `fun`

③ `fun` can be called like a regular method

④ we can check that the result is the same as if we had called it directly on `str`

There are multiple advantages in using method pointers. First of all, the type of such a method pointer is a `groovy.lang.Closure`, so it can be used in any place a closure would be used. In particular, it is suitable to convert an existing method for the needs of the strategy pattern:

```
def transform(List elements, Closure action) {                    ①
    def result = []
    elements.each {
        result << action(it)
    }
    result
}
String describe(Person p) {                                       ②
    "$p.name is $p.age"
}
def action = this.&describe                                       ③
def list = [
    new Person(name: 'Bob',   age: 42),
    new Person(name: 'Julia', age: 35)]                           ④
assert transform(list, action) == ['Bob is 42', 'Julia is 35']    ⑤
```

① the `transform` method takes each element of the list and calls the `action` closure on them, returning a new list

② we define a function that takes a `Person` and returns a `String`

③ we create a method pointer on that function

④ we create the list of elements we want to collect the descriptors

⑤ the method pointer can be used where a `Closure` was expected

Method pointers are bound by the receiver and a method name. Arguments are resolved at runtime, meaning that if you have multiple methods with the same name, the syntax is not different, only resolution of the appropriate method to be called will be done at runtime:

```
def doSomething(String str) { str.toUpperCase() }    ①
def doSomething(Integer x) { 2*x }                   ②
def reference = this.&doSomething                    ③
assert reference('foo') == 'FOO'                     ④
```

```
assert reference(123)    == 246                    ⑤
```

① define an overloaded doSomething method accepting a String as an argument

② define an overloaded doSomething method accepting an Integer as an argument

③ create a single method pointer on doSomething, without specifying argument types

④ using the method pointer with a String calls the String version of doSomething

⑤ using the method pointer with an Integer calls the Integer version of doSomething

To align with Java 8 method reference expectations, in Groovy 3 and above, you can use new as the method name to obtain a method pointer to the constructor:

```
def foo  = BigInteger.&new
def fortyTwo = foo('42')
assert fortyTwo == 42G
```

Also in Groovy 3 and above, you can obtain a method pointer to an instance method of a class. This method pointer takes an additional parameter being the receiver instance to invoke the method on:

```
def instanceMethod = String.&toUpperCase
assert instanceMethod('foo') == 'FOO'
```

For backwards compatibility, any static methods that happen to have the correct parameters for the call will be given precedence over instance methods for this case.

Method reference operator

The Parrot parser in Groovy 3+ supports the Java 8+ method reference operator. The method reference operator (::) can be used to reference a method or constructor in contexts expecting a functional interface. This overlaps somewhat with the functionality provided by Groovy's method pointer operator. Indeed, for dynamic Groovy, the method reference operator is just an alias for the method pointer operator. For static Groovy, the operator results in bytecode similar to the bytecode that Java would produce for the same context.

Some examples highlighting various supported method reference cases are shown in the following script:

```
import groovy.transform.CompileStatic
import static java.util.stream.Collectors.toList

@CompileStatic
void methodRefs() {
    assert 6G == [1G, 2G, 3G].stream().reduce(0G, BigInteger::add)
①

    assert [4G, 5G, 6G] == [1G, 2G, 3G].stream().map(3G::add).collect(toList())
②
```

```
    assert [1G, 2G, 3G] == [1L, 2L, 3L].stream().map(BigInteger::valueOf).collect
(toList())  ③

    assert [1G, 2G, 3G] == [1L, 2L, 3L].stream().map(3G::valueOf).collect(toList())
④
}

methodRefs()
```

① class instance method reference: add(BigInteger val) is an instance method in BigInteger

② object instance method reference: add(BigInteger val) is an instance method for object 3G

③ class static method reference: valueOf(long val) is a static method for class BigInteger

④ object static method reference: valueOf(long val) is a static method for object 3G (some consider this bad style in normal circumstances)

Some examples highlighting various supported constructor reference cases are shown in the following script:

```
@CompileStatic
void constructorRefs() {
    assert [1, 2, 3] == ['1', '2', '3'].stream().map(Integer::valueOf).collect(
toList())  ①

    def result = [1, 2, 3].stream().toArray(Integer[]::new)
②
    assert result instanceof Integer[]
    assert result.toString() == '[1, 2, 3]'
}

constructorRefs()
```

① class constructor reference

② array constructor reference

Regular expression operators

Pattern operator

The pattern operator (`~`) provides a simple way to create a `java.util.regex.Pattern` instance:

```
def p = ~/foo/
assert p instanceof Pattern
```

while in general, you find the pattern operator with an expression in a slashy-string, it can be used with any kind of `String` in Groovy:

```
p = ~'foo'                                                  ①
p = ~"foo"                                                  ②
p = ~$/dollar/slashy $ string/$                             ③
p = ~"${pattern}"                                           ④
```

① using single quote strings

② using double quotes strings

③ the dollar-slashy string lets you use slashes and the dollar sign without having to escape them

④ you can also use a GString!

NOTE While you can use most String forms with the Pattern, Find and Match operators, we recommend using the slashy string most of the time to save having to remember the otherwise needed escaping requirements.

Find operator

Alternatively to building a pattern, you can use the find operator `=~` to directly create a `java.util.regex.Matcher` instance:

```
def text = "some text to match"
def m = text =~ /match/                                     ①
assert m instanceof Matcher                                 ②
if (!m) {                                                   ③
    throw new RuntimeException("Oops, text not found!")
}
```

① `=~` creates a matcher against the `text` variable, using the pattern on the right hand side

② the return type of `=~` is a `Matcher`

③ equivalent to calling `if (!m.find(0))`

Since a `Matcher` coerces to a `boolean` by calling its `find` method, the `=~` operator is consistent with the simple use of Perl's `=~` operator, when it appears as a predicate (in `if`, `?:`, etc.). When the intent is to iterate over matches of the specified pattern (in `while`, etc.) call `find()` directly on the matcher or use the `iterator` DGM.

Match operator

The match operator (`==~`) is a slight variation of the find operator, that does not return a `Matcher` but a boolean and requires a strict match of the input string:

```
m = text ==~ /match/                                        ①
assert m instanceof Boolean                                 ②
if (m) {                                                    ③
    throw new RuntimeException("Should not reach that point!")
}
```

① `==~` matches the subject with the regular expression, but match must be strict

② the return type of `==~` is therefore a `boolean`

③ equivalent to calling `if (text ==~ /match/)`

Comparing Find vs Match operators

Typically, the match operator is used when the pattern involves a single exact match, otherwise the find operator might be more useful.

```
assert 'two words' ==~ /\S+\s+\S+/
assert 'two words' ==~ /^\S+\s+\S+$/         ①
assert !(' leading space' ==~ /\S+\s+\S+/)   ②

def m1 = 'two words' =~ /^\S+\s+\S+$/
assert m1.size() == 1                         ③
def m2 = 'now three words' =~ /^\S+\s+\S+$/   ④
assert m2.size() == 0                         ⑤
def m3 = 'now three words' =~ /\S+\s+\S+/
assert m3.size() == 1                         ⑥
assert m3[0] == 'now three'
def m4 = ' leading space' =~ /\S+\s+\S+/
assert m4.size() == 1                         ⑦
assert m4[0] == 'leading space'
def m5 = 'and with four words' =~ /\S+\s+\S+/
assert m5.size() == 2                         ⑧
assert m5[0] == 'and with'
assert m5[1] == 'four words'
```

① equivalent, but explicit ^ and $ are discouraged since they aren't needed

② no match because of leading space

③ one match

④ ^ and $ indicate exact match required

⑤ zero matches

⑥ one match, greedily starting at first word

⑦ one match, ignores leading space

⑧ two matches

Other operators

Spread operator

The Spread-dot Operator (`*.`), often abbreviated to just Spread Operator, is used to invoke an action on all items of an aggregate object. It is equivalent to calling the action on each item and collecting the result into a list:

```
class Car {
    String make
    String model
}
def cars = [
       new Car(make: 'Peugeot', model: '508'),
       new Car(make: 'Renault', model: 'Clio')]       ①
def makes = cars*.make                                ②
assert makes == ['Peugeot', 'Renault']                ③
```

① build a list of `Car` items. The list is an aggregate of objects.

② call the spread operator on the list, accessing the `make` property of each item

③ returns a list of strings corresponding to the collection of `make` items

The expression `cars*.make` is equivalent to `cars.collect{ it.make }`. Groovy's GPath notation allows a short-cut when the referenced property isn't a property of the containing list, in that case it is automatically spread. In the previously mentioned case, the expression `cars.make` can be used, though retaining the explicit spread-dot operator is often recommended.

The spread operator is null-safe, meaning that if an element of the collection is null, it will return null instead of throwing a `NullPointerException`:

```
cars = [
   new Car(make: 'Peugeot', model: '508'),
   null,                                              ①
   new Car(make: 'Renault', model: 'Clio')]
assert cars*.make == ['Peugeot', null, 'Renault']     ②
assert null*.make == null                             ③
```

① build a list for which one of the elements is `null`

② using the spread operator will **not** throw a `NullPointerException`

③ the receiver might also be null, in which case the return value is `null`

The spread operator can be used on any class which implements the `Iterable` interface:

```
class Component {
    Integer id
    String name
}
class CompositeObject implements Iterable<Component> {
    def components = [
        new Component(id: 1, name: 'Foo'),
        new Component(id: 2, name: 'Bar')]

    @Override
    Iterator<Component> iterator() {
        components.iterator()
```

```
    }
}
def composite = new CompositeObject()
assert composite*.id == [1,2]
assert composite*.name == ['Foo','Bar']
```

Use multiple invocations of the spread-dot operator (here `cars*.models*.name`) when working with aggregates of data structures which themselves contain aggregates:

```
class Make {
    String name
    List<Model> models
}

@Canonical
class Model {
    String name
}

def cars = [
    new Make(name: 'Peugeot',
             models: [new Model('408'), new Model('508')]),
    new Make(name: 'Renault',
             models: [new Model('Clio'), new Model('Captur')])
]

def makes = cars*.name
assert makes == ['Peugeot', 'Renault']

def models = cars*.models*.name
assert models == [['408', '508'], ['Clio', 'Captur']]
assert models.sum() == ['408', '508', 'Clio', 'Captur'] // flatten one level
assert models.flatten() == ['408', '508', 'Clio', 'Captur'] // flatten all levels (one
in this case)
```

Consider using the `collectNested` DGM method instead of the spread-dot operator for collections of collections:

```
class Car {
    String make
    String model
}
def cars = [
   [
       new Car(make: 'Peugeot', model: '408'),
       new Car(make: 'Peugeot', model: '508')
   ], [
       new Car(make: 'Renault', model: 'Clio'),
```

```
        new Car(make: 'Renault', model: 'Captur')
    ]
]
def models = cars.collectNested{ it.model }
assert models == [['408', '508'], ['Clio', 'Captur']]
```

Spreading method arguments

There may be situations when the arguments of a method call can be found in a list that you need to adapt to the method arguments. In such situations, you can use the spread operator to call the method. For example, imagine you have the following method signature:

```
int function(int x, int y, int z) {
    x*y+z
}
```

then if you have the following list:

```
def args = [4,5,6]
```

you can call the method without having to define intermediate variables:

```
assert function(*args) == 26
```

It is even possible to mix normal arguments with spread ones:

```
args = [4]
assert function(*args,5,6) == 26
```

Spread list elements

When used inside a list literal, the spread operator acts as if the spread element contents were inlined into the list:

```
def items = [4,5]                      ①
def list = [1,2,3,*items,6]            ②
assert list == [1,2,3,4,5,6]           ③
```

① `items` is a list

② we want to insert the contents of the `items` list directly into `list` without having to call `addAll`

③ the contents of `items` has been inlined into `list`

Spread map elements

The spread map operator works in a similar manner as the spread list operator, but for maps. It allows you to inline the contents of a map into another map literal, like in the following example:

```
def m1 = [c:3, d:4]                ①
def map = [a:1, b:2, *:m1]         ②
assert map == [a:1, b:2, c:3, d:4] ③
```

① `m1` is the map that we want to inline

② we use the `*:m1` notation to spread the contents of `m1` into `map`

③ `map` contains all the elements of `m1`

The position of the spread map operator is relevant, like illustrated in the following example:

```
def m1 = [c:3, d:4]                ①
def map = [a:1, b:2, *:m1, d: 8]   ②
assert map == [a:1, b:2, c:3, d:8] ③
```

① `m1` is the map that we want to inline

② we use the `*:m1` notation to spread the contents of `m1` into `map`, but redefine the key `d` **after** spreading

③ `map` contains all the expected keys, but `d` was redefined

Range operator

Groovy supports the concept of ranges and provides a notation (`..`) to create ranges of objects:

```
def range = 0..5                             ①
assert (0..5).collect() == [0, 1, 2, 3, 4, 5] ②
assert (0..<5).collect() == [0, 1, 2, 3, 4]   ③
assert (0<..5).collect() == [1, 2, 3, 4, 5]   ④
assert (0<..<5).collect() == [1, 2, 3, 4]     ⑤
assert (0..5) instanceof List                 ⑥
assert (0..5).size() == 6                     ⑦
```

① a simple range of integers, stored into a local variable

② an `IntRange`, with inclusive bounds

③ an `IntRange`, with exclusive upper bound

④ an `IntRange`, with exclusive lower bound

⑤ an `IntRange`, with exclusive lower and upper bounds

⑥ a `groovy.lang.Range` implements the `List` interface

⑦ meaning that you can call the `size` method on it

Ranges implementation is lightweight, meaning that only the lower and upper bounds are stored. You can create a range from any `Comparable` object that has `next()` and `previous()` methods to determine the next / previous item in the range. For example, you can create a range of characters this way:

```
assert ('a'..'d').collect() == ['a','b','c','d']
```

Spaceship operator

The spaceship operator (`<=>`) delegates to the `compareTo` method:

```
assert (1 <=> 1) == 0
assert (1 <=> 2) == -1
assert (2 <=> 1) == 1
assert ('a' <=> 'z') == -1
```

Subscript operator

The subscript operator is a shorthand notation for `getAt` or `putAt`, depending on whether you find it on the left hand side or the right hand side of an assignment:

```
def list = [0,1,2,3,4]
assert list[2] == 2                    ①
list[2] = 4                            ②
assert list[0..2] == [0,1,4]           ③
list[0..2] = [6,6,6]                   ④
assert list == [6,6,6,3,4]             ⑤
```

① `[2]` can be used instead of `getAt(2)`

② if on left hand side of an assignment, will call `putAt`

③ `getAt` also supports ranges

④ so does `putAt`

⑤ the list is mutated

The subscript operator, in combination with a custom implementation of `getAt`/`putAt` is a convenient way for destructuring objects:

```
class User {
    Long id
    String name
    def getAt(int i) {                                          ①
        switch (i) {
            case 0: return id
            case 1: return name
        }
```

```
        throw new IllegalArgumentException("No such element $i")
    }
    void putAt(int i, def value) {                        ②
        switch (i) {
            case 0: id = value; return
            case 1: name = value; return
        }
        throw new IllegalArgumentException("No such element $i")
    }
}
def user = new User(id: 1, name: 'Alex')                  ③
assert user[0] == 1                                       ④
assert user[1] == 'Alex'                                  ⑤
user[1] = 'Bob'                                           ⑥
assert user.name == 'Bob'                                 ⑦
```

① the `User` class defines a custom `getAt` implementation

② the `User` class defines a custom `putAt` implementation

③ create a sample user

④ using the subscript operator with index 0 allows retrieving the user id

⑤ using the subscript operator with index 1 allows retrieving the user name

⑥ we can use the subscript operator to write to a property thanks to the delegation to `putAt`

⑦ and check that it's really the property `name` which was changed

Safe index operator

Groovy 3.0.0 introduces safe indexing operator, i.e. `?[]`, which is similar to `?.`. For example:

```
String[] array = ['a', 'b']
assert 'b' == array?[1]      // get using normal array index
array?[1] = 'c'              // set using normal array index
assert 'c' == array?[1]

array = null
assert null == array?[1]     // return null for all index values
array?[1] = 'c'              // quietly ignore attempt to set value
assert null == array?[1]

def personInfo = [name: 'Daniel.Sun', location: 'Shanghai']
assert 'Daniel.Sun' == personInfo?['name']      // get using normal map index
personInfo?['name'] = 'sunlan'                  // set using normal map index
assert 'sunlan' == personInfo?['name']

personInfo = null
assert null == personInfo?['name']              // return null for all map values
personInfo?['name'] = 'sunlan'                  // quietly ignore attempt to set value
assert null == personInfo?['name']
```

Membership operator

The membership operator (in) is equivalent to calling the isCase method. In the context of a List, it is equivalent to calling contains, like in the following example:

```
def list = ['Grace','Rob','Emmy']
assert ('Emmy' in list)                    ①
assert ('Alex' !in list)                   ②
```

① equivalent to calling list.contains('Emmy') or list.isCase('Emmy')

② membership negation equivalent to calling !list.contains('Emmy') or !list.isCase('Emmy')

Identity operator

In Groovy, using == to test equality is different from using the same operator in Java. In Groovy, it is calling equals. If you want to compare reference equality, you should use is like in the following example:

```
def list1 = ['Groovy 1.8','Groovy 2.0','Groovy 2.3']        ①
def list2 = ['Groovy 1.8','Groovy 2.0','Groovy 2.3']        ②
assert list1 == list2                                       ③
assert !list1.is(list2)                                     ④
assert list1 !== list2                                      ⑤
```

① Create a list of strings

② Create another list of strings containing the same elements

③ using ==, we test object equality, equivalent to list1.equals(list2) in Java

④ using is, we can check that references are distinct, equivalent to list1 == list2 in Java

⑤ using === or !== (supported and recommended since Groovy 3.0.0), we can also check whether references are distinct or not, equivalent to list1 == list2 and list1 != list2 in Java

Coercion operator

The coercion operator (as) is a variant of casting. Coercion converts object from one type to another **without** them being compatible for assignment. Let's take an example:

```
String input = '42'
Integer num = (Integer) input                    ①
```

① String is not assignable to an Integer, so it will produce a ClassCastException at runtime

This can be fixed by using *coercion* instead:

```
String input = '42'
Integer num = input as Integer                   ①
```

① `String` is not assignable to an `Integer`, but use of `as` will *coerce* it to an `Integer`

When an object is coerced into another, unless the target type is the same as the source type, coercion will return a **new** object. The rules of coercion differ depending on the source and target types, and coercion may fail if no conversion rules are found. Custom conversion rules may be implemented thanks to the `asType` method:

```
class Identifiable {
    String name
}
class User {
    Long id
    String name
    def asType(Class target) {                                              ①
        if (target == Identifiable) {
            return new Identifiable(name: name)
        }
        throw new ClassCastException("User cannot be coerced into $target")
    }
}
def u = new User(name: 'Xavier')                                            ②
def p = u as Identifiable                                                   ③
assert p instanceof Identifiable                                            ④
assert !(p instanceof User)                                                 ⑤
```

① the `User` class defines a custom conversion rule from `User` to `Identifiable`

② we create an instance of `User`

③ we coerce the `User` instance into an `Identifiable`

④ the target is an instance of `Identifiable`

⑤ the target is not an instance of `User` anymore

Diamond operator

The diamond operator (`<>`) is a syntactic sugar only operator added to support compatibility with the operator of the same name in Java 7. It is used to indicate that generic types should be inferred from the declaration:

```
List<String> strings = new LinkedList<>()
```

In dynamic Groovy, this is totally unused. In statically type checked Groovy, it is also optional since the Groovy type checker performs type inference whether this operator is present or not.

Call operator

The call operator `()` is used to call a method named `call` implicitly. For any object which defines a `call` method, you can omit the `.call` part and use the call operator instead:

```
class MyCallable {
    int call(int x) {           ①
        2*x
    }
}

def mc = new MyCallable()
assert mc.call(2) == 4          ②
assert mc(2) == 4               ③
```

① MyCallable defines a method named call. Note that it doesn't need to implement java.util.concurrent.Callable

② we can call the method using the classic method call syntax

③ or we can omit .call thanks to the call operator

Operator precedence

The table below lists all groovy operators in order of precedence.

Level	Operator(s)	Name(s)
1	new ()	object creation, explicit parentheses
	() {} []	method call, closure, literal list/map
	. .& .@	member access, method closure, field/attribute access
	?. * *. *:	safe dereferencing, spread, spread-dot, spread-map
	~ ! (type)	bitwise negate/pattern, not, typecast
	[] ?[] ++ --	list/map/array (safe) index, post inc/decrement
2	**	power
3	+` {nbsp} `--` {nbsp} ` -	pre inc/decrement, unary plus, unary minus
4	* / %	multiply, div, remainder
5	+ -	addition, subtraction
6	<< >> >>> .. ..< <..< <..	left/right (unsigned) shift, inclusive/exclusive ranges
7	< <= > >= in !in instanceof !instanceof as	less/greater than/or equal, in, not in, instanceof, not instanceof, type coercion

Level	Operator(s)	Name(s)
8	`==` `!=` `<=>` `===` `!==`	equals, not equals, compare to, identical to, not identical to
	`=~` `==~`	regex find, regex match
9	`&`	binary/bitwise and
10	`^`	binary/bitwise xor
11	`|`	binary/bitwise or
12	`&&`	logical and
13	`||`	logical or
13.5	`==>`	logical implication
14	`? :`	ternary conditional
	`?:`	elvis operator
15	`=` `**=` `*=` `/=` `%=` `+=` `-=` `<<=` `>>=` `>>>=` `&=` `^=` `|=` `?=`	various assignments

Operator overloading

Groovy allows you to overload the various operators so that they can be used with your own classes. Consider this simple class:

```
class Bucket {
    int size

    Bucket(int size) { this.size = size }

    Bucket plus(Bucket other) {                     ①
        return new Bucket(this.size + other.size)
    }
}
```

① `Bucket` implements a special method called `plus()`

Just by implementing the `plus()` method, the `Bucket` class can now be used with the `+` operator like so:

```
def b1 = new Bucket(4)
def b2 = new Bucket(11)
assert (b1 + b2).size == 15                         ①
```

① The two `Bucket` objects can be added together with the `+` operator

All (non-comparator) Groovy operators have a corresponding method that you can implement in your own classes. The only requirements are that your method is public, has the correct name, and has the correct number of arguments. The argument types depend on what types you want to support on the right hand side of the operator. For example, you could support the statement

```
assert (b1 + 11).size == 15
```

by implementing the `plus()` method with this signature:

```
Bucket plus(int capacity) {
    return new Bucket(this.size + capacity)
}
```

Here is a complete list of the operators and their corresponding methods:

<table>
<tr><th>Operator</th><th>Method</th><th>Operator</th><th>Method</th></tr>
<tr><td>+</td><td>a.plus(b)</td><td>a[b]</td><td>a.getAt(b)</td></tr>
<tr><td>-</td><td>a.minus(b)</td><td>a[b] = c</td><td>a.putAt(b, c)</td></tr>
<tr><td>*</td><td>a.multiply(b)</td><td>a in b</td><td>b.isCase(a)</td></tr>
<tr><td>/</td><td>a.div(b)</td><td><<</td><td>a.leftShift(b)</td></tr>
<tr><td>%</td><td>a.mod(b)</td><td>>></td><td>a.rightShift(b)</td></tr>
<tr><td>**</td><td>a.power(b)</td><td>>>></td><td>a.rightShiftUnsigned(b)</td></tr>
<tr><td>|</td><td>a.or(b)</td><td>++</td><td>a.next()</td></tr>
<tr><td>&</td><td>a.and(b)</td><td>--</td><td>a.previous()</td></tr>
<tr><td>^</td><td>a.xor(b)</td><td>+a</td><td>a.positive()</td></tr>
<tr><td>as</td><td>a.asType(b)</td><td>-a</td><td>a.negative()</td></tr>
<tr><td>a()</td><td>a.call()</td><td>~a</td><td>a.bitwiseNegate()</td></tr>
</table>

Program structure

This chapter covers the program structure of the Groovy programming language.

Package names

Package names play exactly the same role as in Java. They allow us to separate the code base without any conflicts. Groovy classes must specify their package before the class definition, else the default package is assumed.

Defining a package is very similar to Java:

```
// defining a package named com.yoursite
package com.yoursite
```

To refer to some class `Foo` in the `com.yoursite.com` package you will need to use the fully qualified name `com.yoursite.com.Foo`, or else you can use an `import` statement as we'll see below.

Imports

In order to refer to any class you need a qualified reference to its package. Groovy follows Java's notion of allowing `import` statement to resolve class references.

For example, Groovy provides several builder classes, such as `MarkupBuilder`. `MarkupBuilder` is inside the package `groovy.xml` so in order to use this class, you need to `import` it as shown:

```
// importing the class MarkupBuilder
import groovy.xml.MarkupBuilder

// using the imported class to create an object
def xml = new MarkupBuilder()

assert xml != null
```

Default imports

Default imports are the imports that Groovy language provides by default. For example look at the following code:

```
new Date()
```

The same code in Java needs an import statement to `Date` class like this: import java.util.Date. Groovy by default imports these classes for you.

The below imports are added by groovy for you:

```
import java.lang.*
import java.util.*
import java.io.*
import java.net.*
import groovy.lang.*
import groovy.util.*
import java.math.BigInteger
import java.math.BigDecimal
```

This is done because the classes from these packages are most commonly used. By importing these boilerplate code is reduced.

Simple import

A simple import is an import statement where you fully define the class name along with the package. For example the import statement `import groovy.xml.MarkupBuilder` in the code below is a simple import which directly refers to a class inside a package.

```
// importing the class MarkupBuilder
import groovy.xml.MarkupBuilder

// using the imported class to create an object
def xml = new MarkupBuilder()

assert xml != null
```

Star import

Groovy, like Java, provides a special way to import all classes from a package using `*`, the so-called on-demand or star import. `MarkupBuilder` is a class which is in package `groovy.xml`, alongside another class called `StreamingMarkupBuilder`. In case you need to use both classes, you can do:

```
import groovy.xml.MarkupBuilder
import groovy.xml.StreamingMarkupBuilder

def markupBuilder = new MarkupBuilder()

assert markupBuilder != null

assert new StreamingMarkupBuilder() != null
```

That's perfectly valid code. But with a `*` import, we can achieve the same effect with just one line. The star imports all the classes under package `groovy.xml`:

```
import groovy.xml.*

def markupBuilder = new MarkupBuilder()

assert markupBuilder != null

assert new StreamingMarkupBuilder() != null
```

One problem with `*` imports is that they can clutter your local namespace. But with the kinds of aliasing provided by Groovy, this can be solved easily.

Static import

Groovy's static import capability allows you to reference imported classes as if they were static methods in your own class:

```
import static java.lang.Boolean.FALSE
```

```
assert !FALSE //use directly, without Boolean prefix!
```

This is similar to Java's static import capability but is a more dynamic than Java in that it allows you to define methods with the same name as an imported method as long as you have different types:

```
import static java.lang.String.format ①

class SomeClass {

    String format(Integer i) { ②
        i.toString()
    }

    static void main(String[] args) {
        assert format('String') == 'String' ③
        assert new SomeClass().format(Integer.valueOf(1)) == '1'
    }
}
```

① static import of method

② declaration of method with same name as method statically imported above, but with a different parameter type

③ compile error in Java, but is valid Groovy code

If you have the same signature, the imported method takes precedence.

Static import aliasing

Static imports with the `as` keyword provide an elegant solution to namespace problems. Suppose you want to get a `Calendar` instance, using its `getInstance()` method. It's a static method, so we can use a static import. But instead of calling `getInstance()` every time, which can be misleading when separated from its class name, we can import it with an alias, to increase code readability:

```
import static Calendar.getInstance as now

assert now().class == Calendar.getInstance().class
```

Now, that's clean!

Static star import

A static star import is very similar to the regular star import. It will import all the static members from the given class.

For example, let's say we need to calculate sines and cosines for our application. The class `java.lang.Math` has static methods named `sin` and `cos` which fit our need. With the help of a static star import, we can do:

```
import static java.lang.Math.*

assert sin(0) == 0.0
assert cos(0) == 1.0
```

As you can see, we were able to access the methods `sin` and `cos` directly, without the `Math.` prefix.

Import aliasing

With type aliasing, we can refer to a fully qualified class name using a name of our choice. This can be done with the `as` keyword, as before.

For example we can import `java.sql.Date` as `SQLDate` and use it in the same file as `java.util.Date` without having to use the fully qualified name of either class:

```
import java.util.Date
import java.sql.Date as SQLDate

Date utilDate = new Date(1000L)
SQLDate sqlDate = new SQLDate(1000L)

assert utilDate instanceof java.util.Date
assert sqlDate instanceof java.sql.Date
```

Namespace conflicts

Similar to Java, it is an error in Groovy to specify multiple imports with the same name but different types:

```
import java.awt.List
import java.util.List // error: name already declared
```

And to declare an import and a top-level type with the same name:

```
import java.util.List
class List { } // error: name already declared
```

However, inner types can shadow names from the unit scope:

```
import java.util.List
class Main {
    class List { } // allowed; "List" refers to this type within `Main`'s scope and
`java.util.List` elsewhere
```

```
}
```

Scripts versus classes

Groovy supports both scripts and classes. From Groovy 5, Groovy also supports JEP 445 compatible scripts.

Motivation for scripts

Take the following code for example:

Main.groovy

```
class Main {                                    ①
    static void main(String... args) {          ②
        println 'Groovy world!'                 ③
    }
}
```

① define a `Main` class, the name is arbitrary

② the `public static void main(String[])` method is usable as the main method of the class

③ the main body of the method

This is typical code that you would find coming from Java, where code **has** to be embedded into a class to be executable. Groovy makes it easier, the following code is equivalent:

Main.groovy

```
println 'Groovy world!'
```

A script can be considered as a class without needing to explicitly declare it. There are some differences which we'll cover next. First, we'll cover Groovy's main `Script` class. Then, we'll cover JEP 445 compatible classes.

`Script` class

A groovy.lang.Script is always compiled into a class. The Groovy compiler will compile the class for you, with the body of the script copied into a `run` method. The previous example is therefore compiled as if it was the following:

Main.groovy

```
import org.codehaus.groovy.runtime.InvokerHelper
class Main extends Script {                     ①
    def run() {                                 ②
        println 'Groovy world!'                 ③
    }
    static void main(String[] args) {           ④
        InvokerHelper.runScript(Main, args)     ⑤
```

```
    }
}
```

① The `Main` class extends the `groovy.lang.Script` class

② `groovy.lang.Script` requires a `run` method returning a value

③ the script body goes into the `run` method

④ the `main` method is automatically generated

⑤ and delegates the execution of the script on the `run` method

If the script is in a file, then the base name of the file is used to determine the name of the generated script class. In this example, if the name of the file is `Main.groovy`, then the script class is going to be `Main`.

Methods

It is possible to define methods into a script, as illustrated here:

```
int fib(int n) {
    n < 2 ? 1 : fib(n-1) + fib(n-2)
}
assert fib(10)==89
```

You can also mix methods and code. The generated script class will carry all methods into the script class, and assemble all script bodies into the `run` method:

```
println 'Hello'                                ①

int power(int n) { 2**n }                      ②

println "2^6==${power(6)}"                     ③
```

① script begins

② a method is defined within the script body

③ and script continues

Statements 1 and 3 are sometimes referred to as "loose" statements. They are not contained within an explicit enclosing method or class. Loose statements are assembled sequentially into the `run` method.

So, the above code is internally converted into:

```
import org.codehaus.groovy.runtime.InvokerHelper
class Main extends Script {
    int power(int n) { 2** n}                  ①
    def run() {
```

```
        println 'Hello'                    ②
        println "2^6==${power(6)}"         ③
    }
    static void main(String[] args) {
        InvokerHelper.runScript(Main, args)
    }
}
```

① the `power` method is copied as-is into the generated script class

② first statement is copied into the `run` method

③ second statement is copied into the `run` method

> **TIP** Even if Groovy creates a class from your script, it is totally transparent for the user. In particular, scripts are compiled to bytecode, and line numbers are preserved. This implies that if an exception is thrown in a script, the stack trace will show line numbers corresponding to the original script, not the generated code that we have shown.

Variables

Variables in a script do not require a type definition. This means that this script:

```
int x = 1
int y = 2
assert x+y == 3
```

will behave the same as:

```
x = 1
y = 2
assert x+y == 3
```

However, there is a semantic difference between the two:

- if the variable is declared as in the first example, it is a *local variable*. It will be declared in the `run` method that the compiler will generate and will **not** be visible outside of the script main body. In particular, such a variable will **not** be visible in other methods of the script
- if the variable is undeclared, it goes into the groovy.lang.Script#getBinding(). The binding is visible from the methods, and is especially important if you use a script to interact with an application and need to share data between the script and the application. Readers might refer to the integration guide for more information.

> **TIP** Another approach to making a variable visible to all methods, is to use the @Field annotation. A variable annotated this way will become a field of the generated script class and, as for local variables, access won't involve the script `Binding`. If you have a local variable or script field with the same name as a binding variable, we recommend

> renaming one of them to avoid potential confusion. If that's not possible, you can use `binding.varName` to access the binding variable.

Convenience variations

As mentioned previously, normally, `public static void main` and `run` methods are automatically added to your script, so it is normally illegal to add your own versions of either of those; you would see a duplicate method compiler error if you tried.

However, there are some exceptions where the above rules don't apply. If your script contains *only* a compatible main method and no other loose statements, or *only* a no-arg `run` instance method (from Groovy 5), then it is allowed. In this case, no loose statements (because there aren't any) are collected into the `run` method. The method you supplied is used instead of Groovy adding the respective method(s).

This can be useful if you need to add an annotation to the otherwise implicitly added `main` or `run` methods as this example shows:

```
@CompileStatic
static main(args) {
    println 'Groovy world!'
}
```

To be recognised as a convenience variation, as well as having no loose statements, the parameter for the `main` method should be:

- untyped as above (`Object` type),
- or of type `String[]`,
- or have no arguments (from Groovy 5).

From Groovy 5, a no-arg instance `run` variant is also supported. This also allows annotations to be added. The `run` variant follows the JEP 445 rules for field declarations (hence doesn't need to use the `@Field` annotation) as this example involving Jackson JSON serialization shows:

```
@JsonIgnoreProperties(["binding"])
def run() {
    var mapper = new ObjectMapper()
    assert mapper.writeValueAsString(this) == '{"pets":["cat","dog"]}'
}

public pets = ['cat', 'dog']
```

The `run` variant is recommended if you need your script to extend the `Script` class and have access to the script context and bindings. If you don't have that requirement, providing one of the `main` variants will create a JEP 445 compatible class which won't extend `Script`. We'll cover JEP 445 compatible scripts in more detail next.

JEP 445 compatible scripts

From Groovy 5, support has been added for JEP 445 compatible scripts containing a `main` method. Such scripts have several differences to normal Groovy `Script` classes:

- they won't have a `public static void main` method added
- they won't extend the `Script` class and hence won't have access to the script context or binding variables
- allows additional class-level *fields* and *methods* to be defined in addition to `main`
- can't have "loose" statements outside the `main` method (excluding any field definitions)

A simple example might look like:

```
void main(args) {
    println new Date()
}
```

An example with additional fields and methods might look like:

```
def main() {
    assert upper(foo) + lower(bar) == 'FOObar'
}

def upper(s) { s.toUpperCase() }

def lower = String::toLowerCase
def (foo, bar) = ['Foo', 'Bar']      ①
```

① Note that multi-assignment syntax is supported and results in separate field definitions for each component.

Differences with Java JEP 445 behavior

There are some differences with Groovy's JEP 445 support and that offered by Java:

- Java supports either a no-arg `main` method or one containing a single `String[]` parameter. Groovy also adds support for a single untyped (`Object`) parameter, e.g. `def main(args) { … }`. This addition is known by the Groovy runner but would not be known by the Java launch protocol for a JDK supporting JEP 445.
- Java supports `void` main methods. Groovy also adds support for untyped `def` (`Object`) methods, e.g. `def main(…)` as well as `void main(…)`. This addition is known by the Groovy runner but would not be known by the Java launch protocol for a JDK supporting JEP 445.
- For static `main` variants, Groovy *promotes* the no-arg or untyped variants to have the standard `public static void main(String[] args)` signature. This is for compatibility with versions of Groovy prior to Groovy 5 (where JEP 445 support was added). As a consequence, such classes are compatible with the Java launch protocol prior to JEP 445 support.

- Groovy's runner has been made aware of JEP 445 compatible classes and can run all variations for JDK11 and above and without the need for preview mode to be enabled.

Object orientation

This chapter covers the object-oriented aspects of the Groovy programming language.

Types

Primitive types

Groovy supports the same primitive types as defined by the Java Language Specification:

- integral types: `byte` (8 bit), `short` (16 bit), `int` (32 bit) and `long` (64 bit)
- floating-point types: `float` (32 bit) and `double` (64 bit)
- the `boolean` type (one of `true` or `false`)
- the `char` type (16 bit, usable as a numeric type, representing a UTF-16 code)

Also like Java, Groovy uses the respective wrapper classes when objects corresponding to any of the primitive types are required:

Table 4. primitive wrappers

Primitive type	Wrapper class
boolean	Boolean
char	Character
short	Short
int	Integer
long	Long
float	Float
double	Double

Automatic boxing and unboxing occur when, for instance, calling a method requiring the wrapper class and passing it a primitive variable as the parameter, or vice-versa. This is similar to Java but Groovy takes the idea further.

In most scenarios, you can treat a primitive just like it was the full object wrapper equivalent. For instance, you can call `.toString()` or `.equals(other)` on a primitive. Groovy autowraps and unwraps between references and primitives as needed.

Here's an example using `int` which is declared as a static field in a class (discussed shortly):

```
class Foo {
    static int i
}
```

```
assert Foo.class.getDeclaredField('i').type == int.class          ①
assert Foo.i.class != int.class && Foo.i.class == Integer.class    ②
```

① Primitive type is respected in the bytecode

② Looking at the field at runtime shows it has been autowrapped

Now you may be concerned that this means every time you use a mathematical operator on a reference to a primitive that you'll incur the cost of unboxing and reboxing the primitive. But this is not the case, as Groovy will compile your operators into their method equivalents and uses those instead. Additionally, Groovy will automatically unbox to a primitive when calling a Java method that takes a primitive parameter and automatically box primitive method return values from Java. However, be aware there are some differences from Java's method resolution.

Reference Types

Apart from primitives, everything else is an object and has an associated class defining its type. We'll discuss classes, and class-related or class-like things like interfaces, traits and records shortly.

We might declare two variables, of type String and List, as follows:

```
String movie = 'The Matrix'
List actors = ['Keanu Reeves', 'Hugo Weaving']
```

Generics

Groovy carries across the same concepts with regard to generics as Java. When defining classes and methods, it is possible to use a type parameter and create a generic class, interface, method or constructor.

Usage of generic classes and methods, regardless of whether they are defined in Java or Groovy, may involve supplying a type argument.

We might declare a variable, of type *"list of string"*, as follows:

```
List<String> roles = ['Trinity', 'Morpheus']
```

Java employs type erasure for backwards compatibility with earlier versions of Java. Dynamic Groovy can be thought of as more aggressively applying type erasure. In general, less generics type information will be checked at compile time. Groovy's static nature employs similar checks to Java with regard to generics information.

Classes

Groovy classes are very similar to Java classes, and are compatible with Java ones at JVM level. They may have methods, fields and properties (think JavaBeans properties but with less boilerplate). Classes and class members can have the same modifiers (public, protected, private, static, etc.) as in Java with some minor differences at the source level which are explained shortly.

The key differences between Groovy classes and their Java counterparts are:

- Classes or methods with no visibility modifier are automatically public (a special annotation can be used to achieve package private visibility).
- Fields with no visibility modifier are turned into properties automatically, which results in less verbose code, since explicit getter and setter methods aren't needed. More on this aspect will be covered in the fields and properties section.
- Classes do not need to have the same base name as their source file definitions but it is highly recommended in most scenarios (see also the next point about scripts).
- One source file may contain one or more classes (but if a file contains any code not in a class, it is considered a script). Scripts are just classes with some special conventions and will have the same name as their source file (so don't include a class definition within a script having the same name as the script source file).

The following code presents an example class.

```
class Person {                       ①

    String name                      ②
    Integer age

    def increaseAge(Integer years) { ③
        this.age += years
    }
}
```

① class beginning, with the name `Person`

② string field and property named `name`

③ method definition

Normal class

Normal classes refer to classes which are top level and concrete. This means they can be instantiated without restrictions from any other classes or scripts. This way, they can only be public (even though the `public` keyword may be suppressed). Classes are instantiated by calling their constructors, using the `new` keyword, as in the following snippet.

```
def p = new Person()
```

Inner class

Inner classes are defined within another classes. The enclosing class can use the inner class as usual. On the other side, an inner class can access members of its enclosing class, even if they are private. Classes other than the enclosing class are not allowed to access inner classes. Here is an example:

```
class Outer {
    private String privateStr

    def callInnerMethod() {
        new Inner().methodA()       ①
    }

    class Inner {                   ②
        def methodA() {
            println "${privateStr}." ③
        }
    }
}
```

① the inner class is instantiated and its method gets called

② inner class definition, inside its enclosing class

③ even being private, a field of the enclosing class is accessed by the inner class

There are some reasons for using inner classes:

- They increase encapsulation by hiding the inner class from other classes, which do not need to know about it. This also leads to cleaner packages and workspaces.
- They provide a good organization, by grouping classes that are used by only one class.
- They lead to more maintainable codes, since inner classes are near the classes that use them.

It is common for an inner class to be an implementation of some interface whose method(s) are needed by the outer class. The code below illustrates this typical usage pattern, here being used with threads.

```
class Outer2 {
    private String privateStr = 'some string'

    def startThread() {
       new Thread(new Inner2()).start()
    }

    class Inner2 implements Runnable {
        void run() {
            println "${privateStr}."
        }
    }
}
```

Note that the class `Inner2` is defined only to provide an implementation of the method `run` to class `Outer2`. Anonymous inner classes help to eliminate verbosity in this case. That topic is covered shortly.

Groovy 3+ also supports Java syntax for non-static inner class instantiation, for example:

```
class Computer {
    class Cpu {
        int coreNumber

        Cpu(int coreNumber) {
            this.coreNumber = coreNumber
        }
    }
}

assert 4 == new Computer().new Cpu(4).coreNumber
```

Anonymous inner class

The earlier example of an inner class (`Inner2`) can be simplified with an anonymous inner class. The same functionality can be achieved with the following code:

```
class Outer3 {
    private String privateStr = 'some string'

    def startThread() {
        new Thread(new Runnable() {      ①
            void run() {
                println "${privateStr}."
            }
        }).start()                       ②
    }
}
```

① comparing with the last example of previous section, the `new Inner2()` was replaced by `new Runnable()` along with all its implementation

② the method `start` is invoked normally

Thus, there was no need to define a new class to be used just once.

Abstract class

Abstract classes represent generic concepts, thus, they cannot be instantiated, being created to be subclassed. Their members include fields/properties and abstract or concrete methods. Abstract methods do not have implementation, and must be implemented by concrete subclasses.

```
abstract class Abstract {         ①
    String name

```

```
    abstract def abstractMethod() ②

    def concreteMethod() {
        println 'concrete'
    }
}
```

① abstract classes must be declared with `abstract` keyword

② abstract methods must also be declared with `abstract` keyword

Abstract classes are commonly compared to interfaces. There are at least two important differences of choosing one or another. First, while abstract classes may contain fields/properties and concrete methods, interfaces may contain only abstract methods (method signatures). Moreover, one class can implement several interfaces, whereas it can extend just one class, abstract or not.

Inheritance

Inheritance in Groovy resembles inheritance in Java. It provides a mechanism for a child class (or subclass) to reuse code or properties from a parent (or super class). Classes related through inheritance form an inheritance hierarchy. Common behavior and members are pushed up the hierarchy to reduce duplication. Specializations occur in child classes.

Different forms of inheritance are supported:

- *implementation* inheritance where code (methods, fields or properties) from a superclass or from one or more traits is reused by a child class
- *contract* inheritance where a class promises to provide particular abstract methods defined in a superclass, or defined in one or more traits or interfaces.

Superclasses

Parent classes share visible fields, properties or methods with child classes. A child class may have at most one parent class. The `extends` keyword is used immediately prior to giving the superclass type.

Interfaces

An interface defines a contract that a class needs to conform to. Typically, an interface defines zero or more abstract method definitions, but does not define the method's implementation.

Here is a `Greeter` interface defining one `greet` method:

```
interface Greeter {                                          ①
    void greet(String name)                                  ②
}
```

① an interface needs to be declared using the `interface` keyword

② the abstract method signature for the `greet` method

Such method signatures are public by default. It is an error to use `protected` or package-private methods in interfaces:

```
interface Greeter {
    protected void greet(String name)                         ①
}
```

① Using `protected` is a compile-time error

A class *implements* an interface if it defines the interface in its `implements` list or if any of its superclasses does:

```
class SystemGreeter implements Greeter {                      ①
    void greet(String name) {                                 ②
        println "Hello $name"
    }
}

def greeter = new SystemGreeter()
assert greeter instanceof Greeter                             ③
```

① The `SystemGreeter` declares the `Greeter` interface using the `implements` keyword

② Then implements the required `greet` method

③ Any instance of `SystemGreeter` is also an instance of the `Greeter` interface

An interface can extend another interface:

```
interface ExtendedGreeter extends Greeter {                   ①
    void sayBye(String name)
}
```

① the `ExtendedGreeter` interface extends the `Greeter` interface using the `extends` keyword

It is worth noting that for a class to be an instance of an interface, it has to be explicit. For example, the following class defines the `greet` method as it is declared in the `Greeter` interface, but does not declare `Greeter` in its interfaces:

```
class DefaultGreeter {
    void greet(String name) { println "Hello" }
}

greeter = new DefaultGreeter()
assert !(greeter instanceof Greeter)
```

In other words, Groovy does not define structural typing. It is however possible to make an instance of an object implement an interface at runtime, using the `as` coercion operator:

```
greeter = new DefaultGreeter()                           ①
coerced = greeter as Greeter                             ②
assert coerced instanceof Greeter                        ③
```

① create an instance of `DefaultGreeter` that does not implement the interface

② coerce the instance into a `Greeter` at runtime

③ the coerced instance implements the `Greeter` interface

You can see that there are two distinct objects: one is the source object, a `DefaultGreeter` instance, which does not implement the interface. The other is an instance of `Greeter` that delegates to the coerced object.

TIP	Groovy traits are close to interfaces, but support other important features described elsewhere in this manual. If you need more power than offered by interfaces, consider using traits.

While interfaces typically contain abstract method definitions, non-abstract methods are also possible. Variants allowed are `default`, `static`, or `private`:

- Default methods provide a mechanism to evolve API functionality. You can add new functionality to existing interfaces but maintain binary compatibility with code written for older versions of those interfaces. Shared functionality for default methods may be placed in private methods.
- Static methods provide a mechanism to associate methods directly an interface class without it impacting the OO contracts or being overridden. You could use them for writing factory or utility methods without creating an additional utility class.

Class members

Constructors

Constructors are special methods used to initialize an object with a specific state. As with normal methods, it is possible for a class to declare more than one constructor, so long as each constructor has a unique type signature. If an object doesn't require any parameters during construction, it may use a *no-arg* constructor. If no constructors are supplied, an empty no-arg constructor will be provided by the Groovy compiler.

Groovy supports two invocation styles:

- *positional parameters* are used in a similar to how you would use Java constructors
- *named parameters* allow you to specify parameter names when invoking the constructor.

Positional parameters

To create an object by using positional parameters, the respective class needs to declare one or more constructors. In the case of multiple constructors, each must have a unique type signature. The constructors can also be added to the class using the groovy.transform.TupleConstructor annotation.

Typically, once at least one constructor is declared, the class can only be instantiated by having one of its constructors called. It is worth noting that, in this case, you can't normally create the class with named parameters. Groovy does support named parameters so long as the class contains a no-arg constructor or provides a constructor which takes a `Map` argument as the first (and potentially only) argument - see the next section for details.

There are three forms of using a declared constructor. The first one is the normal Java way, with the `new` keyword. The others rely on coercion of lists into the desired types. In this case, it is possible to coerce with the `as` keyword and by statically typing the variable.

```
class PersonConstructor {
    String name
    Integer age

    PersonConstructor(name, age) {          ①
        this.name = name
        this.age = age
    }
}

def person1 = new PersonConstructor('Marie', 1)  ②
def person2 = ['Marie', 2] as PersonConstructor  ③
PersonConstructor person3 = ['Marie', 3]         ④
```

① Constructor declaration

② Constructor invocation, classic Java way

③ Constructor usage, using coercion with `as` keyword

④ Constructor usage, using coercion in assignment

Named parameters

If no (or a no-arg) constructor is declared, it is possible to create objects by passing parameters in the form of a map (property/value pairs). This can be in handy in cases where one wants to allow several combinations of parameters. Otherwise, by using traditional positional parameters it would be necessary to declare all possible constructors. Having a constructor where the first (and perhaps only) argument is a `Map` argument is also supported - such a constructor may also be added using the groovy.transform.MapConstructor annotation.

```
class PersonWOConstructor {                                  ①
    String name
    Integer age
}

def person4 = new PersonWOConstructor()                      ②
def person5 = new PersonWOConstructor(name: 'Marie')         ③
def person6 = new PersonWOConstructor(age: 1)                ④
```

```
def person7 = new PersonWOConstructor(name: 'Marie', age: 2) ⑤
```

① No constructor declared

② No parameters given in the instantiation

③ `name` parameter given in the instantiation

④ `age` parameter given in the instantiation

⑤ `name` and `age` parameters given in the instantiation

It is important to highlight, however, that this approach gives more power to the constructor caller, while imposing an increased responsibility on the caller to get the names and value types correct. Thus, if greater control is desired, declaring constructors using positional parameters might be preferred.

Notes:

- While the example above supplied no constructor, you can also supply a no-arg constructor or a constructor where the first argument is a `Map`, most typically it's the only argument.
- When no (or a no-arg) constructor is declared, Groovy replaces the named constructor call by a call to the no-arg constructor followed by calls to the setter for each supplied named property.
- When the first argument is a Map, Groovy combines all named parameters into a Map (regardless of ordering) and supplies the map as the first parameter. This can be a good approach if your properties are declared as `final` (since they will be set in the constructor rather than after the fact with setters).
- You can support both named and positional construction by supply both positional constructors as well as a no-arg or Map constructor.
- You can support hybrid construction by having a constructor where the first argument is a Map but there are also additional positional parameters. Use this style with caution.

Methods

Groovy methods are quite similar to other languages. Some peculiarities will be shown in the next subsections.

Method definition

A method is defined with a return type or with the `def` keyword, to make the return type untyped. A method can also receive any number of arguments, which may not have their types explicitly declared. Java modifiers can be used normally, and if no visibility modifier is provided, the method is public.

Methods in Groovy always return some value. If no `return` statement is provided, the value evaluated in the last line executed will be returned. For instance, note that none of the following methods uses the `return` keyword.

```
def someMethod() { 'method called' }                      ①
String anotherMethod() { 'another method called' }        ②
```

```
def thirdMethod(param1) { "$param1 passed" }                ③
static String fourthMethod(String param1) { "$param1 passed" } ④
```

① Method with no return type declared and no parameter

② Method with explicit return type and no parameter

③ Method with a parameter with no type defined

④ Static method with a String parameter

Named parameters

Like constructors, normal methods can also be called with named parameters. To support this notation, a convention is used where the first argument to the method is a `Map`. In the method body, the parameter values can be accessed as in normal maps (`map.key`). If the method has just a single Map argument, all supplied parameters must be named.

```
def foo(Map args) { "${args.name}: ${args.age}" }
foo(name: 'Marie', age: 1)
```

Mixing named and positional parameters

Named parameters can be mixed with positional parameters. The same convention applies, in this case, in addition to the `Map` argument as the first argument, the method in question will have additional positional arguments as needed. Supplied positional parameters when calling the method must be in order. The named parameters can be in any position. They are grouped into the map and supplied as the first parameter automatically.

```
def foo(Map args, Integer number) { "${args.name}: ${args.age}, and the number is
${number}" }
foo(name: 'Marie', age: 1, 23)  ①
foo(23, name: 'Marie', age: 1)  ②
```

① Method call with additional `number` argument of `Integer` type

② Method call with changed order of arguments

If we don't have the Map as the first argument, then a Map must be supplied for that argument instead of named parameters. Failure to do so will lead to `groovy.lang.MissingMethodException`:

```
def foo(Integer number, Map args) { "${args.name}: ${args.age}, and the number is
${number}" }
foo(name: 'Marie', age: 1, 23)  ①
```

① Method call throws `groovy.lang.MissingMethodException: No signature of method: foo() is applicable for argument types: (LinkedHashMap, Integer) values: [[name:Marie, age:1], 23]`, because the named argument `Map` parameter is not defined as the first argument

Above exception can be avoided if we replace named arguments with an explicit `Map` argument:

```
def foo(Integer number, Map args) { "${args.name}: ${args.age}, and the number is
${number}" }
foo(23, [name: 'Marie', age: 1])  ①
```

① Explicit `Map` argument in place of named arguments makes invocation valid

> **TIP** Although Groovy allows you to mix named and positional parameters, it can lead to unnecessary confusion. Mix named and positional arguments with caution.

Default arguments

Default arguments make parameters optional. If the argument is not supplied, the method assumes a default value.

```
def foo(String par1, Integer par2 = 1) { [name: par1, age: par2] }
assert foo('Marie').age == 1
```

Parameters are dropped from the right, however mandatory parameters are never dropped.

```
def baz(a = 'a', int b, c = 'c', boolean d, e = 'e') { "$a $b $c $d $e" }

assert baz(42, true) == 'a 42 c true e'
assert baz('A', 42, true) == 'A 42 c true e'
assert baz('A', 42, 'C', true) == 'A 42 C true e'
assert baz('A', 42, 'C', true, 'E') == 'A 42 C true E'
```

The same rule applies to constructors as well as methods. If using `@TupleConstructor`, additional configuration options apply.

Varargs

Groovy supports methods with a variable number of arguments. They are defined like this: `def foo(p1, …, pn, T… args)`. Here `foo` supports `n` arguments by default, but also an unspecified number of further arguments exceeding `n`.

```
def foo(Object... args) { args.length }
assert foo() == 0
assert foo(1) == 1
assert foo(1, 2) == 2
```

This example defines a method `foo`, that can take any number of arguments, including no arguments at all. `args.length` will return the number of arguments given. Groovy allows `T[]` as an alternative notation to `T…`. That means any method with an array as last parameter is seen by Groovy as a method that can take a variable number of arguments.

```
def foo(Object[] args) { args.length }
assert foo() == 0
assert foo(1) == 1
assert foo(1, 2) == 2
```

If a method with varargs is called with `null` as the vararg parameter, then the argument will be `null` and not an array of length one with `null` as the only element.

```
def foo(Object... args) { args }
assert foo(null) == null
```

If a varargs method is called with an array as an argument, then the argument will be that array instead of an array of length one containing the given array as the only element.

```
def foo(Object... args) { args }
Integer[] ints = [1, 2]
assert foo(ints) == [1, 2]
```

Another important point are varargs in combination with method overloading. In case of method overloading Groovy will select the most specific method. For example if a method `foo` takes a varargs argument of type `T` and another method `foo` also takes one argument of type `T`, the second method is preferred.

```
def foo(Object... args) { 1 }
def foo(Object x) { 2 }
assert foo() == 1
assert foo(1) == 2
assert foo(1, 2) == 1
```

Method selection algorithm

Dynamic Groovy supports multiple dispatch (aka multimethods). When calling a method, the actual method invoked is determined dynamically based on the run-time type of methods arguments. First the method name and number of arguments will be considered (including allowance for varargs), and then the type of each argument. Consider the following method definitions:

```
def method(Object o1, Object o2) { 'o/o' }
def method(Integer i, String  s) { 'i/s' }
def method(String  s, Integer i) { 's/i' }
```

Perhaps as expected, calling `method` with `String` and `Integer` parameters, invokes our third method definition.

```
assert method('foo', 42) == 's/i'
```

Of more interest here is when the types are not known at compile time. Perhaps the arguments are declared to be of type `Object` (a list of such objects in our case). Java would determine that the `method(Object, Object)` variant would be selected in all cases (unless casts were used) but as can be seen in the following example, Groovy uses the runtime type and will invoke each of our methods once (and normally, no casting is needed):

```
List<List<Object>> pairs = [['foo', 1], [2, 'bar'], [3, 4]]
assert pairs.collect { a, b -> method(a, b) } == ['s/i', 'i/s', 'o/o']
```

For each of the first two of our three method invocations an exact match of argument types was found. For the third invocation, an exact match of `method(Integer, Integer)` wasn't found but `method(Object, Object)` is still valid and will be selected.

Method selection then is about finding the *closest fit* from valid method candidates which have compatible parameter types. So, `method(Object, Object)` is also valid for the first two invocations but is not as close a match as the variants where types exactly match. To determine the closest fit, the runtime has a notion of the *distance* an actual argument type is away from the declared parameter type and tries to minimise the total distance across all parameters.

The following table illustrates some factors which affect the distance calculation.

<table>
<tr><th>Aspect</th><th>Example</th></tr>
<tr><td>Directly implemented interfaces match more closely than ones from further up the inheritance hierarchy.</td><td>Given these interface and method definitions:
<pre>interface I1 {}
interface I2 extends I1 {}
interface I3 {}
class Clazz implements I3, I2 {}

def method(I1 i1) { 'I1' }
def method(I3 i3) { 'I3' }</pre>The directly implemented interface will match:
<pre>assert method(new Clazz()) == 'I3'</pre></td></tr>
<tr><td>An Object array is preferred over an Object.</td><td><pre>def method(Object[] arg) { 'array' }
def method(Object arg) { 'object' }

assert method([] as Object[]) == 'array'</pre></td></tr>
</table>

<table>
<tr><th>Aspect</th><th>Example</th></tr>
<tr><td>Non-vararg variants are favored over vararg variants.</td><td><pre>def method(String s, Object... vargs) {
'vararg' }
def method(String s) { 'non-vararg' }

assert method('foo') == 'non-vararg'</pre></td></tr>
<tr><td>If two vararg variants are applicable, the one which uses the minimum number of vararg arguments is preferred.</td><td><pre>def method(String s, Object... vargs) {
'two vargs' }
def method(String s, Integer i,
Object... vargs) { 'one varg' }

assert method('foo', 35, new Date()) ==
'one varg'</pre></td></tr>
<tr><td>Interfaces are preferred over super classes.</td><td><pre>interface I {}
class Base {}
class Child extends Base implements I {}

def method(Base b) { 'superclass' }
def method(I i) { 'interface' }

assert method(new Child()) ==
'interface'</pre></td></tr>
<tr><td>For a primitive argument type, a declared parameter type which is the same or slightly larger is preferred.</td><td><pre>def method(Long l) { 'Long' }
def method(Short s) { 'Short' }
def method(BigInteger bi) { 'BigInteger'
}

assert method(35) == 'Long'</pre></td></tr>
</table>

In the case where two variants have exactly the same distance, this is deemed ambiguous and will cause a runtime exception:

```
def method(Date d, Object o) { 'd/o' }
def method(Object o, String s) { 'o/s' }

def ex = shouldFail {
    println method(new Date(), 'baz')
}
assert ex.message.contains('Ambiguous method overloading')
```

Casting can be used to select the desired method:

```
assert method(new Date(), (Object)'baz') == 'd/o'
assert method((Object)new Date(), 'baz') == 'o/s'
```

Exception declaration

Groovy automatically allows you to treat checked exceptions like unchecked exceptions. This means that you don't need to declare any checked exceptions that a method may throw as shown in the following example which can throw a `FileNotFoundException` if the file isn't found:

```
def badRead() {
    new File('doesNotExist.txt').text
}

shouldFail(FileNotFoundException) {
    badRead()
}
```

Nor will you be required to surround the call to the `badRead` method in the previous example within a try/catch block - though you are free to do so if you wish.

If you wish to declare any exceptions that your code might throw (checked or otherwise) you are free to do so. Adding exceptions won't change how the code is used from any other Groovy code but can be seen as documentation for the human reader of your code. The exceptions will become part of the method declaration in the bytecode, so if your code might be called from Java, it might be useful to include them. Using an explicit checked exception declaration is illustrated in the following example:

```
def badRead() throws FileNotFoundException {
    new File('doesNotExist.txt').text
}

shouldFail(FileNotFoundException) {
    badRead()
}
```

Fields and Properties

Fields

A field is a member of a class, interface or trait which stores data. A field defined in a Groovy source file has:

- a mandatory *access modifier* (`public`, `protected`, or `private`)
- one or more optional *modifiers* (`static`, `final`, `synchronized`)
- an optional *type*
- a mandatory *name*

```
class Data {
    private int id                                  ①
    protected String description                    ②
    public static final boolean DEBUG = false       ③
}
```

① a `private` field named `id`, of type `int`

② a `protected` field named `description`, of type `String`

③ a `public static final` field named *DEBUG* of type `boolean`

A field may be initialized directly at declaration:

```
class Data {
    private String id = IDGenerator.next() ①
    // ...
}
```

① the private field `id` is initialized with `IDGenerator.next()`

It is possible to omit the type declaration of a field. This is however considered a bad practice and in general it is a good idea to use strong typing for fields:

```
class BadPractice {
    private mapping                         ①
}
class GoodPractice {
    private Map<String,String> mapping      ②
}
```

① the field `mapping` doesn't declare a type

② the field `mapping` has a strong type

The difference between the two is important if you want to use optional type checking later. It is also important as a way to document the class design. However, in some cases like scripting or if you want to rely on duck typing it may be useful to omit the type.

Properties

A property is an externally visible feature of a class. Rather than just using a public field to represent such features (which provides a more limited abstraction and would restrict refactoring possibilities), the typical approach in Java is to follow the conventions outlined in the JavaBeans Specification, i.e. represent the property using a combination of a private backing field and getters/setters. Groovy follows these same conventions but provides a simpler way to define the property. You can define a property with:

- an **absent** access modifier (no `public`, `protected` or `private`)
- one or more optional *modifiers* (`static`, `final`, `synchronized`)

- an optional *type*
- a mandatory *name*

Groovy will then generate the getters/setters appropriately. For example:

```
class Person {
    String name                             ①
    int age                                 ②
}
```

① creates a backing `private String name` field, a `getName` and a `setName` method

② creates a backing `private int age` field, a `getAge` and a `setAge` method

If a property is declared `final`, no setter is generated:

```
class Person {
    final String name                   ①
    final int age                       ②
    Person(String name, int age) {
        this.name = name                ③
        this.age = age                  ④
    }
}
```

① defines a read-only property of type `String`

② defines a read-only property of type `int`

③ assigns the `name` parameter to the `name` field

④ assigns the `age` parameter to the `age` field

Properties are accessed by name and will call the getter or setter transparently, unless the code is in the class which defines the property:

```
class Person {
    String name
    void name(String name) {
        this.name = "Wonder $name"      ①
    }
    String title() {
        this.name                       ②
    }
}
def p = new Person()
p.name = 'Diana'                        ③
assert p.name == 'Diana'                ④
p.name('Woman')                         ⑤
assert p.title() == 'Wonder Woman'      ⑥
```

① `this.name` will directly access the field because the property is accessed from within the class that defines it

② similarly a read access is done directly on the `name` field

③ write access to the property is done outside of the `Person` class so it will implicitly call `setName`

④ read access to the property is done outside of the `Person` class so it will implicitly call `getName`

⑤ this will call the `name` method on `Person` which performs a direct access to the field

⑥ this will call the `title` method on `Person` which performs a direct read access to the field

It is worth noting that this behavior of accessing the backing field directly is done in order to prevent a stack overflow when using the property access syntax within a class that defines the property.

It is possible to list the properties of a class thanks to the meta `properties` field of an instance:

```
class Person {
    String name
    int age
}
def p = new Person()
assert p.properties.keySet().containsAll(['name','age'])
```

By convention, Groovy will recognize properties even if there is no backing field provided there are getters or setters that follow the Java Beans specification. For example:

```
class PseudoProperties {
    // a pseudo property "name"
    void setName(String name) {}
    String getName() {}

    // a pseudo read-only property "age"
    int getAge() { 42 }

    // a pseudo write-only property "groovy"
    void setGroovy(boolean groovy) {  }
}
def p = new PseudoProperties()
p.name = 'Foo'                      ①
assert p.age == 42                  ②
p.groovy = true                     ③
```

① writing `p.name` is allowed because there is a pseudo-property `name`

② reading `p.age` is allowed because there is a pseudo-readonly property `age`

③ writing `p.groovy` is allowed because there is a pseudo-write-only property `groovy`

This syntactic sugar is at the core of many DSLs written in Groovy.

Property naming conventions

It is generally recommended that the first two letters of a property name are lowercase and for multi-word properties that camel case is used. In those cases, generated getters and setters will have a name formed by capitalizing the property name and adding a `get` or `set` prefix (or optionally "is" for a boolean getter). So, `getLength` would be a getter for a `length` property and `setFirstName` a setter for a `firstName` property. `isEmpty` might be the getter method name for a property named `empty`.

NOTE	Property names starting with a capital letter would have getters/setters with just the prefix added. So, the property `Foo` is allowed even though it isn't following the recommended naming conventions. For this property, the accessor methods would be `setFoo` and `getFoo`. A consequence of this is that you aren't allowed to have both a `foo` and a `Foo` property, since they would have the same named accessor methods.

The JavaBeans specification makes a special case for properties which typically might be acronyms. If the first two letters of a property name are uppercase, no capitalization is performed (or more importantly, no decapitalization is done if generating the property name from the accessor method name). So, `getURL` would be the getter for a `URL` property.

NOTE	Because of the special "acronym handling" property naming logic in the JavaBeans specification, the conversion to and from a property name are non-symmetrical. This leads to some strange edge cases. Groovy adopts a naming convention that avoids one ambiguity that might seem a little strange but was popular at the time of Groovy's design and has remained (so far) for historical reasons. Groovy looks at the second letter of a property name. If that is a capital, the property is deemed to be one of the acronym style properties and no capitalization is done, otherwise normal capitalization is done. Although we *never* recommend it, it does allow you to have what might seem like "duplicate named" properties, e.g. you can have `aProp` and `AProp`, or `pNAME` and `PNAME`. The getters would be `getaProp` and `getAProp`, and `getpNAME` and `getPNAME` respectively.

Modifiers on a property

We have already seen that properties are defined by omitting the visibility modifier. In general, any other modifiers, e.g. `transient` would be copied across to the field. Two special cases are worth noting:

- `final`, which we saw earlier is for read-only properties, is copied onto the backing field but also causes no setter to be defined
- `static` is copied onto the backing field but also causes the accessor methods to be static

If you wish to have a modifier like `final` also carried over to the accessor methods, you can write your properties long hand or consider using a split property definition.

Annotations on a property

Annotations, including those associated with AST transforms, are copied on to the backing field for the property. This allows AST transforms which are applicable to fields to be applied to properties, e.g.:

```
class Animal {
    int lowerCount = 0
    @Lazy String name = { lower().toUpperCase() }()
    String lower() { lowerCount++; 'sloth' }
}

def a = new Animal()
assert a.lowerCount == 0  ①
assert a.name == 'SLOTH'  ②
assert a.lowerCount == 1  ③
```

① Confirms no eager initialization

② Normal property access

③ Confirms initialization upon property access

Split property definition with an explicit backing field

Groovy's property syntax is a convenient shorthand when your class design follows certain conventions which align with common JavaBean practice. If your class doesn't exactly fit these conventions, you can certainly write the getter, setter and backing field long hand like you would in Java. However, Groovy does provide a split definition capability which still provides a shortened syntax while allowing slight adjustments to the conventions. For a split definition, you write a field and a property with the same name and type. Only one of the field or property may have an initial value.

For split properties, annotations on the field remain on the backing field for the property. Annotations on the property part of the definition are copied onto the getter and setter methods.

This mechanism allows a number of common variations that property users may wish to use if the standard property definition doesn't exactly fit their needs. For example, if the backing field should be `protected` rather than `private`:

```
class HasPropertyWithProtectedField {
    protected String name  ①
    String name            ②
}
```

① Protected backing field for name property instead of normal private one

② Declare name property

Or, the same example but with a package-private backing field:

```
class HasPropertyWithPackagePrivateField {
    String name                ①
```

```
    @PackageScope String name  ②
}
```

① Declare name property

② Package-private backing field for name property instead of normal private one

As a final example, we may wish to apply method-related AST transforms, or in general, any annotation to the setters/getters, e.g. to have the accessors be synchronized:

```
class HasPropertyWithSynchronizedAccessorMethods {
    private String name        ①
    @Synchronized String name  ②
}
```

① Backing field for name property

② Declare name property with annotation for setter/getter

Explicit accessor methods

The automatic generation of accessor methods doesn't occur if there is an explicit definition of the getter or setter in the class. This allows you to modify the normal behavior of such a getter or setter if needed. Inherited accessor methods aren't normally considered but if an inherited accessor method is marked final, that will also cause no generation of an additional accessor method to honor the `final` requirement of no subclassing of such methods.

Annotations

Annotation definition

An annotation is a kind of special interface dedicated at annotating elements of the code. An annotation is a type which superinterface is the java.lang.annotation.Annotation interface. Annotations are declared in a very similar way to interfaces, using the `@interface` keyword:

```
@interface SomeAnnotation {}
```

An annotation may define members in the form of methods without bodies and an optional default value. The possible member types are limited to:

- primitive types
- java.lang.String
- java.lang.Class
- an java.lang.Enum
- another java.lang.annotation.Annotation
- or any array of the above

For example:

```
@interface SomeAnnotation {
    String value()                      ①
}
@interface SomeAnnotation {
    String value() default 'something'      ②
}
@interface SomeAnnotation {
    int step()                          ③
}
@interface SomeAnnotation {
    Class appliesTo()                   ④
}
@interface SomeAnnotation {}
@interface SomeAnnotations {
    SomeAnnotation[] value()            ⑤
}
enum DayOfWeek { mon, tue, wed, thu, fri, sat, sun }
@interface Scheduled {
    DayOfWeek dayOfWeek()               ⑥
}
```

① an annotation defining a `value` member of type `String`

② an annotation defining a `value` member of type `String` with a default value of `something`

③ an annotation defining a `step` member of type the primitive type `int`

④ an annotation defining a `appliesTo` member of type `Class`

⑤ an annotation defining a `value` member which type is an array of another annotation type

⑥ an annotation defining a `dayOfWeek` member which type is the enumeration type `DayOfWeek`

Unlike in the Java language, in Groovy, an annotation can be used to alter the semantics of the language. It is especially true of AST transformations which will generate code based on annotations.

Annotation placement

An annotation can be applied on various elements of the code:

```
@SomeAnnotation                 ①
void someMethod() {
    // ...
}

@SomeAnnotation                 ②
class SomeClass {}

@SomeAnnotation String someVar  ③
```

① `@SomeAnnotation` applies to the `someMethod` method

② `@SomeAnnotation` applies to the `SomeClass` class

③ `@SomeAnnotation` applies to the `someVar` variable

In order to limit the scope where an annotation can be applied, it is necessary to declare it on the annotation definition, using the java.lang.annotation.Target annotation. For example, here is how you would declare that an annotation can be applied to a class or a method:

```
import java.lang.annotation.ElementType
import java.lang.annotation.Target

@Target([ElementType.METHOD, ElementType.TYPE])     ①
@interface SomeAnnotation {}                        ②
```

① the `@Target` annotation is meant to annotate an annotation with a scope.

② `@SomeAnnotation` will therefore only be allowed on `TYPE` or `METHOD`

The list of possible targets is available in the java.lang.annotation.ElementType.

WARNING	Groovy does not support the java.lang.annotation.ElementType#TYPE_PARAMETER and java.lang.annotation.ElementType#TYPE_PARAMETER element types which were introduced in Java 8.

Annotation member values

When an annotation is used, it is required to set at least all members that do not have a default value. For example:

```
@interface Page {
    int statusCode()
}

@Page(statusCode=404)
void notFound() {
    // ...
}
```

However it is possible to omit `value=` in the declaration of the value of an annotation if the member `value` is the only one being set:

```
@interface Page {
    String value()
    int statusCode() default 200
}
```

```
@Page(value='/home')                    ①
void home() {
    // ...
}

@Page('/users')                         ②
void userList() {
    // ...
}

@Page(value='error',statusCode=404)     ③
void notFound() {
    // ...
}
```

① we can omit the `statusCode` because it has a default value, but `value` needs to be set

② since `value` is the only mandatory member without a default, we can omit `value=`

③ if both `value` and `statusCode` need to be set, it is required to use `value=` for the default `value` member

Retention policy

The visibility of an annotation depends on its retention policy. The retention policy of an annotation is set using the java.lang.annotation.Retention annotation:

```
import java.lang.annotation.Retention
import java.lang.annotation.RetentionPolicy

@Retention(RetentionPolicy.SOURCE)                  ①
@interface SomeAnnotation {}                        ②
```

① the `@Retention` annotation annotates the `@SomeAnnotation` annotation

② so `@SomeAnnotation` will have a `SOURCE` retention

The list of possible retention targets and description is available in the java.lang.annotation.RetentionPolicy enumeration. The choice usually depends on whether you want an annotation to be visible at compile time or runtime.

Closure annotation parameters

An interesting feature of annotations in Groovy is that you can use a closure as an annotation value. Therefore annotations may be used with a wide variety of expressions and still have IDE support. For example, imagine a framework where you want to execute some methods based on environmental constraints like the JDK version or the OS. One could write the following code:

```
class Tasks {
    Set result = []
    void alwaysExecuted() {
```

```
        result << 1
    }
    @OnlyIf({ jdk>=6 })
    void supportedOnlyInJDK6() {
        result << 'JDK 6'
    }
    @OnlyIf({ jdk>=7 && windows })
    void requiresJDK7AndWindows() {
        result << 'JDK 7 Windows'
    }
}
```

For the `@OnlyIf` annotation to accept a `Closure` as an argument, you only have to declare the `value` as a `Class`:

```
@Retention(RetentionPolicy.RUNTIME)
@interface OnlyIf {
    Class value()                    ①
}
```

To complete the example, let's write a sample runner that would use that information:

```
class Runner {
    static <T> T run(Class<T> taskClass) {
        def tasks = taskClass.newInstance()                                              ①
        def params = [jdk: 6, windows: false]                                            ②
        tasks.class.declaredMethods.each { m ->                                          ③
            if (Modifier.isPublic(m.modifiers) && m.parameterTypes.length == 0) {        ④
                def onlyIf = m.getAnnotation(OnlyIf)                                     ⑤
                if (onlyIf) {
                    Closure cl = onlyIf.value().newInstance(tasks,tasks)                 ⑥
                    cl.delegate = params                                                 ⑦
                    if (cl()) {                                                          ⑧
                        m.invoke(tasks)                                                  ⑨
                    }
                } else {
                    m.invoke(tasks)                                                      ⑩
                }
            }
        }
        tasks                                                                            ⑪
    }
}
```

① create a new instance of the class passed as an argument (the task class)

② emulate an environment which is JDK 6 and not Windows

③ iterate on all declared methods of the task class

④ if the method is public and takes no arguments

⑤ try to find the `@OnlyIf` annotation

⑥ if it is found get the `value` and create a new `Closure` out of it

⑦ set the `delegate` of the closure to our environment variable

⑧ call the closure, which is the annotation closure. It will return a `boolean`

⑨ if it is `true`, call the method

⑩ if the method is not annotated with `@OnlyIf`, execute the method anyway

⑪ after that, return the task object

Then the runner can be used this way:

```
def tasks = Runner.run(Tasks)
assert tasks.result == [1, 'JDK 6'] as Set
```

Meta-annotations

Declaring meta-annotations

Meta-annotations, also known as annotation aliases are annotations that are replaced at compile time by other annotations (one meta-annotation is an alias for one or more annotations). Meta-annotations can be used to reduce the size of code involving multiple annotations.

Let's start with a simple example. Imagine you have the `@Service` and `@Transactional` annotations and that you want to annotate a class with both:

```
@Service
@Transactional
class MyTransactionalService {}
```

Given the multiplication of annotations that you could add to the same class, a meta-annotation could help by reducing the two annotations with a single one having the very same semantics. For example, we might want to write this instead:

```
@TransactionalService                              ①
class MyTransactionalService {}
```

① `@TransactionalService` is a meta-annotation

A meta-annotation is declared as a regular annotation but annotated with `@AnnotationCollector` and the list of annotations it is collecting. In our case, the `@TransactionalService` annotation can be written:

```
import groovy.transform.AnnotationCollector
```

```
@Service                                       ①
@Transactional                                 ②
@AnnotationCollector                           ③
@interface TransactionalService {
}
```

① annotate the meta-annotation with `@Service`

② annotate the meta-annotation with `@Transactional`

③ annotate the meta-annotation with `@AnnotationCollector`

Behavior of meta-annotations

Groovy supports both *precompiled* and *source form* meta-annotations. This means that your meta-annotation *may* be precompiled, or you can have it in the same source tree as the one you are currently compiling.

INFO: Meta-annotations are a Groovy-only feature. There is no chance for you to annotate a Java class with a meta-annotation and hope it will do the same as in Groovy. Likewise, you cannot write a meta-annotation in Java: both the meta-annotation definition **and** usage have to be Groovy code. But you can happily collect Java annotations and Groovy annotations within your meta-annotation.

When the Groovy compiler encounters a class annotated with a meta-annotation, it **replaces** it with the collected annotations. So, in our previous example, it will replace `@TransactionalService` with `@Transactional` and `@Service`:

```
def annotations = MyTransactionalService.annotations*.annotationType()
assert (Service in annotations)
assert (Transactional in annotations)
```

The conversion from a meta-annotation to the collected annotations is performed during the *semantic analysis* compilation phase.

In addition to replacing the alias with the collected annotations, a meta-annotation is capable of processing them, including arguments.

Meta-annotation parameters

Meta-annotations can collect annotations which have parameters. To illustrate this, we will imagine two annotations, each of them accepting one argument:

```
@Timeout(after=3600)
@Dangerous(type='explosive')
```

And suppose that you want to create a meta-annotation named `@Explosive`:

```
@Timeout(after=3600)
@Dangerous(type='explosive')
```

```
@AnnotationCollector
public @interface Explosive {}
```

By default, when the annotations are replaced, they will get the annotation parameter values **as they were defined in the alias**. More interesting, the meta-annotation supports overriding specific values:

```
@Explosive(after=0)                 ①
class Bomb {}
```

① the `after` value provided as a parameter to `@Explosive` overrides the one defined in the `@Timeout` annotation

If two annotations define the same parameter name, the default processor will copy the annotation value to all annotations that accept this parameter:

```
@Retention(RetentionPolicy.RUNTIME)
public @interface Foo {
   String value()                                  ①
}
@Retention(RetentionPolicy.RUNTIME)
public @interface Bar {
    String value()                                 ②
}

@Foo
@Bar
@AnnotationCollector
public @interface FooBar {}                        ③

@Foo('a')
@Bar('b')
class Bob {}                                       ④

assert Bob.getAnnotation(Foo).value() == 'a'       ⑤
println Bob.getAnnotation(Bar).value() == 'b'      ⑥

@FooBar('a')
class Joe {}                                       ⑦
assert Joe.getAnnotation(Foo).value() == 'a'       ⑧
println Joe.getAnnotation(Bar).value() == 'a'      ⑨
```

① the `@Foo` annotation defines the `value` member of type `String`

② the `@Bar` annotation also defines the `value` member of type `String`

③ the `@FooBar` meta-annotation aggregates `@Foo` and `@Bar`

④ class `Bob` is annotated with `@Foo` and `@Bar`

⑤ the value of the `@Foo` annotation on `Bob` is `a`

⑥ while the value of the `@Bar` annotation on `Bob` is `b`

⑦ class `Joe` is annotated with `@FooBar`

⑧ then the value of the `@Foo` annotation on `Joe` is `a`

⑨ and the value of the `@Bar` annotation on `Joe` is also `a`

In the second case, the meta-annotation value was copied in both `@Foo` and `@Bar` annotations.

WARNING	It is a compile time error if the collected annotations define the same members with incompatible types. For example if on the previous example `@Foo` defined a value of type `String` but `@Bar` defined a value of type `int`.

It is however possible to customize the behavior of meta-annotations and describe how collected annotations are expanded. We'll look at how to do that shortly but first there is an advanced processing option to cover.

Handling duplicate annotations in meta-annotations

The `@AnnotationCollector` annotation supports a `mode` parameter which can be used to alter how the default processor handles annotation replacement in the presence of duplicate annotations.

INFO: Custom processors (discussed next) may or may not support this parameter.

As an example, suppose you create a meta-annotation containing the `@ToString` annotation and then place your meta-annotation on a class that already has an explicit `@ToString` annotation. Should this be an error? Should both annotations be applied? Does one take priority over the other? There is no correct answer. In some scenarios it might be quite appropriate for any of these answers to be correct. So, rather than trying to preempt one correct way to handle the duplicate annotation issue, Groovy lets you write your own custom meta-annotation processors (covered next) and lets you write whatever checking logic you like within AST transforms - which are a frequent target for aggregating. Having said that, by simply setting the `mode`, a number of commonly expected scenarios are handled automatically for you within any extra coding. The behavior of the `mode` parameter is determined by the `AnnotationCollectorMode` enum value chosen and is summarized in the following table.

Mode	Description
DUPLICATE	Annotations from the annotation collection will always be inserted. After all transforms have been run, it will be an error if multiple annotations (excluding those with SOURCE retention) exist.
PREFER_COLLECTOR	Annotations from the collector will be added and any existing annotations with the same name will be removed.

PREFER_COLLECTOR_MERGED	Annotations from the collector will be added and any existing annotations with the same name will be removed but any new parameters found within existing annotations will be merged into the added annotation.
PREFER_EXPLICIT	Annotations from the collector will be ignored if any existing annotations with the same name are found.
PREFER_EXPLICIT_MERGED	Annotations from the collector will be ignored if any existing annotations with the same name are found but any new parameters on the collector annotation will be added to existing annotations.

Custom meta-annotation processors

A custom annotation processor will let you choose how to expand a meta-annotation into collected annotations. The behaviour of the meta-annotation is, in this case, totally up to you. To do this, you must:

- create a meta-annotation processor, extending org.codehaus.groovy.transform.AnnotationCollectorTransform
- declare the processor to be used in the meta-annotation declaration

To illustrate this, we are going to explore how the meta-annotation `@CompileDynamic` is implemented.

`@CompileDynamic` is a meta-annotation that expands itself to `@CompileStatic(TypeCheckingMode.SKIP)`. The problem is that the default meta annotation processor doesn't support enums and the annotation value `TypeCheckingMode.SKIP` is one.

The naive implementation here would not work:

```
@CompileStatic(TypeCheckingMode.SKIP)
@AnnotationCollector
public @interface CompileDynamic {}
```

Instead, we will define it like this:

```
@AnnotationCollector(processor =
"org.codehaus.groovy.transform.CompileDynamicProcessor")
public @interface CompileDynamic {
}
```

The first thing you may notice is that our interface is no longer annotated with `@CompileStatic`. The reason for this is that we rely on the `processor` parameter instead, that references a class which will **generate** the annotation.

Here is how the custom processor is implemented:

CompileDynamicProcessor.groovy

```
@CompileStatic                                                                              ①
class CompileDynamicProcessor extends AnnotationCollectorTransform {                        ②
    private static final ClassNode CS_NODE = ClassHelper.make(CompileStatic)                ③
    private static final ClassNode TC_NODE = ClassHelper.make(TypeCheckingMode)             ④

    List<AnnotationNode> visit(AnnotationNode collector,                                    ⑤
                               AnnotationNode aliasAnnotationUsage,                         ⑥
                               AnnotatedNode aliasAnnotated,                                ⑦
                               SourceUnit source) {                                         ⑧
        def node = new AnnotationNode(CS_NODE)                                              ⑨
        def enumRef = new PropertyExpression(
            new ClassExpression(TC_NODE), "SKIP")                                           ⑩
        node.addMember("value", enumRef)                                                    ⑪
        Collections.singletonList(node)                                                     ⑫
    }
}
```

① our custom processor is written in Groovy, and for better compilation performance, we use static compilation

② the custom processor has to extend org.codehaus.groovy.transform.AnnotationCollectorTransform

③ create a class node representing the `@CompileStatic` annotation type

④ create a class node representing the `TypeCheckingMode` enum type

⑤ `collector` is the `@AnnotationCollector` node found in the meta-annotation. Usually unused.

⑥ `aliasAnnotationUsage` is the meta-annotation being expanded, here it is `@CompileDynamic`

⑦ `aliasAnnotated` is the node being annotated with the meta-annotation

⑧ `sourceUnit` is the `SourceUnit` being compiled

⑨ we create a new annotation node for `@CompileStatic`

⑩ we create an expression equivalent to `TypeCheckingMode.SKIP`

⑪ we add that expression to the annotation node, which is now `@CompileStatic(TypeCheckingMode.SKIP)`

⑫ return the generated annotation

In the example, the `visit` method is the only method which has to be overridden. It is meant to return a list of annotation nodes that will be added to the node annotated with the meta-annotation. In this example, we return a single one corresponding to `@CompileStatic(TypeCheckingMode.SKIP)`.

Traits

Traits are a structural construct of the language which allows:

- composition of behaviors
- runtime implementation of interfaces
- behavior overriding
- compatibility with static type checking/compilation

They can be seen as **interfaces** carrying both **default implementations** and **state**. A trait is defined using the `trait` keyword:

```
trait FlyingAbility {                           ①
        String fly() { "I'm flying!" }          ②
}
```

① declaration of a trait

② declaration of a method inside a trait

Then it can be used like a normal interface using the `implements` keyword:

```
class Bird implements FlyingAbility {}          ①
def b = new Bird()                              ②
assert b.fly() == "I'm flying!"                 ③
```

① Adds the trait `FlyingAbility` to the `Bird` class capabilities

② instantiate a new `Bird`

③ the `Bird` class automatically gets the behavior of the `FlyingAbility` trait

Traits allow a wide range of capabilities, from simple composition to testing, which are described thoroughly in this section.

Methods

Public methods

Declaring a method in a trait can be done like any regular method in a class:

```
trait FlyingAbility {                           ①
        String fly() { "I'm flying!" }          ②
}
```

① declaration of a trait

② declaration of a method inside a trait

Abstract methods

In addition, traits may declare *abstract* methods too, which therefore need to be implemented in the class implementing the trait:

```
trait Greetable {
    abstract String name()                              ①
    String greeting() { "Hello, ${name()}!" }           ②
}
```

① implementing class will have to declare the `name` method

② can be mixed with a concrete method

Then the trait can be used like this:

```
class Person implements Greetable {                     ①
    String name() { 'Bob' }                             ②
}

def p = new Person()
assert p.greeting() == 'Hello, Bob!'                    ③
```

① implement the trait `Greetable`

② since `name` was abstract, it is required to implement it

③ then `greeting` can be called

Private methods

Traits may also define private methods. Those methods will not appear in the trait contract interface:

```
trait Greeter {
    private String greetingMessage() {                      ①
        'Hello from a private method!'
    }
    String greet() {
        def m = greetingMessage()                           ②
        println m
        m
    }
}
class GreetingMachine implements Greeter {}                 ③
def g = new GreetingMachine()
assert g.greet() == "Hello from a private method!"          ④
try {
    assert g.greetingMessage()                              ⑤
} catch (MissingMethodException e) {
    println "greetingMessage is private in trait"
}
```

① define a private method `greetingMessage` in the trait

② the public `greet` message calls `greetingMessage` by default

③ create a class implementing the trait

④ `greet` can be called

⑤ but not `greetingMessage`

WARNING Traits only support `public` and `private` methods. Neither `protected` nor `package private` scopes are supported.

Final methods

If we have a class implementing a trait, conceptually implementations from the trait methods are "inherited" into the class. But, in reality, there is no base class containing such implementations. Rather, they are woven directly into the class. A final modifier on a method just indicates what the modifier will be for the woven method. While it would likely be considered bad style to inherit and override or multiply inherit methods with the same signature but a mix of final and non-final variants, Groovy doesn't prohibit this scenario. Normal method selection applies and the modifier used will be determined from the resulting method. You might consider creating a base class which implements the desired trait(s) if you want trait implementation methods that can't be overridden.

The meaning of this

`this` represents the implementing instance. Think of a trait as a superclass. This means that when you write:

```
trait Introspector {
    def whoAmI() { this }
}
class Foo implements Introspector {}
def foo = new Foo()
```

then calling:

```
foo.whoAmI()
```

will return the same instance:

```
assert foo.whoAmI().is(foo)
```

Interfaces

Traits may implement interfaces, in which case the interfaces are declared using the `implements` keyword:

```
interface Named {                                   ①
    String name()
```

```
}
trait Greetable implements Named {                     ②
    String greeting() { "Hello, ${name()}!" }
}
class Person implements Greetable {                    ③
    String name() { 'Bob' }                            ④
}

def p = new Person()
assert p.greeting() == 'Hello, Bob!'                   ⑤
assert p instanceof Named                              ⑥
assert p instanceof Greetable                          ⑦
```

① declaration of a normal interface

② add `Named` to the list of implemented interfaces

③ declare a class that implements the `Greetable` trait

④ implement the missing `name` method

⑤ the `greeting` implementation comes from the trait

⑥ make sure `Person` implements the `Named` interface

⑦ make sure `Person` implements the `Greetable` trait

Properties

A trait may define properties, like in the following example:

```
trait Named {
    String name                           ①
}
class Person implements Named {}          ②
def p = new Person(name: 'Bob')           ③
assert p.name == 'Bob'                    ④
assert p.getName() == 'Bob'               ⑤
```

① declare a property `name` inside a trait

② declare a class which implements the trait

③ the property is automatically made visible

④ it can be accessed using the regular property accessor

⑤ or using the regular getter syntax

Fields

Private fields

Since traits allow the use of private methods, it can also be interesting to use private fields to store state. Traits will let you do that:

```
trait Counter {
    private int count = 0                   ①
    int count() { count += 1; count }       ②
}
class Foo implements Counter {}             ③
def f = new Foo()
assert f.count() == 1                       ④
assert f.count() == 2
```

① declare a private field `count` inside a trait

② declare a public method `count` that increments the counter and returns it

③ declare a class that implements the `Counter` trait

④ the `count` method can use the private field to keep state

> **TIP** This is a major difference with Java 8 virtual extension methods. While virtual extension methods do not carry state, traits can. Moreover, traits in Groovy are supported starting with Java 6, because their implementation does not rely on virtual extension methods. This means that even if a trait can be seen from a Java class as a regular interface, that interface will **not** have default methods, only abstract ones.

Public fields

Public fields work the same way as private fields, but in order to avoid the diamond problem, field names are remapped in the implementing class:

```
trait Named {
    public String name                      ①
}
class Person implements Named {}            ②
def p = new Person()                        ③
p.Named__name = 'Bob'                       ④
```

① declare a public **field** inside the trait

② declare a class implementing the trait

③ create an instance of that class

④ the public field is available, but renamed

The name of the field depends on the fully qualified name of the trait. All dots (`.`) in package are replaced with an underscore (`_`), and the final name includes a double underscore. So if the type of the field is `String`, the name of the package is `my.package`, the name of the trait is `Foo` and the name of the field is `bar`, in the implementing class, the public field will appear as:

```
String my_package_Foo__bar
```

WARNING While traits support public fields, it is not recommended to use them and considered as a bad practice.

Composition of behaviors

Traits can be used to implement multiple inheritance in a controlled way. For example, we can have the following traits:

```
trait FlyingAbility {                           ①
        String fly() { "I'm flying!" }          ②
}
trait SpeakingAbility {
    String speak() { "I'm speaking!" }
}
```

And a class implementing both traits:

```
class Duck implements FlyingAbility, SpeakingAbility {} ①

def d = new Duck()                                      ②
assert d.fly() == "I'm flying!"                         ③
assert d.speak() == "I'm speaking!"                     ④
```

① the `Duck` class implements both `FlyingAbility` and `SpeakingAbility`

② creates a new instance of `Duck`

③ we can call the method `fly` from `FlyingAbility`

④ but also the method `speak` from `SpeakingAbility`

Traits encourage the reuse of capabilities among objects, and the creation of new classes by the composition of existing behavior.

Overriding default methods

Traits provide default implementations for methods, but it is possible to override them in the implementing class. For example, we can slightly change the example above, by having a duck which quacks:

```
class Duck implements FlyingAbility, SpeakingAbility {
    String quack() { "Quack!" }                         ①
    String speak() { quack() }                          ②
}

def d = new Duck()
assert d.fly() == "I'm flying!"                         ③
assert d.quack() == "Quack!"                            ④
assert d.speak() == "Quack!"                            ⑤
```

① define a method specific to Duck, named quack

② override the default implementation of speak so that we use quack instead

③ the duck is still flying, from the default implementation

④ quack comes from the Duck class

⑤ speak no longer uses the default implementation from SpeakingAbility

Extending traits

Simple inheritance

Traits may extend another trait, in which case you must use the extends keyword:

```
trait Named {
    String name                                         ①
}
trait Polite extends Named {                            ②
    String introduce() { "Hello, I am $name" }          ③
}
class Person implements Polite {}
def p = new Person(name: 'Alice')                       ④
assert p.introduce() == 'Hello, I am Alice'             ⑤
```

① the Named trait defines a single name property

② the Polite trait **extends** the Named trait

③ Polite adds a new method which has access to the name property of the super-trait

④ the name property is visible from the Person class implementing Polite

⑤ as is the introduce method

Multiple inheritance

Alternatively, a trait may extend multiple traits. In that case, all super traits must be declared in the implements clause:

```
trait WithId {                                          ①
    Long id
}
trait WithName {                                        ②
    String name
}
trait Identified implements WithId, WithName {}         ③
```

① WithId trait defines the id property

② WithName trait defines the name property

③ Identified is a trait which inherits both WithId and WithName

Duck typing and traits

Dynamic code

Traits can call any dynamic code, like a normal Groovy class. This means that you can, in the body of a method, call methods which are supposed to exist in an implementing class, without having to explicitly declare them in an interface. This means that traits are fully compatible with duck typing:

```
trait SpeakingDuck {
    String speak() { quack() }                  ①
}
class Duck implements SpeakingDuck {
    String methodMissing(String name, args) {
        "${name.capitalize()}!"                 ②
    }
}
def d = new Duck()
assert d.speak() == 'Quack!'                    ③
```

① the `SpeakingDuck` expects the `quack` method to be defined

② the `Duck` class does implement the method using *methodMissing*

③ calling the `speak` method triggers a call to `quack` which is handled by `methodMissing`

Dynamic methods in a trait

It is also possible for a trait to implement MOP methods like `methodMissing` or `propertyMissing`, in which case implementing classes will inherit the behavior from the trait, like in this example:

```
trait DynamicObject {                           ①
    private Map props = [:]
    def methodMissing(String name, args) {
        name.toUpperCase()
    }
    def propertyMissing(String name) {
        props.get(name)
    }
    void setProperty(String name, Object value) {
        props.put(name, value)
    }
}

class Dynamic implements DynamicObject {
    String existingProperty = 'ok'              ②
    String existingMethod() { 'ok' }            ③
}
def d = new Dynamic()
assert d.existingProperty == 'ok'               ④
assert d.foo == null                            ⑤
d.foo = 'bar'                                   ⑥
```

```
assert d.foo == 'bar'                                   ⑦
assert d.existingMethod() == 'ok'                       ⑧
assert d.someMethod() == 'SOMEMETHOD'                   ⑨
```

① create a trait implementing several MOP methods

② the `Dynamic` class defines a property

③ the `Dynamic` class defines a method

④ calling an existing property will call the method from `Dynamic`

⑤ calling a non-existing property will call the method from the trait

⑥ will call `setProperty` defined on the trait

⑦ will call `getProperty` defined on the trait

⑧ calling an existing method on `Dynamic`

⑨ but calling a non-existing method thanks to the trait `methodMissing`

Multiple inheritance conflicts

Default conflict resolution

It is possible for a class to implement multiple traits. If some trait defines a method with the same signature as a method in another trait, we have a conflict:

```
trait A {
    String exec() { 'A' }               ①
}
trait B {
    String exec() { 'B' }               ②
}
class C implements A,B {}               ③
```

① trait `A` defines a method named `exec` returning a `String`

② trait `B` defines the very same method

③ class `C` implements both traits

In this case, the default behavior is that the method from the **last declared trait** in the `implements` clause wins. Here, `B` is declared after `A` so the method from `B` will be picked up:

```
def c = new C()
assert c.exec() == 'B'
```

User conflict resolution

In case this behavior is not the one you want, you can explicitly choose which method to call using the `Trait.super.foo` syntax. In the example above, we can ensure the method from trait A is invoked by writing this:

```
class C implements A,B {
    String exec() { A.super.exec() }    ①
}
def c = new C()
assert c.exec() == 'A'                  ②
```

① explicit call of `exec` from the trait `A`

② calls the version from `A` instead of using the default resolution, which would be the one from `B`

Runtime implementation of traits

Implementing a trait at runtime

Groovy also supports implementing traits dynamically at runtime. It allows you to "decorate" an existing object using a trait. As an example, let's start with this trait and the following class:

```
trait Extra {
    String extra() { "I'm an extra method" }            ①
}
class Something {                                       ②
    String doSomething() { 'Something' }                ③
}
```

① the `Extra` trait defines an `extra` method

② the `Something` class does **not** implement the `Extra` trait

③ `Something` only defines a method `doSomething`

Then if we do:

```
def s = new Something()
s.extra()
```

the call to extra would fail because `Something` is not implementing `Extra`. It is possible to do it at runtime with the following syntax:

```
def s = new Something() as Extra                        ①
s.extra()                                               ②
s.doSomething()                                         ③
```

① use of the **as** keyword to coerce an object to a trait **at runtime**

② then `extra` can be called on the object

③ and `doSomething` is still callable

IMPORTANT	When coercing an object to a trait, the result of the operation is not the same instance. It is guaranteed that the coerced object will implement both the

trait **and** the interfaces that the original object implements, but the result will **not** be an instance of the original class.

Implementing multiple traits at once

Should you need to implement several traits at once, you can use the `withTraits` method instead of the `as` keyword:

```
trait A { void methodFromA() {} }
trait B { void methodFromB() {} }

class C {}

def c = new C()
c.methodFromA()                 ①
c.methodFromB()                 ②
def d = c.withTraits A, B       ③
d.methodFromA()                 ④
d.methodFromB()                 ⑤
```

① call to `methodFromA` will fail because `C` doesn't implement `A`

② call to `methodFromB` will fail because `C` doesn't implement `B`

③ `withTraits` will wrap `c` into something which implements `A` and `B`

④ `methodFromA` will now pass because `d` implements `A`

⑤ `methodFromB` will now pass because `d` also implements `B`

IMPORTANT	When coercing an object to multiple traits, the result of the operation is not the same instance. It is guaranteed that the coerced object will implement both the traits **and** the interfaces that the original object implements, but the result will **not** be an instance of the original class.

Chaining behavior

Groovy supports the concept of *stackable traits*. The idea is to delegate from one trait to the other if the current trait is not capable of handling a message. To illustrate this, let's imagine a message handler interface like this:

```
interface MessageHandler {
    void on(String message, Map payload)
}
```

Then you can compose a message handler by applying small behaviors. For example, let's define a default handler in the form of a trait:

```
trait DefaultHandler implements MessageHandler {
    void on(String message, Map payload) {
```

```
        println "Received $message with payload $payload"
    }
}
```

Then any class can inherit the behavior of the default handler by implementing the trait:

```
class SimpleHandler implements DefaultHandler {}
```

Now what if you want to log all messages, in addition to the default handler? One option is to write this:

```
class SimpleHandlerWithLogging implements DefaultHandler {
    void on(String message, Map payload) {                                  ①
        println "Seeing $message with payload $payload"                     ②
        DefaultHandler.super.on(message, payload)                           ③
    }
}
```

① explicitly implement the `on` method

② perform logging

③ continue by delegating to the `DefaultHandler` trait

This works but this approach has drawbacks:

1. the logging logic is bound to a "concrete" handler
2. we have an explicit reference to `DefaultHandler` in the `on` method, meaning that if we happen to change the trait that our class implements, code will be broken

As an alternative, we can write another trait which responsibility is limited to logging:

```
trait LoggingHandler implements MessageHandler {                            ①
    void on(String message, Map payload) {
        println "Seeing $message with payload $payload"                     ②
        super.on(message, payload)                                          ③
    }
}
```

① the logging handler is itself a handler

② prints the message it receives

③ then `super` makes it delegate the call to the next trait in the chain

Then our class can be rewritten as this:

```
class HandlerWithLogger implements DefaultHandler, LoggingHandler {}
def loggingHandler = new HandlerWithLogger()
```

```
loggingHandler.on('test logging', [:])
```

which will print:

```
Seeing test logging with payload [:]
Received test logging with payload [:]
```

As the priority rules imply that `LoggerHandler` wins because it is declared last, then a call to `on` will use the implementation from `LoggingHandler`. But the latter has a call to `super`, which means the next trait in the chain. Here, the next trait is `DefaultHandler` so **both** will be called:

The interest of this approach becomes more evident if we add a third handler, which is responsible for handling messages that start with `say`:

```
trait SayHandler implements MessageHandler {
    void on(String message, Map payload) {
        if (message.startsWith("say")) {                              ①
            println "I say ${message - 'say'}!"
        } else {
            super.on(message, payload)                                ②
        }
    }
}
```

① a handler specific precondition

② if the precondition is not met, pass the message to the next handler in the chain

Then our final handler looks like this:

```
class Handler implements DefaultHandler, SayHandler, LoggingHandler {}
def h = new Handler()
h.on('foo', [:])
h.on('sayHello', [:])
```

Which means:

- messages will first go through the logging handler
- the logging handler calls `super` which will delegate to the next handler, which is the `SayHandler`
- if the message starts with `say`, then the handler consumes the message
- if not, the `say` handler delegates to the next handler in the chain

This approach is very powerful because it allows you to write handlers that do not know each other and yet let you combine them in the order you want. For example, if we execute the code, it will print:

```
Seeing foo with payload [:]
Received foo with payload [:]
Seeing sayHello with payload [:]
I say Hello!
```

but if we move the logging handler to be the second one in the chain, the output is different:

```
class AlternateHandler implements DefaultHandler, LoggingHandler, SayHandler {}
h = new AlternateHandler()
h.on('foo', [:])
h.on('sayHello', [:])
```

prints:

```
Seeing foo with payload [:]
Received foo with payload [:]
I say Hello!
```

The reason is that now, since the `SayHandler` consumes the message without calling `super`, the logging handler is not called anymore.

Semantics of super inside a trait

If a class implements multiple traits and a call to an unqualified `super` is found, then:

1. if the class implements another trait, the call delegates to the next trait in the chain
2. if there isn't any trait left in the chain, `super` refers to the super class of the implementing class (*this*)

For example, it is possible to decorate final classes thanks to this behavior:

```
trait Filtering {                                       ①
    StringBuilder append(String str) {                  ②
        def subst = str.replace('o','')                 ③
        super.append(subst)                             ④
    }
    String toString() { super.toString() }              ⑤
}
def sb = new StringBuilder().withTraits Filtering       ⑥
sb.append('Groovy')
assert sb.toString() == 'Grvy'                          ⑦
```

① define a trait named `Filtering`, supposed to be applied on a `StringBuilder` at runtime

② redefine the `append` method

③ remove all 'o's from the string

④ then delegate to `super`

⑤ in case `toString` is called, delegate to `super.toString`

⑥ runtime implementation of the `Filtering` trait on a `StringBuilder` instance

⑦ the string which has been appended no longer contains the letter `o`

In this example, when `super.append` is encountered, there is no other trait implemented by the target object, so the method which is called is the original `append` method, that is to say the one from `StringBuilder`. The same trick is used for `toString`, so that the string representation of the proxy object which is generated delegates to the `toString` of the `StringBuilder` instance.

Advanced features

SAM type coercion

If a trait defines a single abstract method, it is candidate for SAM (Single Abstract Method) type coercion. For example, imagine the following trait:

```
trait Greeter {
    String greet() { "Hello $name" }        ①
    abstract String getName()               ②
}
```

① the `greet` method is not abstract and calls the abstract method `getName`

② `getName` is an abstract method

Since `getName` is the *single abstract method* in the `Greeter` trait, you can write:

```
Greeter greeter = { 'Alice' }               ①
```

① the closure "becomes" the implementation of the `getName` single abstract method

or even:

```
void greet(Greeter g) { println g.greet() } ①
greet { 'Alice' }                           ②
```

① the greet method accepts the SAM type Greeter as parameter

② we can call it directly with a closure

Differences with Java 8 default methods

In Java 8, interfaces can have default implementations of methods. If a class implements an interface and does not provide an implementation for a default method, then the implementation from the interface is chosen. Traits behave the same but with a major difference: the implementation from the trait is **always** used if the class declares the trait in its interface list **and** that it doesn't provide an implementation **even** if a super class does.

This feature can be used to compose behaviors in a very precise way, in case you want to override the behavior of an already implemented method.

To illustrate the concept, let's start with this simple example:

```
import groovy.test.GroovyTestCase
import groovy.transform.CompileStatic
import org.codehaus.groovy.control.CompilerConfiguration
import org.codehaus.groovy.control.customizers.ASTTransformationCustomizer
import org.codehaus.groovy.control.customizers.ImportCustomizer

class SomeTest extends GroovyTestCase {
    def config
    def shell

    void setup() {
        config = new CompilerConfiguration()
        shell = new GroovyShell(config)
    }
    void testSomething() {
        assert shell.evaluate('1+1') == 2
    }
    void otherTest() { /* ... */ }
}
```

In this example, we create a simple test case which uses two properties (*config* and *shell*) and uses those in multiple test methods. Now imagine that you want to test the same, but with another distinct compiler configuration. One option is to create a subclass of `SomeTest`:

```
class AnotherTest extends SomeTest {
    void setup() {
        config = new CompilerConfiguration()
        config.addCompilationCustomizers( ... )
        shell = new GroovyShell(config)
    }
}
```

It works, but what if you have actually multiple test classes, and that you want to test the new configuration for all those test classes? Then you would have to create a distinct subclass for each test class:

```
class YetAnotherTest extends SomeTest {
    void setup() {
        config = new CompilerConfiguration()
        config.addCompilationCustomizers( ... )
        shell = new GroovyShell(config)
    }
```

```
}
```

Then what you see is that the `setup` method of both tests is the same. The idea, then, is to create a trait:

```
trait MyTestSupport {
    void setup() {
        config = new CompilerConfiguration()
        config.addCompilationCustomizers( new ASTTransformationCustomizer
(CompileStatic) )
        shell = new GroovyShell(config)
    }
}
```

Then use it in the subclasses:

```
class AnotherTest extends SomeTest implements MyTestSupport {}
class YetAnotherTest extends SomeTest2 implements MyTestSupport {}
...
```

It would allow us to dramatically reduce the boilerplate code, and reduces the risk of forgetting to change the setup code in case we decide to change it. Even if `setup` is already implemented in the super class, since the test class declares the trait in its interface list, the behavior will be borrowed from the trait implementation!

This feature is in particular useful when you don't have access to the super class source code. It can be used to mock methods or force a particular implementation of a method in a subclass. It lets you refactor your code to keep the overridden logic in a single trait and inherit a new behavior just by implementing it. The alternative, of course, is to override the method in **every** place you would have used the new code.

IMPORTANT	It's worth noting that if you use runtime traits, the methods from the trait are **always** preferred to those of the proxied object:

```
class Person {
    String name                                         ①
}
trait Bob {
    String getName() { 'Bob' }                          ②
}

def p = new Person(name: 'Alice')
assert p.name == 'Alice'                                ③
def p2 = p as Bob                                       ④
assert p2.name == 'Bob'                                 ⑤
```

① the `Person` class defines a `name` property which results in a `getName` method

② `Bob` is a trait which defines `getName` as returning `Bob`

③ the default object will return *Alice*

④ `p2` coerces `p` into `Bob` at runtime

⑤ `getName` returns *Bob* because `getName` is taken from the **trait**

IMPORTANT	Again, don't forget that dynamic trait coercion returns a distinct object which only implements the original interfaces, as well as the traits.

Differences with mixins

There are several conceptual differences with mixins, as they are available in Groovy. Note that we are talking about runtime mixins, not the @Mixin annotation which is deprecated in favour of traits.

First of all, methods defined in a trait are visible in bytecode:

- internally, the trait is represented as an interface (without default or static methods) and several helper classes
- this means that an object implementing a trait effectively implements an *interface*
- those methods are visible from Java
- they are compatible with type checking and static compilation

Methods added through a mixin are, on the contrary, only visible at runtime:

```
class A { String methodFromA() { 'A' } }        ①
class B { String methodFromB() { 'B' } }        ②
A.metaClass.mixin B                             ③
def o = new A()
assert o.methodFromA() == 'A'                   ④
assert o.methodFromB() == 'B'                   ⑤
assert o instanceof A                           ⑥
assert !(o instanceof B)                        ⑦
```

① class `A` defines `methodFromA`

② class `B` defines `methodFromB`

③ mixin B into A

④ we can call `methodFromA`

⑤ we can also call `methodFromB`

⑥ the object is an instance of `A`

⑦ but it's **not** an instanceof `B`

The last point is actually a very important and illustrates a place where mixins have an advantage over traits: the instances are **not** modified, so if you mixin some class into another, there isn't a third class generated, and methods which respond to A will continue responding to A even if mixed in.

Static methods, properties and fields

WARNING	The following instructions are subject to caution. Static member support is work in progress and still experimental. The information below is valid for {groovyVersion} only.

It is possible to define static methods in a trait, but it comes with numerous limitations:

- Traits with static methods cannot be compiled statically or type checked. All static methods, properties and field are accessed dynamically (it's a limitation from the JVM).
- Static methods do not appear within the generated interfaces for each trait.
- The trait is interpreted as a *template* for the implementing class, which means that each implementing class will get its own static methods, properties and fields. So a static member declared on a trait doesn't belong to the `Trait`, but to its implementing class.
- You should typically not mix static and instance methods of the same signature. The normal rules for applying traits apply (including multiple inheritance conflict resolution). If the method chosen is static but some implemented trait has an instance variant, a compilation error will occur. If the method chosen is the instance variant, the static variant will be ignored (the behavior is similar to static methods in Java interfaces for this case).

Let's start with a simple example:

```
trait TestHelper {
    public static boolean CALLED = false        ①
    static void init() {                        ②
        CALLED = true                           ③
    }
}
class Foo implements TestHelper {}
Foo.init()                                      ④
assert Foo.TestHelper__CALLED                   ⑤
```

① the static field is declared in the trait

② a static method is also declared in the trait

③ the static field is updated *within* the trait

④ a static method *init* is made available to the implementing class

⑤ the static field is *remapped* to avoid the diamond issue

As usual, it is not recommended to use public fields. Anyway, should you want this, you must understand that the following code would fail:

```
Foo.CALLED = true
```

because there is *no* static field *CALLED* defined on the trait itself. Likewise, if you have two distinct implementing classes, each one gets a distinct static field:

```
class Bar implements TestHelper {}                 ①
class Baz implements TestHelper {}                 ②
Bar.init()                                         ③
assert Bar.TestHelper__CALLED                      ④
assert !Baz.TestHelper__CALLED                     ⑤
```

① class `Bar` implements the trait

② class `Baz` also implements the trait

③ `init` is only called on `Bar`

④ the static field `CALLED` on `Bar` is updated

⑤ but the static field `CALLED` on `Baz` is not, because it is **distinct**

Inheritance of state gotchas

We have seen that traits are stateful. It is possible for a trait to define fields or properties, but when a class implements a trait, it gets those fields/properties on a per-trait basis. So consider the following example:

```
trait IntCouple {
    int x = 1
    int y = 2
    int sum() { x+y }
}
```

The trait defines two properties, `x` and `y`, as well as a `sum` method. Now let's create a class which implements the trait:

```
class BaseElem implements IntCouple {
    int f() { sum() }
}
def base = new BaseElem()
assert base.f() == 3
```

The result of calling `f` is `3`, because `f` delegates to `sum` in the trait, which has state. But what if we write this instead?

```
class Elem implements IntCouple {
    int x = 3                                          ①
    int y = 4                                          ②
    int f() { sum() }                                  ③
}
```

```
def elem = new Elem()
```

① Override property x

② Override property y

③ Call sum from trait

If you call elem.f(), what is the expected output? Actually it is:

```
assert elem.f() == 3
```

The reason is that the sum method accesses the *fields* of the trait. So it is using the x and y values defined in the trait. If you want to use the values from the implementing class, then you need to dereference fields by using getters and setters, like in this last example:

```
trait IntCouple {
    int x = 1
    int y = 2
    int sum() { getX()+getY() }
}

class Elem implements IntCouple {
    int x = 3
    int y = 4
    int f() { sum() }
}
def elem = new Elem()
assert elem.f() == 7
```

Self types

Type constraints on traits

Sometimes you will want to write a trait that can only be applied to some type. For example, you may want to apply a trait on a class that extends another class which is beyond your control, and still be able to call those methods. To illustrate this, let's start with this example:

```
class CommunicationService {
    static void sendMessage(String from, String to, String message) {       ①
        println "$from sent [$message] to $to"
    }
}

class Device { String id }                                                   ②

trait Communicating {
    void sendMessage(Device to, String message) {
        CommunicationService.sendMessage(id, to.id, message)                 ③
```

```
    }
}

class MyDevice extends Device implements Communicating {}                    ④

def bob = new MyDevice(id:'Bob')
def alice = new MyDevice(id:'Alice')
bob.sendMessage(alice,'secret')                                              ⑤
```

① A Service class, beyond your control (in a library, …) defines a sendMessage method

② A Device class, beyond your control (in a library, …)

③ Defines a communicating trait for devices that can call the service

④ Defines MyDevice as a communicating device

⑤ The method from the trait is called, and id is resolved

It is clear, here, that the Communicating trait can only apply to Device. However, there's no explicit contract to indicate that, because traits cannot extend classes. However, the code compiles and runs perfectly fine, because id in the trait method will be resolved dynamically. The problem is that there is nothing that prevents the trait from being applied to any class which is **not** a Device. Any class which has an id would work, while any class that does not have an id property would cause a runtime error.

The problem is even more complex if you want to enable type checking or apply @CompileStatic on the trait: because the trait knows nothing about itself being a Device, the type checker will complain saying that it does not find the id property.

One possibility is to explicitly add a getId method in the trait, but it would not solve all issues. What if a method requires this as a parameter, and actually requires it to be a Device?

```
class SecurityService {
    static void check(Device d) { if (d.id==null) throw new SecurityException() }
}
```

If you want to be able to call this in the trait, then you will explicitly need to cast this into a Device. This can quickly become unreadable with explicit casts to this everywhere.

The @SelfType annotation

In order to make this contract explicit, and to make the type checker aware of the *type of itself*, Groovy provides a @SelfType annotation that will:

- let you declare the types that a class that implements this trait must inherit or implement
- throw a compile-time error if those type constraints are not satisfied

So in our previous example, we can fix the trait using the @groovy.transform.SelfType annotation:

```
@SelfType(Device)
```

```
@CompileStatic
trait Communicating {
    void sendMessage(Device to, String message) {
        SecurityService.check(this)
        CommunicationService.sendMessage(id, to.id, message)
    }
}
```

Now if you try to implement this trait on a class that is **not** a device, a compile-time error will occur:

```
class MyDevice implements Communicating {} // forgot to extend Device
```

The error will be:

```
class 'MyDevice' implements trait 'Communicating' but does not extend self type class
'Device'
```

In conclusion, self types are a powerful way of declaring constraints on traits without having to declare the contract directly in the trait or having to use casts everywhere, maintaining separation of concerns as tight as it should be.

Differences with Sealed annotation (incubating)

Both `@Sealed` and `@SelfType` restrict classes which use a trait but in orthogonal ways. Consider the following example:

```
interface HasHeight { double getHeight() }
interface HasArea { double getArea() }

@SelfType([HasHeight, HasArea])                       ①
@Sealed(permittedSubclasses=[UnitCylinder,UnitCube])  ②
trait HasVolume {
    double getVolume() { height * area }
}

final class UnitCube implements HasVolume, HasHeight, HasArea {
    // for the purposes of this example: h=1, w=1, l=1
    double height = 1d
    double area = 1d
}

final class UnitCylinder implements HasVolume, HasHeight, HasArea {
    // for the purposes of this example: h=1, diameter=1
    // radius=diameter/2, area=PI * r^2
    double height = 1d
    double area = Math.PI * 0.5d**2
```

```
}

assert new UnitCube().volume == 1d
assert new UnitCylinder().volume == 0.7853981633974483d
```

① All usages of the `HasVolume` trait must implement or extend both `HasHeight` and `HasArea`

② Only `UnitCube` or `UnitCylinder` can use the trait

For the degenerate case where a single class implements a trait, e.g.:

```
final class Foo implements FooTrait {}
```

Then, either:

```
@SelfType(Foo)
trait FooTrait {}
```

or:

```
@Sealed(permittedSubclasses='Foo') ①
trait FooTrait {}
```

① Or just `@Sealed` if `Foo` and `FooTrait` are in the same source file

could express this constraint. Generally, the former of these is preferred.

Limitations

Compatibility with AST transformations

CAUTION	Traits are not officially compatible with AST transformations. Some of them, like `@CompileStatic` will be applied on the trait itself (not on implementing classes), while others will apply on both the implementing class and the trait. There is absolutely no guarantee that an AST transformation will run on a trait as it does on a regular class, so use it at your own risk!

Prefix and postfix operations

Within traits, prefix and postfix operations are not allowed if they update a field of the trait:

```
trait Counting {
    int x
    void inc() {
        x++                             ①
    }
    void dec() {
```

```
        --x                             ②
    }
}
class Counter implements Counting {}
def c = new Counter()
c.inc()
```

① x is defined within the trait, postfix increment is not allowed

② x is defined within the trait, prefix decrement is not allowed

A workaround is to use the += operator instead.

Record classes (incubating)

Record classes, or *records* for short, are a special kind of class useful for modelling plain data aggregates. They provide a compact syntax with less ceremony than normal classes. Groovy already has AST transforms such as @Immutable and @Canonical which already dramatically reduce ceremony but records have been introduced in Java and record classes in Groovy are designed to align with Java record classes.

For example, suppose we want to create a Message record representing an email message. For the purposes of this example, let's simplify such a message to contain just a *from* email address, a *to* email address, and a message *body*. We can define such a record as follows:

```
record Message(String from, String to, String body) { }
```

We'd use the record class in the same way as a normal class, as shown below:

```
def msg = new Message('me@myhost.com', 'you@yourhost.net', 'Hello!')
assert msg.toString() == 'Message[from=me@myhost.com, to=you@yourhost.net,
body=Hello!]'
```

The reduced ceremony saves us from defining explicit fields, getters and toString, equals and hashCode methods. In fact, it's a shorthand for the following rough equivalent:

```
final class Message extends Record {
    private final String from
    private final String to
    private final String body
    private static final long serialVersionUID = 0

    /* constructor(s) */

    final String toString() { /*...*/ }

    final boolean equals(Object other) { /*...*/ }
```

```
    final int hashCode() { /*...*/ }

    String from() { from }
    // other getters ...
}
```

Note the special naming convention for record getters. They are the same name as the field (rather than the often common JavaBean convention of capitalized with a "get" prefix). Rather than referring to a record's fields or properties, the term *component* is typically used for records. So our `Message` record has `from`, `to`, and `body` components.

Like in Java, you can override the normally implicitly supplied methods by writing your own:

```
record Point3D(int x, int y, int z) {
    String toString() {
        "Point3D[coords=$x,$y,$z]"
    }
}

assert new Point3D(10, 20, 30).toString() == 'Point3D[coords=10,20,30]'
```

You can also use generics with records in the normal way. For example, consider the following `Coord` record definition:

```
record Coord<T extends Number>(T v1, T v2){
    double distFromOrigin() { Math.sqrt(v1()**2 + v2()**2 as double) }
}
```

It can be used as follows:

```
def r1 = new Coord<Integer>(3, 4)
assert r1.distFromOrigin() == 5
def r2 = new Coord<Double>(6d, 2.5d)
assert r2.distFromOrigin() == 6.5d
```

Special record features

Compact constructor

Records have an implicit constructor. This can be overridden in the normal way by providing your own constructor - you need to make sure you set all the fields if you do this. However, for succinctness, a compact constructor syntax can be used where the parameter declaration part of a normal constructor is elided. For this special case, the normal implicit constructor is still provided but is augmented by the supplied statements in the compact constructor definition:

```
public record Warning(String message) {
```

```
    public Warning {
        Objects.requireNonNull(message)
        message = message.toUpperCase()
    }
}

def w = new Warning('Help')
assert w.message() == 'HELP'
```

Serializability

Groovy *native* records follow the special conventions for serializability which apply to Java records. Groovy *record-like* classes (discussed below) follow normal Java class serializability conventions.

Groovy enhancements

Argument defaults

Groovy supports default values for constructor arguments. This capability is also available for records as shown in the following record definition which has default values for `y` and `color`:

```
record ColoredPoint(int x, int y = 0, String color = 'white') {}
```

Arguments when left off (dropping one or more arguments from the right) are replaced with their defaults values as shown in the following example:

```
assert new ColoredPoint(5, 5, 'black').toString() == 'ColoredPoint[x=5, y=5,
color=black]'
assert new ColoredPoint(5, 5).toString() == 'ColoredPoint[x=5, y=5, color=white]'
assert new ColoredPoint(5).toString() == 'ColoredPoint[x=5, y=0, color=white]'
```

This processing follows normal Groovy conventions for default arguments for constructors, essentially automatically providing the constructors with the following signatures:

```
ColoredPoint(int, int, String)
ColoredPoint(int, int)
ColoredPoint(int)
```

Named arguments may also be used (default values also apply here):

```
assert new ColoredPoint(x: 5).toString() == 'ColoredPoint[x=5, y=0, color=white]'
assert new ColoredPoint(x: 0, y: 5).toString() == 'ColoredPoint[x=0, y=5,
color=white]'
```

You can disable default argument processing as shown here:

```
@TupleConstructor(defaultsMode=DefaultsMode.OFF)
record ColoredPoint2(int x, int y, String color) {}
assert new ColoredPoint2(4, 5, 'red').toString() == 'ColoredPoint2[x=4, y=5,
color=red]'
```

This will produce a single constructor as per the default with Java. It will be an error if you drop off arguments in this scenario.

You can force all properties to have a default value as shown here:

```
@TupleConstructor(defaultsMode=DefaultsMode.ON)
record ColoredPoint3(int x, int y = 0, String color = 'white') {}
assert new ColoredPoint3(y: 5).toString() == 'ColoredPoint3[x=0, y=5, color=white]'
```

Any property/field without an explicit initial value will be given the default value for the argument's type (null, or zero/false for primitives).

Diving deeper

We previously described a `Message` record and displayed it's rough equivalent. Groovy in fact steps through an intermediate stage where the `record` keyword is replaced by the `class` keyword and an accompanying `@RecordType` annotation:

```
@RecordType
class Message {
    String from
    String to
    String body
}
```

Then `@RecordType` itself is processed as a *meta-annotation* (annotation collector) and expanded into its constituent sub-annotations such as `@TupleConstructor`, `@POJO`, `@RecordBase`, and others. This is in some sense an implementation detail which can often be ignored. However, if you wish to customise or configure the record implementation, you may wish to drop back to the `@RecordType` style or augment your record class with one of the constituent sub-annotations.

Declarative `toString` customization

As per Java, you can customize a record's `toString` method by writing your own. If you prefer a more declarative style, you can alternatively use Groovy's `@ToString` transform to override the default record `toString`. As an example, you can a three-dimensional point record as follows:

```
package threed

import groovy.transform.ToString
```

```
@ToString(ignoreNulls=true, cache=true, includeNames=true,
          leftDelimiter='[', rightDelimiter=']', nameValueSeparator='=')
record Point(Integer x, Integer y, Integer z=null) { }

assert new Point(10, 20).toString() == 'threed.Point[x=10, y=20]'
```

We customise the `toString` by including the package name (excluded by default for records) and by caching the `toString` value since it won't change for this immutable record. We are also ignoring null values (the default value for `z` in our definition).

We can have a similar definition for a two-dimensional point:

```
package twod

import groovy.transform.ToString

@ToString(ignoreNulls=true, cache=true, includeNames=true,
          leftDelimiter='[', rightDelimiter=']', nameValueSeparator='=')
record Point(Integer x, Integer y) { }

assert new Point(10, 20).toString() == 'twod.Point[x=10, y=20]'
```

We can see here that without the package name it would have the same toString as our previous example.

Obtaining a list of the record component values

We can obtain the component values from a record as a list like so:

```
record Point(int x, int y, String color) { }

def p = new Point(100, 200, 'green')
def (x, y, c) = p.toList()
assert x == 100
assert y == 200
assert c == 'green'
```

You can use `@RecordOptions(toList=false)` to disable this feature.

Obtaining a map of the record component values

We can obtain the component values from a record as a map like so:

```
record Point(int x, int y, String color) { }

def p = new Point(100, 200, 'green')
```

```
assert p.toMap() == [x: 100, y: 200, color: 'green']
```

You can use `@RecordOptions(toMap=false)` to disable this feature.

Obtaining the number of components in a record

We can obtain the number of components in a record like so:

```
record Point(int x, int y, String color) { }

def p = new Point(100, 200, 'green')
assert p.size() == 3
```

You can use `@RecordOptions(size=false)` to disable this feature.

Obtaining the n^th component from a record

We can use Groovy's normal positional indexing to obtain a particular component in a record like so:

```
record Point(int x, int y, String color) { }

def p = new Point(100, 200, 'green')
assert p[1] == 200
```

You can use `@RecordOptions(getAt=false)` to disable this feature.

Optional Groovy features

Copying

It can be useful to make a copy of a record with some components changed. This can be done using an optional `copyWith` method which takes named arguments. Record components are set from the supplied arguments. For components not mentioned, a (shallow) copy of the original record component is used. Here is how you might use `copyWith` for the `Fruit` record:

```
@RecordOptions(copyWith=true)
record Fruit(String name, double price) {}
def apple = new Fruit('Apple', 11.6)
assert 'Apple' == apple.name()
assert 11.6 == apple.price()

def orange = apple.copyWith(name: 'Orange')
assert orange.toString() == 'Fruit[name=Orange, price=11.6]'
```

The `copyWith` functionality can be disabled by setting the `RecordOptions#copyWith` annotation attribute to `false`.

Deep immutability

As with Java, records by default offer shallow immutability. Groovy's `@Immutable` transform performs defensive copying for a range of mutable data types. Records can make use of this defensive copying to gain deep immutability as follows:

```
@ImmutableProperties
record Shopping(List items) {}

def items = ['bread', 'milk']
def shop = new Shopping(items)
items << 'chocolate'
assert shop.items() == ['bread', 'milk']
```

These examples illustrate the principal behind Groovy's record feature offering three levels of convenience:

- Using the `record` keyword for maximum succinctness
- Supporting low-ceremony customization using declarative annotations
- Allowing normal method implementations when full control is required

Obtaining the components of a record as a typed tuple

You can obtain the components of a record as a typed tuple:

```
import groovy.transform.*

@RecordOptions(components=true)
record Point(int x, int y, String color) { }

@CompileStatic
def method() {
    def p1 = new Point(100, 200, 'green')
    def (int x1, int y1, String c1) = p1.components()
    assert x1 == 100
    assert y1 == 200
    assert c1 == 'green'

    def p2 = new Point(10, 20, 'blue')
    def (x2, y2, c2) = p2.components()
    assert x2 * 10 == 100
    assert y2 ** 2 == 400
    assert c2.toUpperCase() == 'BLUE'

    def p3 = new Point(1, 2, 'red')
    assert p3.components() instanceof Tuple3
}
```

```
method()
```

Groovy has a limited number of `TupleN` classes. If you have a large number of components in your record, you might not be able to use this feature.

Other differences to Java

Groovy supports creating *record-like* classes as well as native records. Record-like classes don't extend Java's `Record` class and such classes won't be seen by Java as records but will otherwise have similar properties.

The `@RecordOptions` annotation (part of `@RecordType`) supports a `mode` annotation attribute which can take one of three values (with `AUTO` being the default):

NATIVE
: Produces a class similar to what Java would do. Produces an error when compiling on JDKs earlier than JDK16.

EMULATE
: Produces a record-like class for all JDK versions.

AUTO
: Produces a native record for JDK16+ and emulates the record otherwise.

Whether you use the `record` keyword or the `@RecordType` annotation is independent of the mode.

Sealed hierarchies (incubating)

Sealed classes, interfaces and traits restrict which subclasses can extend/implement them. Prior to sealed classes, class hierarchy designers had two main options:

- Make a class final to allow no extension.
- Make the class public and non-final to allow extension by anyone.

Sealed classes provide a middle-ground compared to these all or nothing choices.

Sealed classes are also more flexible than other tricks previously used to try to achieve a middle-ground. For example, for class hierarchies, access modifiers like protected and package-private give some ability to restrict inheritance hierarchies but often at the expense of flexible use of those hierarchies.

Sealed hierarchies provide full inheritance within a known hierarchy of classes, interfaces and traits but disable or only provide controlled inheritance outside the hierarchy.

As an example, suppose we want to create a shape hierarchy containing only circles and squares. We also want a shape interface to be able to refer to instances in our hierarchy. We can create the hierarchy as follows:

```
sealed interface ShapeI permits Circle,Square { }
```

```
final class Circle implements ShapeI { }
final class Square implements ShapeI { }
```

Groovy also supports an alternative annotation syntax. We think the keyword style is nicer but you might choose the annotation style if your editor doesn't yet have Groovy 4 support.

```
@Sealed(permittedSubclasses=[Circle,Square]) interface ShapeI { }
final class Circle implements ShapeI { }
final class Square implements ShapeI { }
```

We can have a reference of type `ShapeI` which, thanks to the `permits` clause, can point to either a `Circle` or `Square` and, since our classes are `final`, we know no additional classes will be added to our hierarchy in the future. At least not without changing the `permits` clause and recompiling.

In general, we might want to have some parts of our class hierarchy immediately locked down like we have here, where we marked the subclasses as `final` but other times we might want to allow further controlled inheritance.

```
sealed class Shape permits Circle,Polygon,Rectangle { }

final class Circle extends Shape { }

class Polygon extends Shape { }
non-sealed class RegularPolygon extends Polygon { }
final class Hexagon extends Polygon { }

sealed class Rectangle extends Shape permits Square{ }
final class Square extends Rectangle { }
```

▼ *<Click to see the alternate annotations syntax>*

```
@Sealed(permittedSubclasses=[Circle,Polygon,Rectangle]) class Shape { }

final class Circle extends Shape { }

class Polygon extends Shape { }
@NonSealed class RegularPolygon extends Polygon { }
final class Hexagon extends Polygon { }

@Sealed(permittedSubclasses=Square) class Rectangle extends Shape { }
final class Square extends Rectangle { }
```

In this example, our permitted subclasses for `Shape` are `Circle`, `Polygon`, and `Rectangle`. `Circle` is `final` and hence that part of the hierarchy cannot be extended. `Polygon` is implicitly non-sealed and `RegularPolygon` is explicitly marked as `non-sealed`. That means our hierarchy is open to any further extension by subclassing, as seen with `Polygon → RegularPolygon` and `RegularPolygon → Hexagon`.

Rectangle is itself sealed which means that part of the hierarchy can be extended but only in a controlled way (only Square is permitted).

Sealed classes are useful for creating enum-like related classes which need to contain instance specific data. For instance, we might have the following enum:

```
enum Weather { Rainy, Cloudy, Sunny }
def forecast = [Weather.Rainy, Weather.Sunny, Weather.Cloudy]
assert forecast.toString() == '[Rainy, Sunny, Cloudy]'
```

but we now wish to also add weather specific instance data to weather forecasts. We can alter our abstraction as follows:

```
sealed abstract class Weather { }
@Immutable(includeNames=true) class Rainy extends Weather { Integer expectedRainfall }
@Immutable(includeNames=true) class Sunny extends Weather { Integer expectedTemp }
@Immutable(includeNames=true) class Cloudy extends Weather { Integer expectedUV }
def forecast = [new Rainy(12), new Sunny(35), new Cloudy(6)]
assert forecast.toString() == '[Rainy(expectedRainfall:12), Sunny(expectedTemp:35),
Cloudy(expectedUV:6)]'
```

Sealed hierarchies are also useful when specifying Algebraic or Abstract Data Types (ADTs) as shown in the following example:

```
import groovy.transform.*

sealed interface Tree<T> {}
@Singleton final class Empty implements Tree {
    String toString() { 'Empty' }
}
@Canonical final class Node<T> implements Tree<T> {
    T value
    Tree<T> left, right
}

Tree<Integer> tree = new Node<>(42, new Node<>(0, Empty.instance, Empty.instance),
Empty.instance)
assert tree.toString() == 'Node(42, Node(0, Empty, Empty), Empty)'
```

Sealed hierarchies work well with records as shown in the following example:

```
sealed interface Expr {}
record ConstExpr(int i) implements Expr {}
record PlusExpr(Expr e1, Expr e2) implements Expr {}
record MinusExpr(Expr e1, Expr e2) implements Expr {}
record NegExpr(Expr e) implements Expr {}
```

```
def threePlusNegOne = new PlusExpr(new ConstExpr(3), new NegExpr(new ConstExpr(1)))
assert threePlusNegOne.toString() == 'PlusExpr[e1=ConstExpr[i=3],
e2=NegExpr[e=ConstExpr[i=1]]]'
```

Differences to Java

- Java provides no default modifier for subclasses of sealed classes and requires that one of `final`, `sealed` or `non-sealed` be specified. Groovy defaults to *non-sealed* but you can still use `non-sealed/@NonSealed` if you wish. We anticipate the style checking tool CodeNarc will eventually have a rule that looks for the presence of `non-sealed` so developers wanting that stricter style will be able to use CodeNarc and that rule if they want.
- Currently, Groovy doesn't check that all classes mentioned in `permittedSubclasses` are available at compile-time and compiled along with the base sealed class. This may change in a future version of Groovy.

Groovy supports annotating classes as sealed as well as "native" sealed classes.

The `@SealedOptions` annotation supports a `mode` annotation attribute which can take one of three values (with `AUTO` being the default):

NATIVE
: Produces a class similar to what Java would do. Produces an error when compiling on JDKs earlier than JDK17.

EMULATE
: Indicates the class is sealed using the `@Sealed` annotation. This mechanism works with the Groovy compiler for JDK8+ but is not recognised by the Java compiler.

AUTO
: Produces a native record for JDK17+ and emulates the record otherwise.

Whether you use the `sealed` keyword or the `@Sealed` annotation is independent of the mode.

Closures

This chapter covers Groovy Closures. A closure in Groovy is an open, anonymous, block of code that can take arguments, return a value and be assigned to a variable. A closure may reference variables declared in its surrounding scope. In opposition to the formal definition of a closure, `Closure` in the Groovy language can also contain free variables which are defined outside of its surrounding scope. While breaking the formal concept of a closure, it offers a variety of advantages which are described in this chapter.

Syntax

Defining a closure

A closure definition follows this syntax:

```
{ [closureParameters -> ] statements }
```

Where [closureParameters->] is an optional comma-delimited list of parameters, and statements are 0 or more Groovy statements. The parameters look similar to a method parameter list, and these parameters may be typed or untyped.

When a parameter list is specified, the -> character is required and serves to separate the arguments from the closure body. The *statements* portion consists of 0, 1, or many Groovy statements.

Some examples of valid closure definitions:

```
{ item++ }                                          ①

{ -> item++ }                                       ②

{ println it }                                      ③

{ it -> println it }                                ④

{ name -> println name }                            ⑤

{ String x, int y ->                                ⑥
    println "hey ${x} the value is ${y}"
}

{ reader ->                                         ⑦
    def line = reader.readLine()
    line.trim()
}
```

① A closure referencing a variable named item

② It is possible to explicitly separate closure parameters from code by adding an arrow (->)

③ A closure using an implicit parameter (it)

④ An alternative version where it is an explicit parameter

⑤ In that case it is often better to use an explicit name for the parameter

⑥ A closure accepting two typed parameters

⑦ A closure can contain multiple statements

Closures as an object

A closure is an instance of the groovy.lang.Closure class, making it assignable to a variable or a field as any other variable, despite being a block of code:

```
def listener = { e -> println "Clicked on $e.source" }      ①
```

```
assert listener instanceof Closure
Closure callback = { println 'Done!' }                        ②
Closure<Boolean> isTextFile = {
    File it -> it.name.endsWith('.txt')                       ③
}
```

① You can assign a closure to a variable, and it is an instance of `groovy.lang.Closure`

② If not using `def` or `var`, use `groovy.lang.Closure` as the type

③ Optionally, you can specify the return type of the closure by using the generic type of `groovy.lang.Closure`

Calling a closure

A closure, as an anonymous block of code, can be called like any other method. If you define a closure which takes no argument like this:

```
def code = { 123 }
```

Then the code inside the closure will only be executed when you *call* the closure, which can be done by using the variable as if it was a regular method:

```
assert code() == 123
```

Alternatively, you can be explicit and use the `call` method:

```
assert code.call() == 123
```

The principle is the same if the closure accepts arguments:

```
def isOdd = { int i -> i%2 != 0 }                             ①
assert isOdd(3) == true                                       ②
assert isOdd.call(2) == false                                 ③

def isEven = { it%2 == 0 }                                    ④
assert isEven(3) == false                                     ⑤
assert isEven.call(2) == true                                 ⑥
```

① define a closure which accepts an `int` as a parameter

② it can be called directly

③ or using the `call` method

④ same goes for a closure with an implicit argument (`it`)

⑤ which can be called directly using `(arg)`

⑥ or using `call`

Unlike a method, a closure **always** returns a value when called. The next section discusses how to declare closure arguments, when to use them and what is the implicit "it" parameter.

Parameters

Normal parameters

Parameters of closures follow the same principle as parameters of regular methods:

- an optional type
- a name
- an optional default value

Parameters are separated with commas:

```
def closureWithOneArg = { str -> str.toUpperCase() }
assert closureWithOneArg('groovy') == 'GROOVY'

def closureWithOneArgAndExplicitType = { String str -> str.toUpperCase() }
assert closureWithOneArgAndExplicitType('groovy') == 'GROOVY'

def closureWithTwoArgs = { a,b -> a+b }
assert closureWithTwoArgs(1,2) == 3

def closureWithTwoArgsAndExplicitTypes = { int a, int b -> a+b }
assert closureWithTwoArgsAndExplicitTypes(1,2) == 3

def closureWithTwoArgsAndOptionalTypes = { a, int b -> a+b }
assert closureWithTwoArgsAndOptionalTypes(1,2) == 3

def closureWithTwoArgAndDefaultValue = { int a, int b=2 -> a+b }
assert closureWithTwoArgAndDefaultValue(1) == 3
```

Implicit parameter

When a closure does not explicitly define a parameter list (using `->`), a closure **always** defines an implicit parameter, named `it`. This means that this code:

```
def greeting = { "Hello, $it!" }
assert greeting('Patrick') == 'Hello, Patrick!'
```

is strictly equivalent to this one:

```
def greeting = { it -> "Hello, $it!" }
assert greeting('Patrick') == 'Hello, Patrick!'
```

If you want to declare a closure which accepts no argument and must be restricted to calls without arguments, then you **must** declare it with an explicit empty argument list:

```
def magicNumber = { -> 42 }

// this call will fail because the closure doesn't accept any argument
magicNumber(11)
```

Varargs

It is possible for a closure to declare variable arguments like any other method. *Vargs* methods are methods that can accept a variable number of arguments if the last parameter is of variable length (or an array) like in the next examples:

```
def concat1 = { String... args -> args.join('') }              ①
assert concat1('abc','def') == 'abcdef'                         ②
def concat2 = { String[] args -> args.join('') }                ③
assert concat2('abc', 'def') == 'abcdef'

def multiConcat = { int n, String... args ->                    ④
    args.join('')*n
}
assert multiConcat(2, 'abc','def') == 'abcdefabcdef'
```

① A closure accepting a variable number of strings as first parameter

② It may be called using any number of arguments **without** having to explicitly wrap them into an array

③ The same behavior is directly available if the *args* parameter is declared as an array

④ As long as the **last** parameter is an array or an explicit vargs type

Delegation strategy

Groovy closures vs lambda expressions

Groovy defines closures as instances of the Closure class. It makes it very different from lambda expressions in Java 8. Delegation is a key concept in Groovy closures which has no equivalent in lambdas. The ability to *change the delegate* or *change the delegation strategy* of closures make it possible to design beautiful domain specific languages (DSLs) in Groovy.

Owner, delegate and this

To understand the concept of delegate, we must first explain the meaning of `this` inside a closure. A closure actually defines 3 distinct things:

- `this` corresponds to the *enclosing class* where the closure is defined
- `owner` corresponds to the *enclosing object* where the closure is defined, which may be either a

class or a closure

- `delegate` corresponds to a third party object where methods calls or properties are resolved whenever the receiver of the message is not defined

The meaning of this

In a closure, calling `getThisObject` will return the enclosing class where the closure is defined. It is equivalent to using an explicit `this`:

```
class Enclosing {
    void run() {
        def whatIsThisObject = { getThisObject() }          ①
        assert whatIsThisObject() == this                   ②
        def whatIsThis = { this }                           ③
        assert whatIsThis() == this                         ④
    }
}
class EnclosedInInnerClass {
    class Inner {
        Closure cl = { this }                               ⑤
    }
    void run() {
        def inner = new Inner()
        assert inner.cl() == inner                          ⑥
    }
}
class NestedClosures {
    void run() {
        def nestedClosures = {
            def cl = { this }                               ⑦
            cl()
        }
        assert nestedClosures() == this                     ⑧
    }
}
```

① a closure is defined inside the `Enclosing` class, and returns `getThisObject`

② calling the closure will return the instance of `Enclosing` where the closure is defined

③ in general, you will just want to use the shortcut `this` notation

④ and it returns **exactly** the same object

⑤ if the closure is defined in an inner class

⑥ `this` in the closure **will** return the inner class, not the top-level one

⑦ in case of nested closures, like here `cl` being defined inside the scope of `nestedClosures`

⑧ then `this` corresponds to the closest outer class, not the enclosing closure!

It is of course possible to call methods from the enclosing class this way:

```
class Person {
    String name
    int age
    String toString() { "$name is $age years old" }

    String dump() {
        def cl = {
            String msg = this.toString()               ①
            println msg
            msg
        }
        cl()
    }
}
def p = new Person(name:'Janice', age:74)
assert p.dump() == 'Janice is 74 years old'
```

① the closure calls `toString` on `this`, which will actually call the `toString` method on the enclosing object, that is to say the `Person` instance

Owner of a closure

The owner of a closure is very similar to the definition of this in a closure with a subtle difference: it will return the direct enclosing object, be it a closure or a class:

```
class Enclosing {
    void run() {
        def whatIsOwnerMethod = { getOwner() }               ①
        assert whatIsOwnerMethod() == this                   ②
        def whatIsOwner = { owner }                          ③
        assert whatIsOwner() == this                         ④
    }
}
class EnclosedInInnerClass {
    class Inner {
        Closure cl = { owner }                               ⑤
    }
    void run() {
        def inner = new Inner()
        assert inner.cl() == inner                           ⑥
    }
}
class NestedClosures {
    void run() {
        def nestedClosures = {
            def cl = { owner }                               ⑦
            cl()
        }
        assert nestedClosures() == nestedClosures            ⑧
    }
```

```
}
```

① a closure is defined inside the Enclosing class, and returns getOwner

② calling the closure will return the instance of Enclosing where the closure is defined

③ in general, you will just want to use the shortcut owner notation

④ and it returns **exactly** the same object

⑤ if the closure is defined in an inner class

⑥ owner in the closure **will** return the inner class, not the top-level one

⑦ but in case of nested closures, like here cl being defined inside the scope of nestedClosures

⑧ then owner corresponds to the enclosing closure, hence a different object from this!

Delegate of a closure

The delegate of a closure can be accessed by using the delegate property or calling the getDelegate method. It is a powerful concept for building domain specific languages in Groovy. While this and owner refer to the lexical scope of a closure, the delegate is a user defined object that a closure will use. By default, the delegate is set to owner:

```
class Enclosing {
    void run() {
        def cl = { getDelegate() }                          ①
        def cl2 = { delegate }                              ②
        assert cl() == cl2()                                ③
        assert cl() == this                                 ④
        def enclosed = {
            { -> delegate }.call()                          ⑤
        }
        assert enclosed() == enclosed                       ⑥
    }
}
```

① you can get the delegate of a closure calling the getDelegate method

② or using the delegate property

③ both return the same object

④ which is the enclosing class or closure

⑤ in particular in case of nested closures

⑥ delegate will correspond to the owner

The delegate of a closure can be changed to **any object**. Let's illustrate this by creating two classes which are not subclasses of each other but both define a property called name:

```
class Person {
    String name
}
```

```
class Thing {
    String name
}

def p = new Person(name: 'Norman')
def t = new Thing(name: 'Teapot')
```

Then let's define a closure which fetches the `name` property on the delegate:

```
def upperCasedName = { delegate.name.toUpperCase() }
```

Then by changing the delegate of the closure, you can see that the target object will change:

```
upperCasedName.delegate = p
assert upperCasedName() == 'NORMAN'
upperCasedName.delegate = t
assert upperCasedName() == 'TEAPOT'
```

At this point, the behavior is not different from having a `target` variable defined in the lexical scope of the closure:

```
def target = p
def upperCasedNameUsingVar = { target.name.toUpperCase() }
assert upperCasedNameUsingVar() == 'NORMAN'
```

However, there are major differences:

- in the last example, *target* is a local variable referenced from within the closure
- the delegate can be used transparently, that is to say without prefixing method calls with `delegate.` as explained in the next paragraph.

Delegation strategy

Whenever, in a closure, a property is accessed without explicitly setting a receiver object, then a delegation strategy is involved:

```
class Person {
    String name
}
def p = new Person(name:'Igor')
def cl = { name.toUpperCase() }                 ①
cl.delegate = p                                 ②
assert cl() == 'IGOR'                           ③
```

① `name` is not referencing a variable in the lexical scope of the closure

② we can change the delegate of the closure to be an instance of Person

③ and the method call will succeed

The reason this code works is that the name property will be resolved transparently on the delegate object! This is a very powerful way to resolve properties or method calls inside closures. There's no need to set an explicit delegate. receiver: the call will be made because the default delegation strategy of the closure makes it so. A closure actually defines multiple resolution strategies that you can choose:

- Closure.OWNER_FIRST is the **default strategy**. If a property/method exists on the **owner**, then it will be called on the owner. If not, then the **delegate** is used.
- Closure.DELEGATE_FIRST reverses the logic: the **delegate** is used first, then the **owner**
- Closure.OWNER_ONLY will only resolve the property/method lookup on the owner: the delegate will be ignored.
- Closure.DELEGATE_ONLY will only resolve the property/method lookup on the delegate: the owner will be ignored.
- Closure.TO_SELF can be used by developers who need advanced meta-programming techniques and wish to implement a custom resolution strategy: the resolution will not be made on the owner or the delegate but only on the closure class itself. It makes only sense to use this if you implement your own subclass of Closure.

Let's illustrate the default "owner first" strategy with this code:

```
class Person {
    String name
    def pretty = { "My name is $name" }             ①
    String toString() {
        pretty()
    }
}
class Thing {
    String name                                     ②
}

def p = new Person(name: 'Sarah')
def t = new Thing(name: 'Teapot')

assert p.toString() == 'My name is Sarah'           ③
p.pretty.delegate = t                               ④
assert p.toString() == 'My name is Sarah'           ⑤
```

① for the illustration, we define a closure member which references "name"

② both the Person and the Thing class define a name property

③ Using the default strategy, the name property is resolved on the owner first

④ so if we change the delegate to t which is an instance of Thing

⑤ there is no change in the result: `name` is first resolved on the `owner` of the closure

However, it is possible to change the resolution strategy of the closure:

```
p.pretty.resolveStrategy = Closure.DELEGATE_FIRST
assert p.toString() == 'My name is Teapot'
```

By changing the `resolveStrategy`, we are modifying the way Groovy will resolve the "implicit this" references: in this case, `name` will first be looked in the delegate, then if not found, on the owner. Since `name` is defined in the delegate, an instance of `Thing`, then this value is used.

The difference between "delegate first" and "delegate only" or "owner first" and "owner only" can be illustrated if one of the delegate (resp. owner) does **not** have such a method or property:

```
class Person {
    String name
    int age
    def fetchAge = { age }
}
class Thing {
    String name
}

def p = new Person(name:'Jessica', age:42)
def t = new Thing(name:'Printer')
def cl = p.fetchAge
cl.delegate = p
assert cl() == 42          ①
cl.delegate = t
assert cl() == 42          ①

cl.resolveStrategy = Closure.DELEGATE_ONLY
cl.delegate = p
assert cl() == 42          ②
cl.delegate = t
try {
    cl()                   ③
    assert false
} catch (MissingPropertyException ex) {
    // "age" is not defined on the delegate
}
```

① for "owner first" it doesn't matter what the delegate is

② for "delegate only" having `p` as the delegate succeeds

③ for "delegate only" having `t` as the delegate fails

In this example, we define two classes which both have a `name` property but only the `Person` class declares an `age`. The `Person` class also declares a closure which references `age`. We can change the default resolution strategy from "owner first" to "delegate only". Since the owner of the closure is the `Person` class, then we can check that if the delegate is an instance of `Person`, calling the closure is successful, but if we call it with a delegate being an instance of `Thing`, it fails with a `groovy.lang.MissingPropertyException`. Despite the closure being defined inside the `Person` class, the owner is not used.

NOTE	A comprehensive explanation about how to use this feature to develop DSLs can be found in a dedicated section of the manual.

Delegation strategy in the presence of metaprogramming

When describing the "owner first" delegation strategy we spoke about using a property/method from the owner if it "*existed*" otherwise using the respective property/method from the delegate. And a similar story for "delegate first" but in reverse. Instead of using the word "*existed*", it would have been more accurate to use the wording "*handled*". That means that for "owner first", if the property/method exists in the owner, or it has a propertyMissing/methodMissing hook, then the owner will handle the member access.

We can see this in action with a slightly altered version of our previous example:

```
class Person {
    String name
    int age
    def fetchAge = { age }
}
class Thing {
    String name
    def propertyMissing(String name) { -1 }
}

def p = new Person(name:'Jessica', age:42)
def t = new Thing(name:'Printer')
def cl = p.fetchAge
cl.resolveStrategy = Closure.DELEGATE_FIRST
cl.delegate = p
assert cl() == 42
cl.delegate = t
assert cl() == -1
```

In this example, even though our instance of the `Thing` class (our delegate for the last use of `cl`) has no `age` property, the fact that it handles the missing property via its `propertyMissing` hook, means that `age` will be `-1`.

Closures in GStrings

Take the following code:

```
def x = 1
```

```
def gs = "x = ${x}"
assert gs == 'x = 1'
```

The code behaves as you would expect, but what happens if you add:

```
x = 2
assert gs == 'x = 2'
```

You will see that the assert fails! There are two reasons for this:

- a GString only evaluates lazily the `toString` representation of values
- the syntax `${x}` in a GString does **not** represent a closure but an **expression** to `$x`, evaluated when the GString is created.

In our example, the `GString` is created with an expression referencing `x`. When the `GString` is created, the **value** of `x` is 1, so the `GString` is created with a value of 1. When the assert is triggered, the `GString` is evaluated and 1 is converted to a `String` using `toString`. When we change `x` to 2, we did change the value of `x`, but it is a different object, and the `GString` still references the old one.

TIP	A `GString` will only change its `toString` representation if the values it references are mutating. If the references change, nothing will happen.

If you need a real closure in a GString and for example enforce lazy evaluation of variables, you need to use the alternate syntax `${→ x}` like in the fixed example:

```
def x = 1
def gs = "x = ${-> x}"
assert gs == 'x = 1'

x = 2
assert gs == 'x = 2'
```

And let's illustrate how it differs from mutation with this code:

```
class Person {
    String name
    String toString() { name }          ①
}
def sam = new Person(name:'Sam')        ②
def lucy = new Person(name:'Lucy')      ③
def p = sam                             ④
def gs = "Name: ${p}"                   ⑤
assert gs == 'Name: Sam'                ⑥
p = lucy                                ⑦
assert gs == 'Name: Sam'                ⑧
sam.name = 'Lucy'                       ⑨
```

```
assert gs == 'Name: Lucy'              ⑩
```

① the `Person` class has a `toString` method returning the `name` property

② we create a first `Person` named *Sam*

③ we create another `Person` named *Lucy*

④ the `p` variable is set to `Sam`

⑤ and a closure is created, referencing the value of `p`, that is to say *Sam*

⑥ so when we evaluate the string, it returns *Sam*

⑦ if we change `p` to *Lucy*

⑧ the string still evaluates to *Sam* because it was the **value** of `p` when the `GString` was created

⑨ so if we mutate *Sam* to change the name to *Lucy*

⑩ this time the `GString` is correctly mutated

So if you don't want to rely on mutating objects or wrapping objects, you **must** use closures in `GString` by explicitly declaring an empty argument list:

```
class Person {
    String name
    String toString() { name }
}
def sam = new Person(name:'Sam')
def lucy = new Person(name:'Lucy')
def p = sam
// Create a GString with lazy evaluation of "p"
def gs = "Name: ${-> p}"
assert gs == 'Name: Sam'
p = lucy
assert gs == 'Name: Lucy'
```

Closure coercion

Closures can be converted into interfaces or single-abstract method types. Please refer to this section of the manual for a complete description.

Functional programming

Closures, like lambda expressions in Java 8 are at the core of the functional programming paradigm in Groovy. Some functional programming operations on functions are available directly on the `Closure` class, like illustrated in this section.

Currying

In Groovy, currying refers to the concept of partial application. It does **not** correspond to the real concept of currying in functional programming because of the different scoping rules that Groovy applies on closures. Currying in Groovy will let you set the value of one parameter of a closure, and it will return a new closure accepting one less argument.

Left currying

Left currying is the fact of setting the left-most parameter of a closure, like in this example:

```
def nCopies = { int n, String str -> str*n }    ①
def twice = nCopies.curry(2)                    ②
assert twice('bla') == 'blabla'                 ③
assert twice('bla') == nCopies(2, 'bla')        ④
```

① the `nCopies` closure defines two parameters

② `curry` will set the first parameter to `2`, creating a new closure (function) which accepts a single `String`

③ so the new function call be called with only a `String`

④ and it is equivalent to calling `nCopies` with two parameters

Right currying

Similarly to left currying, it is possible to set the right-most parameter of a closure:

```
def nCopies = { int n, String str -> str*n }    ①
def blah = nCopies.rcurry('bla')                ②
assert blah(2) == 'blabla'                      ③
assert blah(2) == nCopies(2, 'bla')             ④
```

① the `nCopies` closure defines two parameters

② `rcurry` will set the last parameter to `bla`, creating a new closure (function) which accepts a single `int`

③ so the new function call be called with only an `int`

④ and it is equivalent to calling `nCopies` with two parameters

Index based currying

In case a closure accepts more than 2 parameters, it is possible to set an arbitrary parameter using `ncurry`:

```
def volume = { double l, double w, double h -> l*w*h }      ①
def fixedWidthVolume = volume.ncurry(1, 2d)                 ②
assert volume(3d, 2d, 4d) == fixedWidthVolume(3d, 4d)       ③
def fixedWidthAndHeight = volume.ncurry(1, 2d, 4d)          ④
assert volume(3d, 2d, 4d) == fixedWidthAndHeight(3d)        ⑤
```

① the `volume` function defines 3 parameters

② `ncurry` will set the second parameter (index = 1) to `2d`, creating a new volume function which accepts length and height

③ that function is equivalent to calling `volume` omitting the width

④ it is also possible to set multiple parameters, starting from the specified index

⑤ the resulting function accepts as many parameters as the initial one minus the number of parameters set by `ncurry`

Memoization

Memoization allows the result of the call of a closure to be cached. It is interesting if the computation done by a function (closure) is slow, but you know that this function is going to be called often with the same arguments. A typical example is the Fibonacci suite. A naive implementation may look like this:

```
def fib
fib = { long n -> n<2?n:fib(n-1)+fib(n-2) }
assert fib(15) == 610 // slow!
```

It is a naive implementation because 'fib' is often called recursively with the same arguments, leading to an exponential algorithm:

- computing `fib(15)` requires the result of `fib(14)` and `fib(13)`
- computing `fib(14)` requires the result of `fib(13)` and `fib(12)`

Since calls are recursive, you can already see that we will compute the same values again and again, although they could be cached. This naive implementation can be "fixed" by caching the result of calls using `memoize`:

```
fib = { long n -> n<2?n:fib(n-1)+fib(n-2) }.memoize()
assert fib(25) == 75025 // fast!
```

WARNING	The cache works **using the actual values of the arguments**. This means that you should be very careful if you use memoization with something else than primitive or boxed primitive types.

The behavior of the cache can be tweaked using alternate methods:

- `memoizeAtMost` will generate a new closure which caches **at most** *n* values
- `memoizeAtLeast` will generate a new closure which caches **at least** *n* values
- `memoizeBetween` will generate a new closure which caches **at least** *n* values and **at most** *n* values

The cache used in all memoize variants is an LRU cache.

Composition

Closure composition corresponds to the concept of function composition, that is to say creating a new function by composing two or more functions (chaining calls), as illustrated in this example:

```
def plus2  = { it + 2 }
def times3 = { it * 3 }

def times3plus2 = plus2 << times3
assert times3plus2(3) == 11
assert times3plus2(4) == plus2(times3(4))

def plus2times3 = times3 << plus2
assert plus2times3(3) == 15
assert plus2times3(5) == times3(plus2(5))

// reverse composition
assert times3plus2(3) == (times3 >> plus2)(3)
```

Trampoline

Recursive algorithms are often restricted by a physical limit: the maximum stack height. For example, if you call a method that recursively calls itself too deep, you will eventually receive a `StackOverflowException`.

An approach that helps in those situations is by using `Closure` and its trampoline capability.

Closures are wrapped in a `TrampolineClosure`. Upon calling, a trampolined `Closure` will call the original `Closure` waiting for its result. If the outcome of the call is another instance of a `TrampolineClosure`, created perhaps as a result to a call to the `trampoline()` method, the `Closure` will again be invoked. This repetitive invocation of returned trampolined Closures instances will continue until a value other than a trampolined `Closure` is returned. That value will become the final result of the trampoline. That way, calls are made serially, rather than filling the stack.

Here's an example of the use of `trampoline()` to implement the factorial function:

```
def factorial
factorial = { int n, def accu = 1G ->
    if (n < 2) return accu
    factorial.trampoline(n - 1, n * accu)
}
factorial = factorial.trampoline()

assert factorial(1)    == 1
assert factorial(3)    == 1 * 2 * 3
assert factorial(1000) // == 402387260.. plus another 2560 digits
```

Method pointers

It is often practical to be able to use a regular method as a closure. For example, you might want to use the currying abilities of a closure, but those are not available to normal methods. In Groovy, you can obtain a closure from any method with the method pointer operator.

Semantics

This chapter covers the semantics of the Groovy programming language.

Statements

Variable definition

Variables can be defined using either their type (like `String`) or by using the keyword `def` followed by a variable name:

```
String x
def y
```

`def` acts as a type placeholder, i.e. a replacement for the type name, when you do not want to give an explicit type. It could be that you don't care about the type at compile time or are relying on type inference (with Groovy's static nature). It is mandatory for variable definitions to have a type or placeholder. If left out, the type name will be deemed to refer to an existing variable (presumably declared earlier). For scripts, undeclared variables are assumed to come from the Script binding. In other cases, you will get a missing property (dynamic Groovy) or compile time error (static Groovy). If you think of `def` as an alias of `Object`, you will understand in an instant.

Variable definitions can provide an initial value, in which case it's like having a declaration and assignment (which we cover next) all in one.

NOTE Variable definition types can be refined by using generics, like in `List<String> names`. To learn more about the generics support, please read the generics section.

NOTE Java introduced the `var` reserved type from Java 10. It also acts like a type placeholder for variable definitions, similar to `def` above. So, for compatibility with Java, Groovy also lets you define variables using `var` as follows:

```
var z
```

In the context of variable definitions, you can think of `var` as an alias for `def`. You might use `var` if you have cut-n-pasted some Java code into your codebase, or if the audience (readers or maintainers) of your codebase are primarily Java-aware folks, and you want to make the code look familiar to them.

Variable assignment

You can assign values to variables for later use. Try the following:

```
x = 1
println x
```

```
x = new java.util.Date()
println x

x = -3.1499392
println x

x = false
println x

x = "Hi"
println x
```

Multiple assignment

Groovy supports multiple assignment, i.e. where multiple variables can be assigned at once, e.g.:

```
def (a, b, c) = [10, 20, 'foo']
assert a == 10 && b == 20 && c == 'foo'
```

You can provide types as part of the declaration if you wish:

```
def (int i, String j) = [10, 'foo']
assert i == 10 && j == 'foo'
```

As well as used when declaring variables it also applies to existing variables:

```
def nums = [1, 3, 5]
def a, b, c
(a, b, c) = nums
assert a == 1 && b == 3 && c == 5
```

The syntax works for arrays as well as lists, as well as methods that return either of these:

```
def (_, month, year) = "18th June 2009".split()
assert "In $month of $year" == 'In June of 2009'
```

Overflow and Underflow

If the left hand side has too many variables, excess ones are filled with null's:

```
def (a, b, c) = [1, 2]
assert a == 1 && b == 2 && c == null
```

If the right hand side has too many variables, the extra ones are ignored:

```
def (a, b) = [1, 2, 3]
assert a == 1 && b == 2
```

Object destructuring with multiple assignment

In the section describing Groovy's operators, the case of the subscript operator has been covered, explaining how you can override the `getAt()`/`putAt()` method.

With this technique, we can combine multiple assignments and the subscript operator methods to implement *object destructuring*.

Consider the following immutable `Coordinates` class, containing a pair of longitude and latitude doubles, and notice our implementation of the `getAt()` method:

```
@Immutable
class Coordinates {
    double latitude
    double longitude

    double getAt(int idx) {
        if (idx == 0) latitude
        else if (idx == 1) longitude
        else throw new Exception('Wrong coordinate index, use 0 or 1')
    }
}
```

Now let's instantiate this class and destructure its longitude and latitude:

```
def coordinates = new Coordinates(latitude: 43.23, longitude: 3.67) ①

def (la, lo) = coordinates                                          ②

assert la == 43.23                                                  ③
assert lo == 3.67
```

① we create an instance of the `Coordinates` class

② then, we use a multiple assignment to get the individual longitude and latitude values

③ and we can finally assert their values.

Control structures

Conditional structures

if / else

Groovy supports the usual if - else syntax from Java

```
def x = false
def y = false

if ( !x ) {
    x = true
}

assert x == true

if ( x ) {
    x = false
} else {
    y = true
}

assert x == y
```

Groovy also supports the normal Java "nested" if then else if syntax:

```
if ( ... ) {
    ...
} else if (...) {
    ...
} else {
    ...
}
```

switch / case

The switch statement in Groovy is backwards compatible with Java code; so you can fall through cases sharing the same code for multiple matches.

One difference though is that the Groovy switch statement can handle any kind of switch value and different kinds of matching can be performed.

```
def x = 1.23
def result = ""

switch (x) {
  case "foo":
    result = "found foo"
    // lets fall through

  case "bar":
    result += "bar"

  case [4, 5, 6, 'inList']:
    result = "list"
```

```
    break

  case 12..30:
    result = "range"
    break

  case Integer:
    result = "integer"
    break

  case Number:
    result = "number"
    break

  case ~/fo*/: // toString() representation of x matches the pattern?
    result = "foo regex"
    break

  case { it < 0 }: // or { x < 0 }
    result = "negative"
    break

  default:
    result = "default"
}

assert result == "number"
```

Switch supports the following kinds of comparisons:

- Class case values match if the switch value is an instance of the class
- Regular expression case values match if the `toString()` representation of the switch value matches the regex
- Collection case values match if the switch value is contained in the collection. This also includes ranges (since they are Lists)
- Closure case values match if the calling the closure returns a result which is true according to the Groovy truth
- If none of the above are used then the case value matches if the case value equals the switch value

NOTE	When using a closure case value, the default `it` parameter is actually the switch value (in our example, variable `x`).

Groovy also supports switch expressions as shown in the following example:

```
def partner = switch(person) {
    case 'Romeo'  -> 'Juliet'
```

```
    case 'Adam'   -> 'Eve'
    case 'Antony' -> 'Cleopatra'
    case 'Bonnie' -> 'Clyde'
}
```

Looping structures

Classic for loop

Groovy supports the standard Java / C for loop:

```
String message = ''
for (int i = 0; i < 5; i += 1) {
    message += 'Hi '
}
assert message == 'Hi Hi Hi Hi Hi '
```

Enhanced classic Java-style for loop

The more elaborate form of Java's classic for loop with comma-separate expressions is now supported. Example:

```
def facts = []
def count = 5
for (int fact = 1, i = 1; i <= count; i++, fact *= i) {
    facts << fact
}
assert facts == [1, 2, 6, 24, 120]
```

Multi-assignment in combination with for loop

Groovy has supported multi-assignment statements since Groovy 1.6:

```
// multi-assignment with types
def (String x, int y) = ['foo', 42]
assert "$x $y" == 'foo 42'
```

These can now appear in for loops:

```
// multi-assignment goes loopy
def baNums = []
for (def (String u, int v) = ['bar', 42]; v < 45; u++, v++) {
    baNums << "$u $v"
}
assert baNums == ['bar 42', 'bas 43', 'bat 44']
```

for in loop

The for loop in Groovy is much simpler and works with any kind of array, collection, Map, etc.

```
// iterate over a range
def x = 0
for ( i in 0..9 ) {
    x += i
}
assert x == 45

// iterate over a list
x = 0
for ( i in [0, 1, 2, 3, 4] ) {
    x += i
}
assert x == 10

// iterate over an array
x = 0
for ( i in new int[]{0, 1, 2, 3, 4} ) {
    x += i
}
assert x == 10

// iterate over a map
def map = [a:1, b:2, c:3]
x = 0
for ( e in map ) {
    x += e.value
}
assert x == 6

// iterate over values in a map
x = 0
for ( v in map.values() ) {
    x += v
}
assert x == 6

// iterate over the characters in a string
def list = []
for ( c in 'abc' ) {
    list.add(c)
}
assert list == ['a', 'b', 'c']

// iterate with index
for ( int i, k in map.keySet() ) {
    assert map.get(k) == i + 1
```

```
}
```

NOTE Groovy also supports the Java colon variation with colons: `for (char c : text) {}`

while loop

Groovy supports the usual while {…} loops like Java:

```
def x = 0
def y = 5

while ( y-- > 0 ) {
    x++
}

assert x == 5
```

do/while loop

Java's class do/while loop is now supported. Example:

```
// classic Java-style do..while loop
def count = 5
def fact = 1
do {
    fact *= count--
} while(count > 1)
assert fact == 120
```

Exception handling

Exception handling is the same as Java.

try / catch / finally

You can specify a complete `try-catch-finally`, a `try-catch`, or a `try-finally` set of blocks.

NOTE Braces are required around each block's body.

```
try {
    'moo'.toLong()   // this will generate an exception
    assert false     // asserting that this point should never be reached
} catch ( e ) {
    assert e in NumberFormatException
}
```

We can put code within a 'finally' clause following a matching 'try' clause, so that regardless of whether the code in the 'try' clause throws an exception, the code in the finally clause will always execute:

```
def z
try {
    def i = 7, j = 0
    try {
        def k = i / j
        assert false        //never reached due to Exception in previous line
    } finally {
        z = 'reached here'  //always executed even if Exception thrown
    }
} catch ( e ) {
    assert e in ArithmeticException
    assert z == 'reached here'
}
```

Multi-catch

With the multi catch block (since Groovy 2.0), we're able to define several exceptions to be catch and treated by the same catch block:

```
try {
    /* ... */
} catch ( IOException | NullPointerException e ) {
    /* one block to handle 2 exceptions */
}
```

ARM Try with resources

Groovy often provides better alternatives to Java 7's `try`-with-resources statement for Automatic Resource Management (ARM). That syntax is now supported for Java programmers migrating to Groovy and still wanting to use the old style:

```
class FromResource extends ByteArrayInputStream {
    @Override
    void close() throws IOException {
        super.close()
        println "FromResource closing"
    }

    FromResource(String input) {
        super(input.toLowerCase().bytes)
    }
}

class ToResource extends ByteArrayOutputStream {
```

```
    @Override
    void close() throws IOException {
        super.close()
        println "ToResource closing"
    }
}

def wrestle(s) {
    try (
            FromResource from = new FromResource(s)
            ToResource to = new ToResource()
    ) {
        to << from
        return to.toString()
    }
}

def wrestle2(s) {
    FromResource from = new FromResource(s)
    try (from; ToResource to = new ToResource()) { // Enhanced try-with-resources in
Java 9+
        to << from
        return to.toString()
    }
}

assert wrestle("ARM was here!").contains('arm')
assert wrestle2("ARM was here!").contains('arm')
```

Which yields the following output:

```
ToResource closing
FromResource closing
ToResource closing
FromResource closing
```

Power assertion

Unlike Java with which Groovy shares the `assert` keyword, the latter in Groovy behaves very differently. First of all, an assertion in Groovy is always executed, independently of the `-ea` flag of the JVM. It makes this a first class choice for unit tests. The notion of "power asserts" is directly related to how the Groovy `assert` behaves.

A power assertion is decomposed into 3 parts:

```
assert [left expression] == [right expression] : (optional message)
```

The result of the assertion is very different from what you would get in Java. If the assertion is true, then nothing happens. If the assertion is false, then it provides a visual representation of the value of each sub-expressions of the expression being asserted. For example:

```
assert 1+1 == 3
```

Will yield:

```
Caught: Assertion failed:

assert 1+1 == 3
        |  |
        2  false
```

Power asserts become very interesting when the expressions are more complex, like in the next example:

```
def x = 2
def y = 7
def z = 5
def calc = { a,b -> a*b+1 }
assert calc(x,y) == [x,z].sum()
```

Which will print the value for each sub-expression:

```
assert calc(x,y) == [x,z].sum()
       |    | |  |   | |  |
       15   2 7  |   2 5  7
                 false
```

In case you don't want a pretty printed error message like above, you can fall back to a custom error message by changing the optional message part of the assertion, like in this example:

```
def x = 2
def y = 7
def z = 5
def calc = { a,b -> a*b+1 }
assert calc(x,y) == z*z : 'Incorrect computation result'
```

Which will print the following error message:

```
Incorrect computation result. Expression: (calc.call(x, y) == (z * z)). Values: z = 5,
z = 5
```

Labeled statements

Any statement can be associated with a label. Labels do not impact the semantics of the code and can be used to make the code easier to read like in the following example:

```
given:
    def x = 1
    def y = 2
when:
    def z = x+y
then:
    assert z == 3
```

Despite not changing the semantics of the labelled statement, it is possible to use labels in the `break` instruction as a target for jump, as in the next example. However, even if this is allowed, this coding style is in general considered a bad practice:

```
for (int i=0;i<10;i++) {
    for (int j=0;j<i;j++) {
        println "j=$j"
        if (j == 5) {
            break exit
        }
    }
    exit: println "i=$i"
}
```

It is important to understand that by default labels have no impact on the semantics of the code, however they belong to the abstract syntax tree (AST) so it is possible for an AST transformation to use that information to perform transformations over the code, hence leading to different semantics. This is in particular what the Spock Framework does to make testing easier.

Expressions

Expressions are the building blocks of Groovy programs that are used to reference existing values and execute code to create new ones.

Groovy supports many of the same kinds of expressions as Java, including:

Table 5. Expressions like Java

Example expression(s)	Description
`foo`	the name of a variable, field, parameter, …
`this`, `super`, `it`	special names
`true`, `10`, `"bar"`	literals
`String.class`	Class literal

(*expression*)	parenthesised expressions
foo++, ~bar	Unary operator expressions
foo + bar, bar * baz	Binary operator expressions
foo ? bar : baz	Ternary operator expressions
(Integer x, Integer y) → x + y	Lambda expressions
`assert 'bar' == switch('foo') { case 'foo' -> 'bar' }`	switch expressions

Groovy also has some of its own special expressions:

Table 6. Special expressions

Example expression(s)	Description
String	Abbreviated class literal (when not ambiguous)
{ x, y → x + y }	Closure expressions
[1, 3, 5]	literal list expressions
[a:2, b:4, c:6]	literal map expressions

Groovy also expands on the normal dot-notation used in Java for member access. Groovy provides special support for accessing hierarchical data structures by specifying the path in the hierarchy of some data of interest. These *Groovy path* expressions are known as GPath expressions.

GPath expressions

`GPath` is a path expression language integrated into Groovy which allows parts of nested structured data to be identified. In this sense, it has similar aims and scope as XPath does for XML. GPath is often used in the context of processing XML, but it really applies to any object graph. Where XPath uses a filesystem-like path notation, a tree hierarchy with parts separated by a slash `/`, GPath **use a dot-object notation** to perform object navigation.

As an example, you can specify a path to an object or element of interest:

- `a.b.c` → for XML, yields all the `c` elements inside `b` inside `a`
- `a.b.c` → for POJOs, yields the `c` properties for all the `b` properties of `a` (sort of like `a.getB().getC()` in JavaBeans)

In both cases, the GPath expression can be viewed as a query on an object graph. For POJOs, the object graph is most often built by the program being written through object instantiation and composition; for XML processing, the object graph is the result of `parsing` the XML text, most often with classes like XmlParser or XmlSlurper. See Processing XML for more in-depth details on consuming XML in Groovy.

TIP	When querying the object graph generated from XmlParser or XmlSlurper, a GPath

expression can refer to attributes defined on elements with the `@` notation:

- `a["@href"]` → map-like notation : the href attribute of all the a elements
- `a.'@href'` → property notation : an alternative way of expressing this
- `a.@href` → direct notation : yet another alternative way of expressing this

Object navigation

Let's see an example of a GPath expression on a simple *object graph*, the one obtained using java reflection. Suppose you are in a non-static method of a class having another method named `aMethodFoo`

```
void aMethodFoo() { println "This is aMethodFoo." } ⑳
```

the following GPath expression will get the name of that method:

```
assert ['aMethodFoo'] == this.class.methods.name.grep(~/.*Foo/)
```

More precisely, the above GPath expression produces a list of String, each being the name of an existing method on `this` where that name ends with `Foo`.

Now, given the following methods also defined in that class:

```
void aMethodBar() { println "This is aMethodBar." } ①
void anotherFooMethod() { println "This is anotherFooMethod." } ②
void aSecondMethodBar() { println "This is aSecondMethodBar." } ③
```

then the following GPath expression will get the names of **(1)** and **(3)**, but not **(2)** or **(0)**:

```
assert ['aMethodBar', 'aSecondMethodBar'] as Set == this.class.methods.name.grep
(~/.*Bar/) as Set
```

Expression Deconstruction

We can decompose the expression `this.class.methods.name.grep(~/.*Bar/)` to get an idea of how a GPath is evaluated:

`this.class`
: property accessor, equivalent to `this.getClass()` in Java, yields a `Class` object.

`this.class.methods`
: property accessor, equivalent to `this.getClass().getMethods()`, yields an array of `Method` objects.

`this.class.methods.name`
: apply a property accessor on each element of an array and produce a list of the results.

`this.class.methods.name.grep(…)`

call method `grep` on each element of the list yielded by `this.class.methods.name` and produce a list of the results.

WARNING A sub-expression like `this.class.methods` yields an array because this is what calling `this.getClass().getMethods()` in Java would produce. `GPath` expressions do not have a convention where a `s` means a list or anything like that.

One powerful feature of GPath expression is that property access on a collection is converted to a *property access on each element of the collection* with the results collected into a collection. Therefore, the expression `this.class.methods.name` could be expressed as follows in Java:

```
List<String> methodNames = new ArrayList<String>();
for (Method method : this.getClass().getMethods()) {
   methodNames.add(method.getName());
}
return methodNames;
```

Array access notation can also be used in a GPath expression where a collection is present :

```
assert 'aSecondMethodBar' == this.class.methods.name.grep(~/.*Bar/).sort()[1]
```

NOTE array access are zero-based in GPath expressions

GPath for XML navigation

Here is an example with an XML document and various form of GPath expressions:

```
def xmlText = """
              | <root>
              |   <level>
              |      <sublevel id='1'>
              |        <keyVal>
              |          <key>mykey</key>
              |          <value>value 123</value>
              |        </keyVal>
              |      </sublevel>
              |      <sublevel id='2'>
              |        <keyVal>
              |          <key>anotherKey</key>
              |          <value>42</value>
              |        </keyVal>
              |        <keyVal>
              |          <key>mykey</key>
              |          <value>fizzbuzz</value>
              |        </keyVal>
              |      </sublevel>
```

```
            |   </level>
            | </root>
            """
def root = new XmlSlurper().parseText(xmlText.stripMargin())
assert root.level.size() == 1 ①
assert root.level.sublevel.size() == 2 ②
assert root.level.sublevel.findAll { it.@id == 1 }.size() == 1 ③
assert root.level.sublevel[1].keyVal[0].key.text() == 'anotherKey' ④
```

① There is one `level` node under `root`

② There are two `sublevel` nodes under `root/level`

③ There is one element `sublevel` having an attribute `id` with value `1`

④ Text value of `key` element of first `keyVal` element of second `sublevel` element under `root/level` is 'anotherKey'

Further details about GPath expressions for XML are in the XML User Guide.

Promotion and coercion

Number promotion

The rules of number promotion are specified in the section on math operations.

Closure to type coercion

Assigning a closure to a SAM type

A SAM type is a type which defines a single abstract method. This includes:

Functional interfaces

```
interface Predicate<T> {
    boolean accept(T obj)
}
```

Abstract classes with single abstract method

```
abstract class Greeter {
    abstract String getName()
    void greet() {
        println "Hello, $name"
    }
}
```

Any closure can be converted into a SAM type using the `as` operator:

```
Predicate filter = { it.contains 'G' } as Predicate
assert filter.accept('Groovy') == true
```

```
Greeter greeter = { 'Groovy' } as Greeter
greeter.greet()
```

However, the `as Type` expression is optional since Groovy 2.2.0. You can omit it and simply write:

```
Predicate filter = { it.contains 'G' }
assert filter.accept('Groovy') == true

Greeter greeter = { 'Groovy' }
greeter.greet()
```

which means you are also allowed to use method pointers, as shown in the following example:

```
boolean doFilter(String s) { s.contains('G') }

Predicate filter = this.&doFilter
assert filter.accept('Groovy') == true

Greeter greeter = GroovySystem.&getVersion
greeter.greet()
```

Calling a method accepting a SAM type with a closure

The second and probably more important use case for closure to SAM type coercion is calling a method which accepts a SAM type. Imagine the following method:

```
public <T> List<T> filter(List<T> source, Predicate<T> predicate) {
    source.findAll { predicate.accept(it) }
}
```

Then you can call it with a closure, without having to create an explicit implementation of the interface:

```
assert filter(['Java','Groovy'], { it.contains 'G'} as Predicate) == ['Groovy']
```

But since Groovy 2.2.0, you are also able to omit the explicit coercion and call the method as if it used a closure:

```
assert filter(['Java','Groovy']) { it.contains 'G'} == ['Groovy']
```

As you can see, this has the advantage of letting you use the closure syntax for method calls, that is to say put the closure outside the parenthesis, improving the readability of your code.

Closure to arbitrary type coercion

In addition to SAM types, a closure can be coerced to any type and in particular interfaces. Let's define the following interface:

```
interface FooBar {
    int foo()
    void bar()
}
```

You can coerce a closure into the interface using the `as` keyword:

```
def impl = { println 'ok'; 123 } as FooBar
```

This produces a class for which all methods are implemented using the closure:

```
assert impl.foo() == 123
impl.bar()
```

But it is also possible to coerce a closure to any class. For example, we can replace the `interface` that we defined with `class` without changing the assertions:

```
class FooBar {
    int foo() { 1 }
    void bar() { println 'bar' }
}

def impl = { println 'ok'; 123 } as FooBar

assert impl.foo() == 123
impl.bar()
```

Map to type coercion

Usually using a single closure to implement an interface or a class with multiple methods is not the way to go. As an alternative, Groovy allows you to coerce a map into an interface or a class. In that case, keys of the map are interpreted as method names, while the values are the method implementation. The following example illustrates the coercion of a map into an `Iterator`:

```
def map
map = [
  i: 10,
  hasNext: { map.i > 0 },
  next: { map.i-- },
]
```

```
def iter = map as Iterator
```

Of course this is a rather contrived example, but illustrates the concept. You only need to implement those methods that are actually called, but if a method is called that doesn't exist in the map a `MissingMethodException` or an `UnsupportedOperationException` is thrown, depending on the arguments passed to the call, as in the following example:

```
interface X {
    void f()
    void g(int n)
    void h(String s, int n)
}

x = [ f: {println "f called"} ] as X
x.f() // method exists
x.g() // MissingMethodException here
x.g(5) // UnsupportedOperationException here
```

The type of the exception depends on the call itself:

- `MissingMethodException` if the arguments of the call do not match those from the interface/class
- `UnsupportedOperationException` if the arguments of the call match one of the overloaded methods of the interface/class

String to enum coercion

Groovy allows transparent `String` (or `GString`) to enum values coercion. Imagine you define the following enum:

```
enum State {
    up,
    down
}
```

then you can assign a string to the enum without having to use an explicit `as` coercion:

```
State st = 'up'
assert st == State.up
```

It is also possible to use a `GString` as the value:

```
def val = "up"
State st = "${val}"
assert st == State.up
```

However, this would throw a runtime error (IllegalArgumentException):

```
State st = 'not an enum value'
```

Note that it is also possible to use implicit coercion in switch statements:

```
State switchState(State st) {
    switch (st) {
        case 'up':
            return State.down // explicit constant
        case 'down':
            return 'up' // implicit coercion for return types
    }
}
```

in particular, see how the case use string constants. But if you call a method that uses an enum with a String argument, you still have to use an explicit as coercion:

```
assert switchState('up' as State) == State.down
assert switchState(State.down) == State.up
```

Custom type coercion

It is possible for a class to define custom coercion strategies by implementing the asType method. Custom coercion is invoked using the as operator and is never implicit. As an example, imagine you defined two classes, Polar and Cartesian, like in the following example:

```
class Polar {
    double r
    double phi
}
class Cartesian {
   double x
   double y
}
```

And that you want to convert from polar coordinates to cartesian coordinates. One way of doing this is to define the asType method in the Polar class:

```
def asType(Class target) {
    if (Cartesian==target) {
        return new Cartesian(x: r*cos(phi), y: r*sin(phi))
    }
}
```

which allows you to use the as coercion operator:

```
def sigma = 1E-16
def polar = new Polar(r:1.0,phi:PI/2)
def cartesian = polar as Cartesian
assert abs(cartesian.x-sigma) < sigma
```

Putting it all together, the Polar class looks like this:

```
class Polar {
    double r
    double phi
    def asType(Class target) {
        if (Cartesian==target) {
            return new Cartesian(x: r*cos(phi), y: r*sin(phi))
        }
    }
}
```

but it is also possible to define asType outside of the Polar class, which can be practical if you want to define custom coercion strategies for "closed" classes or classes for which you don't own the source code, for example using a metaclass:

```
Polar.metaClass.asType = { Class target ->
    if (Cartesian==target) {
        return new Cartesian(x: r*cos(phi), y: r*sin(phi))
    }
}
```

Class literals vs variables and the as operator

Using the as keyword is only possible if you have a static reference to a class, like in the following code:

```
interface Greeter {
    void greet()
}
def greeter = { println 'Hello, Groovy!' } as Greeter // Greeter is known statically
greeter.greet()
```

But what if you get the class by reflection, for example by calling Class.forName?

```
Class clazz = Class.forName('Greeter')
```

Trying to use the reference to the class with the as keyword would fail:

```
greeter = { println 'Hello, Groovy!' } as clazz
// throws:
// unable to resolve class clazz
// @ line 9, column 40.
//   greeter = { println 'Hello, Groovy!' } as clazz
```

It is failing because the `as` keyword only works with class literals. Instead, you need to call the `asType` method:

```
greeter = { println 'Hello, Groovy!' }.asType(clazz)
greeter.greet()
```

Optionality

Optional parentheses

Method calls can omit the parentheses if there is at least one parameter and there is no ambiguity:

```
println 'Hello World'
def maximum = Math.max 5, 10
```

Parentheses are required for method calls without parameters or ambiguous method calls:

```
println()
println(Math.max(5, 10))
```

Optional semicolons

In Groovy semicolons at the end of the line can be omitted, if the line contains only a single statement.

This means that:

```
assert true;
```

can be more idiomatically written as:

```
assert true
```

Multiple statements in a line require semicolons to separate them:

```
boolean a = true; assert a
```

Optional return keyword

In Groovy, the last expression evaluated in the body of a method or a closure is returned. This means that the `return` keyword is optional.

```
int add(int a, int b) {
    return a+b
}
assert add(1, 2) == 3
```

Can be shortened to:

```
int add(int a, int b) {
    a+b
}
assert add(1, 2) == 3
```

Optional public keyword

By default, Groovy classes and methods are `public`. Therefore this class:

```
public class Server {
    public String toString() { "a server" }
}
```

is identical to this class:

```
class Server {
    String toString() { "a server" }
}
```

The Groovy Truth

Groovy decides whether an expression is true or false by applying the rules given below.

Boolean expressions

True if the corresponding Boolean value is `true`.

```
assert true
assert !false
```

Collections and Arrays

Non-empty Collections and arrays are true.

```
assert [1, 2, 3]
assert ![]
```

Matchers

True if the Matcher has at least one match.

```
assert ('a' =~ /a/)
assert !('a' =~ /b/)
```

Iterators and Enumerations

Iterators and Enumerations with further elements are coerced to true.

```
assert [0].iterator()
assert ![].iterator()
Vector v = [0] as Vector
Enumeration enumeration = v.elements()
assert enumeration
enumeration.nextElement()
assert !enumeration
```

Maps

Non-empty Maps are evaluated to true.

```
assert ['one' : 1]
assert ![:]
```

Strings

Non-empty Strings, GStrings and CharSequences are coerced to true.

```
assert 'a'
assert !''
def nonEmpty = 'a'
assert "$nonEmpty"
def empty = ''
assert !"$empty"
```

Numbers

Non-zero numbers are true.

```
assert 1
assert 3.5
assert !0
```

Object References

Non-null object references are coerced to true.

```
assert new Object()
assert !null
```

Customizing the truth with asBoolean() methods

In order to customize whether groovy evaluates your object to `true` or `false` implement the `asBoolean()` method:

```
class Color {
    String name

    boolean asBoolean(){
        name == 'green' ? true : false
    }
}
```

Groovy will call this method to coerce your object to a boolean value, e.g.:

```
assert new Color(name: 'green')
assert !new Color(name: 'red')
```

Typing

Optional typing

Optional typing is the idea that a program can work even if you don't put an explicit type on a variable. Being a dynamic language, Groovy naturally implements that feature, for example when you declare a variable:

```
String aString = 'foo'                      ①
assert aString.toUpperCase()                ②
```

① `foo` is declared using an explicit type, `String`

② we can call the `toUpperCase` method on a `String`

Groovy will let you write this instead:

```
def aString = 'foo'                          ①
assert aString.toUpperCase()                 ②
```

① foo is declared using def

② we can still call the toUpperCase method, because the type of aString is resolved at runtime

So it doesn't matter that you use an explicit type here. It is in particular interesting when you combine this feature with static type checking, because the type checker performs type inference.

Likewise, Groovy doesn't make it mandatory to declare the types of a parameter in a method:

```
String concat(String a, String b) {
    a+b
}
assert concat('foo','bar') == 'foobar'
```

can be rewritten using def as both return type and parameter types, in order to take advantage of duck typing, as illustrated in this example:

```
def concat(def a, def b) {                         ①
    a+b
}
assert concat('foo','bar') == 'foobar'             ②
assert concat(1,2) == 3                            ③
```

① both the return type and the parameter types use def

② it makes it possible to use the method with String

③ but also with int since the plus method is defined

TIP Using the def keyword here is recommended to describe the intent of a method which is supposed to work on any type, but technically, we could use Object instead and the result would be the same: def is, in Groovy, strictly equivalent to using Object.

Eventually, the type can be removed altogether from both the return type and the descriptor. But if you want to remove it from the return type, you then need to add an explicit modifier for the method, so that the compiler can make a difference between a method declaration and a method call, like illustrated in this example:

```
private concat(a,b) {                              ①
    a+b
}
assert concat('foo','bar') == 'foobar'             ②
assert concat(1,2) == 3                            ③
```

① if we want to omit the return type, an explicit modifier has to be set.

② it is still possible to use the method with `String`

③ and also with `int`

TIP Omitting types is in general considered a bad practice in method parameters or method return types for public APIs. While using `def` in a local variable is not really a problem because the visibility of the variable is limited to the method itself, while set on a method parameter, `def` will be converted to `Object` in the method signature, making it difficult for users to know which is the expected type of the arguments. This means that you should limit this to cases where you are explicitly relying on duck typing.

Static type checking

By default, Groovy performs minimal type checking at compile time. Since it is primarily a dynamic language, most checks that a static compiler would normally do aren't possible at compile time. A method added via runtime metaprogramming might alter a class or object's runtime behavior. Let's illustrate why in the following example:

```
class Person {                                                  ①
    String firstName
    String lastName
}
def p = new Person(firstName: 'Raymond', lastName: 'Devos')     ②
assert p.formattedName == 'Raymond Devos'                       ③
```

① the `Person` class only defines two properties, `firstName` and `lastName`

② we can create an instance of Person

③ and call a method named `formattedName`

It is quite common in dynamic languages for code such as the above example not to throw any error. How can this be? In Java, this would typically fail at compile time. However, in Groovy, it will not fail at compile time, and if coded correctly, will also not fail at runtime. In fact, to make this work at runtime, **one** possibility is to rely on runtime metaprogramming. So just adding this line after the declaration of the `Person` class is enough:

```
Person.metaClass.getFormattedName = { "$delegate.firstName $delegate.lastName" }
```

This means that in general, in Groovy, you can't make any assumption about the type of an object beyond its declaration type, and even if you know it, you can't determine at compile time what method will be called, or which property will be retrieved. It has a lot of interest, going from writing DSLs to testing, which is discussed in other sections of this manual.

However, if your program doesn't rely on dynamic features and that you come from the static world (in particular, from a Java mindset), not catching such "errors" at compile time can be surprising. As we have seen in the previous example, the compiler cannot be sure this is an error. To make it aware that it is, you have to explicitly instruct the compiler that you are switching to a type checked mode. This can be done by annotating a class or a method with `@groovy.transform.TypeChecked`.

When type checking is activated, the compiler performs much more work:

- type inference is activated, meaning that even if you use `def` on a local variable for example, the type checker will be able to infer the type of the variable from the assignments
- method calls are resolved at compile time, meaning that if a method is not declared on a class, the compiler will throw an error
- in general, all the compile time errors that you are used to find in a static language will appear: method not found, property not found, incompatible types for method calls, number precision errors, …

In this section, we will describe the behavior of the type checker in various situations and explain the limits of using `@TypeChecked` on your code.

The `@TypeChecked` annotation

Activating type checking at compile time

The `groovy.transform.TypeChecked` annotation enables type checking. It can be placed on a class:

```
@groovy.transform.TypeChecked
class Calculator {
    int sum(int x, int y) { x+y }
}
```

Or on a method:

```
class Calculator {
    @groovy.transform.TypeChecked
    int sum(int x, int y) { x+y }
}
```

In the first case, all methods, properties, fields, inner classes, … of the annotated class will be type checked, whereas in the second case, only the method and potential closures or anonymous inner classes that it contains will be type checked.

Skipping sections

The scope of type checking can be restricted. For example, if a class is type checked, you can instruct the type checker to skip a method by annotating it with `@TypeChecked(TypeCheckingMode.SKIP)`:

```
import groovy.transform.TypeChecked
import groovy.transform.TypeCheckingMode
```

```groovy
@TypeChecked                                             ①
class GreetingService {
    String greeting() {                                  ②
        doGreet()
    }

    @TypeChecked(TypeCheckingMode.SKIP)                  ③
    private String doGreet() {
        def b = new SentenceBuilder()
        b.Hello.my.name.is.John                          ④
        b
    }
}
def s = new GreetingService()
assert s.greeting() == 'Hello my name is John'
```

① the `GreetingService` class is marked as type checked

② so the `greeting` method is automatically type checked

③ but `doGreet` is marked with `SKIP`

④ the type checker doesn't complain about missing properties here

In the previous example, `SentenceBuilder` relies on dynamic code. There's no real `Hello` method or property, so the type checker would normally complain and compilation would fail. Since the method that uses the builder is marked with `TypeCheckingMode.SKIP`, type checking is *skipped* for this method, so the code will compile, even if the rest of the class is type checked.

The following sections describe the semantics of type checking in Groovy.

Type checking assignments

An object `o` of type `A` can be assigned to a variable of type `T` if and only if:

- `T` equals `A`

```groovy
Date now = new Date()
```

- *or* `T` is one of `String`, `boolean`, `Boolean` or `Class`

```groovy
String s = new Date() // implicit call to toString
Boolean boxed = 'some string'       // Groovy truth
boolean prim = 'some string'        // Groovy truth
Class clazz = 'java.lang.String'    // class coercion
```

- *or* `o` is null and `T` is not a primitive type

```
String s = null          // passes
int i = null             // fails
```

- *or* T is an array and A is an array and the component type of A is assignable to the component type of T

```
int[] i = new int[4]        // passes
int[] i = new String[4]     // fails
```

- *or* T is an array and A is a collection or stream and the component type of A is assignable to the component type of T

```
int[] i = [1,2,3]               // passes
int[] i = [1,2, new Date()]     // fails
Set set = [1,2,3]
Number[] na = set               // passes
def stream = Arrays.stream(1,2,3)
int[] i = stream                // passes
```

- *or* T is a superclass of A

```
AbstractList list = new ArrayList()     // passes
LinkedList list = new ArrayList()       // fails
```

- *or* T is an interface implemented by A

```
List list = new ArrayList()             // passes
RandomAccess list = new LinkedList()    // fails
```

- *or* T or A are a primitive type and their boxed types are assignable

```
int i = 0
Integer bi = 1
int x = Integer.valueOf(123)
```

```
double d = Float.valueOf(5f)
```

- *or* `T` extends `groovy.lang.Closure` and `A` is a SAM-type (single abstract method type)

```
Runnable r = { println 'Hello' }
interface SAMType {
    int doSomething()
}
SAMType sam = { 123 }
assert sam.doSomething() == 123
abstract class AbstractSAM {
    int calc() { 2* value() }
    abstract int value()
}
AbstractSAM c = { 123 }
assert c.calc() == 246
```

- *or* `T` and `A` derive from `java.lang.Number` and conform to the following table

Table 7. Number types (java.lang.XXX)

T	A	Examples

Double	Any but BigDecimal or BigInteger	`Double d1 = 4d`
		`Double d2 = 4f`
		`Double d3 = 4l`
		`Double d4 = 4i`
		`Double d5 = (short) 4`
		`Double d6 = (byte) 4`

Float	Any type but BigDecimal, BigInteger or Double	`Float f1 = 4f`
		`Float f2 = 4l`
		`Float f3 = 4i`
		`Float f4 = (short) 4`
		`Float f5 = (byte) 4`

Long	Any type but BigDecimal, BigInteger, Double or Float	`Long l1 = 4l`
		`Long l2 = 4i`
		`Long l3 = (short) 4`
		`Long l4 = (byte) 4`

T	A	Examples

Integer	Any type but BigDecimal, BigInteger, Double, Float or Long	`Integer i1 = 4i`
		`Integer i2 = (short) 4`
		`Integer i3 = (byte) 4`

Short	Any type but BigDecimal, BigInteger, Double, Float, Long or Integer	`Short s1 = (short) 4` `Short s2 = (byte) 4`
Byte	Byte	`Byte b1 = (byte) 4`

List and map constructors

In addition to the assignment rules above, if an assignment is deemed invalid, in type checked mode, a *list* literal or a *map* literal `A` can be assigned to a variable of type `T` if:

- the assignment is a variable declaration and `A` is a list literal and `T` has a constructor whose parameters match the types of the elements in the list literal
- the assignment is a variable declaration and `A` is a map literal and `T` has a no-arg constructor and a property for each of the map keys

For example, instead of writing:

```
@groovy.transform.TupleConstructor
class Person {
    String firstName
    String lastName
}
Person classic = new Person('Ada','Lovelace')
```

You can use a "list constructor":

```
Person list = ['Ada','Lovelace']
```

or a "map constructor":

```
Person map = [firstName:'Ada', lastName:'Lovelace']
```

If you use a map constructor, additional checks are done on the keys of the map to check if a property of the same name is defined. For example, the following will fail at compile time:

```
@groovy.transform.TupleConstructor
class Person {
```

```
    String firstName
    String lastName
}
Person map = [firstName:'Ada', lastName:'Lovelace', age: 24]     ①
```

① The type checker will throw an error `No such property: age for class: Person` at compile time

Method resolution

In type checked mode, methods are resolved at compile time. Resolution works by name and arguments. The return type is irrelevant to method selection. Types of arguments are matched against the types of the parameters following those rules:

An argument `o` of type `A` can be used for a parameter of type `T` if and only if:

- `T` equals `A`

  ```
  int sum(int x, int y) {
      x+y
  }
  assert sum(3,4) == 7
  ```

- *or* `T` is a `String` and `A` is a `GString`

  ```
  String format(String str) {
      "Result: $str"
  }
  assert format("${3+4}") == "Result: 7"
  ```

- *or* `o` is null and `T` is not a primitive type

  ```
  String format(int value) {
      "Result: $value"
  }
  assert format(7) == "Result: 7"
  format(null)           // fails
  ```

- *or* `T` is an array and `A` is an array and the component type of `A` is assignable to the component type of `T`

  ```
  String format(String[] values) {
  ```

```
    "Result: ${values.join(' ')}"
}
assert format(['a','b'] as String[]) == "Result: a b"
format([1,2] as int[])              // fails
```

- *or* T is a superclass of A

```
String format(AbstractList list) {
    list.join(',')
}
format(new ArrayList())              // passes
String format(LinkedList list) {
    list.join(',')
}
format(new ArrayList())              // fails
```

- *or* T is an interface implemented by A

```
String format(List list) {
    list.join(',')
}
format(new ArrayList())                  // passes
String format(RandomAccess list) {
    'foo'
}
format(new LinkedList())                 // fails
```

- *or* T or A are a primitive type and their boxed types are assignable

```
int sum(int x, Integer y) {
    x+y
}
assert sum(3, new Integer(4)) == 7
assert sum(new Integer(3), 4) == 7
assert sum(new Integer(3), new Integer(4)) == 7
assert sum(new Integer(3), 4) == 7
```

- *or* T extends `groovy.lang.Closure` and A is a SAM-type (single abstract method type)

```
interface SAMType {
```

```
    int doSomething()
}
int twice(SAMType sam) { 2*sam.doSomething() }
assert twice { 123 } == 246
abstract class AbstractSAM {
    int calc() { 2* value() }
    abstract int value()
}
int eightTimes(AbstractSAM sam) { 4*sam.calc() }
assert eightTimes { 123 } == 984
```

* *or* `T` and `A` derive from `java.lang.Number` and conform to the same rules as assignment of numbers

If a method with the appropriate name and arguments is not found at compile time, an error is thrown. The difference with "normal" Groovy is illustrated in the following example:

```
class MyService {
    void doSomething() {
        printLine 'Do something'            ①
    }
}
```

① `printLine` is an error, but since we're in a dynamic mode, the error is not caught at compile time

The example above shows a class that Groovy will be able to compile. However, if you try to create an instance of `MyService` and call the `doSomething` method, then it will fail **at runtime**, because `printLine` doesn't exist. Of course, we already showed how Groovy could make this a perfectly valid call, for example by catching `MethodMissingException` or implementing a custom metaclass, but if you know you're not in such a case, `@TypeChecked` comes handy:

```
@groovy.transform.TypeChecked
class MyService {
    void doSomething() {
        printLine 'Do something'            ①
    }
}
```

① `printLine` is this time a compile-time error

Just adding `@TypeChecked` will trigger compile time method resolution. The type checker will try to find a method `printLine` accepting a `String` on the `MyService` class, but cannot find one. It will fail compilation with the following message:

`Cannot find matching method MyService#printLine(java.lang.String)`

IMPORTANT	It is important to understand the logic behind the type checker: it is a

compile-time check, so by definition, the type checker is not aware of any kind of **runtime** metaprogramming that you do. This means that code which is perfectly valid without `@TypeChecked` will **not** compile anymore if you activate type checking. This is in particular true if you think of duck typing:

```
class Duck {
    void quack() {              ①
        println 'Quack!'
    }
}
class QuackingBird {
    void quack() {              ②
        println 'Quack!'
    }
}
@groovy.transform.TypeChecked
void accept(quacker) {
    quacker.quack()             ③
}
accept(new Duck())              ④
```

① we define a `Duck` class which defines a `quack` method

② we define another `QuackingBird` class which also defines a `quack` method

③ `quacker` is loosely typed, so since the method is `@TypeChecked`, we will obtain a compile-time error

④ even if in non type-checked Groovy, this would have passed

There are possible workarounds, like introducing an interface, but basically, by activating type checking, you gain type safety but you loose some features of the language. Hopefully, Groovy introduces some features like flow typing to reduce the gap between type-checked and non type-checked Groovy.

Type inference

Principles

When code is annotated with `@TypeChecked`, the compiler performs type inference. It doesn't simply rely on static types, but also uses various techniques to infer the types of variables, return types, literals, … so that the code remains as clean as possible even if you activate the type checker.

The simplest example is inferring the type of a variable:

```
def message = 'Welcome to Groovy!'              ①
println message.toUpperCase()                   ②
println message.upper() // compile time error   ③
```

① a variable is declared using the `def` keyword

② calling `toUpperCase` is allowed by the type checker

③ calling `upper` will fail at compile time

The reason the call to `toUpperCase` works is because the type of `message` was *inferred* as being a `String`.

Variables vs fields in type inference

It is worth noting that although the compiler performs type inference on local variables, it does **not** perform any kind of type inference on fields, always falling back to the **declared type** of a field. To illustrate this, let's take a look at this example:

```
class SomeClass {
    def someUntypedField
①
    String someTypedField
②

    void someMethod() {
        someUntypedField = '123'
③
        someUntypedField = someUntypedField.toUpperCase()  // compile-time error
④
    }

    void someSafeMethod() {
        someTypedField = '123'
⑤
        someTypedField = someTypedField.toUpperCase()
⑥
    }

    void someMethodUsingLocalVariable() {
        def localVariable = '123'
⑦
        someUntypedField = localVariable.toUpperCase()
⑧
    }
}
```

① `someUntypedField` uses `def` as a declaration type

② `someTypedField` uses `String` as a declaration type

③ we can assign **anything** to `someUntypedField`

④ yet calling `toUpperCase` fails at compile time because the field is not typed properly

⑤ we can assign a `String` to a field of type `String`

⑥ and this time `toUpperCase` is allowed

⑦ if we assign a `String` to a local variable

⑧ then calling `toUpperCase` is allowed on the local variable

Why such a difference? The reason is *thread safety*. At compile time, we can't make **any** guarantee about the type of a field. Any thread can access any field at any time and between the moment a field is assigned a variable of some type in a method and the time is used the line after, another thread may have changed the contents of the field. This is not the case for local variables: we know if they "escape" or not, so we can make sure that the type of a variable is constant (or not) over time. Note that even if a field is final, the JVM makes no guarantee about it, so the type checker doesn't behave differently if a field is final or not.

TIP	This is one of the reasons why we recommend to use **typed** fields. While using `def` for local variables is perfectly fine thanks to type inference, this is not the case for fields, which also belong to the public API of a class, hence the type is important.

Collection literal type inference

Groovy provides a syntax for various type literals. There are three native collection literals in Groovy:

- lists, using the `[]` literal
- maps, using the `[:]` literal
- ranges, using `from..to` (inclusive), `from..<to` (right exclusive),`from<..to` (left exclusive) and `from<..<to` (full exclusive)

The inferred type of a literal depends on the elements of the literal, as illustrated in the following table:

Literal	Inferred type
`def list = []`	`java.util.List`
`def list = ['foo','bar']`	`java.util.List<String>`
`def list = ["${foo}","${bar}"]`	`java.util.List<GString>` be careful, a `GString` is **not** a `String`!
`def map = [:]`	`java.util.LinkedHashMap`
`def map1 = [someKey: 'someValue']` `def map2 = ['someKey': 'someValue']`	`java.util.LinkedHashMap<String,String>`

Literal	Inferred type
`def map = ["${someKey}": 'someValue']`	`java.util.LinkedHashMap<GString,String>` be careful, the key is a `GString`!
`def intRange = (0..10)`	`groovy.lang.IntRange`
`def charRange = ('a'..'z')`	`groovy.lang.Range<String>` : uses the type of the bounds to infer the component type of the range

As you can see, with the noticeable exception of the `IntRange`, the inferred type makes use of generics types to describe the contents of a collection. In case the collection contains elements of different types, the type checker still performs type inference of the components, but uses the notion of least upper bound.

Least upper bound

In Groovy, the *least upper bound* of two types `A` and `B` is defined as a type which:

- superclass corresponds to the common super class of `A` and `B`
- interfaces correspond to the interfaces implemented by both `A` and `B`
- if `A` or `B` is a primitive type and that `A` isn't equal to `B`, the least upper bound of `A` and `B` is the least upper bound of their wrapper types

If `A` and `B` only have one (1) interface in common and that their common superclass is `Object`, then the LUB of both is the common interface.

The least upper bound represents the minimal type to which both `A` and `B` can be assigned. So for example, if `A` and `B` are both `String`, then the LUB (least upper bound) of both is also `String`.

```
class Top {}
class Bottom1 extends Top {}
class Bottom2 extends Top {}

assert leastUpperBound(String, String) == String                    ①
assert leastUpperBound(ArrayList, LinkedList) == AbstractList       ②
assert leastUpperBound(ArrayList, List) == List                     ③
assert leastUpperBound(List, List) == List                          ④
assert leastUpperBound(Bottom1, Bottom2) == Top                     ⑤
assert leastUpperBound(List, Serializable) == Object                ⑥
```

① the LUB of `String` and `String` is `String`

② the LUB of `ArrayList` and `LinkedList` is their common super type, `AbstractList`

③ the LUB of `ArrayList` and `List` is their only common interface, `List`

④ the LUB of two identical interfaces is the interface itself

⑤ the LUB of `Bottom1` and `Bottom2` is their superclass `Top`

⑥ the LUB of two types which have nothing in common is `Object`

In those examples, the LUB is always representable as a normal, JVM supported, type. But Groovy internally represents the LUB as a type which can be more complex, and that you wouldn't be able to use to define a variable for example. To illustrate this, let's continue with this example:

```
interface Foo {}
class Top {}
class Bottom extends Top implements Serializable, Foo {}
class SerializableFooImpl implements Serializable, Foo {}
```

What is the least upper bound of `Bottom` and `SerializableFooImpl`? They don't have a common super class (apart from `Object`), but they do share 2 interfaces (`Serializable` and `Foo`), so their least upper bound is a type which represents the union of two interfaces (`Serializable` and `Foo`). This type cannot be defined in the source code, yet Groovy knows about it.

In the context of collection type inference (and generic type inference in general), this becomes handy, because the type of the components is inferred as the least upper bound. We can illustrate why this is important in the following example:

```
interface Greeter { void greet() }                  ①
interface Salute { void salute() }                  ②

class A implements Greeter, Salute {                ③
    void greet() { println "Hello, I'm A!" }
    void salute() { println "Bye from A!" }
}
class B implements Greeter, Salute {                ④
    void greet() { println "Hello, I'm B!" }
    void salute() { println "Bye from B!" }
    void exit() { println 'No way!' }               ⑤
}
def list = [new A(), new B()]                       ⑥
list.each {
    it.greet()                                      ⑦
    it.salute()                                     ⑧
    it.exit()                                       ⑨
}
```

① the `Greeter` interface defines a single method, `greet`

② the `Salute` interface defines a single method, `salute`

③ class `A` implements both `Greeter` and `Salute` but there's no explicit interface extending both

④ same for `B`

⑤ but `B` defines an additional `exit` method

⑥ the type of list is inferred as "list of the LUB of A and `B`"

⑦ so it is possible to call greet which is defined on both A and B through the Greeter interface

⑧ and it is possible to call salute which is defined on both A and B through the Salute interface

⑨ yet calling exit is a compile time error because it doesn't belong to the LUB of A and B (only defined in B)

The error message will look like:

```
[Static type checking] - Cannot find matching method Greeter or Salute#exit()
```

which indicates that the exit method is neither defines on Greeter nor Salute, which are the two interfaces defined in the least upper bound of A and B.

instanceof inference

In normal, non type checked, Groovy, you can write things like:

```
class Greeter {
    String greeting() { 'Hello' }
}

void doSomething(def o) {
    if (o instanceof Greeter) {     ①
        println o.greeting()        ②
    }
}

doSomething(new Greeter())
```

① guard the method call with an instanceof check

② make the call

The method call works because of dynamic dispatch (the method is selected at runtime). The equivalent code in Java would require to cast o to a Greeter before calling the greeting method, because methods are selected at compile time:

```
if (o instanceof Greeter) {
    System.out.println(((Greeter)o).greeting());
}
```

However, in Groovy, even if you add @TypeChecked (and thus activate type checking) on the doSomething method, the cast is **not** necessary. The compiler embeds *instanceof* inference that makes the cast optional.

Flow typing

Flow typing is an important concept of Groovy in type checked mode and an extension of type inference. The idea is that the compiler is capable of inferring the type of variables in the flow of the code, not just at initialization:

```
@groovy.transform.TypeChecked
void flowTyping() {
    def o = 'foo'                    ①
    o = o.toUpperCase()              ②
    o = 9d                           ③
    o = Math.sqrt(o)                 ④
}
```

① first, `o` is declared using `def` and assigned a `String`

② the compiler inferred that `o` is a `String`, so calling `toUpperCase` is allowed

③ `o` is reassigned with a `double`

④ calling `Math.sqrt` passes compilation because the compiler knows that at this point, `o` is a `double`

So the type checker is *aware* of the fact that the concrete type of a variable is different over time. In particular, if you replace the last assignment with:

```
o = 9d
o = o.toUpperCase()
```

The type checker will now fail at compile time, because it knows that `o` is a `double` when `toUpperCase` is called, so it's a type error.

It is important to understand that it is not the fact of declaring a variable with `def` that triggers type inference. Flow typing works for **any** variable of any type. Declaring a variable with an explicit type only constrains what you can assign to the variable:

```
@groovy.transform.TypeChecked
void flowTypingWithExplicitType() {
    List list = ['a','b','c']        ①
    list = list*.toUpperCase()       ②
    list = 'foo'                     ③
}
```

① `list` is declared as an unchecked `List` and assigned a list literal of strings

② this line passes compilation because of flow typing: the type checker knows that `list` is at this point an `ArrayList<String>`

③ but you can't assign a `String` to a `List` so this is a type checking error

You can also note that even if the variable is declared **without** generics information, the type checker knows what is the component type. Therefore, such code would fail compilation:

```
@groovy.transform.TypeChecked
void flowTypingTypeConstraints1() {
    def list = ['a','b','c']          ①
    list.add(1)                       ②
}
@groovy.transform.TypeChecked
void flowTypingTypeConstraints2() {
    List<?> list = []                 ③
    list.addAll(['a','b','c'])        ④
    list.add(1)                       ⑤
}
```

① `list` is inferred as `ArrayList<String>`

② so adding an `int` to a `ArrayList<String>` is a compile-time error

③ `list` is declared as `List<?>`

④ the inferred type of `list` here is `List<capture-of ?>`, so calling `addAll` with a list of anything is a compile-time error

⑤ and calling `add` with an `int` is also a compile-time error for the same reason; only `add(null)` is allowed

Fixing this requires adding an explicit, non-wildcard type argument:

```
@groovy.transform.TypeChecked
void flowTypingTypeConstraints3() {
    List<Serializable> list = []      ①
    list.addAll(['a','b','c'])        ②
    list.add(1)                       ③
}
```

① `list` is declared as `List<Serializable>` and initialized with an empty list

② elements added to the list conform to the declaration type of the list

③ and adding an integer is allowed

Flow typing has been introduced to reduce the difference in semantics between classic and static Groovy. In particular, consider the behavior of this code in Java:

```
public Integer compute(String str) {
    return str.length();
}
public String compute(Object o) {
    return "Nope";
}
// ...
Object string = "Some string";        ①
Object result = compute(string);      ②
```

```
System.out.println(result);            ③
```

① o is declared as an Object and assigned a String

② we call the compute method with o

③ and print the result

In Java, this code will output Nope, because method selection is done at compile time and based on the **declared** types. So even if o is a String at runtime, it is still the Object version which is called, because o has been declared as an Object. To be short, in Java, declared types are most important, be it variable types, parameter types or return types.

In Groovy, we could write:

```
int compute(String string) { string.length() }
String compute(Object o) { "Nope" }
Object o = 'string'
def result = compute(o)
println result
```

But this time, it will return 6, because the method which is chosen **at runtime**, based on the *actual* argument types. So at runtime, o is a String so the String variant is used. Note that this behavior has nothing to do with type checking, it's the way Groovy works in general: dynamic dispatch.

In type checked Groovy, we want to make sure the type checker selects the same method **at compile time**, that the runtime would choose. It is not possible in general, due to the semantics of the language, but we can make things better with flow typing. With flow typing, o is *inferred* as a String when the compute method is called, so the version which takes a String and returns an int is chosen. This means that we can infer the return type of the method to be an int, and not a String. This is important for subsequent calls and type safety.

So in type checked Groovy, flow typing is a very important concept, which also implies that if @TypeChecked is applied, methods are selected based on the *inferred types* of the arguments, not on the declared types. This doesn't ensure 100% type safety, because the type checker *may* select a wrong method, but it ensures the closest semantics to dynamic Groovy.

Advanced type inference

A combination of flow typing and least upper bound inference is used to perform advanced type inference and ensure type safety in multiple situations. In particular, program control structures are likely to alter the inferred type of a variable:

```
class Top {
   void methodFromTop() {}
}
class Bottom extends Top {
   void methodFromBottom() {}
}
def o
```

```
if (someCondition) {
    o = new Top()                                   ①
} else {
    o = new Bottom()                                ②
}
o.methodFromTop()                                   ③
o.methodFromBottom()  // compilation error          ④
```

① if someCondition is true, o is assigned a Top

② if someCondition is false, o is assigned a Bottom

③ calling methodFromTop is safe

④ but calling methodFromBottom is not, so it's a compile time error

When the type checker visits an if/else control structure, it checks all variables which are assigned in if/else branches and computes the least upper bound of all assignments. This type is the type of the inferred variable after the if/else block, so in this example, o is assigned a Top in the if branch and a Bottom in the else branch. The LUB of those is a Top, so after the conditional branches, the compiler infers o as being a Top. Calling methodFromTop will therefore be allowed, but not methodFromBottom.

The same reasoning exists with closures and in particular closure shared variables. A closure shared variable is a variable which is defined outside of a closure, but used inside a closure, as in this example:

```
def text = 'Hello, world!'                          ①
def closure = {
    println text                                    ②
}
```

① a variable named text is declared

② text is used from inside a closure. It is a *closure shared variable*.

Groovy allows developers to use those variables without requiring them to be final. This means that a closure shared variable can be reassigned inside a closure:

```
String result
doSomething { String it ->
    result = "Result: $it"
}
result = result?.toUpperCase()
```

The problem is that a closure is an independent block of code that can be executed (or not) at **any** time. In particular, doSomething may be asynchronous, for example. This means that the body of a closure doesn't belong to the main control flow. For that reason, the type checker also computes, for each closure shared variable, the LUB of all assignments of the variable, and will use that LUB as the inferred type outside of the scope of the closure, like in this example:

```
class Top {
   void methodFromTop() {}
}
class Bottom extends Top {
   void methodFromBottom() {}
}
def o = new Top()                              ①
Thread.start {
    o = new Bottom()                           ②
}
o.methodFromTop()                              ③
o.methodFromBottom()  // compilation error     ④
```

① a closure-shared variable is first assigned a `Top`

② inside the closure, it is assigned a `Bottom`

③ `methodFromTop` is allowed

④ `methodFromBottom` is a compilation error

Here, it is clear that when `methodFromBottom` is called, there's no guarantee, at compile-time or runtime that the type of `o` will *effectively* be a `Bottom`. There are chances that it will be, but we can't make sure, because it's asynchronous. So the type checker will only allow calls on the least upper bound, which is here a `Top`.

Closures and type inference

The type checker performs special inference on closures, resulting on additional checks on one side and improved fluency on the other side.

Return type inference

The first thing that the type checker is capable of doing is inferring the *return type* of a closure. This is simply illustrated in the following example:

```
@groovy.transform.TypeChecked
int testClosureReturnTypeInference(String arg) {
    def cl = { "Arg: $arg" }                             ①
    def val = cl()                                       ②

    val.length()                                         ③
}
```

① a closure is defined, and it returns a string (more precisely a `GString`)

② we call the closure and assign the result to a variable

③ the type checker inferred that the closure would return a string, so calling `length()` is allowed

As you can see, unlike a method which declares its return type explicitly, there's no need to declare the return type of a closure: its type is inferred from the body of the closure.

Closures vs methods

It's worth noting that return type inference is only applicable to closures. While the type checker could do the same on a method, it is in practice not desirable: *in general*, methods can be overridden and it is not statically possible to make sure that the method which is called is not an overridden version. So flow typing would actually think that a method returns something, while in reality, it could return something else, like illustrated in the following example:

```
@TypeChecked
class A {
    def compute() { 'some string' }             ①
    def computeFully() {
        compute().toUpperCase()                  ②
    }
}
@TypeChecked
class B extends A {
    def compute() { 123 }                        ③
}
```

① class `A` defines a method `compute` which effectively returns a `String`

② this will fail compilation because the return type of `compute` is `def`(aka `Object`)

③ class `B` extends `A` and redefines `compute`, this type returning an `int`

As you can see, if the type checker relied on the inferred return type of a method, with flow typing, the type checker could determine that it is ok to call `toUpperCase`. It is in fact an **error**, because a subclass can override `compute` and return a different object. Here, `B#compute` returns an `int`, so someone calling `computeFully` on an instance of `B` would see a runtime error. The compiler prevents this from happening by using the declared return type of methods instead of the inferred return type.

For consistency, this behavior is the same for **every** method, even if they are static or final.

Parameter type inference

In addition to the return type, it is possible for a closure to infer its parameter types from the context. There are two ways for the compiler to infer the parameter types:

- through *implicit SAM type coercion*
- through API metadata

To illustrate this, lets start with an example that will fail compilation due to the inability for the type checker to infer the parameter types:

```
class Person {
```

```
    String name
    int age
}

void inviteIf(Person p, Closure<Boolean> predicate) {          ①
    if (predicate.call(p)) {
        // send invite
        // ...
    }
}

@groovy.transform.TypeChecked
void failCompilation() {
    Person p = new Person(name: 'Gerard', age: 55)
    inviteIf(p) {                                               ②
        it.age >= 18 // No such property: age                   ③
    }
}
```

① the `inviteIf` method accepts a `Person` and a `Closure`

② we call it with a `Person` and a `Closure`

③ yet `it` is not statically known as being a `Person` and compilation fails

In this example, the closure body contains `it.age`. With dynamic, not type checked code, this would work, because the type of `it` would be a `Person` at runtime. Unfortunately, at compile-time, there's no way to know what is the type of `it`, just by reading the signature of `inviteIf`.

Explicit closure parameters

To be short, the type checker doesn't have enough contextual information on the `inviteIf` method to determine statically the type of `it`. This means that the method call needs to be rewritten like this:

```
inviteIf(p) { Person it ->                                  ①
    it.age >= 18
}
```

① the type of `it` needs to be declared explicitly

By explicitly declaring the type of the `it` variable, you can work around the problem and make this code statically checked.

Parameters inferred from single-abstract method types

For an API or framework designer, there are two ways to make this more elegant for users, so that they don't have to declare an explicit type for the closure parameters. The first one, and easiest, is to replace the closure with a SAM type:

```
interface Predicate<On> { boolean apply(On e) }                    ①

void inviteIf(Person p, Predicate<Person> predicate) {             ②
    if (predicate.apply(p)) {
        // send invite
        // ...
    }
}

@groovy.transform.TypeChecked
void passesCompilation() {
    Person p = new Person(name: 'Gerard', age: 55)

    inviteIf(p) {                                                  ③
        it.age >= 18                                               ④
    }
}
```

① declare a `SAM` interface with an `apply` method

② `inviteIf` now uses a `Predicate<Person>` instead of a `Closure<Boolean>`

③ there's no need to declare the type of the `it` variable anymore

④ `it.age` compiles properly, the type of `it` is inferred from the `Predicate#apply` method signature

TIP By using this technique, we leverage the *automatic coercion of closures to SAM types* feature of Groovy. Whether you should use a *SAM type* or a *Closure* really depends on what you need to do. In a lot of cases, using a SAM interface is enough, especially if you consider functional interfaces as they are found in Java 8. However, closures provide features that are not accessible to functional interfaces. In particular, closures can have a delegate, and owner and can be manipulated as objects (for example, cloned, serialized, curried, …) before being called. They can also support multiple signatures (polymorphism). So if you need that kind of manipulation, it is preferable to switch to the most advanced type inference annotations which are described below.

The original issue that needs to be solved when it comes to closure parameter type inference, that is to say, statically determining the types of the arguments of a closure *without* having to have them explicitly declared, is that the Groovy type system inherits the Java type system, which is insufficient to describe the types of the arguments.

The `@ClosureParams` annotation

Groovy provides an annotation, `@ClosureParams` which is aimed at completing type information. This annotation is primarily aimed at framework and API developers who want to extend the capabilities of the type checker by providing type inference metadata. This is important if your library makes use of closures and that you want the maximum level of tooling support too.

Let's illustrate this by fixing the original example, introducing the `@ClosureParams` annotation:

```
import groovy.transform.stc.ClosureParams
import groovy.transform.stc.FirstParam
void inviteIf(Person p, @ClosureParams(FirstParam) Closure<Boolean> predicate) {
①
    if (predicate.call(p)) {
        // send invite
        // ...
    }
}
inviteIf(p) {                                                                   ②
    it.age >= 18
}
```

① the closure parameter is annotated with `@ClosureParams`

② it's not necessary to use an explicit type for `it`, which is inferred

The `@ClosureParams` annotation minimally accepts one argument, which is named a *type hint*. A type hint is a class which is responsible for completing type information at compile time for the closure. In this example, the type hint being used is `groovy.transform.stc.FirstParam` which indicated to the type checker that the closure will accept one parameter whose type is the type of the first parameter of the method. In this case, the first parameter of the method is `Person`, so it indicates to the type checker that the first parameter of the closure is in fact a `Person`.

A second optional argument is named *options*. Its semantics depend on the *type hint* class. Groovy comes with various bundled type hints, illustrated in the table below:

Table 8. Predefined type hints

<table>
<tr><th>Type hint</th><th>Polymorphic?</th><th>Description and examples</th></tr>
<tr><td>

`FirstParam`
`SecondParam`
`ThirdParam`

</td><td>No</td><td>

The first (resp. second, third) parameter type of the method

```
import groovy.transform.stc.FirstParam
void doSomething(String str, @ClosureParams(FirstParam)
Closure c) {
    c(str)
}
doSomething('foo') { println it.toUpperCase() }
```

```
import groovy.transform.stc.SecondParam
void withHash(String str, int seed, @ClosureParams
(SecondParam) Closure c) {
    c(31*str.hashCode()+seed)
}
withHash('foo', (int)System.currentTimeMillis()) {
    int mod = it%2
}
```

```
import groovy.transform.stc.ThirdParam
String format(String prefix, String postfix, String o,
@ClosureParams(ThirdParam) Closure c) {
    "$prefix${c(o)}$postfix"
}
assert format('foo', 'bar', 'baz') {
    it.toUpperCase()
} == 'fooBAZbar'
```

</td></tr>
<tr><td>

`FirstParam.FirstGenericType`
`SecondParam.FirstGenericType`
`ThirdParam.FirstGenericType`

</td><td>No</td><td>

The first generic type of the first (resp. second, third) parameter of the method

```
import groovy.transform.stc.FirstParam
public <T> void doSomething(List<T> strings,
@ClosureParams(FirstParam.FirstGenericType) Closure c)
{
    strings.each {
        c(it)
    }
}
doSomething(['foo','bar']) { println it.toUpperCase() }
doSomething([1,2,3]) { println(2*it) }
```

Variants for `SecondGenericType` and `ThirdGenericType` exist for all `FirstParam`, `SecondParam` and `ThirdParam` type hints.

</td></tr>
</table>

<table>
<tr><th>Type hint</th><th>Polymorphic?</th><th>Description and examples</th></tr>
<tr><td>SimpleType</td><td>No</td><td>

A type hint for which the type of closure parameters comes from the options string.

```
import groovy.transform.stc.SimpleType
public void doSomething(@ClosureParams(value=
SimpleType,options=['java.lang.String','int']) Closure
c) {
    c('foo',3)
}
doSomething { str, len ->
    assert str.length() == len
}
```

This type hint supports a **single** signature and each of the parameter is specified as a value of the *options* array using a fully-qualified type name or a primitive type.

</td></tr>
<tr><td>MapEntryOrKeyValue</td><td>Yes</td><td>

A dedicated type hint for closures that either work on a `Map.Entry` single parameter, or two parameters corresponding to the key and the value.

```
import groovy.transform.stc.MapEntryOrKeyValue
public <K,V> void doSomething(Map<K,V> map,
@ClosureParams(MapEntryOrKeyValue) Closure c) {
    // ...
}
doSomething([a: 'A']) { k,v ->
    assert k.toUpperCase() == v.toUpperCase()
}
doSomething([abc: 3]) { e ->
    assert e.key.length() == e.value
}
```

This type hint **requires** that the first argument is a `Map` type, and infers the closure parameter types from the map actual key/value types.

</td></tr>
</table>

<table>
<tr><th>Type hint</th><th>Polymorphic?</th><th>Description and examples</th></tr>
<tr><td><code>FromAbstractTypeMethods</code></td><td>Yes</td><td>Infers closure parameter types from the abstract method of some type. A signature is inferred for each abstract method.

```
import groovy.transform.stc.FromAbstractTypeMethods
abstract class Foo {
    abstract void firstSignature(int x, int y)
    abstract void secondSignature(String str)
}
void doSomething(@ClosureParams(value
=FromAbstractTypeMethods, options=["Foo"]) Closure cl)
{
    // ...
}
doSomething { a, b -> a+b }
doSomething { s -> s.toUpperCase() }
```

If there are multiple signatures like in the example above, the type checker will only be able to infer the types of the arguments if the arity of each method is different. In the example above, <code>firstSignature</code> takes 2 arguments and <code>secondSignature</code> takes 1 argument, so the type checker can infer the argument types based on the number of arguments. But see the optional resolver class attribute discussed next.</td></tr>
</table>

<table>
<tr><th>Type hint</th><th>Polymorphic?</th><th>Description and examples</th></tr>
<tr><td>FromString</td><td>Yes</td><td>

Infers the closure parameter types from the options argument. The options argument consists of an array of comma-separated non-primitive types. Each element of the array corresponds to a single signature, and each comma in an element separate parameters of the signature. In short, this is the most generic type hint, and each string of the options map is **parsed** as if it was a signature literal. While being very powerful, this type hint must be avoided if you can because it increases the compilation times due to the necessity of parsing the type signatures.

A single signature for a closure accepting a String:

```
import groovy.transform.stc.FromString
void doSomething(@ClosureParams(value=FromString,
options=["String","String,Integer"]) Closure cl) {
    // ...
}
doSomething { s -> s.toUpperCase() }
doSomething { s,i -> s.toUpperCase()*i }
```

A polymorphic closure, accepting either a String or a String, Integer:

```
import groovy.transform.stc.FromString
void doSomething(@ClosureParams(value=FromString,
options=["String","String,Integer"]) Closure cl) {
    // ...
}
doSomething { s -> s.toUpperCase() }
doSomething { s,i -> s.toUpperCase()*i }
```

A polymorphic closure, accepting either a T or a pair T,T:

```
import groovy.transform.stc.FromString
public <T> void doSomething(T e, @ClosureParams(value
=FromString, options=["T","T,T"]) Closure cl) {
    // ...
}
doSomething('foo') { s -> s.toUpperCase() }
doSomething('foo') { s1,s2 -> assert s1.toUpperCase()
== s2.toUpperCase() }
```

</td></tr>
</table>

TIP Even though you use FirstParam, SecondParam or ThirdParam as a type hint, it doesn't strictly mean that the argument which will be passed to the closure **will** be the first

> (resp. second, third) argument of the method call. It only means that the **type** of the parameter of the closure will be the **same** as the type of the first (resp. second, third) argument of the method call.

In short, the lack of the `@ClosureParams` annotation on a method accepting a `Closure` will **not** fail compilation. If present (and it can be present in Java sources as well as Groovy sources), then the type checker has **more** information and can perform additional type inference. This makes this feature particularly interesting for framework developers.

A third optional argument is named *conflictResolutionStrategy*. It can reference a class (extending from `ClosureSignatureConflictResolver`) that can perform additional resolution of parameter types if more than one are found after initial inference calculations are complete. Groovy comes with a default type resolver which does nothing, and another which selects the first signature if multiple are found. The resolver is only invoked if more than one signature is found and is by design a post processor. Any statements which need injected typing information must pass one of the parameter signatures determined through type hints. The resolver then picks among the returned candidate signatures.

`@DelegatesTo`

The `@DelegatesTo` annotation is used by the type checker to infer the type of the delegate. It allows the API designer to instruct the compiler what is the type of the delegate and the delegation strategy. The `@DelegatesTo` annotation is discussed in a specific section.

Static compilation

Dynamic vs static

In the type checking section, we have seen that Groovy provides optional type checking thanks to the `@TypeChecked` annotation. The type checker runs at compile time and performs a static analysis of dynamic code. The program will behave exactly the same whether type checking has been enabled or not. This means that the `@TypeChecked` annotation is neutral in regard to the semantics of a program. Even though it may be necessary to add type information in the sources so that the program is considered type safe, in the end, the semantics of the program are the same.

While this may sound fine, there is actually one issue with this: type checking of dynamic code, done at compile time, is by definition only correct if no runtime specific behavior occurs. For example, the following program passes type checking:

```
class Computer {
    int compute(String str) {
        str.length()
    }
    String compute(int x) {
        String.valueOf(x)
    }
}

@groovy.transform.TypeChecked
void test() {
```

```
    def computer = new Computer()
    computer.with {
        assert compute(compute('foobar')) =='6'
    }
}
```

There are two `compute` methods. One accepts a `String` and returns an `int`, the other accepts an `int` and returns a `String`. If you compile this, it is considered type safe: the inner `compute('foobar')` call will return an `int`, and calling `compute` on this `int` will in turn return a `String`.

Now, before calling `test()`, consider adding the following line:

```
Computer.metaClass.compute = { String str -> new Date() }
```

Using runtime metaprogramming, we're actually modifying the behavior of the `compute(String)` method, so that instead of returning the length of the provided argument, it will return a `Date`. If you execute the program, it will fail at runtime. Since this line can be added from anywhere, in any thread, there's absolutely no way for the type checker to statically make sure that no such thing happens. In short, the type checker is vulnerable to monkey patching. This is just one example, but this illustrates the concept that doing static analysis of a dynamic program is inherently wrong.

The Groovy language provides an alternative annotation to `@TypeChecked` which will actually make sure that the methods which are inferred as being called **will** effectively be called at runtime. This annotation turns the Groovy compiler into a **static compiler**, where all method calls are resolved at compile time **and** the generated bytecode makes sure that this happens: the annotation is `@groovy.transform.CompileStatic`.

The `@CompileStatic` annotation

The `@CompileStatic` annotation can be added anywhere the `@TypeChecked` annotation can be used, that is to say on a class or a method. It is not necessary to add both `@TypeChecked` and `@CompileStatic`, as `@CompileStatic` performs everything `@TypeChecked` does, but in addition triggers static compilation.

Let's take the example which failed, but this time let's replace the `@TypeChecked` annotation with `@CompileStatic`:

```
class Computer {
    int compute(String str) {
        str.length()
    }
    String compute(int x) {
        String.valueOf(x)
    }
}

@groovy.transform.CompileStatic
void test() {
```

```
    def computer = new Computer()
    computer.with {
        assert compute(compute('foobar')) =='6'
    }
}
Computer.metaClass.compute = { String str -> new Date() }
test()
```

This is the **only** difference. If we execute this program, this time, there is no runtime error. The `test` method became immune to monkey patching, because the `compute` methods which are called in its body are linked at compile time, so even if the metaclass of `Computer` changes, the program still behaves **as expected by the type checker**.

Key benefits

There are several benefits of using `@CompileStatic` on your code:

- type safety
- immunity to monkey patching
- performance improvements

The performance improvements depend on the kind of program you are executing. If it is I/O bound, the difference between statically compiled code and dynamic code is barely noticeable. On highly CPU intensive code, since the bytecode which is generated is very close, if not equal, to the one that Java would produce for an equivalent program, the performance is greatly improved.

> **TIP** Using the *invokedynamic* version of Groovy, which is accessible to people using JDK 7 and above, the performance of the dynamic code should be very close to the performance of statically compiled code. Sometimes, it can even be faster! There is only one way to determine which version you should choose: measuring. The reason is that depending on your program **and** the JVM that you use, the performance can be significantly different. In particular, the *invokedynamic* version of Groovy is very sensitive to the JVM version in use.

Type checking extensions

Writing a type checking extension

Towards a smarter type checker

Despite being a dynamic language, Groovy can be used with a static type checker at compile time, enabled using the `@TypeChecked` annotation. In this mode, the compiler becomes more verbose and throws errors for, example, typos, non-existent methods, etc. This comes with a few limitations though, most of them coming from the fact that Groovy remains inherently a dynamic language. For example, you wouldn't be able to use type checking on code that uses the markup builder:

```
def builder = new MarkupBuilder(out)
builder.html {
```

```
    head {
        // ...
    }
    body {
        p 'Hello, world!'
    }
}
```

In the previous example, none of the `html`, `head`, `body` or `p` methods exist. However if you execute the code, it works because Groovy uses dynamic dispatch and converts those method calls at runtime. In this builder, there's no limitation about the number of tags that you can use, nor the attributes, which means there is no chance for a type checker to know about all the possible methods (tags) at compile time, unless you create a builder dedicated to HTML for example.

Groovy is a platform of choice when it comes to implement internal DSLs. The flexible syntax, combined with runtime and compile-time metaprogramming capabilities make Groovy an interesting choice because it allows the programmer to focus on the DSL rather than on tooling or implementation. Since Groovy DSLs are Groovy code, it's easy to have IDE support without having to write a dedicated plugin for example.

In a lot of cases, DSL engines are written in Groovy (or Java) then user code is executed as scripts, meaning that you have some kind of wrapper on top of user logic. The wrapper may consist, for example, in a `GroovyShell` or `GroovyScriptEngine` that performs some tasks transparently before running the script (adding imports, applying AST transforms, extending a base script,…). Often, user written scripts come to production without testing because the DSL logic comes to a point where **any** user may write code using the DSL syntax. In the end, a user may just ignore that what they write is actually **code**. This adds some challenges for the DSL implementer, such as securing execution of user code or, in this case, early reporting of errors.

For example, imagine a DSL which goal is to drive a rover on Mars remotely. Sending a message to the rover takes around 15 minutes. If the rover executes the script and fails with an error (say a typo), you have two problems:

- first, feedback comes only after 30 minutes (the time needed for the rover to get the script and the time needed to receive the error)
- second, some portion of the script has been executed and you may have to change the fixed script significantly (implying that you need to know the current state of the rover…)

Type checking extensions is a mechanism that will allow the developer of a DSL engine to make those scripts safer by applying the same kind of checks that static type checking allows on regular groovy classes.

The principle, here, is to fail early, that is to say fail compilation of scripts as soon as possible, and if possible provide feedback to the user (including nice error messages).

In short, the idea behind type checking extensions is to make the compiler aware of all the runtime metaprogramming tricks that the DSL uses, so that scripts can benefit the same level of compile-time checks as a verbose statically compiled code would have. We will see that you can go even further by performing checks that a normal type checker wouldn't do, delivering powerful compile-time checks for your users.

The extensions attribute

The `@TypeChecked` annotation supports an attribute named `extensions`. This parameter takes an array of strings corresponding to a list of *type checking extensions scripts*. Those scripts are found at **compile time** on classpath. For example, you would write:

```
@TypeChecked(extensions='/path/to/myextension.groovy')
void foo() { ...}
```

In that case, the *foo* methods would be type checked with the rules of the normal type checker completed by those found in the *myextension.groovy* script. Note that while internally the type checker supports multiple mechanisms to implement type checking extensions (including plain old java code), the recommended way is to use those type checking extension scripts.

A DSL for type checking

The idea behind type checking extensions is to use a DSL to extend the type checker capabilities. This DSL allows you to hook into the compilation process, more specifically the type checking phase, using an "event-driven" API. For example, when the type checker enters a method body, it throws a *beforeVisitMethod* event that the extension can react to:

```
beforeVisitMethod { methodNode ->
 println "Entering ${methodNode.name}"
}
```

Imagine that you have this rover DSL at hand. A user would write:

```
robot.move 100
```

If you have a class defined as such:

```
class Robot {
    Robot move(int qt) { this }
}
```

The script can be type checked before being executed using the following script:

```
def config = new CompilerConfiguration()
config.addCompilationCustomizers(
    new ASTTransformationCustomizer(TypeChecked)            ①
)
def shell = new GroovyShell(config)                         ②
def robot = new Robot()
```

```
shell.setVariable('robot', robot)
shell.evaluate(script)                                    ③
```

① a compiler configuration adds the `@TypeChecked` annotation to all classes

② use the configuration in a `GroovyShell`

③ so that scripts compiled using the shell are compiled with `@TypeChecked` without the user having to add it explicitly

Using the compiler configuration above, we can apply *@TypeChecked* transparently to the script. In that case, it will fail at compile time:

```
[Static type checking] - The variable [robot] is undeclared.
```

Now, we will slightly update the configuration to include the ``extensions'' parameter:

```
config.addCompilationCustomizers(
    new ASTTransformationCustomizer(
        TypeChecked,
        extensions:['robotextension.groovy'])
)
```

Then add the following to your classpath:

robotextension.groovy

```
unresolvedVariable { var ->
    if ('robot'==var.name) {
        storeType(var, classNodeFor(Robot))
        handled = true
    }
}
```

Here, we're telling the compiler that if an *unresolved variable* is found and that the name of the variable is *robot*, then we can make sure that the type of this variable is `Robot`.

Type checking extensions API

AST

The type checking API is a low level API, dealing with the Abstract Syntax Tree. You will have to know your AST well to develop extensions, even if the DSL makes it much easier than just dealing with AST code from plain Java or Groovy.

Events

The type checker sends the following events, to which an extension script can react:

Event name	setup
Called When	Called after the type checker finished initialization
Arguments	none

Usage

```
setup {
    // this is called before anything else
}
```

Can be used to perform setup of your extension

Event name	finish
Called When	Called after the type checker completed type checking
Arguments	none

Usage

```
finish {
    // this is after completion
    // of all type checking
}
```

Can be used to perform additional checks after the type checker has finished its job.

Event name	unresolvedVariable
Called When	Called when the type checker finds an unresolved variable
Arguments	VariableExpression vexp

Usage

```
unresolvedVariable { VariableExpression vexp ->
    if (vexp.name == 'people') {
        storeType(vexp, LIST_TYPE)
        handled = true
    }
}
```

Allows the developer to help the type checker with user-injected variables.

Event name	unresolvedProperty
Called When	Called when the type checker cannot find a property on the receiver
Arguments	PropertyExpression pexp

Usage

```
unresolvedProperty { PropertyExpression pexp ->
    if (pexp.propertyAsString == 'longueur' &&
            getType(pexp.objectExpression) == STRING_TYPE) {
        storeType(pexp, int_TYPE)
        handled = true
    }
}
```

Allows the developer to handle "dynamic" properties

Event name	unresolvedAttribute
Called When	Called when the type checker cannot find an attribute on the receiver
Arguments	AttributeExpression aexp

Usage

```
unresolvedAttribute { AttributeExpression aexp ->
    if (getType(aexp.objectExpression) == STRING_TYPE) {
        storeType(aexp, STRING_TYPE)
        handled = true
    }
}
```

Allows the developer to handle missing attributes

Event name	beforeMethodCall
Called When	Called before the type checker starts type checking a method call
Arguments	MethodCall call

Usage

```
beforeMethodCall { call ->
    if (isMethodCallExpression(call)
            && call.methodAsString=='toUpperCase') {
        addStaticTypeError('Not allowed',call)
        handled = true
    }
}
```

Allows you to intercept method calls before the type checker performs its own checks. This is useful if you want to replace the default type checking with a custom one for a limited scope. In that case, you must set the handled flag to true, so that the type checker skips its own checks.

Event name	afterMethodCall
Called When	Called once the type checker has finished type checking a method call
Arguments	MethodCall call

<table>
<tr><td>Usage</td><td>

```
afterMethodCall { call ->
    if (getTargetMethod(call).name=='toUpperCase') {
        addStaticTypeError('Not allowed',call)
        handled = true
    }
}
```

Allow you to perform additional checks after the type checker has done its own checks. This is in particular useful if you want to perform the standard type checking tests but also want to ensure additional type safety, for example checking the arguments against each other.Note that `afterMethodCall` is called even if you did `beforeMethodCall` and set the handled flag to true.

</td></tr>
</table>

<table>
<tr><td>Event name</td><td>onMethodSelection</td></tr>
<tr><td>Called When</td><td>Called by the type checker when it finds a method appropriate for a method call</td></tr>
<tr><td>Arguments</td><td>Expression expr, MethodNode node</td></tr>
<tr><td>Usage</td><td>

```
onMethodSelection { expr, node ->
    if (node.declaringClass.name == 'java.lang.String') {
        // calling a method on 'String'
        // let’s perform additional checks!
        if (++count>2) {
            addStaticTypeError("You can use only 2 calls on
String in your source code",expr)
        }
    }
}
```

The type checker works by inferring argument types of a method call, then chooses a target method. If it finds one that corresponds, then it triggers this event. It is for example interesting if you want to react on a specific method call, such as entering the scope of a method that takes a closure as argument (as in builders).Please note that this event may be thrown for various types of expressions, not only method calls (binary expressions for example).

</td></tr>
</table>

Event name	methodNotFound
Called When	Called by the type checker when it fails to find an appropriate method for a method call
Arguments	ClassNode receiver, String name, ArgumentListExpression argList, ClassNode[] argTypes,MethodCall call

Usage

```
methodNotFound { receiver, name, argList, argTypes, call ->
    // receiver is the inferred type of the receiver
    // name is the name of the called method
    // argList is the list of arguments the method was called
with
    // argTypes is the array of inferred types for each
argument
    // call is the method call for which we couldn’t find a
target method
    if (receiver==classNodeFor(String)
            && name=='longueur'
            && argList.size()==0) {
        handled = true
        return newMethod('longueur', classNodeFor(String))
    }
}
```

Unlike `onMethodSelection`, this event is sent when the type checker cannot find a target method for a method call (instance or static). It gives you the chance to intercept the error before it is sent to the user, but also set the target method.For this, you need to return a list of `MethodNode`. In most situations, you would either return: an empty list, meaning that you didn’t find a corresponding method, a list with exactly one element, saying that there’s no doubt about the target methodIf you return more than one MethodNode, then the compiler would throw an error to the user stating that the method call is ambiguous, listing the possible methods.For convenience, if you want to return only one method, you are allowed to return it directly instead of wrapping it into a list.

Event name	beforeVisitMethod
Called When	Called by the type checker before type checking a method body
Arguments	MethodNode node

Usage

```
beforeVisitMethod { methodNode ->
    // tell the type checker we will handle the body by
ourselves
    handled = methodNode.name.startsWith('skip')
}
```

The type checker will call this method before starting to type check a method body. If you want, for example, to perform type checking by yourself instead of letting the type checker do it, you have to set the handled flag to true. This event can also be used to help define the scope of your extension (for example, applying it only if you are inside method foo).

Event name	afterVisitMethod
Called When	Called by the type checker after type checking a method body
Arguments	MethodNode node

Usage	`afterVisitMethod { methodNode ->`
	`    scopeExit {`
	`        if (methods>2) {`
	`            addStaticTypeError("Method ${methodNode.name} contains more than 2 method calls", methodNode)`
	`        }`
	`    }`
	`}`
	
	Gives you the opportunity to perform additional checks after a method body is visited by the type checker. This is useful if you collect information, for example, and want to perform additional checks once everything has been collected.

Event name	beforeVisitClass
Called When	Called by the type checker before type checking a class
Arguments	ClassNode node

Usage	`beforeVisitClass { ClassNode classNode ->`
	`    def name = classNode.nameWithoutPackage`
	`    if (!(name[0] in 'A'..'Z')) {`
	`        addStaticTypeError("Class '${name}' doesn't start with an uppercase letter",classNode)`
	`    }`
	`}`
	
	If a class is type checked, then before visiting the class, this event will be sent. It is also the case for inner classes defined inside a class annotated with `@TypeChecked`. It can help you define the scope of your extension, or you can even totally replace the visit of the type checker with a custom type checking implementation. For that, you would have to set the `handled` flag to `true`.

Event name	afterVisitClass
Called When	Called by the type checker after having finished the visit of a type checked class
Arguments	ClassNode node

Usage	<pre>afterVisitClass { ClassNode classNode ->
	    def name = classNode.nameWithoutPackage
	    if (!(name[0] in 'A'..'Z')) {
	        addStaticTypeError("Class '${name}' doesn't start with
	an uppercase letter",classNode)
	    }
	}</pre> Called for every class being type checked after the type checker finished its work. This includes classes annotated with `@TypeChecked` and any inner/anonymous class defined in the same class with is not skipped.

Event name	incompatibleAssignment
Called When	Called when the type checker thinks that an assignment is incorrect, meaning that the right-hand side of an assignment is incompatible with the left-hand side
Arguments	ClassNode lhsType, ClassNode rhsType, Expression assignment

Usage	<pre>incompatibleAssignment { lhsType, rhsType, expr ->
	    if (isBinaryExpression(expr) && isAssignment(expr
	.operation.type)) {
	        if (lhsType==classNodeFor(int) && rhsType
	==classNodeFor(Closure)) {
	            handled = true
	        }
	    }
	}</pre> Gives the developer the ability to handle incorrect assignments. This is for example useful if a class overrides `setProperty`, because in that case it is possible that assigning a variable of one type to a property of another type is handled through that runtime mechanism. In that case, you can help the type checker just by telling it that the assignment is valid (using `handled` set to `true`).

Event name	incompatibleReturnType
Called When	Called when the type checker thinks that a return value is incompatibe with the return type of the enclosing closure or method
Arguments	ReturnStatement statement, ClassNode valueType

Usage	`incompatibleReturnType { stmt, type -> if (type == STRING_TYPE) { handled = true } }` Gives the developer the ability to handle incorrect return values. This is for example useful when the return value will undergo implicit conversion or the enclosing closure's target type is difficult to infer properly. In that case, you can help the type checker just by telling it that the assignment is valid (by setting the `handled` property).

```
incompatibleReturnType { stmt, type ->
    if (type == STRING_TYPE) {
        handled = true
    }
}
```

Event name	ambiguousMethods
Called When	Called when the type checker cannot choose between several candidate methods
Arguments	List<MethodNode> methods, Expression origin
Usage	(see code below) Gives the developer the ability to handle incorrect assignments. This is for example useful if a class overrides `setProperty`, because in that case it is possible that assigning a variable of one type to a property of another type is handled through that runtime mechanism. In that case, you can help the type checker just by telling it that the assignment is valid (using `handled` set to `true`).

```
ambiguousMethods { methods, origin ->
    // choose the method which has an Integer as parameter
type
    methods.find { it.parameters.any { it.type ==
classNodeFor(Integer) } }
}
```

Of course, an extension script may consist of several blocks, and you can have multiple blocks responding to the same event. This makes the DSL look nicer and easier to write. However, reacting to events is far from sufficient. If you know you can react to events, you also need to deal with the errors, which implies several *helper* methods that will make things easier.

Working with extensions

Support classes

The DSL relies on a support class called org.codehaus.groovy.transform.stc.GroovyTypeCheckingExtensionSupport . This class itself extends org.codehaus.groovy.transform.stc.TypeCheckingExtension . Those two classes define a number of *helper* methods that will make working with the AST easier, especially regarding type checking. One interesting thing to know is that you **have access to the type checker**. This means that you can programmatically call methods of the type checker, including those that allow you to

throw compilation errors.

The extension script delegates to the org.codehaus.groovy.transform.stc.GroovyTypeCheckingExtensionSupport class, meaning that you have direct access to the following variables:

- *context*: the type checker context, of type org.codehaus.groovy.transform.stc.TypeCheckingContext
- *typeCheckingVisitor*: the type checker itself, a org.codehaus.groovy.transform.stc.StaticTypeCheckingVisitor instance
- *generatedMethods*: a list of "generated methods", which is in fact the list of "dummy" methods that you can create inside a type checking extension using the `newMethod` calls

The type checking context contains a lot of information that is useful in context for the type checker. For example, the current stack of enclosing method calls, binary expressions, closures, … This information is in particular important if you have to know *where* you are when an error occurs and that you want to handle it.

In addition to facilities provided by `GroovyTypeCheckingExtensionSupport` and `StaticTypeCheckingVisitor`, a type-checking DSL script imports static members from org.codehaus.groovy.ast.ClassHelper and org.codehaus.groovy.transform.stc.StaticTypeCheckingSupport granting access to common types via `OBJECT_TYPE`, `STRING_TYPE`, `THROWABLE_TYPE`, etc. and checks like `missesGenericsTypes(ClassNode)`, `isClassClassNodeWrappingConcreteType(ClassNode)` and so on.

Class nodes

Handling class nodes is something that needs particular attention when you work with a type checking extension. Compilation works with an abstract syntax tree (AST) and the tree may not be complete when you are type checking a class. This also means that when you refer to types, you must not use class literals such as `String` or `HashSet`, but to class nodes representing those types. This requires a certain level of abstraction and understanding how Groovy deals with class nodes. To make things easier, Groovy supplies several helper methods to deal with class nodes. For example, if you want to say "the type for String", you can write:

```
assert classNodeFor(String) instanceof ClassNode
```

You would also note that there is a variant of *classNodeFor* that takes a `String` as an argument, instead of a `Class`. In general, you should **not** use that one, because it would create a class node for which the name is `String`, but without any method, any property, … defined on it. The first version returns a class node that is *resolved* but the second one returns one that is *not*. So the latter should be reserved for very special cases.

The second problem that you might encounter is referencing a type which is not yet compiled. This may happen more often than you think. For example, when you compile a set of files together. In that case, if you want to say "that variable is of type Foo" but `Foo` is not yet compiled, you can still refer to the `Foo` class node using `lookupClassNodeFor`:

```
assert lookupClassNodeFor('Foo') instanceof ClassNode
```

Helping the type checker

Say that you know that variable `foo` is of type `Foo` and you want to tell the type checker about it. Then you can use the `storeType` method, which takes two arguments: the first one is the node for which you want to store the type and the second one is the type of the node. If you look at the implementation of `storeType`, you would see that it delegates to the type checker equivalent method, which itself does a lot of work to store node metadata. You would also see that storing the type is not limited to variables: you can set the type of any expression.

Likewise, getting the type of an AST node is just a matter of calling `getType` on that node. This would in general be what you want, but there's something that you must understand:

- `getType` returns the **inferred type** of an expression. This means that it will not return, for a variable declared of type `Object` the class node for `Object`, but the inferred type of this variable **at this point of the code** (flow typing)
- if you want to access the origin type of a variable (or field/parameter), then you must call the appropriate method on the AST node

Throwing an error

To throw a type checking error, you only have to call the `addStaticTypeError` method which takes two arguments:

- a *message* which is a string that will be displayed to the end user
- an *AST node* responsible for the error. It's better to provide the best suiting AST node because it will be used to retrieve the line and column numbers

isXXXExpression

It is often required to know the type of an AST node. For readability, the DSL provides a special isXXXExpression method that will delegate to `x instance of XXXExpression`. For example, instead of writing:

```
if (node instanceof BinaryExpression) {
   ...
}
```

you can just write:

```
if (isBinaryExpression(node)) {
   ...
}
```

Virtual methods

When you perform type checking of dynamic code, you may often face the case when you know that a method call is valid but there is no "real" method behind it. As an example, take the Grails dynamic finders. You can have a method call consisting of a method named *findByName(…)*. As there’s no *findByName* method defined in the bean, the type checker would complain. Yet, you would know that this method wouldn’t fail at runtime, and you can even tell what is the return type of this method. For this case, the DSL supports two special constructs that consist of *phantom methods*. This means that you will return a method node that doesn’t really exist but is defined in the context of type checking. Three methods exist:

- `newMethod(String name, Class returnType)`
- `newMethod(String name, ClassNode returnType)`
- `newMethod(String name, Callable<ClassNode> return Type)`

All three variants do the same: they create a new method node which name is the supplied name and define the return type of this method. Moreover, the type checker would add those methods in the `generatedMethods` list (see `isGenerated` below). The reason why we only set a name and a return type is that it is only what you need in 90% of the cases. For example, in the `findByName` example upper, the only thing you need to know is that `findByName` wouldn’t fail at runtime, and that it returns a domain class. The `Callable` version of return type is interesting because it defers the computation of the return type when the type checker actually needs it. This is interesting because in some circumstances, you may not know the actual return type when the type checker demands it, so you can use a closure that will be called each time `getReturnType` is called by the type checker on this method node. If you combine this with deferred checks, you can achieve pretty complex type checking including handling of forward references.

```
newMethod(name) {
    // each time getReturnType on this method node will be called, this closure will
be called!
    println 'Type checker called me!'
    lookupClassNodeFor(Foo) // return type
}
```

Should you need more than the name and return type, you can always create a new `MethodNode` by yourself.

Scoping

Scoping is very important in DSL type checking and is one of the reasons why we couldn’t use a *pointcut* based approach to DSL type checking. Basically, you must be able to define very precisely when your extension applies and when it does not. Moreover, you must be able to handle situations that a regular type checker would not be able to handle, such as forward references:

```
point a(1,1)
line a,b // b is referenced afterwards!
point b(5,2)
```

Say for example that you want to handle a builder:

```
builder.foo {
   bar
   baz(bar)
}
```

Your extension, then, should only be active once you've entered the foo method, and inactive outside this scope. But you could have complex situations like multiple builders in the same file or embedded builders (builders in builders). While you should not try to fix all this from start (you must accept limitations to type checking), the type checker does offer a nice mechanism to handle this: a scoping stack, using the newScope and scopeExit methods.

- newScope creates a new scope and puts it on top of the stack
- scopeExits pops a scope from the stack

A scope consists of:

- a parent scope
- a map of custom data

If you want to look at the implementation, it's simply a LinkedHashMap (org.codehaus.groovy.transform.stc.GroovyTypeCheckingExtensionSupport.TypeCheckingScope), but it's quite powerful. For example, you can use such a scope to store a list of closures to be executed when you exit the scope. This is how you would handle forward references:

```
def scope = newScope()
scope.secondPassChecks = []
//...
scope.secondPassChecks << { println 'executed later' }
// ...
scopeExit {
    secondPassChecks*.run() // execute deferred checks
}
```

That is to say, that if at some point you are not able to determine the type of an expression, or that you are not able to check at this point that an assignment is valid or not, you can still make the check later… This is a very powerful feature. Now, newScope and scopeExit provide some interesting syntactic sugar:

```
newScope {
    secondPassChecks = []
}
```

At anytime in the DSL, you can access the current scope using getCurrentScope() or more simply currentScope:

```
//...
currentScope.secondPassChecks << { println 'executed later' }
// ...
```

The general schema would then be:

- determine a *pointcut* where you push a new scope on stack and initialize custom variables within this scope
- using the various events, you can use the information stored in your custom scope to perform checks, defer checks,...
- determine a *pointcut* where you exit the scope, call `scopeExit` and eventually perform additional checks

Other useful methods

For the complete list of helper methods, please refer to the org.codehaus.groovy.transform.stc.GroovyTypeCheckingExtensionSupport and org.codehaus.groovy.transform.stc.TypeCheckingExtension classes. However, take special attention to those methods:

- `isDynamic`: takes a VariableExpression as argument and returns true if the variable is a DynamicExpression, which means, in a script, that it wasn't defined using a type or `def`.
- `isGenerated`: takes a MethodNode as an argument and tells if the method is one that was generated by the type checker extension using the `newMethod` method
- `isAnnotatedBy`: takes an AST node and a Class (or ClassNode), and tells if the node is annotated with this class. For example: `isAnnotatedBy(node, NotNull)`
- `getTargetMethod`: takes a method call as argument and returns the `MethodNode` that the type checker has determined for it
- `delegatesTo`: emulates the behaviour of the `@DelegatesTo` annotation. It allows you to tell that the argument will delegate to a specific type (you can also specify the delegation strategy)

Advanced type checking extensions

Precompiled type checking extensions

All the examples above use type checking scripts. They are found in source form in classpath, meaning that:

- a Groovy source file, corresponding to the type checking extension, is available on compilation classpath
- this file is compiled by the Groovy compiler for each source unit being compiled (often, a source unit corresponds to a single file)

It is a very convenient way to develop type checking extensions, however it implies a slower compilation phase, because of the compilation of the extension itself for each file being compiled. For those reasons, it can be practical to rely on a precompiled extension. You have two options to do this:

- write the extension in Groovy, compile it, then use a reference to the extension class instead of the source
- write the extension in Java, compile it, then use a reference to the extension class

Writing a type checking extension in Groovy is the easiest path. Basically, the idea is that the type checking extension script becomes the body of the main method of a type checking extension class, as illustrated here:

```
import org.codehaus.groovy.transform.stc.GroovyTypeCheckingExtensionSupport

class PrecompiledExtension extends GroovyTypeCheckingExtensionSupport.TypeCheckingDSL
{     ①
    @Override
    Object run() {
②
        unresolvedVariable { var ->
            if ('robot'==var.name) {
                storeType(var, classNodeFor(Robot))
③
                handled = true
            }
        }
    }
}
```

① extending the `TypeCheckingDSL` class is the easiest

② then the extension code needs to go inside the `run` method

③ and you can use the very same events as an extension written in source form

Setting up the extension is very similar to using a source form extension:

```
config.addCompilationCustomizers(
    new ASTTransformationCustomizer(
        TypeChecked,
        extensions:['typing.PrecompiledExtension'])
)
```

The difference is that instead of using a path in classpath, you just specify the fully qualified class name of the precompiled extension.

In case you really want to write an extension in Java, then you will not benefit from the type checking extension DSL. The extension above can be rewritten in Java this way:

```
import org.codehaus.groovy.ast.ClassHelper;
import org.codehaus.groovy.ast.expr.VariableExpression;
```

```
import org.codehaus.groovy.transform.stc.AbstractTypeCheckingExtension;


import org.codehaus.groovy.transform.stc.StaticTypeCheckingVisitor;

public class PrecompiledJavaExtension extends AbstractTypeCheckingExtension {
①

    public PrecompiledJavaExtension(final StaticTypeCheckingVisitor
typeCheckingVisitor) {
        super(typeCheckingVisitor);
    }

    @Override
    public boolean handleUnresolvedVariableExpression(final VariableExpression vexp) {
②
        if ("robot".equals(vexp.getName())) {
            storeType(vexp, ClassHelper.make(Robot.class));
            setHandled(true);
            return true;
        }
        return false;
    }

}
```

① extend the `AbstractTypeCheckingExtension` class

② then override the `handleXXX` methods as required

Using @Grab in a type checking extension

It is totally possible to use the `@Grab` annotation in a type checking extension. This means you can include libraries that would only be available at compile time. In that case, you must understand that you would increase the time of compilation significantly (at least, the first time it grabs the dependencies).

Sharing or packaging type checking extensions

A type checking extension is just a script that need to be on classpath. As such, you can share it as is, or bundle it in a jar file that would be added to classpath.

Global type checking extensions

While you can configure the compiler to transparently add type checking extensions to your script, there is currently no way to apply an extension transparently just by having it on classpath.

Type checking extensions and @CompileStatic

Type checking extensions are used with `@TypeChecked` but can also be used with `@CompileStatic`. However, you must be aware that:

- a type checking extension used with `@CompileStatic` will in general not be sufficient to let the compiler know how to generate statically compilable code from "unsafe" code
- it is possible to use a type checking extension with `@CompileStatic` just to enhance type checking, that is to say introduce **more** compilation errors, without actually dealing with dynamic code

Let's explain the first point, which is that even if you use an extension, the compiler will not know how to compile your code statically: technically, even if you tell the type checker what is the type of a dynamic variable, for example, it would not know how to compile it. Is it `getBinding('foo')`, `getProperty('foo')`, `delegate.getFoo()`,...? There's absolutely no direct way to tell the static compiler how to compile such code even if you use a type checking extension (that would, again, only give hints about the type).

One possible solution for this particular example is to instruct the compiler to use mixed mode compilation. The more advanced one is to use AST transformations during type checking but it is far more complex.

Type checking extensions allow you to help the type checker where it fails, but it also allows you to fail where it doesn't. In that context, it makes sense to support extensions for `@CompileStatic` too. Imagine an extension that is capable of type checking SQL queries. In that case, the extension would be valid in both dynamic and static context, because without the extension, the code would still pass.

Mixed mode compilation

In the previous section, we highlighted the fact that you can activate type checking extensions with `@CompileStatic`. In that context, the type checker would not complain anymore about some unresolved variables or unknown method calls, but it would still wouldn't know how to compile them statically.

Mixed mode compilation offers a third way, which is to instruct the compiler that whenever an unresolved variable or method call is found, then it should fall back to a dynamic mode. This is possible thanks to type checking extensions and a special `makeDynamic` call.

To illustrate this, let's come back to the `Robot` example:

```
robot.move 100
```

And let's try to activate our type checking extension using `@CompileStatic` instead of `@TypeChecked`:

```
def config = new CompilerConfiguration()
config.addCompilationCustomizers(
    new ASTTransformationCustomizer(
        CompileStatic,                                      ①
        extensions:['robotextension.groovy'])               ②
)
def shell = new GroovyShell(config)
def robot = new Robot()
shell.setVariable('robot', robot)
```

```
shell.evaluate(script)
```

① Apply `@CompileStatic` transparently

② Activate the type checking extension

The script will run fine because the static compiler is told about the type of the `robot` variable, so it is capable of making a direct call to `move`. But before that, how did the compiler know how to get the `robot` variable? In fact by default, in a type checking extension, setting `handled=true` on an unresolved variable will automatically trigger a dynamic resolution, so in this case you don't have anything special to make the compiler use a mixed mode. However, let's slightly update our example, starting from the robot script:

```
move 100
```

Here you can notice that there is no reference to `robot` anymore. Our extension will not help then because we will not be able to instruct the compiler that `move` is done on a `Robot` instance. This example of code can be executed in a totally dynamic way thanks to the help of a groovy.util.DelegatingScript:

```
def config = new CompilerConfiguration()
config.scriptBaseClass = 'groovy.util.DelegatingScript'     ①
def shell = new GroovyShell(config)
def runner = shell.parse(script)                            ②
runner.setDelegate(new Robot())                             ③
runner.run()                                                ④
```

① we configure the compiler to use a `DelegatingScript` as the base class

② the script source needs to be parsed and will return an instance of `DelegatingScript`

③ we can then call `setDelegate` to use a `Robot` as the delegate of the script

④ then execute the script. `move` will be directly executed on the delegate

If we want this to pass with `@CompileStatic`, we have to use a type checking extension, so let's update our configuration:

```
config.addCompilationCustomizers(
    new ASTTransformationCustomizer(
        CompileStatic,                                      ①
        extensions:['robotextension2.groovy'])              ②
)
```

① apply `@CompileStatic` transparently

② use an alternate type checking extension meant to recognize the call to `move`

Then in the previous section we have learnt how to deal with unrecognized method calls, so we are able to write this extension:

robotextension2.groovy

```
methodNotFound { receiver, name, argList, argTypes, call ->
    if (isMethodCallExpression(call)                        ①
        && call.implicitThis                                ②
        && 'move'==name                                     ③
        && argTypes.length==1                               ④
        && argTypes[0] == classNodeFor(int)                 ⑤
    ) {
        handled = true                                      ⑥
        newMethod('move', classNodeFor(Robot))              ⑦
    }
}
```

① if the call is a method call (not a static method call)

② that this call is made on "implicit this" (no explicit `this.`)

③ that the method being called is `move`

④ and that the call is done with a single argument

⑤ and that argument is of type `int`

⑥ then tell the type checker that the call is valid

⑦ and that the return type of the call is `Robot`

If you try to execute this code, then you could be surprised that it actually fails at runtime:

```
java.lang.NoSuchMethodError: java.lang.Object.move()Ltyping/Robot;
```

The reason is very simple: while the type checking extension is sufficient for `@TypeChecked`, which does not involve static compilation, it is not enough for `@CompileStatic` which requires additional information. In this case, you told the compiler that the method existed, but you didn't explain to it **what** method it is in reality, and what is the receiver of the message (the delegate).

Fixing this is very easy and just implies replacing the `newMethod` call with something else:

robotextension3.groovy

```
methodNotFound { receiver, name, argList, argTypes, call ->
    if (isMethodCallExpression(call)
        && call.implicitThis
        && 'move'==name
        && argTypes.length==1
        && argTypes[0] == classNodeFor(int)
    ) {
        makeDynamic(call, classNodeFor(Robot))              ①
    }
}
```

① tell the compiler that the call should be make dynamic

The `makeDynamic` call does 3 things:

- it returns a virtual method just like `newMethod`
- automatically sets the `handled` flag to `true` for you
- but also marks the `call` to be done dynamically

So when the compiler will have to generate bytecode for the call to `move`, since it is now marked as a dynamic call, it will fall back to the dynamic compiler and let it handle the call. And since the extension tells us that the return type of the dynamic call is a `Robot`, subsequent calls will be done statically!

Some would wonder why the static compiler doesn't do this by default without an extension. It is a design decision:

- if the code is statically compiled, we normally want type safety and best performance
- so if unrecognized variables/method calls are made dynamic, you loose type safety, but also all support for typos at compile time!

In short, if you want to have mixed mode compilation, it **has** to be explicit, through a type checking extension, so that the compiler, and the designer of the DSL, are totally aware of what they are doing.

`makeDynamic` can be used on 3 kind of AST nodes:

- a method node (`MethodNode`)
- a variable (`VariableExpression`)
- a property expression (`PropertyExpression`)

If that is not enough, then it means that static compilation cannot be done directly and that you have to rely on AST transformations.

Transforming the AST in an extension

Type checking extensions look very attractive from an AST transformation design point of view: extensions have access to context like inferred types, which is often nice to have. And an extension has a direct access to the abstract syntax tree. Since you have access to the AST, there is nothing in theory that prevents you from modifying the AST. However, we do not recommend you to do so, unless you are an advanced AST transformation designer and well aware of the compiler internals:

- First of all, you would explicitly break the contract of type checking, which is to annotate, and only annotate the AST. Type checking should **not** modify the AST tree because you wouldn't be able to guarantee anymore that code without the *@TypeChecked* annotation behaves the same without the annotation.
- If your extension is meant to work with *@CompileStatic*, then you **can** modify the AST because this is indeed what *@CompileStatic* will eventually do. Static compilation doesn't guarantee the same semantics at dynamic Groovy so there is effectively a difference between code compiled

with *@CompileStatic* and code compiled with *@TypeChecked*. It's up to you to choose whatever strategy you want to update the AST, but probably using an AST transformation that runs before type checking is easier.

- if you cannot rely on a transformation that kicks in before the type checker, then you must be **very** careful

WARNING	The type checking phase is the last phase running in the compiler before bytecode generation. All other AST transformations run before that and the compiler does a very good job at "fixing" incorrect AST generated before the type checking phase. As soon as you perform a transformation during type checking, for example directly in a type checking extension, then you have to do all this work of generating a 100% compiler compliant abstract syntax tree by yourself, which can easily become complex. That's why we do not recommend to go that way if you are beginning with type checking extensions and AST transformations.

Examples

Examples of real life type checking extensions are easy to find. You can download the source code for Groovy and take a look at the TypeCheckingExtensionsTest class which is linked to various extension scripts.

An example of a complex type checking extension can be found in the Markup Template Engine source code: this template engine relies on a type checking extension and AST transformations to transform templates into fully statically compiled code. Sources for this can be found here.

Tools

Running Groovy from the commandline

groovy, the Groovy command

`groovy` invokes the Groovy command line processor. It allows you to run inline Groovy expressions, and scripts, tests or application within groovy files. It plays a similar role to `java` in the Java world but handles inline scripts and rather than invoking class files, it is normally called with scripts and will automatically call the Groovy compiler as needed.

The easiest way to run a Groovy script, test or application is to run the following command at your shell prompt:

```
> groovy MyScript.groovy
```

The `.groovy` part is optional. The `groovy` command supports a number of command line switches:

Short version	Long version	Description	Example
-a	--autosplit <splitPattern>	split lines using splitPattern (default '\s') using implicit 'split' variable	
-b	--basescript <class>	Base class name for scripts (must derive from Script)	
-c	--encoding <charset>	specify the encoding of the files	
-cp <path>	-classpath <path> --classpath <path>	Specify the compilation classpath. Must be the first argument.	groovy -cp lib/dep.jar MyScript
	--configscript <path>	Advanced compiler configuration script	groovy --configscript config/config.groovy src/Person.groovy
-D	--define <name=value>	define a system property	
-d	--debug	debug mode will print out full stack traces	

Short version	Long version	Description	Example
	--disableopt <optlist>	disables one or all optimization elements. optlist can be a comma separated list with the elements: all (disables all optimizations), int (disable any int based optimizations)	
-e <script>		specify an inline command line script	groovy -e "println new Date()"
-h	--help	Displays usage information for the command line groovy command	groovy --help
-i <extension>		modify files in place; create backup if extension is given (e.g. '.bak')	
-l <port>		listen on a port and process inbound lines (default: 1960)	
-n		process files line by line using implicit 'line' variable	
-p		process files line by line and print result (see also -n)	
-v	--version	display the Groovy and JVM versions	groovy -v
-pa	--parameters	Generates metadata for reflection on method parameter names on JDK 8 and above. Defaults to false.	groovy --parameters Person.groovy
-pr	--enable-preview	Enable preview Java features (jdk12+ only).	groovy --enable -preview Person.groovy

Compiling Groovy

groovyc, the Groovy compiler

`groovyc` is the Groovy compiler command line tool. It allows you to compile Groovy sources into bytecode. It plays the same role as `javac` in the Java world. The easiest way to compile a Groovy script or class is to run the following command:

```
groovyc MyClass.groovy
```

This will produce a `MyClass.class` file (as well as other .class files depending on the contents of the source). `groovyc` supports a number of command line switches:

Short version	Long version	Description	Example
-cp	-classpath, --classpath	Specify the compilation classpath. Must be the first argument.	groovyc -cp lib/dep.jar MyClass.groovy
	--sourcepath	Directory where to find source files. Not used anymore. Specifying this parameter will have no effect.	
	--temp	Temporary directory for the compiler	
	--encoding	Encoding of the source files	groovyc --encoding utf-8 script.groovy
	--help	Displays help for the command line groovyc tool	groovyc --help
-d		Specify where to place generated class files.	groovyc -d target Person.groovy
-v	--version	Displays the compiler version	groovyc -v
-e	--exception	Displays the stack trace in case of compilation error	groovyc -e script.groovy
-j	--jointCompilation*	Enables joint compilation	groovyc -j A.groovy B.java
-b	--basescript	Base class name for scripts (must derive from Script)	
	--configscript	Advanced compiler configuration script	groovyc --configscript config/config.groovy src/Person.groovy

Short version	Long version	Description	Example
-Jproperty=value		Properties to be passed to `javac` if joint compilation is enabled	groovyc -j -Jtarget=1.6 -Jsource=1.6 A.groovy B.java
-Fflag		Flags to be passed to `javac` if joint compilation is enabled	groovyc -j -Fnowarn A.groovy B.java
-pa	--parameters	Generates metadata for reflection on method parameter names. Requires Java 8+.	groovyc --parameters Person.groovy
-pr	--enable-preview	Enable preview Java features (jdk12+ only).	groovy --enable -preview Person.groovy
@argfile		Read options and source files from specified file.	groovyc @conf/args

Notes: * for a full description of joint compilation, see the joint compilation section.

Ant task

See the groovyc Ant task documentation. It allows the Groovy compiler to be invoked from Apache Ant.

Gant

Gant is a tool for scripting Ant tasks using Groovy instead of XML to specify the logic. As such, it has exactly the same features as the Groovyc Ant task.

Gradle

Gradle is a build tool that allows you to leverage the flexibility of Ant, while keeping the simplicity of convention over configuration that tools like Maven offer. Builds are specified using a Groovy DSL, which offers great flexibility and succinctness.

Maven integration

There are several approaches to compiling Groovy code in your Maven projects. GMavenPlus is the most flexible and feature rich, but like most Groovy compiler tools, it can have difficulties with joint Java-Groovy projects (for the same reason GMaven and Gradle can have issues). The Groovy-Eclipse compiler plugin for Maven sidesteps the joint compilation issues. Read this for a deeper discussion of the benefits and disadvantages of the two approaches.

A third approach is to use Maven's Ant plugin to compile a groovy project. Note that the Ant plugin is bound to the compile and test-compile phases of the build in the example below. It will be invoked during these phases and the contained tasks will be carried out which runs the Groovy compiler over the source and test directories. The resulting Java classes will coexist with and be treated like any standard Java classes compiled from Java source and will appear no different to the JRE, or the JUnit runtime.

```
<project xmlns="http://maven.apache.org/POM/4.0.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://maven.apache.org/POM/4.0.0
http://maven.apache.org/maven-v4_0_0.xsd">
    <modelVersion>4.0.0</modelVersion>
    <groupId>com.mycomp.MyGroovy</groupId>
    <artifactId>MyGroovy</artifactId>
    <packaging>jar</packaging>
    <version>1.0-SNAPSHOT</version>
    <name>Maven Example building a Groovy project</name>
    <dependencies>
        <dependency>
            <groupId>junit</groupId>
            <artifactId>junit</artifactId>
            <version>3.8.1</version>
            <scope>test</scope>
        </dependency>
        <dependency>
            <groupId>org.codehaus.groovy</groupId>
            <artifactId>groovy-all</artifactId>
            <version>2.5.0</version>
            <type>pom</type> <!-- required JUST since Groovy 2.5.0 -->
        </dependency>
    </dependencies>
    <build>
        <plugins>
            <plugin>
                <artifactId>maven-antrun-plugin</artifactId>
                <executions>
                    <execution>
                        <id>compile</id>
                        <phase>compile</phase>
                        <configuration>
                            <tasks>
                                <mkdir dir="${basedir}/src/main/groovy"/>
                                <taskdef name="groovyc"
                                    classname="org.codehaus.groovy.ant.Groovyc">
                                    <classpath refid="maven.compile.classpath"/>
                                </taskdef>
                                <mkdir dir="${project.build.outputDirectory}"/>
                                <groovyc destdir="${project.build.outputDirectory}"
                                    srcdir="${basedir}/src/main/groovy/"
listfiles="true">
                                    <classpath refid="maven.compile.classpath"/>
                                </groovyc>
                            </tasks>
```

```
                        </configuration>
                        <goals>
                            <goal>run</goal>
                        </goals>
                    </execution>
                    <execution>
                        <id>test-compile</id>
                        <phase>test-compile</phase>
                        <configuration>
                            <tasks>
                                <mkdir dir="${basedir}/src/test/groovy"/>
                                <taskdef name="groovyc"
                                    classname="org.codehaus.groovy.ant.Groovyc">
                                    <classpath refid="maven.test.classpath"/>
                                </taskdef>
                                <mkdir dir="${project.build.testOutputDirectory}"/>
                                <groovyc
destdir="${project.build.testOutputDirectory}"
                                    srcdir="${basedir}/src/test/groovy/"
listfiles="true">
                                    <classpath refid="maven.test.classpath"/>
                                </groovyc>
                            </tasks>
                        </configuration>
                        <goals>
                            <goal>run</goal>
                        </goals>
                    </execution>
                </executions>
            </plugin>
        </plugins>
    </build>
</project>
```

This assumes you have a Maven project setup with `groovy` subfolders as peers to the java src and test subfolders. You can use the `java`/`jar` archetype to set this up then rename the java folders to groovy or keep the java folders and just create groovy peer folders. There exists, also a groovy plugin which has not been tested or used in production. After defining the build section as in the above example, you can invoke the typical Maven build phases normally. For example, `mvn test` will execute the test phase, compiling Groovy source and Groovy test source and finally executing the unit tests. If you run `mvn jar` it will execute the jar phase bundling up all of your compiled production classes into a jar after all the unit tests pass. For more detail on Maven build phases consult the Maven2 documentation.

GMaven and GMavenPlus

GMaven

GMaven is the original Maven plugin for Groovy, supporting both compiling and scripting Groovy.

Important:

You should be aware that GMaven is **not supported anymore** and can have difficulties with joint compilation. GMavenPlus can be a good replacement, but if you are having problems with joint compilation, you might consider the Groovy Eclipse maven plugin.

GMavenPlus

GMavenPlus is a rewrite of GMaven and is in active development. It supports most of the features of GMaven (a couple notable exceptions being mojo Javadoc tags and support for older Groovy versions). Its joint compilation uses stubs (which means it has the same potential issues as GMaven and Gradle). The main advantages over its predecessor are that it supports recent Groovy versions, InvokeDynamic, Groovy on Android, GroovyDoc, and configuration scripts.

GMaven 2

Unlike the name might seem to suggest, GMaven 2 is not aimed at replacing GMaven. In fact, it removes the non-scripting features of the GMaven plugin. It has not yet had any release and appears to be inactive currently.

The Groovy Eclipse Maven plugin

Groovy-Eclipse provides a compiler plugin for Maven. Using the compiler plugin, it is possible to compile your maven projects using the Groovy-Eclipse compiler. One feature unavailable elsewhere is stubless joint compilation.

Joint compilation

Joint compilation means that the Groovy compiler will parse the Groovy source files, create stubs for all of them, invoke the Java compiler to compile the stubs along with Java sources, and then continue compilation in the normal Groovy compiler way. This allows mixing of Java and Groovy files without constraint.

Joint compilation can be enabled using the `-j` flag with the command-line compiler, or using a nested tag and all the attributes and further nested tags as required for the Ant task.

It is important to know that if you don't enable joint compilation and try to compile Java source files with the Groovy compiler, the Java source files will be compiled as if they were Groovy sources. In some situations, this might work since most of the Java syntax is compatible with Groovy, but there are a number of places where semantics could be different.

Android support

It is possible to write an Android application in Groovy. However this requires a special version of the compiler, meaning that you cannot use the regular groovyc tool to target Android bytecode. In particular, Groovy provides specific JAR files for Android, which have a classifier of `grooid`. In order to make things easier, a Gradle plugin adds support for the Groovy language in the Android Gradle toolchain.

The plugin can be applied like this:

```
buildscript {
    repositories {
        mavenCentral()
    }
    dependencies {
        classpath 'com.android.tools.build:gradle:2.1.2'
        classpath 'org.codehaus.groovy:groovy-android-gradle-plugin:1.0.0'
    }
}

apply plugin: 'groovyx.android'
```

Then you will need to add a dependency on the `grooid` version of the Groovy compiler:

```
dependencies {
    compile 'org.codehaus.groovy:groovy:2.4.7:grooid'
}
```

Note that if a Groovy jar does not provide a `grooid` classifier alternative, then it means that the jar is directly compatible with Android. In that case, you can add the dependency directly like this:

```
dependencies {
    compile 'org.codehaus.groovy:groovy:2.4.7:grooid'       // requires the grooid
classifier
    compile ('org.codehaus.groovy:groovy-json:2.4.7') {     // no grooid version
available
        transitive = false                                  // so do not depend on
non-grooid version
    }
}
```

Note that the `transitive=false` parameter for `groovy-json` will let Gradle download the JSON support jar without adding a dependency onto the normal jar of Groovy.

Please make sure to go to the plugin homepage in order to find the latest documentation and version.

Groovysh, the Groovy shell

Groovy : Groovy Shell

The Groovy Shell, aka. `groovysh` is a command-line application which allows easy access to evaluate Groovy expressions, define classes and run simple experiments.

Features

- No need for `go` command to execute buffer.
- Rich cross-platform edit-line editing, history and completion thanks to JLine2.
- ANSI colors (prompt, exception traces, etc).
- Simple, yet robust, command system with online help, user alias support and more.
- User profile support

Command-line Options and Arguments

The shell supports several options to control verbosity, ANSI coloring and other features.

```
./bin/groovysh --help

Usage: groovysh [options] [...]
The Groovy Shell, aka groovysh, is a command-line application which allows easy
access to evaluate Groovy expressions, define classes and run simple
experiments.
  -C, --color[=<FLAG>]    Enable or disable use of ANSI colors
      -cp, -classpath, --classpath
                          Specify where to find the class files - must be first
                            argument
  -d, --debug             Enable debug output
  -D, --define=<name=value>
                          Define a system property
  -e, --evaluate=<CODE>   Evaluate the code first when starting interactive session
  -h, --help              Display this help message
  -pa, --parameters       Generate metadata for reflection on method parameter names
                            (jdk8+ only)
  -pr, --enable-preview   Enable preview Java features (jdk12+ only)
  -q, --quiet             Suppress superfluous output
  -T, --terminal=<TYPE>   Specify the terminal TYPE to use
  -v, --verbose           Enable verbose output
  -V, --version           Display the version
```

Evaluating Expressions

Simple Expressions

```
println "Hello"
```

Evaluation Result

When a complete expression is found, it is compiled and evaluated. The result of the evaluation is stored into the _ variable.

Multi-line Expressions

Multi-line/complex expressions (like closure or class definitions) may be defined over several lines. When the shell detects that it has a complete expression it will compile and evaluate it.

Define a Class

```
class Foo {
    def bar() {
        println "baz"
    }
}
```

Use the Class

```
foo = new Foo()
foo.bar()
```

Variables

Shell variables are **all** untyped (i.e. no `def` or other type information).

This **will** set a shell variable:

```
foo = "bar"
```

But, this will evaluate a local variable and will **not** be saved to the shell's environment:

```
def foo = "bar"
```

This behavior can be changed by activating interpreter mode.

Functions

Functions can be defined in the shell, and will be saved for later use.

Defining a function is easy:

```
groovy:000> def hello(name) {
groovy:001> println("Hello $name")
groovy:002> }
```

And then using it is as one might expect:

```
hello("Jason")
```

Internally the shell creates a closure to encapsulate the function and then binds the closure to a variable. So variables and functions share the same namespace.

Commands

The shell has a number of different commands, which provide rich access to the shell's environment.

Commands all have a *name* and a *shortcut* (which is something like `\h`). Commands may also have some predefined system *aliases*. Users may also create their own aliases.

Recognized Commands

`help`

Display the list of commands (and aliases) or the help text for specific command.

The Command List

```
groovy:000> :help

For information about Groovy, visit:
    http://groovy-lang.org

Available commands:
  :help      (:h ) Display this help message
  ?          (:? ) Alias to: :help
  :exit      (:x ) Exit the shell
  :quit      (:q ) Alias to: :exit
  import     (:i ) Import a class into the namespace
  :display   (:d ) Display the current buffer
  :clear     (:c ) Clear the buffer and reset the prompt counter
  :show      (:S ) Show variables, classes or imports
  :inspect   (:n ) Inspect a variable or the last result with the GUI object browser
  :purge     (:p ) Purge variables, classes, imports or preferences
  :edit      (:e ) Edit the current buffer
  :load      (:l ) Load a file or URL into the buffer
  .          (:. ) Alias to: :load
  :save      (:s ) Save the current buffer to a file
  :record    (:r ) Record the current session to a file
  :history   (:H ) Display, manage and recall edit-line history
  :alias     (:a ) Create an alias
  :set       (:= ) Set (or list) preferences
  :grab      (:g ) Add a dependency to the shell environment
  :register  (:rc) Register a new command with the shell
  :doc       (:D ) Open a browser window displaying the doc for the argument

For help on a specific command type:
```

```
    :help <command>
```

Help for a Command

While in the interactive shell, you can ask for help for any command to get more details about its syntax or function. Here is an example of what happens when you ask for help for the `help` command:

```
groovy:000> :help :help

usage: :help [<command>]

Display the list of commands or the help text for <command>.
```

`exit`

Exit the shell.

This is the **only** way to exit the shell. Well, you can still `CTRL-C`, but the shell will complain about an abnormal shutdown of the JVM.

`import`

Add a custom import which will be included for all shell evaluations.

This command can be given at any time to add new imports.

`grab`

Grab a dependency (Maven, Ivy, etc.) from Internet sources or cache, and add it to the Groovy Shell environment.

```
groovy:000> :grab 'com.google.guava:guava:19.0'
groovy:000> import com.google.common.collect.BiMap
===> com.google.common.collect.BiMap
```

This command can be given at any time to add new dependencies.

`display`

Display the contents of the current buffer.

This only displays the buffer of an incomplete expression. Once the expression is complete, the buffer is reset. The prompt will update to show the size of the current buffer as well.

Example

```
groovy:000> class Foo {
groovy:001> def bar
```

```
groovy:002> def baz() {
groovy:003> :display
 001> class Foo {
 002> def bar
 003> def baz() {
```

clear

Clears the current buffer, resetting the prompt counter to 000. Can be used to recover from compilation errors.

show

Show variables, classes or preferences or imports.

`show variables`

```
groovy:000> :show variables
Variables:
  _ = true
```

`show classes`

`show imports`

`show preferences`

`show all`

inspect

Opens the GUI object browser to inspect a variable or the result of the last evaluation.

purge

Purges objects from the shell.

`purge variables`

`purge classes`

`purge imports`

`purge preferences`

`purge all`

edit

Edit the current buffer in an external editor.

Currently only works on UNIX systems which have the `EDITOR` environment variable set, or have configured the `editor` preference.

`load`

Load one or more files (or urls) into the buffer.

`save`

Saves the buffer's contents to a file.

`record`

Record the current session to a file.

`record start`

`record stop`

`record status`

`history`

Display, manage and recall edit-line history.

`history show`

`history recall`

`history flush`

`history clear`

`alias`

Create an alias.

`doc`

Opens a browser with documentation for the provided class.

For example, we can get both the Javadoc and GDK enhancements doc for `java.util.List` (shown running on JDK17):

```
groovy:000> :doc java.util.List
https://docs.oracle.com/en/java/javase/17/docs/api/java.base/java/util/List.html
https://docs.groovy-lang.org/{groovy-full-version}/html/groovy-jdk/java/util/List.html
```

This will print the documentation URLs found and open two windows (or tabs, depending on your browser):

- one for the JDK documentation
- one for the GDK documentation

By default, for Java classes, the `java.base` module is assumed. You can specify an optional module for other cases (shown running on JDK17):

```
groovy:000> :doc java.scripting javax.script.ScriptContext
https://docs.oracle.com/en/java/javase/17/docs/api/java.scripting/javax/script/ScriptC
ontext.html
```

For backwards compatibility, if no module is specified when searching for Java classes, and no class is found in the `java.base` module, an additional attempt is made to find documentation for the class in the JDK8 (pre-module) Javadoc:

```
groovy:000> :doc javax.script.ScriptContext
https://docs.oracle.com/javase/8/docs/api/javax/script/ScriptContext.html
```

To get the Groovydoc for `groovy.ant.AntBuilder` and `groovy.xml.XmlSlurper`:

```
groovy:000> :doc groovy.ant.AntBuilder
https://docs.groovy-lang.org/{groovy-full-
version}/html/gapi/groovy/ant/AntBuilder.html
groovy:000> :doc groovy.xml.XmlSlurper
https://docs.groovy-lang.org/{groovy-full-
version}/html/gapi/groovy/xml/XmlSlurper.html
```

To get both the Groovydoc and GDK enhancements doc for `groovy.lang.Closure` and `groovy.sql.GroovyResultSet`:

```
groovy:000> :doc groovy.lang.Closure
https://docs.groovy-lang.org/{groovy-full-version}/html/gapi/groovy/lang/Closure.html
https://docs.groovy-lang.org/{groovy-full-version}/html/groovy-
jdk/groovy/lang/Closure.html
groovy:000> :doc groovy.sql.GroovyResultSet
https://docs.groovy-lang.org/{groovy-full-
version}/html/gapi/groovy/sql/GroovyResultSet.html
https://docs.groovy-lang.org/{groovy-full-version}/html/groovy-
jdk/groovy/sql/GroovyResultSet.html
```

Documentation is also available for the GDK enhancements to primitive arrays and arrays of arrays:

```
groovy:000> :doc int[]
https://docs.groovy-lang.org/{groovy-full-version}/html/groovy-jdk/primitives-and-
primitive-arrays/int%5B%5D.html
groovy:000> :doc double[][]
https://docs.groovy-lang.org/{groovy-full-version}/html/groovy-jdk/primitives-and-
primitive-arrays/double%5B%5D%5B%5D.html
```

NOTE In contexts where opening a browser may not be desirable, e.g. on a CI server, this command can be disabled by setting the `groovysh.disableDocCommand` system property to `true`.

`set`

Set or list preferences.

Preferences

Some aspects of `groovysh` behaviors can be customized by setting preferences. Preferences are set using the `set` command or the `:=` shortcut.

Recognized Preferences

`interpreterMode`

Allows the use of typed variables (i.e. `def` or other type information):

```
groovy:000> def x = 3
===> 3
groovy:000> x
===> 3
```

It’s especially useful for copy&pasting code from tutorials etc. into the running session.

`verbosity`

Set the shell’s verbosity level. Expected to be one of:

- `DEBUG`
- `VERBOSE`
- `INFO`
- `QUIET`

Default is `INFO`.

If this preference is set to an invalid value, then the previous setting will be used, or if there is none, then the preference is removed and the default is used.

`colors`

Set the shell’s use of colors.

Default is `true`.

`show-last-result`

Show the last result after an execution.

Default is `true`.

`sanitize-stack-trace`

Sanitize (trim-down/filter) stack traces.

Default is `true`.

`editor`

Configures the editor used by the `edit` command.

Default is the value of the system environment variable `EDITOR`.

To use TextEdit, the default text editor on macOS, configure: set editor /Applications/TextEdit.app/Contents/MacOS/TextEdit

Setting a Preference

```
groovy:000> :set verbosity DEBUG
```

Listing Preferences

To list the current *set* preferences (and their values):

```
groovy:000> :show preferences
```

Limitation: At the moment, there is no way to list all the known/available preferences to be set.

Clearing Preferences (i.e. Resetting to Defaults)

```
groovy:000> :purge preferences
```

User Profile Scripts and State

Profile Scripts

`$HOME/.groovy/groovysh.profile`

This script, if it exists, is loaded when the shell starts up.

`$HOME/.groovy/groovysh.rc`

This script, if it exists, is loaded when the shell enters interactive mode.

State

`$HOME/.groovy/groovysh.history`

Edit-line history is stored in this file.

Custom commands

The register command allows you to register custom commands in the shell. For example, writing the following will register the Stats command:

```
groovy:000> :register Stats
```

where the Stats class is a class extending the org.apache.groovy.groovysh.CommandSupport class. For example:

```
import org.apache.groovy.groovysh.CommandSupport
import org.apache.groovy.groovysh.Groovysh

class Stats extends CommandSupport {
    protected Stats(final Groovysh shell) {
        super(shell, 'stats', 'T')
    }

    public Object execute(List args) {
        println "Free memory: ${Runtime.runtime.freeMemory()}"
    }

}
```

Then the command can be called using:

```
groovy:000> :stats
stats
Free memory: 139474880
groovy:000>
```

Note that the command class must be found on classpath: you cannot define a new command from within the shell.

Troubleshooting

Please report any problems you run into. Please be sure to mark the JIRA issue with the Groovysh component.

Platform Problems

Problems loading the JLine DLL

On Windows, JLine2 (which is used for the fancy shell input/history/completion fluff), uses a **tiny** DLL file to trick the **evil** Windows faux-shell (CMD.EXE or COMMAND.COM) into providing Java with unbuffered input. In some rare cases, this might fail to load or initialize.

One solution is to disable the frills and use the unsupported terminal instance. You can do that on the command-line using the `--terminal` flag and set it to one of:

- `none`
- `false`
- `off`
- `jline.UnsupportedTerminal`

```
groovysh --terminal=none
```

Problems with Cygwin on Windows

Some people have issues when running groovysh with cygwin. If you have troubles, the following may help:

```
stty -icanon min 1 -echo
groovysh --terminal=unix
stty icanon echo
```

GMavenPlus Maven Plugin

GMavenPlus is a Maven plugin with goals that support launching a Groovy Shell or Groovy Console bound to a Maven project.

Gradle Groovysh Plugin

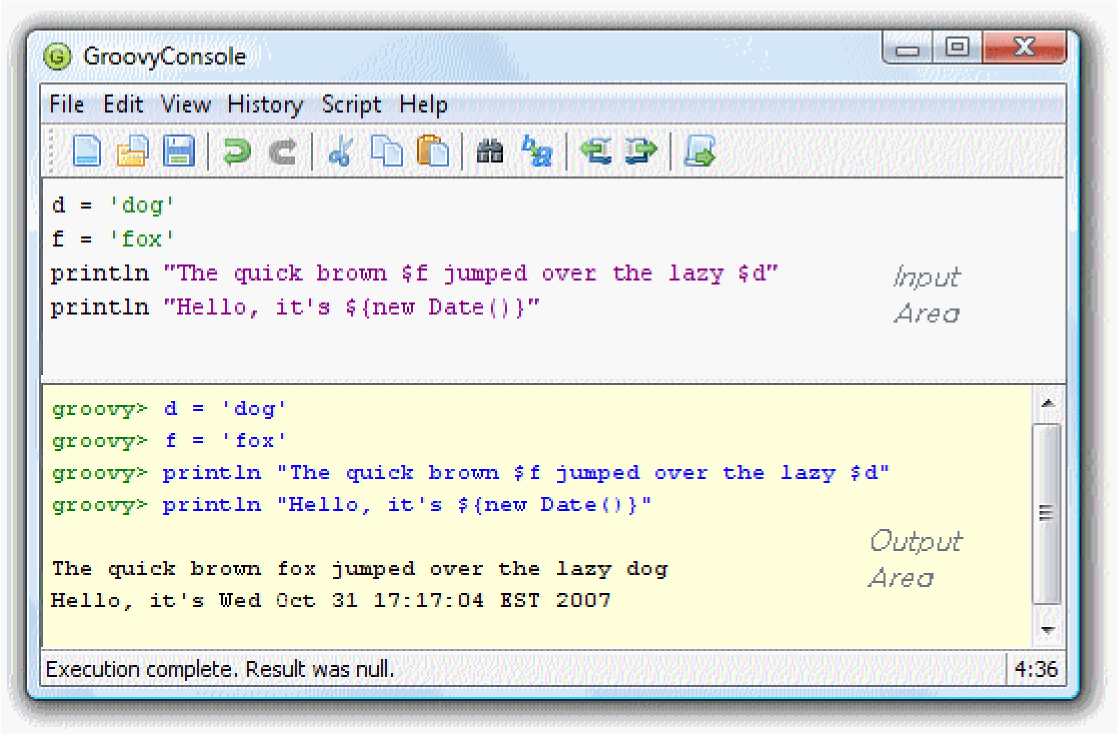
Gradle Groovysh Plugin is a Gradle plugin that provides gradle tasks to start a Groovy Shell bound to a Gradle project.

groovyConsole, the Groovy swing console

Groovy : Groovy Console

The Groovy Swing Console allows a user to enter and run Groovy scripts. This page documents the features of this user interface.

Basics



1. Groovy Console is launched via `groovyConsole` or `groovyConsole.bat`, both located in `$GROOVY_HOME/bin`
2. The Console has an input area and an output area.
3. You type a Groovy script in the input area.
4. When you select `Run` from the `Actions` menu, the console compiles the script and runs it.
5. Anything that would normally be printed on `System.out` is printed in the output area.
6. If the script returns a non-null result, that result is printed.

Features

Command-line Options and Arguments

The Groovy Console supports several options to control classpath and other features.

```
./bin/groovyConsole --help
Usage: groovyConsole [options] [filename]
The Groovy Swing Console allows a user to enter and run Groovy scripts.
      --configscript=PARAM   A script for tweaking the compiler configuration options
      -cp, -classpath, --classpath
                             Specify where to find the class files - must be first
                               argument
  -D, --define=<name=value>  Define a system property
  -h, --help                 Display this help message
  -pa, --parameters          Generate metadata for reflection on method parameter
                               names (jdk8+ only)
  -pr, --enable-preview      Enable preview Java features (jdk12+ only)
  -V, --version              Display the version
```

Running Scripts

There are several shortcuts that you can use to run scripts or code snippets:

- `Ctrl+Enter` and `Ctrl+R` are both shortcut keys for `Run Script`.
- If you highlight just part of the text in the input area, then Groovy runs just that text.
- The result of a script is the value of the last expression executed.
- You can turn the System.out capture on and off by selecting `Capture System.out` from the `Actions` menu

Editing Files

You can open any text file, edit it, run it (as a Groovy Script) and then save it again when you are finished.

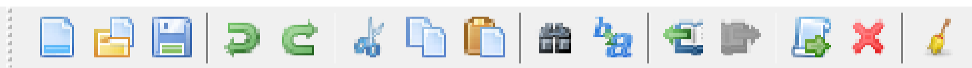
- Select `File > Open` (shortcut key `ctrl+O`) to open a file
- Select `File > Save` (shortcut key `ctrl+S`) to save a file
- Select `File > New File` (shortcut key `ctrl+Q`) to start again with a blank input area

History and results

- You can pop up a gui inspector on the last (non-null) result by selecting `Inspect Last` from the `Actions` menu. The inspector is a convenient way to view lists and maps.
- The console remembers the last ten script runs. You can scroll back and forth through the history by selecting `Next` and `Previous` from the `Edit` menu. `Ctrl-N` and `ctrl-P` are convenient shortcut keys.
- The last (non-null) result is bound to a variable named `_` (an underscore).
- The last result (null and non-null) for every run in the history is bound into a list variable named `(two underscores). The result of the last run is[-1]`, the result of the second to last run is `__[-2]` and so forth.

Interrupting a script

The Groovy console is a very handy tool to develop scripts. Often, you will find yourself running a script multiple times until it works the way you want it to. However, what if your code takes too long to finish or worse, creates an infinite loop? Interrupting script execution can be achieved by clicking the `interrupt` button on the small dialog box that pops up when a script is executing or through the `interrupt` icon in the toolbar.



However, this may not be sufficient to interrupt a script: clicking the button will interrupt the execution thread, but if your code doesn't handle the interrupt flag, the script is likely to keep running without you being able to effectively stop it. To avoid that, you have to make sure that the `Script > Allow interruption` menu item is flagged. This will automatically apply an AST transformation to your script which will take care of checking the interrupt flag (`@ThreadInterrupt`).

This way, you guarantee that the script can be interrupted even if you don't explicitly handle interruption, at the cost of extra execution time.

And more

- You can change the font size by selecting `Smaller Font` or `Larger Font` from the `Actions menu`
- The console can be run as an Applet thanks to `groovy.ui.ConsoleApplet`
- Code is auto indented when you hit return
- You can drag'n'drop a Groovy script over the text area to open a file
- You can modify the classpath with which the script in the console is being run by adding a new JAR or a directory to the classpath from the `Script` menu
- Error hyperlinking from the output area when a compilation error is expected or when an exception is thrown

Embedding the Console

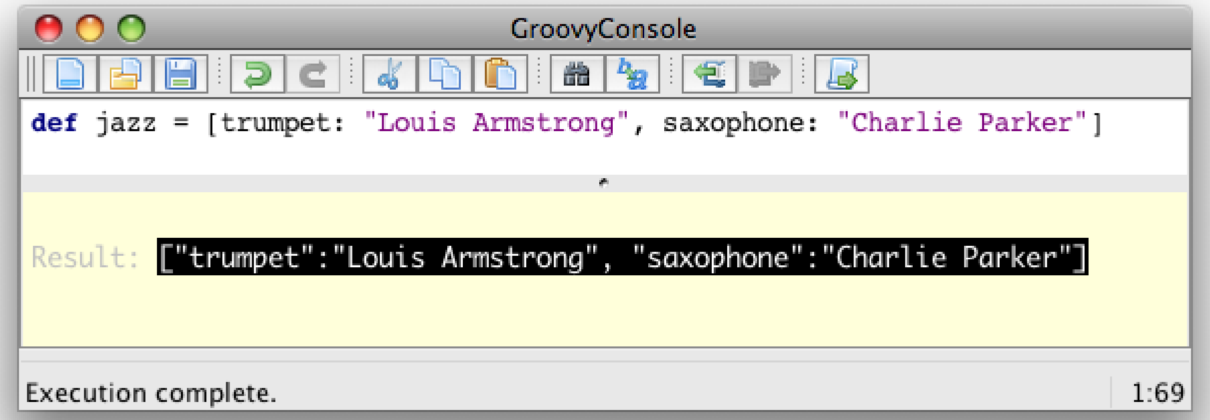
To embed a Swing console in your application, simply create the Console object, load some variables, and then launch it. The console can be embedded in either Java or Groovy code. The Java code for this is:

```
import groovy.ui.Console;

    ...
    Console console = new Console();
    console.setVariable("var1", getValueOfVar1());
    console.setVariable("var2", getValueOfVar2());
    console.run();
    ...
```

Once the console is launched, you can use the variable values in Groovy code.

Visualizing script output results

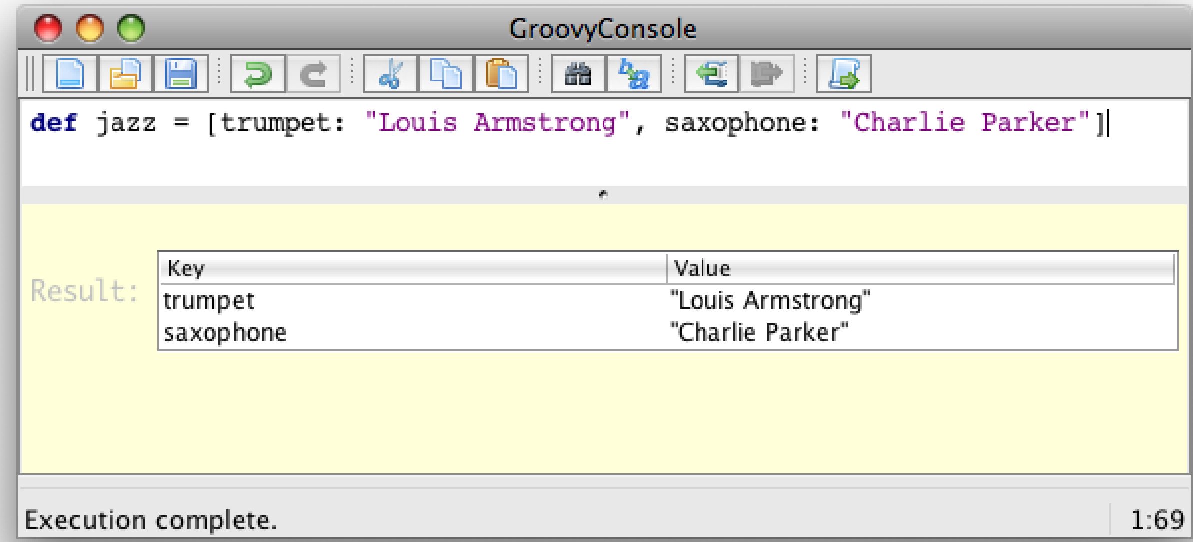
You can customize the way script output results are visualized. Let's see how we can customize this. For example, viewing a map result would show something like this:



What you see here is the usual textual representation of a Map. But, what if we enabled custom visualization of certain results? The Swing console allows you to do just that. First of all, you have to ensure that the visualization option is ticked: `View → Visualize Script Results` — for the record, all settings of the Groovy Console are stored and remembered thanks to the Preference API. There are a few result visualizations built-in: if the script returns a `java.awt.Image`, a `javax.swing.Icon`, or a `java.awt.Component` with no parent, the object is displayed instead of its `toString()` representation. Otherwise, everything else is still just represented as text. Now, create the following Groovy script in `~/.groovy/OutputTransforms.groovy`:

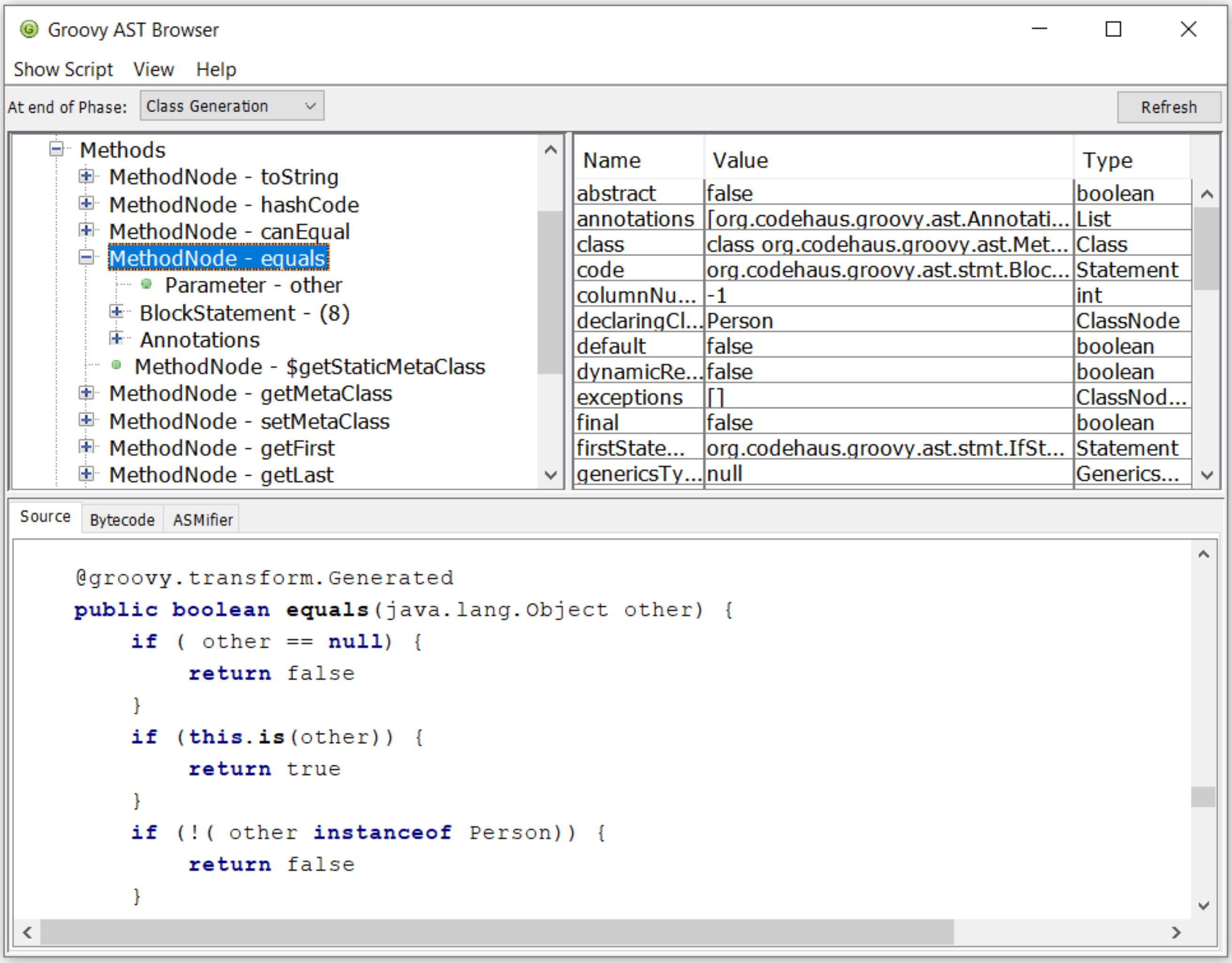
```
import javax.swing.*

transforms << { result ->
    if (result instanceof Map) {
        def table = new JTable(
            result.collect{ k, v ->
                [k, v?.inspect()] as Object[]
            } as Object[][],
            ['Key', 'Value'] as Object[])
        table.preferredViewportSize = table.preferredSize
        return new JScrollPane(table)
    }
}
```

The Groovy Swing console will execute that script on startup, injecting a transforms list in the binding of the script, so that you can add your own script results representations. In our case, we transform the Map into a nice-looking Swing JTable. We're now able to visualize maps in a friendly and attractive fashion, as the screenshot below shows:

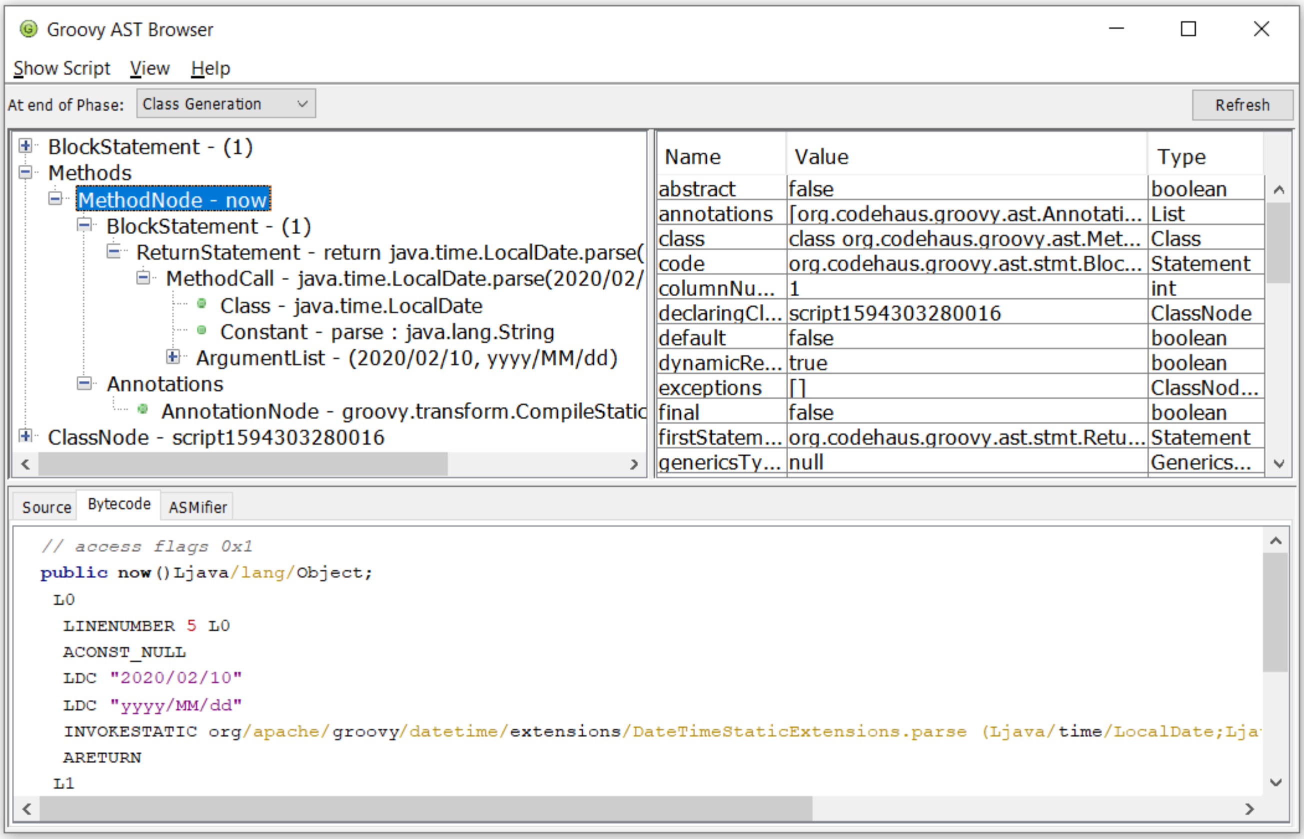


Advanced debugging: AST browser

Groovy Console can visualize the AST (Abstract Syntax Tree) representing the currently edited script, as shown by the screenshot below. This is useful when you want to understand how an AST transformation is working and particularly handy if you are developing your own AST transform. In the example below, we have annotated our class with the `@Immutable` annotation and the Groovy compiler has generated a lot of boilerplate code for us. We can see the code for the generated equals method in the `Source` tab.

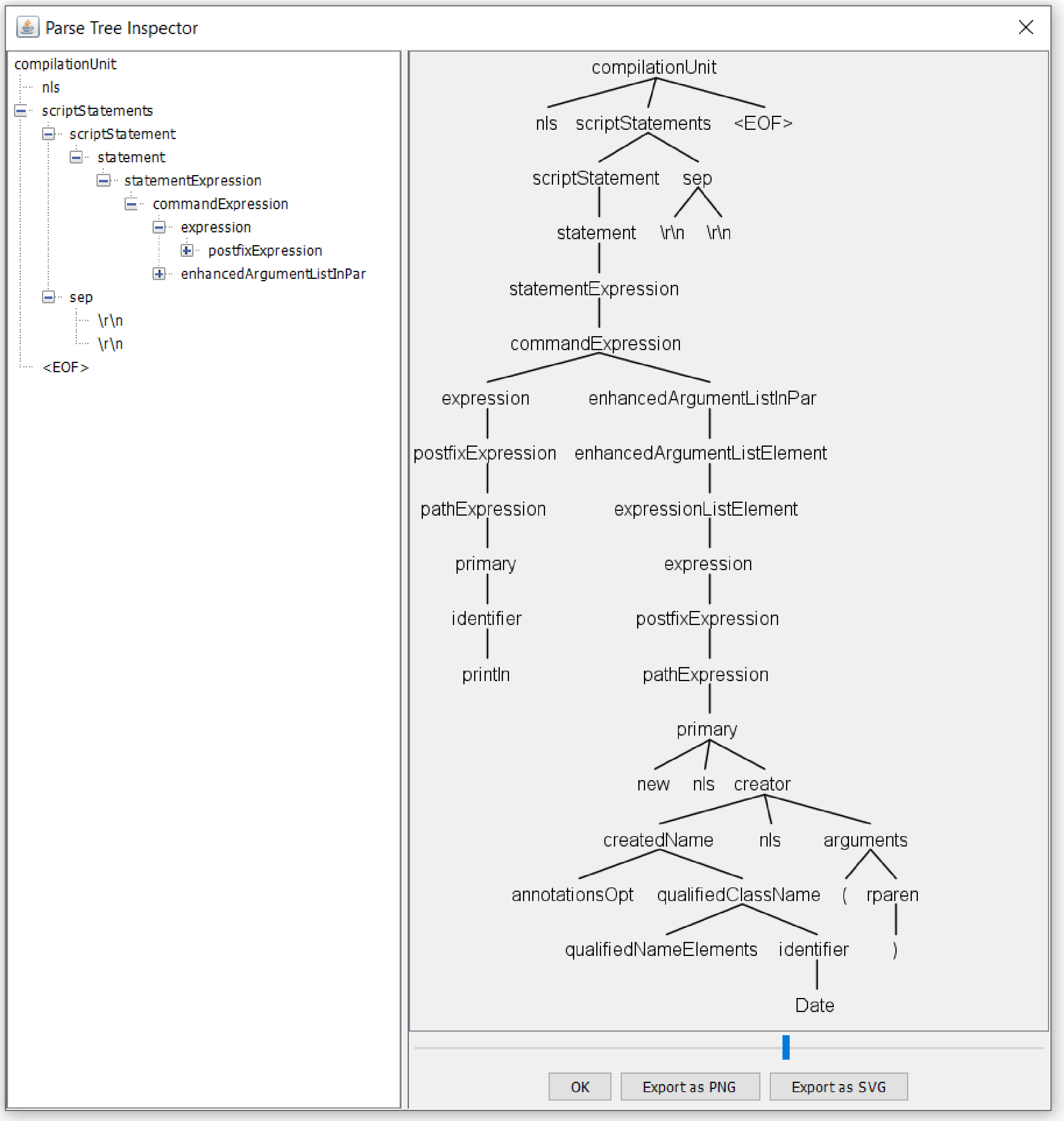


We can even examine the JVM bytecode generated by the compiler. In the image below we are looking at the bytecode for the Groovy expression `LocalDate.parse('2020/02/10', 'yyyy/MM/dd')`.



Advanced debugging: CST browser

Groovy Console can visualize the CST (Concrete Syntax Tree) representing the initial parsing of the script. This is mainly useful for parsing gurus.



groovydoc, the Groovy & Java documentation generator

GroovyDoc is a tool responsible for generating documentation from your code. It acts like the Javadoc tool in the Java world but is capable of handling both `groovy` and `java` files. The distribution comes with two ways of generating documentation: from command line or from Apache Ant. Other build tools like Maven or Gradle also offer wrappers for Groovydoc.

The groovydoc command line tool

The `groovydoc` command line can be invoked to generate groovydocs:

```
groovydoc [options] [packagenames] [sourcefiles]
```

where options must be picked from the following table:

Short version	Long version	Description
-author		Include @author paragraphs (currently not used)
-charset <charset>		Charset for cross-platform viewing of generated documentation
-classpath, -cp	--classpath	Specify where to find the class files - must be first argument
-d	--destdir <dir>	Destination directory for output files
	--debug	Enable debug output
-doctitle <html>		Include title for the overview page
-exclude <pkglist>		Specify a list of packages to exclude (separated by colons for all operating systems)
-fileEncoding <charset>		Charset for generated documentation files
-footer <html>		Include footer text for each page
-header <html>		Include header text for each page
-help	--help	Display help message
-nomainforscripts		Don't include the implicit 'public static void main' method for scripts
-noscripts		Don't process Groovy Scripts
-notimestamp		Don't include timestamp within hidden comment in generated HTML
-noversionstamp		Don't include Groovy version within hidden comment in generated HTML
-overview <file>		Read overview documentation from HTML file
-package		Show package/protected/public classes and members
-private		Show all classes and members
-protected		Show protected/public classes and members (default)
-public		Show only public classes and members
-quiet		Suppress superfluous output
-sourcepath <pathlist>		Specify where to find source files (dirs separated by platform path separator)
-stylesheetfile <path>		File to change style of the generated documentation

Short version	Long version	Description
-verbose		Enable verbose output
	--version	Display the version
-windowtitle <text>		Browser window title for the documentation
-javaversion <version>		The version of the Java source files

Java Versions

The supported Java Versions for `groovydoc` are defined by the JavaParser library's LanguageLevel class.

The groovydoc Ant task

The `groovydoc` Ant task allows generating groovydocs from an Ant build.

Required taskdef

Assuming all the groovy jars you need are in *my.classpath* (this will be `groovy-VERSION.jar`, `groovy-ant-VERSION.jar`, `groovy-groovydoc-VERSION.jar` plus any modules and transitive dependencies you might be using) you will need to declare this task at some point in the build.xml prior to the groovydoc task being invoked.

```
<taskdef name         = "groovydoc"
         classname    = "org.codehaus.groovy.ant.Groovydoc"
         classpathref = "my.classpath"/>
```

<groovydoc> Attributes

Attribute	Description	Required
destdir	Location to store the class files.	Yes
sourcepath	The sourcepath to use.	No
packagenames	Comma separated list of package files (with terminating wildcard).	No
use	Create class and package usage pages.	No
windowtitle	Browser window title for the documentation (text).	No
doctitle	Include title for the package index(first) page (html-code).	No
header	Include header text for each page (html-code).	No
footer	Include footer text for each page (html-code).	No
overview	Read overview documentation from HTML file.	No

Attribute	Description	Required
private	Show all classes and members (i.e. including private ones) if set to ``true''.	No
javaversion	The version of the Java source files.	No

<groovydoc> Nested Elements

link

Create link to groovydoc/javadoc output at the given URL.

Attribute	Description	Required
packages	Comma separated list of package prefixes	Yes
href	Base URL of external site	Yes

Example #1 - <groovydoc> Ant task

```
<taskdef name           = "groovydoc"
         classname      = "org.codehaus.groovy.ant.Groovydoc"
         classpathref   = "path_to_groovy_all"/>

<groovydoc destdir      = "${docsDirectory}/gapi"
           sourcepath   = "${mainSourceDirectory}"
           packagenames = "**.*"
           use          = "true"
           windowtitle  = "${title}"
           doctitle     = "${title}"
           header       = "${title}"
           footer       = "${docFooter}"
           overview     = "src/main/overview.html"
           private      = "false">
        <link packages="java.,org.xml.,javax.,org.xml."
href="http://docs.oracle.com/javase/8/docs/api/"/>
        <link packages="org.apache.tools.ant."          href="http://docs.groovy-
lang.org/docs/ant/api/"/>
        <link packages="org.junit.,junit.framework."
href="http://junit.org/junit4/javadoc/latest/"/>
        <link packages="groovy.,org.codehaus.groovy."   href="http://docs.groovy-
lang.org/latest/html/api/"/>
        <link packages="org.codehaus.gmaven."
href="http://groovy.github.io/gmaven/apidocs/"/>
</groovydoc>
```

Example #2 - Executing <groovydoc> from Groovy

```
def ant = new AntBuilder()
```

```
ant.taskdef(name: "groovydoc", classname: "org.codehaus.groovy.ant.Groovydoc")
ant.groovydoc(
    destdir      : "${docsDirectory}/gapi",
    sourcepath   : "${mainSourceDirectory}",
    packagenames : "**.*",
    use          : "true",
    windowtitle  : "${title}",
    doctitle     : "${title}",
    header       : "${title}",
    footer       : "${docFooter}",
    overview     : "src/main/overview.html",
    private      : "false") {
        link(packages:"java.,org.xml.,javax.,org.xml.",
href:"http://docs.oracle.com/javase/8/docs/api/")
        link(packages:"groovy.,org.codehaus.groovy.",  href:"http://docs.groovy-
lang.org/latest/html/api/")
        link(packages:"org.apache.tools.ant.",         href:"http://docs.groovy-
lang.org/docs/ant/api/")
        link(packages:"org.junit.,junit.framework.",
href:"http://junit.org/junit4/javadoc/latest/")
        link(packages:"org.codehaus.gmaven.",
href:"http://groovy.github.io/gmaven/apidocs/")
}
```

Custom templates

The groovydoc Ant task supports custom templates, but it requires two steps:

1. A custom groovydoc class
2. A new groovydoc task definition

Custom Groovydoc class

The first step requires you to extend the Groovydoc class, like in the following example:

```
package org.codehaus.groovy.tools.groovydoc;

import org.codehaus.groovy.ant.Groovydoc;

/**
 * Overrides GroovyDoc's default class template - for testing purpose only.
 */
public class CustomGroovyDoc extends Groovydoc {

    @Override
    protected String[] getClassTemplates() {
        return new String
[]{"org/codehaus/groovy/tools/groovydoc/testfiles/classDocName.html"};
    }
```

```
}
```

You can override the following methods:

- `getClassTemplates` for class-level templates
- `getPackageTemplates` for package-level templates
- `getDocTemplates` for top-level templates

You can find the list of default templates in the `org.codehaus.groovy.tools.groovydoc.gstringTemplates.GroovyDocTemplateInfo` class.

Using the custom groovydoc task

Once you've written the class, using it is just a matter of redefining the `groovydoc` task:

```
<taskdef name           = "groovydoc"
         classname      = "org.codehaus.groovy.ant.CustomGroovyDoc"
         classpathref   = "path_to_groovy_all"/>
```

Please note that template customization is provided as is. APIs are subject to change, so you must consider this as a fragile feature.

GMavenPlus Maven Plugin

GMavenPlus is a Maven plugin with goals that support GroovyDoc generation.

IDE integration

Many IDEs and text editors support the Groovy programming language.

Editor	Syntax highlighting	Code completion	Refactoring
Groovy Eclipse Plugin	Yes	Yes	Yes
IntelliJ IDEA	Yes	Yes	Yes
Netbeans	Yes	Yes	Yes
Groovy Emacs Modes	Yes	No	No
TextMate	Yes	No	No
vim	Yes	No	No
UltraEdit	Yes	No	No
SlickEdit	Yes	No	No
EditRocket	Yes	No	No
VSCode	Yes	No	Yes

User Guides

Getting started

Download

From the download page, you will be able to download the distribution (binary and source), the Windows installer (a community artifact) and the documentation for **Groovy**.

For a quick and effortless start on Mac OSX, Linux, WSL2 or Cygwin, you can use SDKMAN! (The Software Development Kit Manager) to download and configure any **Groovy** version of your choice. Basic instructions can be found below.

Stable

- **Download zip**: **Binary Release** | Source Release
- **Download documentation**: **JavaDoc and zipped online documentation**
- **Combined binary / source / documentation bundle**: **Distribution bundle**

You can learn more about this version in the release notes or in the changelog.

If you plan on using invokedynamic support, read those notes.

Snapshots

For those who want to test the very latest versions of Groovy and live on the bleeding edge, you can use our snapshot builds. As soon as a build succeeds on our continuous integration server a snapshot is deployed to this repository. These snapshots are not official releases and are intended for integration testing by the development community prior to official versions being released. We welcome any feedback.

Prerequisites

Groovy {groovy-short-version} requires Java 8+ with support for up to Java 16.

Various Groovy CI servers run the test suite (with more than 10000 tests) across numerous versions of Java. Those servers are also useful to look at to confirm supported Java versions for different Groovy releases.

Maven Repository

If you wish to embed Groovy in your application, you may just prefer to point your build to your favourite maven repository or the Groovy artifactory instance. Please see the download page for available modules for each Groovy version.

SDKMAN! (The Software Development Kit Manager)

This tool makes installing Groovy on any Bash platform (Mac OSX, Linux, Cygwin, Solaris or

FreeBSD) very easy.

Simply open a new terminal and enter:

```
$ curl -s "https://get.sdkman.io" | bash
```

Follow the instructions on-screen to complete installation.

Open a new terminal or type the command:

```
$ source "$HOME/.sdkman/bin/sdkman-init.sh"
```

Then install the latest stable Groovy:

```
$ sdk install groovy
```

After installation is complete and you've made it your default version, test it with:

```
$ groovy -version
```

That's all there is to it!

Other ways to get Groovy

Installation on Mac OS X

MacPorts

If you're on macOS and have MacPorts installed, you can run:

```
sudo port install groovy
```

Homebrew

If you're on macOS and have Homebrew installed, you can run:

```
brew install groovy
```

Installation on Windows

If you're on Windows, you can also use the Windows installer.

Other Distributions

You may download other distributions of Groovy from the ASF archive repository or from the Groovy artifactory instance (also includes pre-ASF versions).

Source Code

If you prefer to live on the bleeding edge, you can also grab the source code from GitHub.

IDE plugin

If you are an IDE user, you can just grab the latest IDE plugin and follow the plugin installation instructions.

Install Binary

These instructions describe how to install a binary distribution of **Groovy**:

- Download a binary distribution of Groovy and unpack it into some folder on your local file system.
- Set your `GROOVY_HOME` environment variable to the directory where you unpacked the distribution.
- Add `GROOVY_HOME/bin` to your `PATH` environment variable.
- Set your `JAVA_HOME` environment variable to point to your JDK. On OS X this is `/Library/Java/Home`, on other unixes its often `/usr/java` etc. If you've already installed tools like Ant or Maven you've probably already done this step.

You should now have Groovy installed properly. You can test this by typing the following in a command shell:

```
groovysh
```

Which should create an interactive groovy shell where you can type Groovy statements. Or to run the Swing interactive console type:

```
groovyConsole
```

To run a specific Groovy script type:

```
groovy SomeScript
```

Differences with Java

Groovy tries to be as natural as possible for Java developers. We've tried to follow the principle of least surprise when designing Groovy, particularly for developers learning Groovy who've come from a Java background.

Here we list all the major differences between Java and Groovy.

Default imports

All these packages and classes are imported by default, i.e. you do not have to use an explicit `import` statement to use them:

- java.io.*
- java.lang.*
- java.math.BigDecimal
- java.math.BigInteger
- java.net.*
- java.util.*
- groovy.lang.*
- groovy.util.*

Multi-methods

In Groovy, the methods which will be invoked are chosen at runtime. This is called runtime dispatch or multi-methods. It means that the method will be chosen based on the types of the arguments at runtime. In Java, this is the opposite: methods are chosen at compile time, based on the declared types.

The following code, written as Java code, can be compiled in both Java and Groovy, but it will behave differently:

```
int method(String arg) {
    return 1;
}
int method(Object arg) {
    return 2;
}
Object o = "Object";
int result = method(o);
```

In Java, you would have:

```
assertEquals(2, result);
```

Whereas in Groovy:

```
assertEquals(1, result);
```

That is because Java will use the static information type, which is that `o` is declared as an `Object`, whereas Groovy will choose at runtime, when the method is actually called. Since it is called with a `String`, then the `String` version is called.

Array initializers

In Java, array initializers take either of these two forms:

```
int[] array = {1, 2, 3};             // Java array initializer shorthand syntax
int[] array2 = new int[] {4, 5, 6};  // Java array initializer long syntax
```

In Groovy, the `{ … }` block is reserved for closures. That means that you cannot create array literals using Java's array initializer shorthand syntax. You instead borrow Groovy's literal list notation like this:

```
int[] array = [1, 2, 3]
```

For Groovy 3+, you can optionally use the Java's array initializer long syntax:

```
def array2 = new int[] {1, 2, 3} // Groovy 3.0+ supports the Java-style array
initialization long syntax
```

Package scope visibility

In Groovy, omitting a modifier on a field doesn't result in a package-private field like in Java:

```
class Person {
    String name
}
```

Instead, it is used to create a *property*, that is to say a *private field*, an associated *getter* and an associated *setter*.

It is possible to create a package-private field by annotating it with `@PackageScope`:

```
class Person {
    @PackageScope String name
}
```

ARM blocks

Java 7 introduced ARM (Automatic Resource Management) blocks (also know as try-with-resources) blocks like this:

```
Path file = Paths.get("/path/to/file");
Charset charset = Charset.forName("UTF-8");
try (BufferedReader reader = Files.newBufferedReader(file, charset)) {
    String line;
    while ((line = reader.readLine()) != null) {
        System.out.println(line);
    }

} catch (IOException e) {
    e.printStackTrace();
}
```

Such blocks are supported from Groovy 3+. However, Groovy provides various methods relying on closures, which have the same effect while being more idiomatic. For example:

```
new File('/path/to/file').eachLine('UTF-8') {
   println it
}
```

or, if you want a version closer to Java:

```
new File('/path/to/file').withReader('UTF-8') { reader ->
   reader.eachLine {
       println it
   }
}
```

Inner classes

WARNING	The implementation of anonymous inner classes and nested classes follow Java closely, but there are some differences, e.g. local variables accessed from within such classes don't have to be final. We piggyback on some implementation details we use for `groovy.lang.Closure` when generating inner class bytecode.

Static inner classes

Here's an example of static inner class:

```
class A {
    static class B {}
}

new A.B()
```

The usage of static inner classes is the best supported one. If you absolutely need an inner class, you should make it a static one.

Anonymous Inner Classes

```
import java.util.concurrent.CountDownLatch
import java.util.concurrent.TimeUnit

CountDownLatch called = new CountDownLatch(1)

Timer timer = new Timer()
timer.schedule(new TimerTask() {
    void run() {
        called.countDown()
    }
}, 0)

assert called.await(10, TimeUnit.SECONDS)
```

Creating Instances of Non-Static Inner Classes

In Java you can do this:

```
public class Y {
    public class X {}
    public X foo() {
        return new X();
    }
    public static X createX(Y y) {
        return y.new X();
    }
}
```

Before 3.0.0, Groovy doesn't support the `y.new X()` syntax. Instead, you have to write `new X(y)`, like in the code below:

```
public class Y {
    public class X {}
    public X foo() {
        return new X()
    }
    public static X createX(Y y) {
        return new X(y)
    }
}
```

WARNING Caution though, Groovy supports calling methods with one parameter without giving an argument. The parameter will then have the value null. Basically the same rules apply to calling a constructor. There is a danger that you will write new X() instead of new X(this) for example. Since this might also be the regular way we have not yet found a good way to prevent this problem.

NOTE Groovy 3.0.0 supports Java style syntax for creating instances of non-static inner classes.

Lambda expressions and the method reference operator

Java 8+ supports lambda expressions and the method reference operator (`::`):

```
Runnable run = () -> System.out.println("Run");  // Java
list.forEach(System.out::println);
```

Groovy 3 and above also support these within the Parrot parser. In earlier versions of Groovy you should use closures instead:

```
Runnable run = { println 'run' }
list.each { println it } // or list.each(this.&println)
```

GStrings

As double-quoted string literals are interpreted as `GString` values, Groovy may fail with compile error or produce subtly different code if a class with `String` literal containing a dollar character is compiled with Groovy and Java compiler.

While typically, Groovy will auto-cast between `GString` and `String` if an API declares the type of a parameter, beware of Java APIs that accept an `Object` parameter and then check the actual type.

String and Character literals

Singly-quoted literals in Groovy are used for `String`, and double-quoted result in `String` or `GString`, depending whether there is interpolation in the literal.

```
assert 'c'.class == String
assert "c".class == String
assert "c${1}".class in GString
```

Groovy will automatically cast a single-character `String` to `char` only when assigning to a variable of type `char`. When calling methods with arguments of type `char` we need to either cast explicitly or make sure the value has been cast in advance.

```
char a = 'a'
assert Character.digit(a, 16) == 10: 'But Groovy does boxing'
```

```
assert Character.digit((char) 'a', 16) == 10

try {
  assert Character.digit('a', 16) == 10
  assert false: 'Need explicit cast'
} catch(MissingMethodException e) {
}
```

Groovy supports two styles of casting and in the case of casting to `char` there are subtle differences when casting a multi-char strings. The Groovy style cast is more lenient and will take the first character, while the C-style cast will fail with exception.

```
// for single char strings, both are the same
assert ((char) "c").class == Character
assert ("c" as char).class == Character

// for multi char strings they are not
try {
  ((char) 'cx') == 'c'
  assert false: 'will fail - not castable'
} catch(GroovyCastException e) {
}
assert ('cx' as char) == 'c'
assert 'cx'.asType(char) == 'c'
```

Behaviour of `==`

In Java, `==` means equality of primitive types or identity for objects. In Groovy, `==` means equality in all places. For non-primitives, it translates to `a.compareTo(b) == 0`, when evaluating equality for `Comparable` objects, and `a.equals(b)` otherwise.

To check for identity (reference equality), use the `is` method: `a.is(b)`. From Groovy 3, you can also use the `===` operator (or negated version): `a === b` (or `c !== d`).

Primitives and wrappers

In a pure object-oriented language, everything would be an object. Java takes the stance that primitive types, such as int, boolean and double, are used very frequently and worthy of special treatment. Primitives can be efficiently stored and manipulated but can't be used in all contexts where an object could be used. Luckily, Java auto boxes and unboxes primitives when they are passed as parameters or used as return types:

```
public class Main {           // Java

   float f1 = 1.0f;
   Float f2 = 2.0f;

   float add(Float a1, float a2) { return a1 + a2; }
```

```
    Float calc() { return add(f1, f2); } ①

    public static void main(String[] args) {
        Float calcResult = new Main().calc();
        System.out.println(calcResult); // => 3.0
    }
}
```

① The add method expects wrapper then primitive type arguments, but we are supplying parameters with a primitive then wrapper type. Similarly, the return type from add is primitive, but we need the wrapper type.

Groovy does the same:

```
class Main {

    float f1 = 1.0f
    Float f2 = 2.0f

    float add(Float a1, float a2) { a1 + a2 }

    Float calc() { add(f1, f2) }
}

assert new Main().calc() == 3.0
```

Groovy, also supports primitives and object types, however, it goes a little further in pushing OO purity; it tries hard to treat *everything* as an object. Any primitive typed variable or field can be treated like an object, and it will be auto-wrapped as needed. While primitive types might be used under the covers, their use should be indistinguishable from normal object use whenever possible, and they will be boxed/unboxed as needed.

Here is a little example using Java trying to (incorrectly for Java) dereference a primitive float:

```
public class Main {           // Java

    public float z1 = 0.0f;

    public static void main(String[] args){
      new Main().z1.equals(1.0f); // DOESN'T COMPILE, error: float cannot be
dereferenced
    }
}
```

The same example using Groovy compiles and runs successfully:

```
class Main {
```

```
    float z1 = 0.0f
}
assert !(new Main().z1.equals(1.0f))
```

Because of Groovy's additional use of un/boxing, it does not follow Java's behavior of widening taking priority over boxing. Here's an example using `int`

```
int i
m(i)

void m(long l) {           ①
    println "in m(long)"
}

void m(Integer i) {        ②
    println "in m(Integer)"
}
```

① This is the method that Java would call, since widening has precedence over unboxing.

② This is the method Groovy actually calls, since all primitive references use their wrapper class.

Numeric Primitive Optimisation with `@CompileStatic`

Since Groovy converts to wrapper classes in more places, you might wonder whether it produces less efficient bytecode for numeric expressions. Groovy has a highly optimised set of classes for doing math computations. When using `@CompileStatic`, expressions involving only primitives uses the same bytecode that Java would use.

Positive/Negative zero edge case

Java float/double operations for both primitives and wrapper classes follow the IEEE 754 standard but there is an interesting edge case involving positive and negative zero. The standard supports distinguishing between these two cases and while in many scenarios programmers may not care about the difference, in some mathematical or data science scenarios it is important to cater for the distinction.

For primitives, Java maps down onto a special bytecode instruction when comparing such values which has the property that "Positive zero and negative zero are considered equal".

```
jshell> float f1 = 0.0f
f1 ==> 0.0

jshell> float f2 = -0.0f
f2 ==> -0.0

jshell> f1 == f2
$3 ==> true
```

For the wrapper classes, e.g. java.base/java.lang.Float#equals(java.lang.Object), the result is `false` for this same case.

```
jshell> Float f1 = 0.0f
f1 ==> 0.0

jshell> Float f2 = -0.0f
f2 ==> -0.0

jshell> f1.equals(f2)
$3 ==> false
```

Groovy on the one hand tries to follow Java behavior closely, but on the other switches automatically between primitives and wrapped equivalents in more places. To avoid confusion we recommend the following guidelines:

- If you wish to distinguish between positive and negative zero, use the `equals` method directly or cast any primitives to their wrapper equivalent before using `==`.
- If you wish to ignore the difference between positive and negative zero, use the `equalsIgnoreZeroSign` method directly or cast any non-primitives to their primitive equivalent before using `==`.

These guidelines are illustrated in the following example:

```
float f1 = 0.0f
float f2 = -0.0f
Float f3 = 0.0f
Float f4 = -0.0f

assert f1 == f2
assert (Float) f1 != (Float) f2

assert f3 != f4         ①
assert (float) f3 == (float) f4

assert !f1.equals(f2)
assert !f3.equals(f4)

assert f1.equalsIgnoreZeroSign(f2)
assert f3.equalsIgnoreZeroSign(f4)
```

① Recall that for non-primitives, `==` maps to `.equals()`

Conversions

Java does automatic widening and narrowing conversions.

Table 9. Java Conversions

	Converts to							
Converts from	**boolean**	**byte**	**short**	**char**	**int**	**long**	**float**	**double**
boolean	-	N	N	N	N	N	N	N
byte	N	-	Y	C	Y	Y	Y	Y
short	N	C	-	C	Y	Y	Y	Y
char	N	C	C	-	Y	Y	Y	Y
int	N	C	C	C	-	Y	T	Y
long	N	C	C	C	C	-	T	T
float	N	C	C	C	C	C	-	Y
double	N	C	C	C	C	C	C	-

- 'Y' indicates a conversion Java can make
- 'C' indicates a conversion Java can make when there is an explicit cast
- 'T` indicates a conversion Java can make but data is truncated
- 'N' indicates a conversion Java can't make

Groovy expands greatly on this.

Table 10. Groovy Conversions

	Converts to																	
Converts from	`boolean`	`Boolean`	`byte`	`Byte`	`short`	`Short`	`char`	`Character`	`int`	`Integer`	`long`	`Long`	`BigInteger`	`float`	`Float`	`double`	`Double`	`BigDecimal`
`boolean`	-	B	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
`Boolean`	B	-	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
`byte`	T	T	-	B	Y	Y	Y	D	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
`Byte`	T	T	B	-	Y	Y	Y	D	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
`short`	T	T	D	D	-	B	Y	D	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

`Short`	T	T	D	T	B	-	Y	D	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
`char`	T	T	Y	D	Y	D	-	D	Y	D	Y	D	D	Y	D	Y	D	D
`Character`	T	T	D	D	D	D	D	-	D	D	D	D	D	D	D	D	D	D
`int`	T	T	D	D	D	D	Y	D	-	B	Y	Y	Y	Y	Y	Y	Y	Y
`Integer`	T	T	D	D	D	D	Y	D	B	-	Y	Y	Y	Y	Y	Y	Y	Y
`long`	T	T	D	D	D	D	Y	D	D	D	-	B	Y	T	T	T	T	Y
`Long`	T	T	D	D	D	T	Y	D	D	T	B	-	Y	T	T	T	T	Y
`BigInteger`	T	T	D	D	D	D	D	D	D	D	D	D	-	D	D	D	D	T
`float`	T	T	D	D	D	D	T	D	D	D	D	D	D	-	B	Y	Y	Y
`Float`	T	T	D	T	D	T	T	D	D	T	D	T	D	B	-	Y	Y	Y
`double`	T	T	D	D	D	D	T	D	D	D	D	D	D	D	D	-	B	Y
`Double`	T	T	D	T	D	T	T	D	D	T	D	T	D	D	T	B	-	Y
`BigDecimal`	T	T	D	D	D	D	D	D	D	D	D	D	D	T	D	T	D	-

- 'Y' indicates a conversion Groovy can make
- 'D' indicates a conversion Groovy can make when compiled dynamically or explicitly cast
- 'T' indicates a conversion Groovy can make but data is truncated
- 'B' indicates a boxing/unboxing operation
- 'N' indicates a conversion Groovy can't make.

The truncation uses Groovy Truth when converting to `boolean`/`Boolean`. Converting from a number to a character casts the `Number.intvalue()` to `char`. Groovy constructs `BigInteger` and `BigDecimal` using `Number.doubleValue()` when converting from a `Float` or `Double`, otherwise it constructs using `toString()`. Other conversions have their behavior defined by `java.lang.Number`.

Extra keywords

Groovy has many of the same keywords as Java and Groovy 3 and above also has the same `var` reserved type as Java. In addition, Groovy has the following keywords:

- `as`
- `def`
- `in`
- `trait`
- `it` // within closures

Groovy is less stringent than Java in that it allows some keywords to appear in places that would be illegal in Java, e.g. the following is valid: `var var = [def: 1, as: 2, in: 3, trait: 4]`. Never-the-less, you are discouraged from using the above keywords in places that might cause confusion even when the compiler might be happy. In particular, avoid using them for variable, method and class names, so our previous `var var` example would be considered poor style.

Additional documentation is available for keywords.

Groovy Development Kit

Working with IO

Groovy provides a number of helper methods for working with I/O. While you could use standard Java code in Groovy to deal with those, Groovy provides much more convenient ways to handle files, streams, readers, …

In particular, you should take a look at methods added to:

- the `java.io.File` class : http://docs.groovy-lang.org/latest/html/groovy-jdk/java/io/File.html
- the `java.io.InputStream` class: http://docs.groovy-lang.org/latest/html/groovy-jdk/java/io/InputStream.html
- the `java.io.OutputStream` class: http://docs.groovy-lang.org/latest/html/groovy-jdk/java/io/OutputStream.html
- the `java.io.Reader` class: http://docs.groovy-lang.org/latest/html/groovy-jdk/java/io/Reader.html
- the `java.io.Writer` class: http://docs.groovy-lang.org/latest/html/groovy-jdk/java/io/Writer.html
- the `java.nio.file.Path` class: http://docs.groovy-lang.org/latest/html/groovy-jdk/java/nio/file/Path.html

The following section focuses on sample idiomatic constructs using helper methods available above but is not meant to be a complete description of all available methods. For that, please read the GDK API.

Reading files

As a first example, let's see how you would print all lines of a text file in Groovy:

```
new File(baseDir, 'haiku.txt').eachLine { line ->
    println line
}
```

The `eachLine` method is a method added to the `File` class automatically by Groovy and has many variants, for example if you need to know the line number, you can use this variant:

```
new File(baseDir, 'haiku.txt').eachLine { line, nb ->
    println "Line $nb: $line"
}
```

If for whatever reason an exception is thrown in the `eachLine` body, the method makes sure that the resource is properly closed. This is true for all I/O resource methods that Groovy adds.

For example in some cases you will prefer to use a `Reader`, but still benefit from the automatic resource management from Groovy. In the next example, the reader **will** be closed even if the exception occurs:

```
def count = 0, MAXSIZE = 3
new File(baseDir,"haiku.txt").withReader { reader ->
    while (reader.readLine()) {
        if (++count > MAXSIZE) {
            throw new RuntimeException('Haiku should only have 3 verses')
        }
    }
}
```

Should you need to collect the lines of a text file into a list, you can do:

```
def list = new File(baseDir, 'haiku.txt').collect {it}
```

Or you can even leverage the `as` operator to get the contents of the file into an array of lines:

```
def array = new File(baseDir, 'haiku.txt') as String[]
```

How many times did you have to get the contents of a file into a `byte[]` and how much code does it require? Groovy makes it very easy actually:

```
byte[] contents = file.bytes
```

Working with I/O is not limited to dealing with files. In fact, a lot of operations rely on input/output streams, hence why Groovy adds a lot of support methods to those, as you can see in the documentation.

As an example, you can obtain an `InputStream` from a `File` very easily:

```
def is = new File(baseDir,'haiku.txt').newInputStream()
// do something ...
is.close()
```

However you can see that it requires you to deal with closing the inputstream. In Groovy it is in general a better idea to use the `withInputStream` idiom that will take care of that for you:

```
new File(baseDir,'haiku.txt').withInputStream { stream ->
    // do something ...
}
```

Writing files

Of course in some cases you won't want to read but write a file. One of the options is to use a `Writer`:

```
new File(baseDir,'haiku.txt').withWriter('utf-8') { writer ->
    writer.writeLine 'Into the ancient pond'
    writer.writeLine 'A frog jumps'
    writer.writeLine 'Water's sound!'
}
```

But for such a simple example, using the `<<` operator would have been enough:

```
new File(baseDir,'haiku.txt') << '''Into the ancient pond
A frog jumps
Water's sound!'''
```

Of course we do not always deal with text contents, so you could use the `Writer` or directly write bytes as in this example:

```
file.bytes = [66,22,11]
```

Of course you can also directly deal with output streams. For example, here is how you would create an output stream to write into a file:

```
def os = new File(baseDir,'data.bin').newOutputStream()
// do something ...
os.close()
```

However you can see that it requires you to deal with closing the output stream. Again it is in general a better idea to use the `withOutputStream` idiom that will handle the exceptions and close the stream in any case:

```
new File(baseDir,'data.bin').withOutputStream { stream ->
    // do something ...
}
```

Traversing file trees

In scripting contexts it is a common task to traverse a file tree in order to find some specific files and do something with them. Groovy provides multiple methods to do this. For example you can perform something on all files of a directory:

```
dir.eachFile { file ->                      ①
    println file.name
}
dir.eachFileMatch(~/.*\.txt/) { file ->     ②
    println file.name
}
```

① executes the closure code on each file found in the directory

② executes the closure code on files in the directory matching the specified pattern

Often you will have to deal with a deeper hierarchy of files, in which case you can use `eachFileRecurse`:

```
dir.eachFileRecurse { file ->                      ①
    println file.name
}

dir.eachFileRecurse(FileType.FILES) { file ->      ②
    println file.name
}
```

① executes the closure code on each file or directory found in the directory, recursively

② executes the closure code only on files, but recursively

For more complex traversal techniques you can use the `traverse` method, which requires you to set a special flag indicating what to do with the traversal:

```
dir.traverse { file ->
    if (file.directory && file.name=='bin') {
        FileVisitResult.TERMINATE                    ①
    } else {
        println file.name
        FileVisitResult.CONTINUE                     ②
    }

}
```

① if the current file is a directory and its name is `bin`, stop the traversal

② otherwise print the file name and continue

Data and objects

In Java it is not uncommon to serialize and deserialize data using the `java.io.DataOutputStream` and `java.io.DataInputStream` classes respectively. Groovy will make it even easier to deal with them. For example, you could serialize data into a file and deserialize it using this code:

```
boolean b = true
String message = 'Hello from Groovy'
// Serialize data into a file
file.withDataOutputStream { out ->
    out.writeBoolean(b)
    out.writeUTF(message)
}
// ...
// Then read it back
file.withDataInputStream { input ->
    assert input.readBoolean() == b
    assert input.readUTF() == message
}
```

And similarly, if the data you want to serialize implements the `Serializable` interface, you can proceed with an object output stream, as illustrated here:

```
Person p = new Person(name:'Bob', age:76)
// Serialize data into a file
file.withObjectOutputStream { out ->
    out.writeObject(p)
}
// ...
// Then read it back
file.withObjectInputStream { input ->
    def p2 = input.readObject()
    assert p2.name == p.name
    assert p2.age == p.age
```

```
}
```

Executing External Processes

The previous section described how easy it was to deal with files, readers or streams in Groovy. However in domains like system administration or devops it is often required to communicate with external processes.

Groovy provides a simple way to execute command line processes. Simply write the command line as a string and call the `execute()` method. E.g., on a *nix machine (or a Windows machine with appropriate *nix commands installed), you can execute this:

```
def process = "ls -l".execute()             ①
println "Found text ${process.text}"        ②
```

① executes the `ls` command in an external process

② consume the output of the command and retrieve the text

The `execute()` method returns a `java.lang.Process` instance which will subsequently allow the in/out/err streams to be processed and the exit value from the process to be inspected etc.

e.g. here is the same command as above but we will now process the resulting stream a line at a time:

```
def process = "ls -l".execute()             ①
process.in.eachLine { line ->               ②
    println line                            ③
}
```

① executes the `ls` command in an external process

② for each line of the input stream of the process

③ print the line

It is worth noting that `in` corresponds to an input stream to the standard output of the command. `out` will refer to a stream where you can send data to the process (its standard input).

Remember that many commands are shell built-ins and need special handling. So if you want a listing of files in a directory on a Windows machine and write:

```
def process = "dir".execute()
println "${process.text}"
```

you will receive an `IOException` saying *Cannot run program "dir": CreateProcess error=2, The system cannot find the file specified.*

This is because `dir` is built-in to the Windows shell (`cmd.exe`) and can't be run as a simple executable. Instead, you will need to write:

```
def process = "cmd /c dir".execute()
println "${process.text}"
```

Also, because this functionality currently makes use of `java.lang.Process` undercover, the deficiencies of that class must be taken into consideration. In particular, the javadoc for this class says:

> Because some native platforms only provide limited buffer size for standard input and output streams, failure to promptly write the input stream or read the output stream of the subprocess may cause the subprocess to block, and even deadlock

Because of this, Groovy provides some additional helper methods which make stream handling for processes easier.

Here is how to gobble all of the output (including the error stream output) from your process:

```
def p = "rm -f foo.tmp".execute([], tmpDir)
p.consumeProcessOutput()
p.waitFor()
```

There are also variations of `consumeProcessOutput` that make use of `StringBuffer`, `InputStream`, `OutputStream` etc... For a complete list, please read the GDK API for java.lang.Process

In addition, there is a `pipeTo` command (mapped to `|` to allow overloading) which lets the output stream of one process be fed into the input stream of another process.

Here are some examples of use:

Pipes in action

```
proc1 = 'ls'.execute()
proc2 = 'tr -d o'.execute()
proc3 = 'tr -d e'.execute()
proc4 = 'tr -d i'.execute()
proc1 | proc2 | proc3 | proc4
proc4.waitFor()
if (proc4.exitValue()) {
    println proc4.err.text
} else {
    println proc4.text
}
```

Consuming errors

```
def sout = new StringBuilder()
def serr = new StringBuilder()
proc2 = 'tr -d o'.execute()
proc3 = 'tr -d e'.execute()
proc4 = 'tr -d i'.execute()
proc4.consumeProcessOutput(sout, serr)
proc2 | proc3 | proc4
[proc2, proc3].each { it.consumeProcessErrorStream(serr) }
proc2.withWriter { writer ->
    writer << 'testfile.groovy'
}
proc4.waitForOrKill(1000)
println "Standard output: $sout"
println "Standard error: $serr"
```

Working with collections

Groovy provides native support for various collection types, including lists, maps or ranges. Most of those are based on the Java collection types and decorated with additional methods found in the Groovy development kit.

Lists

List literals

You can create lists as follows. Notice that `[]` is the empty list expression.

```
def list = [5, 6, 7, 8]
assert list.get(2) == 7
assert list[2] == 7
assert list instanceof java.util.List

def emptyList = []
assert emptyList.size() == 0
emptyList.add(5)
assert emptyList.size() == 1
```

Each list expression creates an implementation of java.util.List.

Of course lists can be used as a source to construct another list:

```
def list1 = ['a', 'b', 'c']
//construct a new list, seeded with the same items as in list1
def list2 = new ArrayList<String>(list1)

assert list2 == list1 // == checks that each corresponding element is the same
```

```
// clone() can also be called
def list3 = list1.clone()
assert list3 == list1
```

A list is an ordered collection of objects:

```
def list = [5, 6, 7, 8]
assert list.size() == 4
assert list.getClass() == ArrayList     // the specific kind of list being used

assert list[2] == 7                     // indexing starts at 0
assert list.getAt(2) == 7               // equivalent method to subscript operator []
assert list.get(2) == 7                 // alternative method

list[2] = 9
assert list == [5, 6, 9, 8,]           // trailing comma OK

list.putAt(2, 10)                       // equivalent method to [] when value being
changed
assert list == [5, 6, 10, 8]
assert list.set(2, 11) == 10            // alternative method that returns old value
assert list == [5, 6, 11, 8]

assert ['a', 1, 'a', 'a', 2.5, 2.5f, 2.5d, 'hello', 7g, null, 9 as byte]
//objects can be of different types; duplicates allowed

assert [1, 2, 3, 4, 5][-1] == 5             // use negative indices to count from the
end
assert [1, 2, 3, 4, 5][-2] == 4
assert [1, 2, 3, 4, 5].getAt(-2) == 4       // getAt() available with negative
index...
try {
    [1, 2, 3, 4, 5].get(-2)                 // but negative index not allowed with
get()
    assert false
} catch (e) {
    assert e instanceof IndexOutOfBoundsException
}
```

List as a boolean expression

Lists can be evaluated as a `boolean` value:

```
assert ![]             // an empty list evaluates as false

//all other lists, irrespective of contents, evaluate as true
assert [1] && ['a'] && [0] && [0.0] && [false] && [null]
```

Iterating on a list

Iterating on elements of a list is usually done calling the `each` and `eachWithIndex` methods, which execute code on each item of a list:

```
[1, 2, 3].each {
    println "Item: $it" // `it` is an implicit parameter corresponding to the current
element
}
['a', 'b', 'c'].eachWithIndex { it, i -> // `it` is the current element, while `i` is
the index
    println "$i: $it"
}
```

In addition to iterating, it is often useful to create a new list by transforming each of its elements into something else. This operation, often called mapping, is done in Groovy thanks to the `collect` method:

```
assert [1, 2, 3].collect { it * 2 } == [2, 4, 6]

// shortcut syntax instead of collect
assert [1, 2, 3]*.multiply(2) == [1, 2, 3].collect { it.multiply(2) }

def list = [0]
// it is possible to give `collect` the list which collects the elements
assert [1, 2, 3].collect(list) { it * 2 } == [0, 2, 4, 6]
assert list == [0, 2, 4, 6]
```

Manipulating lists

Filtering and searching

The Groovy development kit contains a lot of methods on collections that enhance the standard collections with pragmatic methods, some of which are illustrated here:

```
assert [1, 2, 3].find { it > 1 } == 2           // find 1st element matching criteria
assert [1, 2, 3].findAll { it > 1 } == [2, 3]   // find all elements matching
critieria
assert ['a', 'b', 'c', 'd', 'e'].findIndexOf {      // find index of 1st element
matching criteria
    it in ['c', 'e', 'g']
} == 2

assert ['a', 'b', 'c', 'd', 'c'].indexOf('c') == 2  // index returned
assert ['a', 'b', 'c', 'd', 'c'].indexOf('z') == -1 // index -1 means value not in
list
assert ['a', 'b', 'c', 'd', 'c'].lastIndexOf('c') == 4
```

```
assert [1, 2, 3].every { it < 5 }               // returns true if all elements match
the predicate
assert ![1, 2, 3].every { it < 3 }
assert [1, 2, 3].any { it > 2 }                 // returns true if any element matches
the predicate
assert ![1, 2, 3].any { it > 3 }

assert [1, 2, 3, 4, 5, 6].sum() == 21                // sum anything with a plus()
method
assert ['a', 'b', 'c', 'd', 'e'].sum {
    it == 'a' ? 1 : it == 'b' ? 2 : it == 'c' ? 3 : it == 'd' ? 4 : it == 'e' ? 5 : 0
    // custom value to use in sum
} == 15
assert ['a', 'b', 'c', 'd', 'e'].sum { ((char) it) - ((char) 'a') } == 10
assert ['a', 'b', 'c', 'd', 'e'].sum() == 'abcde'
assert [['a', 'b'], ['c', 'd']].sum() == ['a', 'b', 'c', 'd']

// an initial value can be provided
assert [].sum(1000) == 1000
assert [1, 2, 3].sum(1000) == 1006

assert [1, 2, 3].join('-') == '1-2-3'           // String joining
assert [1, 2, 3].inject('counting: ') {
    str, item -> str + item                     // reduce operation
} == 'counting: 123'
assert [1, 2, 3].inject(0) { count, item ->
    count + item
} == 6
```

And here is idiomatic Groovy code for finding the maximum and minimum in a collection:

```
def list = [9, 4, 2, 10, 5]
assert list.max() == 10
assert list.min() == 2

// we can also compare single characters, as anything comparable
assert ['x', 'y', 'a', 'z'].min() == 'a'

// we can use a closure to specify the sorting behaviour
def list2 = ['abc', 'z', 'xyzuvw', 'Hello', '321']
assert list2.max { it.size() } == 'xyzuvw'
assert list2.min { it.size() } == 'z'
```

In addition to closures, you can use a `Comparator` to define the comparison criteria:

```
Comparator mc = { a, b -> a == b ? 0 : (a < b ? -1 : 1) }

def list = [7, 4, 9, -6, -1, 11, 2, 3, -9, 5, -13]
assert list.max(mc) == 11
```

```
assert list.min(mc) == -13

Comparator mc2 = { a, b -> a == b ? 0 : (Math.abs(a) < Math.abs(b)) ? -1 : 1 }


assert list.max(mc2) == -13
assert list.min(mc2) == -1

assert list.max { a, b -> a.equals(b) ? 0 : Math.abs(a) < Math.abs(b) ? -1 : 1 } == -
13
assert list.min { a, b -> a.equals(b) ? 0 : Math.abs(a) < Math.abs(b) ? -1 : 1 } == -1
```

Adding or removing elements

We can use `[]` to assign a new empty list and `<<` to append items to it:

```
def list = []
assert list.empty

list << 5
assert list.size() == 1

list << 7 << 'i' << 11
assert list == [5, 7, 'i', 11]

list << ['m', 'o']
assert list == [5, 7, 'i', 11, ['m', 'o']]

//first item in chain of << is target list
assert ([1, 2] << 3 << [4, 5] << 6) == [1, 2, 3, [4, 5], 6]

//using leftShift is equivalent to using <<
assert ([1, 2, 3] << 4) == ([1, 2, 3].leftShift(4))
```

We can add to a list in many ways:

```
assert [1, 2] + 3 + [4, 5] + 6 == [1, 2, 3, 4, 5, 6]
// equivalent to calling the `plus` method
assert [1, 2].plus(3).plus([4, 5]).plus(6) == [1, 2, 3, 4, 5, 6]

def a = [1, 2, 3]
a += 4      // creates a new list and assigns it to `a`
a += [5, 6]
assert a == [1, 2, 3, 4, 5, 6]

assert [1, *[222, 333], 456] == [1, 222, 333, 456]
assert [*[1, 2, 3]] == [1, 2, 3]
assert [1, [2, 3, [4, 5], 6], 7, [8, 9]].flatten() == [1, 2, 3, 4, 5, 6, 7, 8, 9]
```

```
def list = [1, 2]
list.add(3)
list.addAll([5, 4])
assert list == [1, 2, 3, 5, 4]

list = [1, 2]
list.add(1, 3) // add 3 just before index 1
assert list == [1, 3, 2]

list.addAll(2, [5, 4]) //add [5,4] just before index 2
assert list == [1, 3, 5, 4, 2]

list = ['a', 'b', 'z', 'e', 'u', 'v', 'g']
list[8] = 'x' // the [] operator is growing the list as needed
// nulls inserted if required
assert list == ['a', 'b', 'z', 'e', 'u', 'v', 'g', null, 'x']
```

It is however important that the `+` operator on a list is **not mutating**. Compared to `<<`, it will create a new list, which is often not what you want and can lead to performance issues.

The Groovy development kit also contains methods allowing you to easily remove elements from a list by value:

```
assert ['a','b','c','b','b'] - 'c' == ['a','b','b','b']
assert ['a','b','c','b','b'] - 'b' == ['a','c']
assert ['a','b','c','b','b'] - ['b','c'] == ['a']

def list = [1,2,3,4,3,2,1]
list -= 3           // creates a new list by removing `3` from the original one
assert list == [1,2,4,2,1]
assert ( list -= [2,4] ) == [1,1]
```

It is also possible to remove an element by passing its index to the `remove` method, in which case the list is mutated:

```
def list = ['a','b','c','d','e','f','b','b','a']
assert list.remove(2) == 'c'        // remove the third element, and return it
assert list == ['a','b','d','e','f','b','b','a']
```

In case you only want to remove the first element having the same value in a list, instead of removing all elements, you can call the `remove` method passing the value:

```
def list= ['a','b','c','b','b']
assert list.remove('c')             // remove 'c', and return true because element
removed
assert list.remove('b')             // remove first 'b', and return true because
element removed
```

```
assert ! list.remove('z')          // return false because no elements removed
assert list == ['a','b','b']
```

As you can see, there are two `remove` methods available. One that takes an integer and removes an element by its index, and another that will remove the first element that matches the passed value. So what should we do when we have a list of integers? In this case, you may wish to use `removeAt` to remove an element by its index, and `removeElement` to remove the first element that matches a value.

```
def list = [1,2,3,4,5,6,2,2,1]

assert list.remove(2) == 3          // this removes the element at index 2, and
returns it
assert list == [1,2,4,5,6,2,2,1]

assert list.removeElement(2)        // remove first 2 and return true
assert list == [1,4,5,6,2,2,1]

assert ! list.removeElement(8)      // return false because 8 is not in the list
assert list == [1,4,5,6,2,2,1]

assert list.removeAt(1) == 4        // remove element at index 1, and return it
assert list == [1,5,6,2,2,1]
```

Of course, `removeAt` and `removeElement` will work with lists of any type.

Additionally, removing all the elements in a list can be done by calling the `clear` method:

```
def list= ['a',2,'c',4]
list.clear()
assert list == []
```

Set operations

The Groovy development kit also includes methods making it easy to reason on sets:

```
assert 'a' in ['a','b','c']             // returns true if an element belongs to the
list
assert ['a','b','c'].contains('a')      // equivalent to the `contains` method in Java
assert [1,3,4].containsAll([1,4])       // `containsAll` will check that all elements
are found

assert [1,2,3,3,3,3,4,5].count(3) == 4  // count the number of elements which have
some value
assert [1,2,3,3,3,3,4,5].count {
    it%2==0                             // count the number of elements which match
```

```
the predicate
} == 2

assert [1,2,4,6,8,10,12].intersect([1,3,6,9,12]) == [1,6,12]

assert [1,2,3].disjoint( [4,6,9] )
assert ![1,2,3].disjoint( [2,4,6] )
```

Sorting

Working with collections often implies sorting. Groovy offers a variety of options to sort lists, from using closures to comparators, as in the following examples:

```
assert [6, 3, 9, 2, 7, 1, 5].sort() == [1, 2, 3, 5, 6, 7, 9]

def list = ['abc', 'z', 'xyzuvw', 'Hello', '321']
assert list.sort {
    it.size()
} == ['z', 'abc', '321', 'Hello', 'xyzuvw']

def list2 = [7, 4, -6, -1, 11, 2, 3, -9, 5, -13]
assert list2.sort { a, b -> a == b ? 0 : Math.abs(a) < Math.abs(b) ? -1 : 1 } ==
        [-1, 2, 3, 4, 5, -6, 7, -9, 11, -13]

Comparator mc = { a, b -> a == b ? 0 : Math.abs(a) < Math.abs(b) ? -1 : 1 }

// JDK 8+ only
// list2.sort(mc)
// assert list2 == [-1, 2, 3, 4, 5, -6, 7, -9, 11, -13]

def list3 = [6, -3, 9, 2, -7, 1, 5]

Collections.sort(list3)
assert list3 == [-7, -3, 1, 2, 5, 6, 9]

Collections.sort(list3, mc)
assert list3 == [1, 2, -3, 5, 6, -7, 9]
```

Duplicating elements

The Groovy development kit also takes advantage of operator overloading to provide methods allowing duplication of elements of a list:

```
assert [1, 2, 3] * 3 == [1, 2, 3, 1, 2, 3, 1, 2, 3]
assert [1, 2, 3].multiply(2) == [1, 2, 3, 1, 2, 3]
assert Collections.nCopies(3, 'b') == ['b', 'b', 'b']

// nCopies from the JDK has different semantics than multiply for lists
```

```
assert Collections.nCopies(2, [1, 2]) == [[1, 2], [1, 2]] //not [1,2,1,2]
```

Maps

Map literals

In Groovy, maps (also known as associative arrays) can be created using the map literal syntax: `[:]`:

```
def map = [name: 'Gromit', likes: 'cheese', id: 1234]
assert map.get('name') == 'Gromit'
assert map.get('id') == 1234
assert map['name'] == 'Gromit'
assert map['id'] == 1234
assert map instanceof java.util.Map

def emptyMap = [:]
assert emptyMap.size() == 0
emptyMap.put("foo", 5)
assert emptyMap.size() == 1
assert emptyMap.get("foo") == 5
```

Map keys are strings by default: `[a:1]` is equivalent to `['a':1]`. This can be confusing if you define a variable named `a` and that you want the **value** of `a` to be the key in your map. If this is the case, then you **must** escape the key by adding parenthesis, like in the following example:

```
def a = 'Bob'
def ages = [a: 43]
assert ages['Bob'] == null // `Bob` is not found
assert ages['a'] == 43     // because `a` is a literal!

ages = [(a): 43]            // now we escape `a` by using parenthesis
assert ages['Bob'] == 43   // and the value is found!
```

In addition to map literals, it is possible, to get a new copy of a map, to clone it:

```
def map = [
        simple : 123,
        complex: [a: 1, b: 2]
]
def map2 = map.clone()
assert map2.get('simple') == map.get('simple')
assert map2.get('complex') == map.get('complex')
map2.get('complex').put('c', 3)
assert map.get('complex').get('c') == 3
```

The resulting map is a **shallow** copy of the original one, as illustrated in the previous example.

Map property notation

Maps also act like beans so you can use the property notation to get/set items inside the `Map` as long as the keys are strings which are valid Groovy identifiers:

```
def map = [name: 'Gromit', likes: 'cheese', id: 1234]
assert map.name == 'Gromit'     // can be used instead of map.get('name')
assert map.id == 1234

def emptyMap = [:]
assert emptyMap.size() == 0
emptyMap.foo = 5
assert emptyMap.size() == 1
assert emptyMap.foo == 5
```

Note: by design `map.foo` will always look for the key `foo` in the map. This means `foo.class` will return `null` on a map that doesn't contain the `class` key. Should you really want to know the class, then you must use `getClass()`:

```
def map = [name: 'Gromit', likes: 'cheese', id: 1234]
assert map.class == null
assert map.get('class') == null
assert map.getClass() == LinkedHashMap // this is probably what you want

map = [1      : 'a',
       (true) : 'p',
       (false): 'q',
       (null) : 'x',
       'null' : 'z']
assert map.containsKey(1) // 1 is not an identifier so used as is
assert map.true == null
assert map.false == null
assert map.get(true) == 'p'
assert map.get(false) == 'q'
assert map.null == 'z'
assert map.get(null) == 'x'
```

Iterating on maps

As usual in the Groovy development kit, idiomatic iteration on maps makes use of the `each` and `eachWithIndex` methods. It's worth noting that maps created using the map literal notation are **ordered**, that is to say that if you iterate on map entries, it is guaranteed that the entries will be returned in the same order they were added in the map.

```
def map = [
        Bob  : 42,
        Alice: 54,
        Max  : 33
```

```
]

// `entry` is a map entry
map.each { entry ->
    println "Name: $entry.key Age: $entry.value"
}

// `entry` is a map entry, `i` the index in the map
map.eachWithIndex { entry, i ->
    println "$i - Name: $entry.key Age: $entry.value"
}

// Alternatively you can use key and value directly
map.each { key, value ->
    println "Name: $key Age: $value"
}

// Key, value and i as the index in the map
map.eachWithIndex { key, value, i ->
    println "$i - Name: $key Age: $value"
}
```

Manipulating maps

Adding or removing elements

Adding an element to a map can be done either using the `put` method, the subscript operator or using `putAll`:

```
def defaults = [1: 'a', 2: 'b', 3: 'c', 4: 'd']
def overrides = [2: 'z', 5: 'x', 13: 'x']

def result = new LinkedHashMap(defaults)
result.put(15, 't')
result[17] = 'u'
result.putAll(overrides)
assert result == [1: 'a', 2: 'z', 3: 'c', 4: 'd', 5: 'x', 13: 'x', 15: 't', 17: 'u']
```

Removing all the elements of a map can be done by calling the `clear` method:

```
def m = [1:'a', 2:'b']
assert m.get(1) == 'a'
m.clear()
assert m == [:]
```

Maps generated using the map literal syntax are using the object `equals` and `hashcode` methods. This means that you should **never** use an object which hash code is subject to change over time, or you wouldn't be able to get the associated value back.

It is also worth noting that you should **never** use a `GString` as the key of a map, because the hash code of a `GString` is not the same as the hash code of an equivalent `String`:

```
def key = 'some key'
def map = [:]
def gstringKey = "${key.toUpperCase()}"
map.put(gstringKey,'value')
assert map.get('SOME KEY') == null
```

Keys, values and entries

We can inspect the keys, values, and entries in a view:

```
def map = [1:'a', 2:'b', 3:'c']

def entries = map.entrySet()
entries.each { entry ->
  assert entry.key in [1,2,3]
  assert entry.value in ['a','b','c']
}

def keys = map.keySet()
assert keys == [1,2,3] as Set
```

Mutating values returned by the view (be it a map entry, a key or a value) is highly discouraged because success of the operation directly depends on the type of the map being manipulated. In particular, Groovy relies on collections from the JDK that in general make no guarantee that a collection can safely be manipulated through `keySet`, `entrySet`, or `values`.

Filtering and searching

The Groovy development kit contains filtering, searching and collecting methods similar to those found for lists:

```
def people = [
    1: [name:'Bob', age: 32, gender: 'M'],
    2: [name:'Johnny', age: 36, gender: 'M'],
    3: [name:'Claire', age: 21, gender: 'F'],
    4: [name:'Amy', age: 54, gender:'F']
]

def bob = people.find { it.value.name == 'Bob' } // find a single entry
def females = people.findAll { it.value.gender == 'F' }

// both return entries, but you can use collect to retrieve the ages for example
def ageOfBob = bob.value.age
def agesOfFemales = females.collect {
    it.value.age
```

```
}

assert ageOfBob == 32
assert agesOfFemales == [21,54]

// but you could also use a key/pair value as the parameters of the closures
def agesOfMales = people.findAll { id, person ->
    person.gender == 'M'
}.collect { id, person ->
    person.age
}
assert agesOfMales == [32, 36]

// `every` returns true if all entries match the predicate
assert people.every { id, person ->
    person.age > 18
}

// `any` returns true if any entry matches the predicate

assert people.any { id, person ->
    person.age == 54
}
```

Grouping

We can group a list into a map using some criteria:

```
assert ['a', 7, 'b', [2, 3]].groupBy {
    it.class
} == [(String)   : ['a', 'b'],
      (Integer)  : [7],
      (ArrayList): [[2, 3]]
]

assert [
        [name: 'Clark', city: 'London'], [name: 'Sharma', city: 'London'],
        [name: 'Maradona', city: 'LA'], [name: 'Zhang', city: 'HK'],
        [name: 'Ali', city: 'HK'], [name: 'Liu', city: 'HK'],
].groupBy { it.city } == [
        London: [[name: 'Clark', city: 'London'],
                 [name: 'Sharma', city: 'London']],
        LA    : [[name: 'Maradona', city: 'LA']],
        HK    : [[name: 'Zhang', city: 'HK'],
                 [name: 'Ali', city: 'HK'],
                 [name: 'Liu', city: 'HK']],
]
```

Ranges

Ranges allow you to create a list of sequential values. These can be used as `List` since Range extends java.util.List.

Ranges defined with the `..` notation are inclusive (that is the list contains the from and to value).

Ranges defined with the `..<` notation are half-open, they include the first value but not the last value.

Ranges defined with the `<..` notation are also half-open, they include the last value but not the first value.

Ranges defined with the `<..<` notation are full-open, they do not include the first value nor the last value.

```
// an inclusive range
def range = 5..8
assert range.size() == 4
assert range.get(2) == 7
assert range[2] == 7
assert range instanceof java.util.List
assert range.contains(5)
assert range.contains(8)

// lets use a half-open range
range = 5..<8
assert range.size() == 3
assert range.get(2) == 7
assert range[2] == 7
assert range instanceof java.util.List
assert range.contains(5)
assert !range.contains(8)

//get the end points of the range without using indexes
range = 1..10
assert range.from == 1
assert range.to == 10
```

Note that int ranges are implemented efficiently, creating a lightweight Java object containing a from and to value.

Ranges can be used for any Java object which implements java.lang.Comparable for comparison and also have methods `next()` and `previous()` to return the next / previous item in the range. For example, you can create a range of `String` elements:

```
// an inclusive range
def range = 'a'..'d'
assert range.size() == 4
assert range.get(2) == 'c'
```

```
assert range[2] == 'c'
assert range instanceof java.util.List
assert range.contains('a')
assert range.contains('d')
assert !range.contains('e')
```

You can iterate on a range using a `for` loop:

```
for (i in 1..10) {
    println "Hello ${i}"
}
```

but alternatively you can achieve the same effect in a more Groovy idiomatic style, by iterating a range with `each` method:

```
(1..10).each { i ->
    println "Hello ${i}"
}
```

Ranges can be also used in the `switch` statement:

```
switch (years) {
    case 1..10: interestRate = 0.076; break;
    case 11..25: interestRate = 0.052; break;
    default: interestRate = 0.037;
}
```

Syntax enhancements for collections

GPath support

Thanks to the support of property notation for both lists and maps, Groovy provides syntactic sugar making it really easy to deal with nested collections, as illustrated in the following examples:

```
def listOfMaps = [['a': 11, 'b': 12], ['a': 21, 'b': 22]]
assert listOfMaps.a == [11, 21] //GPath notation
assert listOfMaps*.a == [11, 21] //spread dot notation

listOfMaps = [['a': 11, 'b': 12], ['a': 21, 'b': 22], null]
assert listOfMaps*.a == [11, 21, null] // caters for null values
assert listOfMaps*.a == listOfMaps.collect { it?.a } //equivalent notation
// But this will only collect non-null values
assert listOfMaps.a == [11,21]
```

Spread operator

The spread operator can be used to "inline" a collection into another. It is syntactic sugar which often avoids calls to `putAll` and facilitates the realization of one-liners:

```
assert [ 'z': 900,
         *: ['a': 100, 'b': 200], 'a': 300] == ['a': 300, 'b': 200, 'z': 900]
//spread map notation in map definition
assert [*: [3: 3, *: [5: 5]], 7: 7] == [3: 3, 5: 5, 7: 7]

def f = { [1: 'u', 2: 'v', 3: 'w'] }
assert [*: f(), 10: 'zz'] == [1: 'u', 10: 'zz', 2: 'v', 3: 'w']
//spread map notation in function arguments
f = { map -> map.c }
assert f(*: ['a': 10, 'b': 20, 'c': 30], 'e': 50) == 30

f = { m, i, j, k -> [m, i, j, k] }
//using spread map notation with mixed unnamed and named arguments
assert f('e': 100, *[4, 5], *: ['a': 10, 'b': 20, 'c': 30], 6) ==
        [["e": 100, "b": 20, "c": 30, "a": 10], 4, 5, 6]
```

The star-dot `*.' operator

The "star-dot" operator is a shortcut operator allowing you to call a method or a property on all elements of a collection:

```
assert [1, 3, 5] == ['a', 'few', 'words']*.size()

class Person {
    String name
    int age
}
def persons = [new Person(name:'Hugo', age:17), new Person(name:'Sandra',age:19)]
assert [17, 19] == persons*.age
```

Slicing with the subscript operator

You can index into lists, arrays, maps using the subscript expression. It is interesting that strings are considered as special kinds of collections in that context:

```
def text = 'nice cheese gromit!'
def x = text[2]

assert x == 'c'
assert x.class == String

def sub = text[5..10]
assert sub == 'cheese'
```

```
def list = [10, 11, 12, 13]
def answer = list[2,3]
assert answer == [12,13]
```

Notice that you can use ranges to extract part of a collection:

```
list = 100..200
sub = list[1, 3, 20..25, 33]
assert sub == [101, 103, 120, 121, 122, 123, 124, 125, 133]
```

The subscript operator can be used to update an existing collection (for collection type which are not immutable):

```
list = ['a','x','x','d']
list[1..2] = ['b','c']
assert list == ['a','b','c','d']
```

It is worth noting that negative indices are allowed, to extract more easily from the end of a collection:

```
text = "nice cheese gromit!"
x = text[-1]
assert x == "!"
```

You can use negative indices to count from the end of the List, array, String etc.

```
def name = text[-7..-2]
assert name == "gromit"
```

Eventually, if you use a backwards range (the starting index is greater than the end index), then the answer is reversed.

```
text = "nice cheese gromit!"
name = text[3..1]
assert name == "eci"
```

Enhanced Collection Methods

In addition to lists, maps or ranges, Groovy offers a lot of additional methods for filtering, collecting, grouping, counting, … which are directly available on either collections or more easily iterables.

In particular, we invite you to read the Groovy development kit API docs and specifically:

* methods added to `Iterable` can be found here
* methods added to `Iterator` can be found here
* methods added to `Collection` can be found here
* methods added to `List` can be found here
* methods added to `Map` can be found here

Working with arrays

Groovy provides array support based on Java arrays with several extensions found in the Groovy development kit. The overall intention is that whether you are using an array or a collection, the code for working with the aggregate remains the same.

Arrays

Array literals

You can create arrays as follows. Notice that `[]` is also used as the empty array expression when given an explicit array type.

```
Number[] nums = [5, 6, 7, 8]
assert nums[1] == 6
assert nums.getAt(2) == 7                // alternative syntax
assert nums[-1] == 8                     // negative indices
assert nums instanceof Number[]

int[] primes = [2, 3, 5, 7]              // primitives
assert primes instanceof int[]

def odds = [1, 3, 5] as int[]            // alt syntax 1
assert odds instanceof int[]

def evens = new int[]{2, 4, 6}           // alt syntax 2
assert evens instanceof int[]

// empty array examples
Number[] emptyNums = []
assert emptyNums instanceof Number[] && emptyNums.size() == 0

var emptyObjects = new Object[0]         // alternative syntax 1
assert emptyObjects instanceof Object[] && emptyObjects.size() == 0

def emptyStrings = new String[]{}        // alternative syntax 2
assert emptyStrings instanceof String[] && emptyStrings.size() == 0

// multi-dimension examples
int[][] manyInts = [ [1,2], [3,4] ]
assert manyInts instanceof int[][] && manyInts.size() == 2
assert manyInts[0].size() == 2 && manyInts[1].size() == 2
```

```
def manyStrings = new String[][] { {'one','two'}, {'three','four'}, }
assert manyStrings instanceof String[][] && manyStrings.size() == 2
assert manyStrings[0].size() == 2 && manyStrings[1].size() == 2
assert manyStrings[0][0] == 'one'
assert manyStrings[-1][-1] == 'four'
```

Iterating on a list

Iterating on elements of a list is usually done calling the `each` and `eachWithIndex` methods, which execute code on each item of a list:

```
String[] vowels = ['a', 'e', 'i', 'o', 'u']
var result = ''
vowels.each {
    result += it
}
assert result == 'aeiou'
result = ''
vowels.eachWithIndex { v, i ->
    result += v * i         // index starts from 0
}
assert result == 'eiiooouuuu'

result = ''
int[] nums = [0, 1, 2]
nums.eachWithIndex { value, index ->
    result += value.doubleValue()
}
assert result == '0.01.02.0'
```

Other useful methods

There are numerous other GDK methods for working with arrays. Just be a little careful to read the documentation. For collections, there are some mutating methods which alter the original collection and others which produce new collections, leaving the original untouched. Since arrays are of a fixed size, we wouldn't expect mutating methods which altered an array's size. Often instead, such methods return collections. Here are some interesting array GDK methods:

```
int[] nums = [1, 2, 3]
def doubled = nums.collect { it * 2 }
assert doubled == [2, 4, 6] && doubled instanceof List
def tripled = nums*.multiply(3)
assert tripled == [3, 6, 9] && doubled instanceof List

assert nums.any{ it > 2 }
assert nums.every{ it < 4 }
assert nums.average() == 2
```

```
assert nums.min() == 1
assert nums.max() == 3
assert nums.sum() == 6
assert nums.indices == [0, 1, 2]
assert nums.swap(0, 2) == [3, 2, 1] as int[]
```

Working with legacy Date/Calendar types

The groovy-dateutil module supports numerous extensions for working with Java's classic Date and Calendar classes.

You can access the properties of a Date or Calendar using the normal array index notation with the constant field numbers from the Calendar class as shown in the following example:

```
import static java.util.Calendar.*    ①

def cal = Calendar.instance
cal[YEAR] = 2000                      ②
cal[MONTH] = JANUARY                  ②
cal[DAY_OF_MONTH] = 1                 ②
assert cal[DAY_OF_WEEK] == SATURDAY   ③
```

① Import the constants

② Setting the calendar's year, month and day of month

③ Accessing the calendar's day of week

Groovy supports arithmetic on and iteration between Date and Calendar instances as shown in the following example:

```
def utc = TimeZone.getTimeZone('UTC')
Date date = Date.parse("yyyy-MM-dd HH:mm", "2010-05-23 09:01", utc)

def prev = date - 1
def next = date + 1

def diffInDays = next - prev
assert diffInDays == 2

int count = 0
prev.upto(next) { count++ }
assert count == 3
```

You can parse strings into dates and output dates into formatted strings:

```
def orig = '2000-01-01'
def newYear = Date.parse('yyyy-MM-dd', orig)
assert newYear[DAY_OF_WEEK] == SATURDAY
```

```
assert newYear.format('yyyy-MM-dd') == orig
assert newYear.format('dd/MM/yyyy') == '01/01/2000'
```

You can also create a new Date or Calendar based on an existing one:

```
def newYear = Date.parse('yyyy-MM-dd', '2000-01-01')
def newYearsEve = newYear.copyWith(
    year: 1999,
    month: DECEMBER,
    dayOfMonth: 31
)
assert newYearsEve[DAY_OF_WEEK] == FRIDAY
```

Working with Date/Time types

The `groovy-datetime` module supports numerous extensions for working with the Date/Time API introduced in Java 8. This documentation refers to the data types defined by this API as "JSR 310 types."

Formatting and parsing

A common use case when working with date/time types is to convert them to Strings (formatting) and from Strings (parsing). Groovy provides these additional formatting methods:

Method	Description	Example
`getDateString()`	For `LocalDate` and `LocalDateTime`, formats with `DateTimeFormatter.ISO_LOCAL_DATE`	`2018-03-10`
	For `OffsetDateTime`, formats with `DateTimeFormatter.ISO_OFFSET_DATE`	`2018-03-10+04:00`
	For `ZonedDateTime`, formats with `DateTimeFormatter.ISO_LOCAL_DATE` and appends the `ZoneId` short name	`2018-03-10EST`
`getDateTimeString()`	For `LocalDateTime`, formats with `DateTimeFormatter.ISO_LOCAL_DATE_TIME`	`2018-03-10T20:30:45`
	For `OffsetDateTime`, formats with `DateTimeFormatter.ISO_OFFSET_DATE_TIME`	`2018-03-10T20:30:45+04:00`

Method	Description	Example
	For ZonedDateTime, formats with DateTimeFormatter.ISO_LOCAL_DATE_TIME and appends the ZoneId short name	2018-03-10T20:30:45EST
getTimeString()	For LocalTime and LocalDateTime, formats with DateTimeFormatter.ISO_LOCAL_TIME	20:30:45
	For OffsetTime and OffsetDateTime, formats with DateTimeFormatter.ISO_OFFSET_TIME formatter	20:30:45+04:00
	For ZonedDateTime, formats with DateTimeFormatter.ISO_LOCAL_TIME and appends the ZoneId short name	20:30:45EST
format(FormatStyle style)	For LocalTime and OffsetTime, formats with DateTimeFormatter.ofLocalizedTime(style)	4:30 AM (with style FormatStyle.SHORT, e.g.)
	For LocalDate, formats with DateTimeFormatter.ofLocalizedDate(style)	Saturday, March 10, 2018 (with style FormatStyle.FULL, e.g.)
	For LocalDateTime, OffsetDateTime, and ZonedDateTime formats with DateTimeFormatter.ofLocalizedDateTime(style)	Mar 10, 2019 4:30:45 AM (with style FormatStyle.MEDIUM, e.g.)
format(String pattern)	Formats with DateTimeFormatter.ofPattern(pattern)	03/10/2018 (with pattern ’MM/dd/yyyy', e.g.)

For parsing, Groovy adds a static parse method to many of the JSR 310 types. The method takes two arguments: the value to be formatted and the pattern to use. The pattern is defined by the java.time.format.DateTimeFormatter API. As an example:

```
def date = LocalDate.parse('Jun 3, 04', 'MMM d, yy')
assert date == LocalDate.of(2004, Month.JUNE, 3)

def time = LocalTime.parse('4:45', 'H:mm')
assert time == LocalTime.of(4, 45, 0)

def offsetTime = OffsetTime.parse('09:47:51-1234', 'HH:mm:ssZ')
assert offsetTime == OffsetTime.of(9, 47, 51, 0, ZoneOffset.ofHoursMinutes(-12, -34))

def dateTime = ZonedDateTime.parse('2017/07/11 9:47PM Pacific Standard Time',
```

```
'yyyy/MM/dd h:mma zzzz')
assert dateTime == ZonedDateTime.of(
        LocalDate.of(2017, 7, 11),
        LocalTime.of(21, 47, 0),
        ZoneId.of('America/Los_Angeles')
)
```

Note that these `parse` methods have a different argument ordering than the static `parse` method Groovy added to `java.util.Date`. This was done to be consistent with the existing `parse` methods of the Date/Time API.

Manipulating date/time

Addition and subtraction

`Temporal` types have `plus` and `minus` methods for adding or subtracting a provided `java.time.temporal.TemporalAmount` argument. Because Groovy maps the `+` and `-` operators to single-argument methods of these names, a more natural expression syntax can be used to add and subtract.

```
def aprilFools = LocalDate.of(2018, Month.APRIL, 1)

def nextAprilFools = aprilFools + Period.ofDays(365) // add 365 days
assert nextAprilFools.year == 2019

def idesOfMarch = aprilFools - Period.ofDays(17) // subtract 17 days
assert idesOfMarch.dayOfMonth == 15
assert idesOfMarch.month == Month.MARCH
```

Groovy provides additional `plus` and `minus` methods that accept an integer argument, enabling the above to be rewritten more succinctly:

```
def nextAprilFools = aprilFools + 365 // add 365 days
def idesOfMarch = aprilFools - 17 // subtract 17 days
```

The unit of these integers depends on the JSR 310 type operand. As evident above, integers used with `ChronoLocalDate` types like `LocalDate` have a unit of days. Integers used with `Year` and `YearMonth` have a unit of years and months, respectively. All other types have a unit of seconds, such as `LocalTime`, for instance:

```
def mars = LocalTime.of(12, 34, 56) // 12:34:56 pm

def thirtySecondsToMars = mars - 30 // go back 30 seconds
assert thirtySecondsToMars.second == 26
```

Multiplication and division

The `*` operator can be used to multiply `Period` and `Duration` instances by an integer value; the `/` operator can be used to divide `Duration` instances by an integer value.

```
def period = Period.ofMonths(1) * 2 // a 1-month period times 2
assert period.months == 2

def duration = Duration.ofSeconds(10) / 5// a 10-second duration divided by 5
assert duration.seconds == 2
```

Incrementing and decrementing

The `++` and `--` operators can be used increment and decrement date/time values by one unit. Since the JSR 310 types are immutable, the operation will create a new instance with the incremented/decremented value and reassign it to the reference.

```
def year = Year.of(2000)
--year // decrement by one year
assert year.value == 1999

def offsetTime = OffsetTime.of(0, 0, 0, 0, ZoneOffset.UTC) // 00:00:00.000 UTC
offsetTime++ // increment by one second
assert offsetTime.second == 1
```

Negation

The `Duration` and `Period` types represent a negative or positive length of time. These can be negated with the unary `-` operator.

```
def duration = Duration.ofSeconds(-15)
def negated = -duration
assert negated.seconds == 15
```

Interacting with date/time values

Property notation

The `getLong(TemporalField)` method of `TemporalAccessor` types (e.g. `LocalDate`, `LocalTime`, `ZonedDateTime`, etc.) and the `get(TemporalUnit)` method of `TemporalAmount` types (namely `Period` and `Duration`), can be invoked with Groovy's property notation. For example:

```
def date = LocalDate.of(2018, Month.MARCH, 12)
assert date[ChronoField.YEAR] == 2018
assert date[ChronoField.MONTH_OF_YEAR] == Month.MARCH.value
assert date[ChronoField.DAY_OF_MONTH] == 12
assert date[ChronoField.DAY_OF_WEEK] == DayOfWeek.MONDAY.value
```

```
def period = Period.ofYears(2).withMonths(4).withDays(6)
assert period[ChronoUnit.YEARS] == 2
assert period[ChronoUnit.MONTHS] == 4
assert period[ChronoUnit.DAYS] == 6
```

Ranges, `upto`, and `downto`

The JSR 310 types can be used with the range operator. The following example iterates between today and the `LocalDate` six days from now, printing out the day of the week for each iteration. As both range bounds are inclusive, this prints all seven days of the week.

```
def start = LocalDate.now()
def end = start + 6 // 6 days later
(start..end).each { date ->
    println date.dayOfWeek
}
```

The `upto` method will accomplish the same as the range in the above example. The `upto` method iterates from the earlier `start` value (inclusive) to the later `end` value (also inclusive), calling the closure with the incremented `next` value once per iteration.

```
def start = LocalDate.now()
def end = start + 6 // 6 days later
start.upto(end) { next ->
    println next.dayOfWeek
}
```

The `downto` method iterates in the opposite direction, from a later `start` value to an earlier `end` value.

The unit of iteration for `upto`, `downto`, and ranges is the same as the unit for addition and subtraction: `LocalDate` iterates by one day at a time, `YearMonth` iterates by one month, `Year` by one year, and everything else by one second. Both methods also support an optional a `TemporalUnit` argument to change the unit of iteration.

Consider the following example, where March 1st, 2018 is iterated up to March 2nd, 2018 using an iteration unit of months.

```
def start = LocalDate.of(2018, Month.MARCH, 1)
def end = start + 1 // 1 day later

int iterationCount = 0
start.upto(end, ChronoUnit.MONTHS) { next ->
    println next
    ++iterationCount
}
```

```
assert iterationCount == 1
```

Since the `start` date is inclusive, the closure is called with a `next` date value of March 1st. The `upto` method then increments the date by one month, yielding the date, April 1st. Because this date is *after* the specified `end` date of March 2nd, the iteration stops immediately, having only called the closure once. This behavior is the same for the `downto` method except that the iteration will stop as soon as the value of `next` becomes earlier than the targeted `end` date.

In short, when iterating with the `upto` or `downto` methods with a custom unit of iteration, the current value of iteration will never exceed the end value.

Combining date/time values

The left-shift operator (`<<`) can be used to combine two JSR 310 types into an aggregate type. For example, a `LocalDate` can be left-shifted into a `LocalTime` to produce a composite `LocalDateTime` instance.

```
MonthDay monthDay = Month.JUNE << 3 // June 3rd
LocalDate date = monthDay << Year.of(2015) // 3-Jun-2015
LocalDateTime dateTime = date << LocalTime.NOON // 3-Jun-2015 @ 12pm
OffsetDateTime offsetDateTime = dateTime << ZoneOffset.ofHours(-5) // 3-Jun-2015 @
12pm UTC-5
```

The left-shift operator is reflexive; the order of the operands does not matter.

```
def year = Year.of(2000)
def month = Month.DECEMBER

YearMonth a = year << month
YearMonth b = month << year
assert a == b
```

Creating periods and durations

The right-shift operator (`>>`) produces a value representing the period or duration between the operands. For `ChronoLocalDate`, `YearMonth`, and `Year`, the operator yields a `Period` instance:

```
def newYears = LocalDate.of(2018, Month.JANUARY, 1)
def aprilFools = LocalDate.of(2018, Month.APRIL, 1)

def period = newYears >> aprilFools
assert period instanceof Period
assert period.months == 3
```

The operator produces a `Duration` for the time-aware JSR types:

```
def duration = LocalTime.NOON >> (LocalTime.NOON + 30)
assert duration instanceof Duration
assert duration.seconds == 30
```

If the value on the left-hand side of the operator is earlier than the value on the right-hand side, the result is positive. If the left-hand side is later than the right-hand side, the result is negative:

```
def decade = Year.of(2010) >> Year.of(2000)
assert decade.years == -10
```

Converting between legacy and JSR 310 types

Despite the shortcomings of `Date`, `Calendar`, and `TimeZone` types in the `java.util` package they are fairly common in Java APIs (at least in those prior to Java 8). To accommodate use of such APIs, Groovy provides methods for converting between the JSR 310 types and legacy types.

Most JSR types have been fitted with `toDate()` and `toCalendar()` methods for converting to relatively equivalent `java.util.Date` and `java.util.Calendar` values. Both `ZoneId` and `ZoneOffset` have been given a `toTimeZone()` method for converting to `java.util.TimeZone`.

```
// LocalDate to java.util.Date
def valentines = LocalDate.of(2018, Month.FEBRUARY, 14)
assert valentines.toDate().format('MMMM dd, yyyy') == 'February 14, 2018'

// LocalTime to java.util.Date
def noon = LocalTime.of(12, 0, 0)
assert noon.toDate().format('HH:mm:ss') == '12:00:00'

// ZoneId to java.util.TimeZone
def newYork = ZoneId.of('America/New_York')
assert newYork.toTimeZone() == TimeZone.getTimeZone('America/New_York')

// ZonedDateTime to java.util.Calendar
def valAtNoonInNY = ZonedDateTime.of(valentines, noon, newYork)
assert valAtNoonInNY.toCalendar().getTimeZone().toZoneId() == newYork
```

Note that when converting to a legacy type:

- Nanosecond values are truncated to milliseconds. A `LocalTime`, for example, with a `ChronoUnit.NANOS` value of 999,999,999 nanoseconds translates to 999 milliseconds.
- When converting the "local" types (`LocalDate`, `LocalTime`, and `LocalDateTime`), the time zone of the returned `Date` or `Calendar` will be the system default.
- When converting a time-only type (`LocalTime` or `OffsetTime`), the year/month/day of the `Date` or `Calendar` is set to the current date.
- When converting a date-only type (`LocalDate`), the time value of the `Date` or `Calendar` will be

cleared, i.e. 00:00:00.000.

- When converting an OffsetDateTime to a Calendar, only the hours and minutes of the ZoneOffset convey into the corresponding TimeZone. Fortunately, Zone Offsets with non-zero seconds are rare.

Groovy has added a number of methods to Date and Calendar for converting into the various JSR 310 types:

```
Date legacy = Date.parse('yyyy-MM-dd HH:mm:ss.SSS', '2010-04-03 10:30:58.999')

assert legacy.toLocalDate() == LocalDate.of(2010, 4, 3)
assert legacy.toLocalTime() == LocalTime.of(10, 30, 58, 999_000_000) // 999M ns =
999ms
assert legacy.toOffsetTime().hour == 10
assert legacy.toYear() == Year.of(2010)
assert legacy.toMonth() == Month.APRIL
assert legacy.toDayOfWeek() == DayOfWeek.SATURDAY
assert legacy.toMonthDay() == MonthDay.of(Month.APRIL, 3)
assert legacy.toYearMonth() == YearMonth.of(2010, Month.APRIL)
assert legacy.toLocalDateTime().year == 2010
assert legacy.toOffsetDateTime().dayOfMonth == 3
assert legacy.toZonedDateTime().zone == ZoneId.systemDefault()
```

Handy utilities

ConfigSlurper

ConfigSlurper is a utility class for reading configuration files defined in the form of Groovy scripts. Like it is the case with Java *.properties files, ConfigSlurper allows a dot notation. But in addition, it allows for Closure scoped configuration values and arbitrary object types.

```
def config = new ConfigSlurper().parse('''
    app.date = new Date()  ①
    app.age  = 42
    app {                  ②
        name = "Test${42}"
    }
''')

assert config.app.date instanceof Date
assert config.app.age == 42
assert config.app.name == 'Test42'
```

① Usage of the dot notation

② Usage of Closure scopes as an alternative to the dot notation

As can be seen in the above example, the parse method can be used to retrieve groovy.util.ConfigObject instances. The ConfigObject is a specialized java.util.Map implementation that either returns the configured value or a new ConfigObject instance but never null.

```
def config = new ConfigSlurper().parse('''
    app.date = new Date()
    app.age  = 42
    app.name = "Test${42}"
''')

assert config.test != null   ①
```

① config.test has not been specified yet it returns a ConfigObject when being called.

In the case of a dot being part of a configuration variable name, it can be escaped by using single or double quotes.

```
def config = new ConfigSlurper().parse('''
    app."person.age"  = 42
''')

assert config.app."person.age" == 42
```

In addition, ConfigSlurper comes with support for environments. The environments method can be used to hand over a Closure instance that itself may consist of a several sections. Let's say we wanted to create a particular configuration value for the development environment. When creating the ConfigSlurper instance we can use the ConfigSlurper(String) constructor to specify the target environment.

```
def config = new ConfigSlurper('development').parse('''
  environments {
       development {
           app.port = 8080
       }

       test {
           app.port = 8082
       }

       production {
           app.port = 80
       }
  }
''')

assert config.app.port == 8080
```

NOTE The ConfigSlurper environments aren't restricted to any particular environment names. It solely depends on the ConfigSlurper client code what value are supported and interpreted accordingly.

The environments method is built-in but the registerConditionalBlock method can be used to register other method names in addition to the environments name.

```
def slurper = new ConfigSlurper()
slurper.registerConditionalBlock('myProject', 'developers')   ①

def config = slurper.parse('''
  sendMail = true

  myProject {
       developers {
           sendMail = false
       }
  }
''')

assert !config.sendMail
```

① Once the new block is registered ConfigSlurper can parse it.

For Java integration purposes the toProperties method can be used to convert the ConfigObject to a java.util.Properties object that might be stored to a *.properties text file. Be aware though that the configuration values are converted to String instances during adding them to the newly created Properties instance.

```
def config = new ConfigSlurper().parse('''
    app.date = new Date()
    app.age  = 42
    app {
        name = "Test${42}"
    }
''')

def properties = config.toProperties()

assert properties."app.date" instanceof String
assert properties."app.age" == '42'
assert properties."app.name" == 'Test42'
```

Expando

The Expando class can be used to create a dynamically expandable object. Despite its name it does not use the ExpandoMetaClass underneath. Each Expando object represents a standalone, dynamically-crafted instance that can be extended with properties (or methods) at runtime.

```
def expando = new Expando()
expando.name = 'John'

assert expando.name == 'John'
```

A special case occurs when a dynamic property registers a `Closure` code block. Once being registered it can be invoked as it would be done with a method call.

```
def expando = new Expando()
expando.toString = { -> 'John' }
expando.say = { String s -> "John says: ${s}" }

assert expando as String == 'John'
assert expando.say('Hi') == 'John says: Hi'
```

Observable list, map and set

Groovy comes with observable lists, maps and sets. Each of these collections trigger `java.beans.PropertyChangeEvent` events when elements are added, removed or changed. Note that a `PropertyChangeEvent` is not only signalling that a certain event has occurred, moreover, it holds information on the property name and the old/new value a certain property has been changed to.

Depending on the type of change that has happened, observable collections might fire more specialized `PropertyChangeEvent` types. For example, adding an element to an observable list fires an `ObservableList.ElementAddedEvent` event.

```
def event                                       ①
def listener = {
    if (it instanceof ObservableList.ElementEvent)  {  ②
        event = it
    }
} as PropertyChangeListener


def observable = [1, 2, 3] as ObservableList    ③
observable.addPropertyChangeListener(listener)  ④

observable.add 42                               ⑤

assert event instanceof ObservableList.ElementAddedEvent

def elementAddedEvent = event as ObservableList.ElementAddedEvent
assert elementAddedEvent.changeType == ObservableList.ChangeType.ADDED
assert elementAddedEvent.index == 3
assert elementAddedEvent.oldValue == null
assert elementAddedEvent.newValue == 42
```

① Declares a `PropertyChangeEventListener` that is capturing the fired events

② `ObservableList.ElementEvent` and its descendant types are relevant for this listener

③ Creates an `ObservableList` from the given list

④ Registers the listener

⑤ Triggers an `ObservableList.ElementAddedEvent` event

NOTE Be aware that adding an element in fact causes two events to be triggered. The first is of type `ObservableList.ElementAddedEvent`, the second is a plain `PropertyChangeEvent` that informs listeners about the change of property `size`.

The `ObservableList.ElementClearedEvent` event type is another interesting one. Whenever multiple elements are removed, for example when calling `clear()`, it holds the elements being removed from the list.

```
def event
def listener = {
    if (it instanceof ObservableList.ElementEvent)  {
        event = it
    }
} as PropertyChangeListener


def observable = [1, 2, 3] as ObservableList
observable.addPropertyChangeListener(listener)

observable.clear()

assert event instanceof ObservableList.ElementClearedEvent

def elementClearedEvent = event as ObservableList.ElementClearedEvent
assert elementClearedEvent.values == [1, 2, 3]
assert observable.size() == 0
```

To get an overview of all the supported event types the reader is encouraged to have a look at the JavaDoc documentation or the source code of the observable collection in use.

`ObservableMap` and `ObservableSet` come with the same concepts as we have seen for `ObservableList` in this section.

Metaprogramming

The Groovy language supports two flavors of metaprogramming: runtime and compile-time. The first allows altering the class model and the behavior of a program at runtime while the second only occurs at compile-time. Both have pros and cons that we will detail in this section.

Runtime metaprogramming

With runtime metaprogramming we can postpone to runtime the decision to intercept, inject and even synthesize methods of classes and interfaces. For a deep understanding of Groovy's metaobject protocol (MOP) we need to understand Groovy objects and Groovy's method handling. In Groovy we work with three kinds of objects: POJO, POGO and Groovy Interceptors. Groovy allows metaprogramming for all types of objects but in a different manner.

- POJO - A regular Java object whose class can be written in Java or any other language for the JVM.
- POGO - A Groovy object whose class is written in Groovy. It extends `java.lang.Object` and implements the groovy.lang.GroovyObject interface by default.
- Groovy Interceptor - A Groovy object that implements the groovy.lang.GroovyInterceptable interface and has method-interception capability which is discussed in the GroovyInterceptable section.

For every method call Groovy checks whether the object is a POJO or a POGO. For POJOs, Groovy fetches its `MetaClass` from the groovy.lang.MetaClassRegistry and delegates method invocation to it. For POGOs, Groovy takes more steps, as illustrated in the following figure:

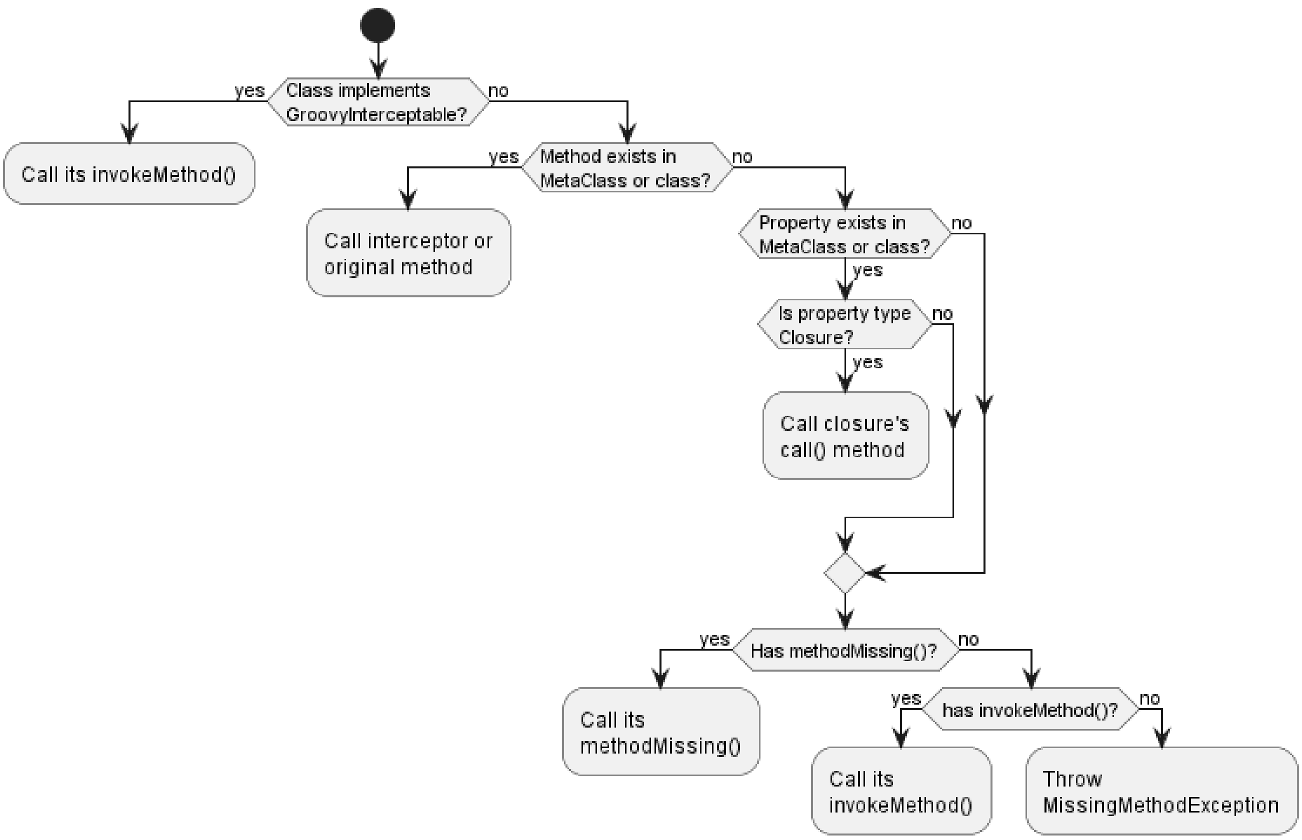


Figure 1. Groovy interception mechanism

GroovyObject interface

groovy.lang.GroovyObject is the main interface in Groovy as the `Object` class is in Java. `GroovyObject` has a default implementation in the groovy.lang.GroovyObjectSupport class and it is responsible to transfer invocation to the groovy.lang.MetaClass object. The `GroovyObject` source looks like this:

```
package groovy.lang;

public interface GroovyObject {

    Object invokeMethod(String name, Object args);

    Object getProperty(String propertyName);

    void setProperty(String propertyName, Object newValue);

    MetaClass getMetaClass();

    void setMetaClass(MetaClass metaClass);
}
```

invokeMethod

This method is primarily intended to be used in conjunction with the GroovyInterceptable interface or an object's `MetaClass` where it will intercept all method calls.

It is also invoked when the method called is not present on a Groovy object. Here is a simple example using an overridden `invokeMethod()` method:

```
class SomeGroovyClass {

    def invokeMethod(String name, Object args) {
        return "called invokeMethod $name $args"
    }

    def test() {
        return 'method exists'
    }
}

def someGroovyClass = new SomeGroovyClass()

assert someGroovyClass.test() == 'method exists'
assert someGroovyClass.someMethod() == 'called invokeMethod someMethod []'
```

However, the use of `invokeMethod` to intercept missing methods is discouraged. In cases where the intent is to only intercept method calls in the case of a failed method dispatch use methodMissing instead.

get/setProperty

Every read access to a property can be intercepted by overriding the `getProperty()` method of the current object. Here is a simple example:

```
class SomeGroovyClass {

    def property1 = 'ha'
    def field2 = 'ho'
    def field4 = 'hu'

    def getField1() {
        return 'getHa'
    }

    def getProperty(String name) {
        if (name != 'field3')
            return metaClass.getProperty(this, name) ①
        else
            return 'field3'
    }
}

def someGroovyClass = new SomeGroovyClass()

assert someGroovyClass.field1 == 'getHa'
assert someGroovyClass.field2 == 'ho'
assert someGroovyClass.field3 == 'field3'
assert someGroovyClass.field4 == 'hu'
```

① Forwards the request to the getter for all properties except `field3`.

You can intercept write access to properties by overriding the `setProperty()` method:

```
class POGO {

    String property

    void setProperty(String name, Object value) {
        this.@"$name" = 'overridden'
    }
}

def pogo = new POGO()
pogo.property = 'a'

assert pogo.property == 'overridden'
```

get/setMetaClass

You can access an object's `metaClass` or set your own `MetaClass` implementation for changing the default interception mechanism. For example, you can write your own implementation of the `MetaClass` interface and assign it to objects in order to change the interception mechanism:

```
// getMetaclass
someObject.metaClass

// setMetaClass
someObject.metaClass = new OwnMetaClassImplementation()
```

NOTE You can find an additional example in the GroovyInterceptable topic.

get/setAttribute

This functionality is related to the `MetaClass` implementation. In the default implementation you can access fields without invoking their getters and setters. The examples below demonstrates this approach:

```
class SomeGroovyClass {

    def field1 = 'ha'
    def field2 = 'ho'

    def getField1() {
        return 'getHa'
    }
}

def someGroovyClass = new SomeGroovyClass()

assert someGroovyClass.metaClass.getAttribute(someGroovyClass, 'field1') == 'ha'
assert someGroovyClass.metaClass.getAttribute(someGroovyClass, 'field2') == 'ho'
```

```
class POGO {

    private String field
    String property1

    void setProperty1(String property1) {
        this.property1 = "setProperty1"
    }
}

def pogo = new POGO()
pogo.metaClass.setAttribute(pogo, 'field', 'ha')
pogo.metaClass.setAttribute(pogo, 'property1', 'ho')

assert pogo.field == 'ha'
assert pogo.property1 == 'ho'
```

methodMissing

Groovy supports the concept of `methodMissing`. This method differs from `invokeMethod` in that it is only invoked in the case of a failed method dispatch when no method can be found for the given name and/or the given arguments:

```
class Foo {

   def methodMissing(String name, def args) {
        return "this is me"
   }
}

assert new Foo().someUnknownMethod(42l) == 'this is me'
```

Typically when using `methodMissing` it is possible to cache the result for the next time the same method is called.

For example, consider dynamic finders in GORM. These are implemented in terms of `methodMissing`. The code resembles something like this:

```
class GORM {

   def dynamicMethods = [...] // an array of dynamic methods that use regex

   def methodMissing(String name, args) {
       def method = dynamicMethods.find { it.match(name) }
       if(method) {
          GORM.metaClass."$name" = { Object[] varArgs ->
             method.invoke(delegate, name, varArgs)
          }
          return method.invoke(delegate,name, args)
       }
       else throw new MissingMethodException(name, delegate, args)
   }
}
```

Notice how, if we find a method to invoke, we then dynamically register a new method on the fly using ExpandoMetaClass. This is so that the next time the same method is called it is more efficient. This way of using `methodMissing` does not have the overhead of `invokeMethod` *and* is not expensive from the second call on.

propertyMissing

Groovy supports the concept of `propertyMissing` for intercepting otherwise failing property resolution attempts. In the case of a getter method, `propertyMissing` takes a single `String` argument containing the property name:

```
class Foo {
   def propertyMissing(String name) { name }
}

assert new Foo().boo == 'boo'
```

The `propertyMissing(String)` method is only called when no getter method for the given property can be found by the Groovy runtime.

For setter methods a second `propertyMissing` definition can be added that takes an additional value argument:

```
class Foo {
   def storage = [:]
   def propertyMissing(String name, value) { storage[name] = value }
   def propertyMissing(String name) { storage[name] }
}

def f = new Foo()
f.foo = "bar"

assert f.foo == "bar"
```

As with `methodMissing` it is best practice to dynamically register new properties at runtime to improve the overall lookup performance.

static methodMissing

Static variant of `methodMissing` method can be added via the ExpandoMetaClass or can be implemented at the class level with `$static_methodMissing` method.

```
class Foo {
    static def $static_methodMissing(String name, Object args) {
        return "Missing static method name is $name"
    }
}

assert Foo.bar() == 'Missing static method name is bar'
```

static propertyMissing

Static variant of `propertyMissing` method can be added via the ExpandoMetaClass or can be implemented at the class level with `$static_propertyMissing` method.

```
class Foo {
    static def $static_propertyMissing(String name) {
```

```
        return "Missing static property name is $name"
    }
}

assert Foo.foobar == 'Missing static property name is foobar'
```

GroovyInterceptable

The groovy.lang.GroovyInterceptable interface is marker interface that extends `GroovyObject` and is used to notify the Groovy runtime that all methods should be intercepted through the method dispatcher mechanism of the Groovy runtime.

```
package groovy.lang;

public interface GroovyInterceptable extends GroovyObject {
}
```

When a Groovy object implements the `GroovyInterceptable` interface, its `invokeMethod()` is called for any method calls. Below you can see a simple example of an object of this type:

```
class Interception implements GroovyInterceptable {

    def definedMethod() { }

    def invokeMethod(String name, Object args) {
        'invokedMethod'
    }
}
```

The next piece of code is a test which shows that both calls to existing and non-existing methods will return the same value.

```
class InterceptableTest extends GroovyTestCase {

    void testCheckInterception() {
        def interception = new Interception()

        assert interception.definedMethod() == 'invokedMethod'
        assert interception.someMethod() == 'invokedMethod'
    }
}
```

NOTE We cannot use default groovy methods like `println` because these methods are injected into all Groovy objects so they will be intercepted too.

If we want to intercept all method calls but do not want to implement the `GroovyInterceptable` interface we can implement invokeMethod() on an object's MetaClass. This approach works for both POGOs and POJOs, as shown by this example:

```
class InterceptionThroughMetaClassTest extends GroovyTestCase {

    void testPOJOMetaClassInterception() {
        String invoking = 'ha'
        invoking.metaClass.invokeMethod = { String name, Object args ->
            'invoked'
        }

        assert invoking.length() == 'invoked'
        assert invoking.someMethod() == 'invoked'
    }

    void testPOGOMetaClassInterception() {
        Entity entity = new Entity('Hello')
        entity.metaClass.invokeMethod = { String name, Object args ->
            'invoked'
        }

        assert entity.build(new Object()) == 'invoked'
        assert entity.someMethod() == 'invoked'
    }
}
```

NOTE Additional information about MetaClass can be found in the MetaClasses section.

Categories

There are situations where it is useful if a class *not* under control had additional methods. In order to enable this capability, Groovy implements a feature borrowed from Objective-C, called *Categories*.

Categories are implemented with so-called *category classes*. A category class is special in that it needs to meet certain pre-defined rules for defining extension methods.

There are a few categories that are included in the system for adding functionality to classes that make them more usable within the Groovy environment:

- groovy.time.TimeCategory
- groovy.servlet.ServletCategory
- groovy.xml.dom.DOMCategory

Category classes aren't enabled by default. To use the methods defined in a category class it is necessary to apply the scoped use method that is provided by the GDK and available from inside every Groovy object instance:

```
use(TimeCategory)  {
    println 1.minute.from.now       ①
    println 10.hours.ago

    def someDate = new Date()       ②
    println someDate - 3.months
}
```

① `TimeCategory` adds methods to `Integer`

② `TimeCategory` adds methods to `Date`

The `use` method takes the category class as its first parameter and a closure code block as second parameter. Inside the `Closure` access to the category methods is available. As can be seen in the example above even JDK classes like `java.lang.Integer` or `java.util.Date` can be enriched with user-defined methods.

A category needs not to be directly exposed to the user code, the following will also do:

```
class JPACategory{
  // Let's enhance JPA EntityManager without getting into the JSR committee
  static void persistAll(EntityManager em , Object[] entities) { //add an interface to
save all
    entities?.each { em.persist(it) }
  }
}

def transactionContext = {
  EntityManager em, Closure c ->
  def tx = em.transaction
  try {
    tx.begin()
    use(JPACategory) {
      c()
    }
    tx.commit()
  } catch (e) {
    tx.rollback()
  } finally {
    //cleanup your resource here
  }
}

// user code, they always forget to close resource in exception, some even forget to
commit, let's not rely on them.
EntityManager em; //probably injected
transactionContext (em) {
 em.persistAll(obj1, obj2, obj3)
 // let's do some logics here to make the example sensible
 em.persistAll(obj2, obj4, obj6)
```

```
}
```

When we have a look at the `groovy.time.TimeCategory` class we see that the extension methods are all declared as `static` methods. In fact, this is one of the requirements that must be met by category classes for its methods to be successfully added to a class inside the `use` code block:

```
public class TimeCategory {

    public static Date plus(final Date date, final BaseDuration duration) {
        return duration.plus(date);
    }

    public static Date minus(final Date date, final BaseDuration duration) {
        final Calendar cal = Calendar.getInstance();

        cal.setTime(date);
        cal.add(Calendar.YEAR, -duration.getYears());
        cal.add(Calendar.MONTH, -duration.getMonths());
        cal.add(Calendar.DAY_OF_YEAR, -duration.getDays());
        cal.add(Calendar.HOUR_OF_DAY, -duration.getHours());
        cal.add(Calendar.MINUTE, -duration.getMinutes());
        cal.add(Calendar.SECOND, -duration.getSeconds());
        cal.add(Calendar.MILLISECOND, -duration.getMillis());

        return cal.getTime();
    }

    // ...
```

Another requirement is the first argument of the static method must define the type the method is attached to once being activated. The other arguments are the normal arguments the method will take as parameters.

Because of the parameter and static method convention, category method definitions may be a bit less intuitive than normal method definitions. As an alternative Groovy comes with a `@Category` annotation that transforms annotated classes into category classes at compile-time.

```
class Distance {
    def number
    String toString() { "${number}m" }
}

@Category(Number)
class NumberCategory {
    Distance getMeters() {
        new Distance(number: this)
    }
}
```

```
use (NumberCategory)  {
    assert 42.meters.toString() == '42m'
}
```

Applying the `@Category` annotation has the advantage of being able to use instance methods without the target type as a first parameter. The target type class is given as an argument to the annotation instead.

NOTE	There is a distinct section on `@Category` in the compile-time metaprogramming section.

Metaclasses

As explained earlier, Metaclasses play a central role in method resolution. For every method invocation from groovy code, Groovy will find the `MetaClass` for the given object and delegate the method resolution to the metaclass via groovy.lang.MetaClass#invokeMethod(java.lang.Class,java.lang.Object,java.lang.String,java.lang.Object,boolean,boolean) which should not be confused with groovy.lang.GroovyObject#invokeMethod(java.lang.String,java.lang.Object) which happens to be a method that the metaclass may eventually call.

The default metaclass `MetaClassImpl`

By default, objects get an instance of `MetaClassImpl` that implements the default method lookup. This method lookup includes looking up of the method in the object class ("regular" method) but also if no method is found this way it will resort to calling `methodMissing` and ultimately groovy.lang.GroovyObject#invokeMethod(java.lang.String,java.lang.Object)

```
class Foo {}

def f = new Foo()

assert f.metaClass =~ /MetaClassImpl/
```

Custom metaclasses

You can change the metaclass of any object or class and replace it with a custom implementation of the `MetaClass` groovy.lang.MetaClass. Usually you will want to extend one of the existing metaclasses such as `MetaClassImpl`, `DelegatingMetaClass`, `ExpandoMetaClass`, or `ProxyMetaClass`; otherwise you will need to implement the complete method lookup logic. Before using a new metaclass instance you should call groovy.lang.MetaClass#initialize(), otherwise the metaclass may or may not behave as expected.

Delegating metaclass

If you only need to decorate an existing metaclass the `DelegatingMetaClass` simplifies that use case. The old metaclass implementation is still accessible via `super` making it easy to apply pretransformations to the inputs, routing to other methods and postprocessing the outputs.

```
class Foo { def bar() { "bar" } }

class MyFooMetaClass extends DelegatingMetaClass {
  MyFooMetaClass(MetaClass metaClass) { super(metaClass) }
  MyFooMetaClass(Class theClass) { super(theClass) }

  Object invokeMethod(Object object, String methodName, Object[] args) {
     def result = super.invokeMethod(object,methodName.toLowerCase(), args)
     result.toUpperCase();
  }
}


def mc =  new MyFooMetaClass(Foo.metaClass)
mc.initialize()

Foo.metaClass = mc
def f = new Foo()

assert f.BAR() == "BAR" // the new metaclass routes .BAR() to .bar() and uppercases
the result
```

Magic package

It is possible to change the metaclass at startup time by giving the metaclass a specially crafted (magic) class name and package name. In order to change the metaclass for `java.lang.Integer` it's enough to put a class `groovy.runtime.metaclass.java.lang.IntegerMetaClass` in the classpath. This is useful, for example, when working with frameworks if you want to do metaclass changes before your code is executed by the framework. The general form of the magic package is `groovy.runtime.metaclass.[package].[class]MetaClass`. In the example below the `[package]` is `java.lang` and the `[class]` is `Integer`:

```
// file: IntegerMetaClass.groovy
package groovy.runtime.metaclass.java.lang;

class IntegerMetaClass extends DelegatingMetaClass {
  IntegerMetaClass(MetaClass metaClass) { super(metaClass) }
  IntegerMetaClass(Class theClass) { super(theClass) }
  Object invokeMethod(Object object, String name, Object[] args) {
    if (name =~ /isBiggerThan/) {
      def other = name.split(/isBiggerThan/)[1].toInteger()
      object > other
    } else {
      return super.invokeMethod(object,name, args);
    }
  }
```

```
}
```

By compiling the above file with `groovyc IntegerMetaClass.groovy` a `./groovy/runtime/metaclass/java/lang/IntegerMetaClass.class` will be generated. The example below will use this new metaclass:

```
// File testInteger.groovy
def i = 10

assert i.isBiggerThan5()
assert !i.isBiggerThan15()

println i.isBiggerThan5()
```

By running that file with `groovy -cp . testInteger.groovy` the `IntegerMetaClass` will be in the classpath and therefore it will become the metaclass for `java.lang.Integer` intercepting the method calls to `isBiggerThan*()` methods.

Per instance metaclass

You can change the metaclass of individual objects separately, so it's possible to have multiple object of the same class with different metaclasses.

```
class Foo { def bar() { "bar" }}

class FooMetaClass extends DelegatingMetaClass {
  FooMetaClass(MetaClass metaClass) { super(metaClass) }
  Object invokeMethod(Object object, String name, Object[] args) {
      super.invokeMethod(object,name,args).toUpperCase()
  }
}

def f1 = new Foo()
def f2 = new Foo()
f2.metaClass = new FooMetaClass(f2.metaClass)

assert f1.bar() == "bar"
assert f2.bar() == "BAR"
assert f1.metaClass =~ /MetaClassImpl/
assert f2.metaClass =~ /FooMetaClass/
assert f1.class.toString() == "class Foo"
assert f2.class.toString() == "class Foo"
```

ExpandoMetaClass

Groovy comes with a special `MetaClass` the so-called `ExpandoMetaClass`. It is special in that it allows for dynamically adding or changing methods, constructors, properties and even static methods by using a neat closure syntax.

Applying those modifications can be especially useful in mocking or stubbing scenarios as shown in the Testing Guide.

Every `java.lang.Class` is supplied by Groovy with a special `metaClass` property that will give you a reference to an `ExpandoMetaClass` instance. This instance can then be used to add methods or change the behaviour of already existing ones.

NOTE	By default `ExpandoMetaClass` doesn't do inheritance. To enable this you must call `ExpandoMetaClass#enableGlobally()` before your app starts such as in the main method or servlet bootstrap.

The following sections go into detail on how `ExpandoMetaClass` can be used in various scenarios.

Methods

Once the `ExpandoMetaClass` is accessed by calling the `metaClass` property, methods can be added by using either the left shift `<<` or the `=` operator.

NOTE	Note that the left shift operator is used to *append* a new method. If a public method with the same name and parameter types is declared by the class or interface, including those inherited from superclasses and superinterfaces but excluding those added to the `metaClass` at runtime, an exception will be thrown. If you want to *replace* a method declared by the class or interface you can use the `=` operator.

The operators are applied on a non-existent property of `metaClass` passing an instance of a `Closure` code block.

```
class Book {
   String title
}

Book.metaClass.titleInUpperCase << {-> title.toUpperCase() }

def b = new Book(title:"The Stand")

assert "THE STAND" == b.titleInUpperCase()
```

The example above shows how a new method can be added to a class by accessing the `metaClass` property and using the `<<` or `=` operator to assign a `Closure` code block. The `Closure` parameters are interpreted as method parameters. Parameterless methods can be added by using the `{→ …}` syntax.

Properties

`ExpandoMetaClass` supports two mechanisms for adding or overriding properties.

Firstly, it has support for declaring a *mutable property* by simply assigning a value to a property of `metaClass`:

```
class Book {
   String title
}

Book.metaClass.author = "Stephen King"
def b = new Book()

assert "Stephen King" == b.author
```

Another way is to add getter and/or setter methods by using the standard mechanisms for adding instance methods.

```
class Book {
  String title
}
Book.metaClass.getAuthor << {-> "Stephen King" }

def b = new Book()

assert "Stephen King" == b.author
```

In the source code example above the property is dictated by the closure and is a read-only property. It is feasible to add an equivalent setter method but then the property value needs to be stored for later usage. This could be done as shown in the following example.

```
class Book {
  String title
}

def properties = Collections.synchronizedMap([:])

Book.metaClass.setAuthor = { String value ->
   properties[System.identityHashCode(delegate) + "author"] = value
}
Book.metaClass.getAuthor = {->
   properties[System.identityHashCode(delegate) + "author"]
}
```

This is not the only technique however. For example in a servlet container one way might be to store the values in the currently executing request as request attributes (as is done in some cases in Grails).

Constructors

Constructors can be added by using a special `constructor` property. Either the `<<` or `=` operator can be used to assign a `Closure` code block. The `Closure` arguments will become the constructor arguments when the code is executed at runtime.

```
class Book {
    String title
}
Book.metaClass.constructor << { String title -> new Book(title:title) }

def book = new Book('Groovy in Action - 2nd Edition')
assert book.title == 'Groovy in Action - 2nd Edition'
```

NOTE Be careful when adding constructors however, as it is very easy to get into stack overflow troubles.

Static Methods

Static methods can be added using the same technique as instance methods with the addition of the `static` qualifier before the method name.

```
class Book {
   String title
}

Book.metaClass.static.create << { String title -> new Book(title:title) }

def b = Book.create("The Stand")
```

Borrowing Methods

With `ExpandoMetaClass` it is possible to use Groovy's method pointer syntax to borrow methods from other classes.

```
class Person {
    String name
}
class MortgageLender {
   def borrowMoney() {
      "buy house"
   }
}

def lender = new MortgageLender()

Person.metaClass.buyHouse = lender.&borrowMoney

def p = new Person()

assert "buy house" == p.buyHouse()
```

Dynamic Method Names

Since Groovy allows you to use Strings as property names this in turns allows you to dynamically create method and property names at runtime. To create a method with a dynamic name simply use the language feature of reference property names as strings.

```
class Person {
   String name = "Fred"
}

def methodName = "Bob"

Person.metaClass."changeNameTo${methodName}" = {-> delegate.name = "Bob" }

def p = new Person()

assert "Fred" == p.name

p.changeNameToBob()

assert "Bob" == p.name
```

The same concept can be applied to static methods and properties.

One application of dynamic method names can be found in the Grails web application framework. The concept of "dynamic codecs" is implemented by using dynamic method names.

`HTMLCodec` *Class*

```
class HTMLCodec {
    static encode = { theTarget ->
        HtmlUtils.htmlEscape(theTarget.toString())
    }

    static decode = { theTarget ->
        HtmlUtils.htmlUnescape(theTarget.toString())
    }
}
```

The example above shows a codec implementation. Grails comes with various codec implementations each defined in a single class. At runtime there will be multiple codec classes in the application classpath. At application startup the framework adds a `encodeXXX` and a `decodeXXX` method to certain metaclasses where `XXX` is the first part of the codec class name (e.g. `encodeHTML`). This mechanism is in the following shown in some Groovy pseudocode:

```
def codecs = classes.findAll { it.name.endsWith('Codec') }

codecs.each { codec ->
    Object.metaClass."encodeAs${codec.name-'Codec'}" = { codec.newInstance().encode
```

```
(delegate) }
    Object.metaClass."decodeFrom${codec.name-'Codec'}" = { codec.newInstance().decode
(delegate) }
}


def html = '<html><body>hello</body></html>'

assert '<html><body>hello</body></html>' == html.encodeAsHTML()
```

Runtime Discovery

At runtime it is often useful to know what other methods or properties exist at the time the method is executed. `ExpandoMetaClass` provides the following methods as of this writing:

- `getMetaMethod`
- `hasMetaMethod`
- `getMetaProperty`
- `hasMetaProperty`

Why can't you just use reflection? Well because Groovy is different, it has the methods that are "real" methods and methods that are available only at runtime. These are sometimes (but not always) represented as MetaMethods. The MetaMethods tell you what methods are available at runtime, thus your code can adapt.

This is of particular use when overriding `invokeMethod`, `getProperty` and/or `setProperty`.

GroovyObject Methods

Another feature of `ExpandoMetaClass` is that it allows to override the methods `invokeMethod`, `getProperty` and `setProperty`, all of them can be found in the `groovy.lang.GroovyObject` class.

The following example shows how to override `invokeMethod`:

```
class Stuff {
   def invokeMe() { "foo" }
}

Stuff.metaClass.invokeMethod = { String name, args ->
   def metaMethod = Stuff.metaClass.getMetaMethod(name, args)
   def result
   if(metaMethod) result = metaMethod.invoke(delegate,args)
   else {
      result = "bar"
   }
   result
}

def stf = new Stuff()
```

```
assert "foo" == stf.invokeMe()
assert "bar" == stf.doStuff()
```

The first step in the `Closure` code is to look up the `MetaMethod` for the given name and arguments. If the method can be found everything is fine and it is delegated to. If not, a dummy value is returned.

NOTE	A `MetaMethod` is a method that is known to exist on the `MetaClass` whether added at runtime or at compile-time.

The same logic can be used to override `setProperty` or `getProperty`.

```
class Person {
   String name = "Fred"
}

Person.metaClass.getProperty = { String name ->
   def metaProperty = Person.metaClass.getMetaProperty(name)
   def result
   if(metaProperty) result = metaProperty.getProperty(delegate)
   else {
      result = "Flintstone"
   }
   result
}

def p = new Person()

assert "Fred" == p.name
assert "Flintstone" == p.other
```

The important thing to note here is that instead of a `MetaMethod` a `MetaProperty` instance is looked up. If that exists the `getProperty` method of the `MetaProperty` is called, passing the delegate.

Overriding Static invokeMethod

`ExpandoMetaClass` even allows for overriding static method with a special `invokeMethod` syntax.

```
class Stuff {
   static invokeMe() { "foo" }
}

Stuff.metaClass.'static'.invokeMethod = { String name, args ->
   def metaMethod = Stuff.metaClass.getStaticMetaMethod(name, args)
   def result
   if(metaMethod) result = metaMethod.invoke(delegate,args)
   else {
      result = "bar"
```

```
    }
    result
}

assert "foo" == Stuff.invokeMe()
assert "bar" == Stuff.doStuff()
```

The logic that is used for overriding the static method is the same as we've seen before for overriding instance methods. The only difference is the access to the `metaClass.static` property and the call to `getStaticMethodName` for retrieving the static `MetaMethod` instance.

Extending Interfaces

It is possible to add methods onto interfaces with `ExpandoMetaClass`. To do this however, it **must** be enabled globally using the `ExpandoMetaClass.enableGlobally()` method before application start-up.

```
List.metaClass.sizeDoubled = {-> delegate.size() * 2 }

def list = []

list << 1
list << 2

assert 4 == list.sizeDoubled()
```

Extension modules

Extending existing classes

An extension module allows you to add new methods to existing classes, including classes which are precompiled, like classes from the JDK. Those new methods, unlike those defined through a metaclass or using a category, are available globally. For example, when you write:

Standard extension method

```
def file = new File(...)
def contents = file.getText('utf-8')
```

The `getText` method doesn't exist on the `File` class. However, Groovy knows it because it is defined in a special class, `ResourceGroovyMethods`:

ResourceGroovyMethods.java

```
public static String getText(File file, String charset) throws IOException {
 return IOGroovyMethods.getText(newReader(file, charset));
}
```

You may notice that the extension method is defined using a static method in a helper class (where various extension methods are defined). The first argument of the `getText` method corresponds to the receiver, while additional parameters correspond to the arguments of the extension method. So here, we are defining a method called *getText* on the `File` class (because the first argument is of type `File`), which takes a single argument as a parameter (the encoding `String`).

The process of creating an extension module is simple:

- write an extension class like above
- write a module descriptor file

Then you have to make the extension module visible to Groovy, which is as simple as having the extension module classes and descriptor available on classpath. This means that you have the choice:

- either provide the classes and module descriptor directly on classpath
- or bundle your extension module into a jar for reusability

An extension module may add two kind of methods to a class:

- instance methods (to be called on an instance of a class)
- static methods (to be called on the class itself)

Instance methods

To add an instance method to an existing class, you need to create an extension class. For example, let's say you want to add a `maxRetries` method on `Integer` which accepts a closure and executes it at most *n* times until no exception is thrown. To do that, you only need to write the following:

MaxRetriesExtension.groovy

```
class MaxRetriesExtension {                                     ①
    static void maxRetries(Integer self, Closure code) {        ②
        assert self >= 0
        int retries = self
        Throwable e = null
        while (retries > 0) {
            try {
                code.call()
                break
            } catch (Throwable err) {
                e = err
                retries--
            }
        }
        if (retries == 0 && e) {
            throw e
        }
    }
}
```

① The extension class

② First argument of the static method corresponds to the receiver of the message, that is to say the extended instance

Then, after having declared your extension class, you can call it this way:

```
int i=0
5.maxRetries {
    i++
}
assert i == 1
i=0
try {
    5.maxRetries {
        i++
        throw new RuntimeException("oops")
    }
} catch (RuntimeException e) {
    assert i == 5
}
```

Static methods

It is also possible to add static methods to a class. In that case, the static method needs to be defined in its **own** file. Static and instance extension methods **cannot** be present in the same class.

StaticStringExtension.groovy

```
class StaticStringExtension {                                    ①
    static String greeting(String self) {                        ②
        'Hello, world!'
    }
}
```

① The static extension class

② First argument of the static method corresponds to the class being extended and is **unused**

In which case you can call it directly on the `String` class:

```
assert String.greeting() == 'Hello, world!'
```

Module descriptor

For Groovy to be able to load your extension methods, you must declare your extension helper classes. You must create a file named `org.codehaus.groovy.runtime.ExtensionModule` into the `META-INF/groovy` directory:

org.codehaus.groovy.runtime.ExtensionModule

```
moduleName=Test module for specifications
moduleVersion=1.0-test
extensionClasses=support.MaxRetriesExtension
staticExtensionClasses=support.StaticStringExtension
```

The module descriptor requires 4 keys:

- *moduleName* : the name of your module
- *moduleVersion*: the version of your module. Note that version number is only used to check that you don't load the same module in two different versions.
- *extensionClasses*: the list of extension helper classes for instance methods. You can provide several classes, given that they are comma separated.
- *staticExtensionClasses*: the list of extension helper classes for static methods. You can provide several classes, given that they are comma separated.

Note that it is not required for a module to define both static helpers and instance helpers, and that you may add several classes to a single module. You can also extend different classes in a single module without problem. It is even possible to use different classes in a single extension class, but it is recommended to group extension methods into classes by feature set.

Extension modules and classpath

It's worth noting that you can't use an extension which is compiled at the same time as code using it. That means that to use an extension, it **has** to be available on classpath, as compiled classes, before the code using it gets compiled. Usually, this means that you can't have the *test* classes in the same source unit as the extension class itself. Since in general, test sources are separated from normal sources and executed in another step of the build, this is not an issue.

Compatibility with type checking

Unlike categories, extension modules are compatible with type checking: if they are found on classpath, then the type checker is aware of the extension methods and will not complain when you call them. It is also compatible with static compilation.

Compile-time metaprogramming

Compile-time metaprogramming in Groovy allows code generation at compile-time. Those transformations are altering the Abstract Syntax Tree (AST) of a program, which is why in Groovy we call it AST transformations. AST transformations allow you to hook into the compilation process, modify the AST and continue the compilation process to generate regular bytecode. Compared to runtime metaprogramming, this has the advantage of making the changes visible in the class file itself (that is to say, in the bytecode). Making it visible in the bytecode is important for example if you want the transformations to be part of the class contract (implementing interfaces, extending abstract classes, …) or even if you need your class to be callable from Java (or other JVM languages). For example, an AST transformation can add methods to a class. If you do it with runtime metaprogramming, the new method would only be visible from Groovy. If you do the same using compile-time metaprogramming, the method would be visible from Java too. Last but not least, performance would likely be better with compile-time metaprogramming (because no initialization phase is required).

In this section, we will start with explaining the various compile-time transformations that are bundled with the Groovy distribution. In a subsequent section, we will describe how you can implement your own AST transformations and what are the disadvantages of this technique.

Available AST transformations

Groovy comes with various AST transformations covering different needs: reducing boilerplate (code generation), implementing design patterns (delegation, …), logging, declarative concurrency, cloning, safer scripting, tweaking the compilation, implementing Swing patterns, testing and eventually managing dependencies. If none of those AST transformations cover your needs, you can still implement your own, as show in section Developing your own AST transformations.

AST transformations can be separated into two categories:

- global AST transformations are applied transparently, globally, as soon as they are found on compile classpath
- local AST transformations are applied by annotating the source code with markers. Unlike global AST transformations, local AST transformations may support parameters.

Groovy doesn't ship with any global AST transformation, but you can find a list of local AST transformations available for you to use in your code here:

Code generation transformations

This category of transformation includes AST transformations which help removing boilerplate code. This is typically code that you have to write but that does not carry any useful information. By autogenerating this boilerplate code, the code you have to write is left clean and concise and the chance of introducing an error by getting such boilerplate code incorrect is reduced.

`@groovy.transform.ToString`

The `@ToString` AST transformation generates a human-readable `toString` representation of the class. For example, annotating the `Person` class like below will automatically generate the `toString` method for you:

```
import groovy.transform.ToString

@ToString
class Person {
    String firstName
    String lastName
}
```

With this definition, then the following assertion passes, meaning that a `toString` method taking the field values from the class and printing them out has been generated:

```
def p = new Person(firstName: 'Jack', lastName: 'Nicholson')
assert p.toString() == 'Person(Jack, Nicholson)'
```

The `@ToString` annotation accepts several parameters which are summarized in the following table:

Attribute	Default value	Description	Example

excludes	Empty list	List of properties to exclude from toString	@ToString(excludes=['firstName'])
			class Person {
			    String firstName
			    String lastName
			}
			
			def p = new Person(firstName: 'Jack', lastName: 'Nicholson')
			assert p.toString() == 'Person(Nicholson)'

includes	Undefined marker list (indicates all fields)	List of fields to include in toString	@ToString(includes=['lastName'])
			class Person {
			    String firstName
			    String lastName
			}
			
			def p = new Person(firstName: 'Jack', lastName: 'Nicholson')
			assert p.toString() == 'Person(Nicholson)'

includeSuper	False	Should superclass be included in toString	@ToString
			class Id { long id }
			
			@ToString(includeSuper=true)
			class Person extends Id {
			    String firstName
			    String lastName
			}
			
			def p = new Person(id:1, firstName: 'Jack', lastName: 'Nicholson')
			assert p.toString() == 'Person(Jack, Nicholson, Id(1))'

Attribute	Default value	Description	Example

includeNames	false	Whether to include names of properties in generated toString.	`@ToString(includeNames=true)`
			`class Person {`
			`    String firstName`
			`    String lastName`
			`}`
			
			`def p = new Person(firstName: 'Jack', lastName: 'Nicholson')`
			`assert p.toString() == 'Person(firstName:Jack, lastName:Nicholson)'`

includeFields	False	Should fields be included in toString, in addition to properties	`@ToString(includeFields=true)`
			`class Person {`
			`    String firstName`
			`    String lastName`
			`    private int age`
			`    void test() {`
			`       age = 42`
			`    }`
			`}`
			
			`def p = new Person(firstName: 'Jack', lastName: 'Nicholson')`
			`p.test()`
			`assert p.toString() == 'Person(Jack, Nicholson, 42)'`

includeSuperProperties	False	Should super properties be included in toString	`class Person {`
			`    String name`
			`}`
			
			`@ToString(includeSuperProperties = true, includeNames = true)`
			`class BandMember extends Person {`
			`    String bandName`
			`}`
			
			`def bono = new BandMember(`
			`name:'Bono', bandName: 'U2'`
			`).toString()`
			
			`assert bono.toString() == 'BandMember(bandName:U2, name:Bono)'`

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>includeSuperFields</td><td>False</td><td>Should visible super fields be included in toString</td><td><pre>class Person {
    protected String name
}

@ToString(includeSuperFields =
true, includeNames = true)
@MapConstructor(includeSuperField
s = true)
class BandMember extends Person {
    String bandName
}

def bono = new BandMember(
name:'Bono', bandName: 'U2'
).toString()

assert bono.toString() ==
'BandMember(bandName:U2,
name:Bono)'</pre></td></tr>
<tr><td>ignoreNulls</td><td>False</td><td>Should properties/fields with null value be displayed</td><td><pre>@ToString(ignoreNulls=true)
class Person {
    String firstName
    String lastName
}

def p = new Person(firstName:
'Jack')
assert p.toString() ==
'Person(Jack)'</pre></td></tr>
<tr><td>includePackage</td><td>True</td><td>Use fully qualified class name instead of simple name in toString</td><td><pre>@ToString(includePackage=true)
class Person {
    String firstName
    String lastName
}

def p = new Person(firstName:
'Jack', lastName:'Nicholson')
assert p.toString() ==
'acme.Person(Jack, Nicholson)'</pre></td></tr>
</table>

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>allProperties</td><td>True</td><td>Include all JavaBean properties in toString</td><td><pre>
@ToString(includeNames=true)
class Person {
    String firstName
    String getLastName() { 'Nicholson' }
}

def p = new Person(firstName: 'Jack')
assert p.toString() == 'acme.Person(firstName:Jack, lastName:Nicholson)'
</pre></td></tr>
<tr><td>cache</td><td>False</td><td>Cache the toString string. Should only be set to true if the class is immutable.</td><td><pre>
@ToString(cache=true)
class Person {
    String firstName
    String lastName
}

def p = new Person(firstName: 'Jack', lastName:'Nicholson')
def s1 = p.toString()
def s2 = p.toString()
assert s1 == s2
assert s1 == 'Person(Jack, Nicholson)'
assert s1.is(s2) // same instance
</pre></td></tr>
<tr><td>allNames</td><td>False</td><td>Should fields and/or properties with internal names be included in the generated toString</td><td><pre>
@ToString(allNames=true)
class Person {
    String $firstName
}

def p = new Person($firstName: "Jack")
assert p.toString() == 'acme.Person(Jack)'
</pre></td></tr>
</table>

`@groovy.transform.EqualsAndHashCode`

The `@EqualsAndHashCode` AST transformation aims at generating `equals` and `hashCode` methods for you. The generated hashcode follows the best practices as described in *Effective Java* by *Josh Bloch*:

```
import groovy.transform.EqualsAndHashCode
```

```
@EqualsAndHashCode
class Person {
    String firstName
    String lastName
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
def p2 = new Person(firstName: 'Jack', lastName: 'Nicholson')

assert p1==p2
assert p1.hashCode() == p2.hashCode()
```

There are several options available to tweak the behavior of `@EqualsAndHashCode`:

Attribute	Default value	Description	Example

excludes	Empty list	List of properties to exclude from equals/hashCode	`import groovy.transform.EqualsAndHashCode`
			
			`@EqualsAndHashCode(excludes=['firstName'])`
			`class Person {`
			`    String firstName`
			`    String lastName`
			`}`
			
			`def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')`
			`def p2 = new Person(firstName: 'Bob', lastName: 'Nicholson')`
			
			`assert p1==p2`
			`assert p1.hashCode() == p2.hashCode()`

Attribute	Default value	Description	Example

includes	Undefined marker list (indicating all fields)	List of fields to include in equals/hashCode	`import groovy.transform.EqualsAndHashCode`
			
			`@EqualsAndHashCode(includes=['lastName'])`
			`class Person {`
			`    String firstName`
			`    String lastName`
			`}`
			
			`def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')`
			`def p2 = new Person(firstName: 'Bob', lastName: 'Nicholson')`
			
			`assert p1==p2`
			`assert p1.hashCode() == p2.hashCode()`

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>cache</td><td>False</td><td>Cache the hashCode computation. Should only be set to true if the class is immutable.</td><td>
<pre>
import groovy.transform.EqualsAndHashCode
import groovy.transform.Immutable

@Immutable
class SlowHashCode {
    static final SLEEP_PERIOD = 500

    int hashCode() {
        sleep SLEEP_PERIOD
        127
    }
}

@EqualsAndHashCode(cache=true)
@Immutable
class Person {
    SlowHashCode slowHashCode = new SlowHashCode()
}

def p = new Person()
p.hashCode()

def start = System.currentTimeMillis()
p.hashCode()
assert System.currentTimeMillis() - start < SlowHashCode.SLEEP_PERIOD
</pre>
</td></tr>
</table>

Attribute	Default value	Description	Example

callSuper	False	Whether to include super in equals and hashCode calculations	`import groovy.transform.EqualsAndHashCode`
			
			`@EqualsAndHashCode`
			`class Living {`
			`    String race`
			`}`
			
			`@EqualsAndHashCode(callSuper=true)`
			`class Person extends Living {`
			`    String firstName`
			`    String lastName`
			`}`
			
			`def p1 = new Person(race:'Human', firstName: 'Jack', lastName: 'Nicholson')`
			`def p2 = new Person(race: 'Human being', firstName: 'Jack', lastName: 'Nicholson')`
			
			`assert p1!=p2`
			`assert p1.hashCode() != p2.hashCode()`

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>includeFields</td><td>False</td><td>Should fields be included in equals/hashCode, in addition to properties</td><td>

```
import groovy.transform.EqualsAndHashCode

@EqualsAndHashCode(includeFields=true)
class Person {
    private String firstName

    Person(String firstName) {
        this.firstName = firstName
    }
}

def p1 = new Person('Jack')
def p2 = new Person('Jack')
def p3 = new Person('Bob')

assert p1 == p2
assert p1 != p3
```

</td></tr>
<tr><td>useCanEqual</td><td>True</td><td>Should equals call canEqual helper method.</td><td>See http://www.artima.com/lejava/articles/equality.html</td></tr>
<tr><td>allProperties</td><td>False</td><td>Should JavaBean properties be included in equals and hashCode calculations</td><td>

```
@EqualsAndHashCode(allProperties=true, excludes='first, last')
class Person {
    String first, last
    String getInitials() { first[0] + last[0] }
}

def p1 = new Person(first: 'Jack', last: 'Smith')
def p2 = new Person(first: 'Jack', last: 'Spratt')
def p3 = new Person(first: 'Bob', last: 'Smith')

assert p1 == p2
assert p1.hashCode() == p2.hashCode()
assert p1 != p3
assert p1.hashCode() != p3.hashCode()
```

</td></tr>
</table>

Attribute	Default value	Description	Example

allNames	False	Should fields and/or properties with internal names be included in equals and hashCode calculations	`import groovy.transform.EqualsAndHashCode`
			
			`@EqualsAndHashCode(allNames=true)`
			`class Person {`
			`    String $firstName`
			`}`
			
			`def p1 = new Person($firstName: 'Jack')`
			`def p2 = new Person($firstName: 'Bob')`
			
			`assert p1 != p2`
			`assert p1.hashCode() != p2.hashCode()`

`@groovy.transform.TupleConstructor`

The `@TupleConstructor` annotation aims at eliminating boilerplate code by generating constructors for you. A tuple constructor is created having a parameter for each property (and possibly each field). Each parameter has a default value (using the initial value of the property if present or otherwise Java's default value according to the properties type).

Implementation Details

Normally you don't need to understand the implementation details of the generated constructor(s); you just use them in the normal way. However, if you want to add multiple constructors, understand Java integration options or meet requirements of some dependency injection frameworks, then some details are useful.

As previously mentioned, the generated constructor has default values applied. In later compilation phases, the Groovy compiler's standard default value processing behavior is then applied. The end result is that multiple constructors are placed within the bytecode of your class. This provides a well understood semantics and is also useful for Java integration purposes. As an example, the following code will generate 3 constructors:

```
import groovy.transform.TupleConstructor

@TupleConstructor
class Person {
    String firstName
    String lastName
}
```

```
// traditional map-style constructor
def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
// generated tuple constructor
def p2 = new Person('Jack', 'Nicholson')
// generated tuple constructor with default value for second property
def p3 = new Person('Jack')
```

The first constructor is a no-arg constructor which allows the traditional map-style construction so long as you don't have final properties. Groovy calls the no-arg constructor and then the relevant setters under the covers. It is worth noting that if the first property (or field) has type LinkedHashMap or if there is a single Map, AbstractMap or HashMap property (or field), then the map-style named arguments won't be available.

The other constructors are generated by taking the properties in the order they are defined. Groovy will generate as many constructors as there are properties (or fields, depending on the options).

Setting the `defaults` attribute (see the available configuration options table) to `false`, disables the normal default values behavior which means:

- Exactly one constructor will be produced
- Attempting to use an initial value will produce an error
- Map-style named arguments won't be available

This attribute is normally only used in situations where another Java framework is expecting exactly one constructor, e.g. injection frameworks or JUnit parameterized runners.

Immutability support

If the `@PropertyOptions` annotation is also found on the class with the `@TupleConstructor` annotation, then the generated constructor may contain custom property handling logic. The `propertyHandler` attribute on the `@PropertyOptions` annotation could for instance be set to `ImmutablePropertyHandler` which will result in the addition of the necessary logic for immutable classes (defensive copy in, cloning, etc.). This normally would happen automatically behind the scenes when you use the `@Immutable` meta-annotation. Some of the annotation attributes might not be supported by all property handlers.

Customization options

The `@TupleConstructor` AST transformation accepts several annotation attributes:

<table>
<thead>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
</thead>
<tbody>
<tr><td>excludes</td><td>Empty list</td><td>List of properties to exclude from tuple constructor generation</td><td><pre><code>import groovy.transform.TupleConstructor

@TupleConstructor(excludes=['lastName'])
class Person {
    String firstName
    String lastName
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
def p2 = new Person('Jack')
try {
    // will fail because the second property is excluded
    def p3 = new Person('Jack', 'Nicholson')
} catch (e) {
    assert e.message.contains('Could not find matching constructor')
}</code></pre></td></tr>
</tbody>
</table>

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>includes</td><td>Undefined list (indicates all fields)</td><td>List of fields to include in tuple constructor generation</td><td>

```
import groovy.transform.TupleConstructor

@TupleConstructor(includes=['firstName'])
class Person {
    String firstName
    String lastName
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
def p2 = new Person('Jack')
try {
    // will fail because the second property is not included
    def p3 = new Person('Jack', 'Nicholson')
} catch (e) {
    assert e.message.contains('Could not find matching constructor')
}
```

</td></tr>
<tr><td>includeProperties</td><td>True</td><td>Should properties be included in tuple constructor generation</td><td>

```
import groovy.transform.TupleConstructor

@TupleConstructor(includeProperties=false)
class Person {
    String firstName
    String lastName
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')

try {
    def p2 = new Person('Jack', 'Nicholson')
} catch(e) {
    // will fail because properties are not included
}
```

</td></tr>
</table>

<table>
<thead>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
</thead>
<tbody>
<tr><td>includeFields</td><td>False</td><td>Should fields be included in tuple constructor generation, in addition to properties</td><td>

```
import groovy.transform.TupleConstructor

@TupleConstructor(includeFields=true)
class Person {
    String firstName
    String lastName
    private String occupation
    public String toString() {
        "$firstName $lastName: $occupation"
    }
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson', occupation: 'Actor')
def p2 = new Person('Jack', 'Nicholson', 'Actor')

assert p1.firstName == p2.firstName
assert p1.lastName == p2.lastName
assert p1.toString() == 'Jack Nicholson: Actor'
assert p1.toString() == p2.toString()
```

</td></tr>
</tbody>
</table>

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>includeSuperProperties</td><td>True</td><td>Should properties from super classes be included in tuple constructor generation</td><td>

```
import groovy.transform.TupleConstructor

class Base {
    String occupation
}

@TupleConstructor(includeSuperProperties=true)
class Person extends Base {
    String firstName
    String lastName
    public String toString() {
        "$firstName $lastName: $occupation"
    }
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')

def p2 = new Person('Actor', 'Jack', 'Nicholson')

assert p1.firstName == p2.firstName
assert p1.lastName == p2.lastName
assert p1.toString() == 'Jack Nicholson: null'
assert p2.toString() == 'Jack Nicholson: Actor'
```

</td></tr>
</table>

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>includeSuperFields</td><td>False</td><td>Should fields from super classes be included in tuple constructor generation</td><td>

```groovy
import groovy.transform.TupleConstructor

class Base {
    protected String occupation
    public String occupation() { this.occupation }
}

@TupleConstructor(includeSuperFields=true)
class Person extends Base {
    String firstName
    String lastName
    public String toString() {
        "$firstName $lastName: ${occupation()}"
    }
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson', occupation: 'Actor')

def p2 = new Person('Actor', 'Jack', 'Nicholson')

assert p1.firstName == p2.firstName
assert p1.lastName == p2.lastName
assert p1.toString() == 'Jack Nicholson: Actor'
assert p2.toString() == p1.toString()
```

</td></tr>
</table>

Attribute	Default value	Description	Example

callSuper	False	Should super properties be called within a call to the parent constructor rather than set as properties	`import groovy.transform.TupleConstructor`
			
			`class Base {`
			`    String occupation`
			`    Base() {}`
			`    Base(String job) { occupation = job?.toLowerCase() }`
			`}`
			
			`@TupleConstructor(includeSuperProperties = true, callSuper=true)`
			`class Person extends Base {`
			`    String firstName`
			`    String lastName`
			`    public String toString() {`
			`        "$firstName $lastName: $occupation"`
			`    }`
			`}`
			
			`def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')`
			
			`def p2 = new Person('ACTOR', 'Jack', 'Nicholson')`
			
			`assert p1.firstName == p2.firstName`
			`assert p1.lastName == p2.lastName`
			`assert p1.toString() == 'Jack Nicholson: null'`
			`assert p2.toString() == 'Jack Nicholson: actor'`

<table>
<thead>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
</thead>
<tbody>
<tr>
<td>force</td>
<td>False</td>
<td>By default, the transformation will do nothing if a constructor is already defined. Setting this attribute to true, the constructor will be generated and it’s your responsibility to ensure that no duplicate constructor is defined.</td>
<td>

```
import groovy.transform.*

@ToString @TupleConstructor(force=true)
final class Person {
    String name
    // explicit constructor would normally disable tuple constructor
    Person(String first, String last) { this("$first $last") }
}

assert new Person('john smith').toString() == 'Person(john smith)'
assert new Person('john', 'smith').toString() == 'Person(john smith)'
```

</td>
</tr>
<tr>
<td>defaults</td>
<td>True</td>
<td>Indicates that default value processing is enabled for constructor parameters. Set to false to obtain exactly one constructor but with initial value support and named-arguments disabled.</td>
<td>

```
@ToString
@TupleConstructor(defaults=false)
class Musician {
  String name
  String instrument
  int born
}

assert new Musician('Jimi', 'Guitar', 1942).toString() == 'Musician(Jimi, Guitar, 1942)'
assert Musician.constructors.size() == 1
```

</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
</thead>
<tbody>
<tr>
<td>useSetters</td>
<td>False</td>
<td>By default, the transformation will directly set the backing field of each property from its corresponding constructor parameter. Setting this attribute to true, the constructor will instead call setters if they exist. It’s usually deemed bad style from within a constructor to call setters that can be overridden. It’s your responsibility to avoid such bad style.</td>
<td><pre><code>import groovy.transform.*

@ToString @TupleConstructor(useSetters=true)
final class Foo {
    String bar
    void setBar(String bar) {
        this.bar = bar?.toUpperCase() // null-safe
    }
}

assert new Foo('cat').toString() == 'Foo(CAT)'
assert new Foo(bar: 'cat').toString() == 'Foo(CAT)'</code></pre></td>
</tr>
<tr>
<td>allNames</td>
<td>False</td>
<td>Should fields and/or properties with internal names be included within the constructor</td>
<td><pre><code>import groovy.transform.TupleConstructor

@TupleConstructor(allNames=true)
class Person {
    String $firstName
}

def p = new Person('Jack')

assert p.$firstName == 'Jack'</code></pre></td>
</tr>
<tr>
<td>allProperties</td>
<td>False</td>
<td>Should JavaBean properties be included within the constructor</td>
<td><pre><code>@TupleConstructor(allProperties=true)
class Person {
    String first
    private String last
    void setLast(String last) {
        this.last = last
    }
    String getName() { "$first $last" }
}

assert new Person('john', 'smith').name == 'john smith'</code></pre></td>
</tr>
</tbody>
</table>

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>pre</td><td>empty</td><td>A closure containing statements to be inserted at the start of the generated constructor(s)</td><td><pre>import
groovy.transform.TupleConstructor

@TupleConstructor(pre={ first =
first?.toLowerCase() })
class Person {
    String first
}

def p = new Person('Jack')

assert p.first == 'jack'</pre></td></tr>
<tr><td>post</td><td>empty</td><td>A closure containing statements to be inserted at the end of the generated constructor(s)</td><td><pre>import
groovy.transform.TupleConstructor
import static groovy.test
.GroovyAssert.shouldFail

@TupleConstructor(post={ assert
first })
class Person {
    String first
}

def jack = new Person('Jack')
shouldFail {
  def unknown = new Person()
}</pre></td></tr>
</table>

Setting the `defaults` annotation attribute to `false` and the `force` annotation attribute to `true` allows multiple tuple constructors to be created by using different customization options for the different cases (provided each case has a different type signature) as shown in the following example:

```
class Named {
  String name
}

@ToString(includeSuperProperties=true, ignoreNulls=true, includeNames=true,
includeFields=true)
@TupleConstructor(force=true, defaults=false)
@TupleConstructor(force=true, defaults=false, includeFields=true)
@TupleConstructor(force=true, defaults=false, includeSuperProperties=true)
class Book extends Named {
  Integer published
```

```
    private Boolean fiction
    Book() {}
}

assert new Book("Regina", 2015).toString() == 'Book(published:2015, name:Regina)'
assert new Book(2015, false).toString() == 'Book(published:2015, fiction:false)'
assert new Book(2015).toString() == 'Book(published:2015)'
assert new Book().toString() == 'Book()'
assert Book.constructors.size() == 4
```

Similarly, here is another example using different options for `includes`:

```
@ToString(includeSuperProperties=true, ignoreNulls=true, includeNames=true,
includeFields=true)
@TupleConstructor(force=true, defaults=false, includes='name,year')
@TupleConstructor(force=true, defaults=false, includes='year,fiction')
@TupleConstructor(force=true, defaults=false, includes='name,fiction')
class Book {
    String name
    Integer year
    Boolean fiction
}

assert new Book("Regina", 2015).toString() == 'Book(name:Regina, year:2015)'
assert new Book(2015, false).toString() == 'Book(year:2015, fiction:false)'
assert new Book("Regina", false).toString() == 'Book(name:Regina, fiction:false)'
assert Book.constructors.size() == 3
```

`@groovy.transform.MapConstructor`

The `@MapConstructor` annotation aims at eliminating boilerplate code by generating a map constructor for you. A map constructor is created such that each property in the class is set based on the value in the supplied map having the key with the name of the property. Usage is as shown in this example:

```
import groovy.transform.*

@ToString
@MapConstructor
class Person {
    String firstName
    String lastName
}

def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
assert p1.toString() == 'Person(Jack, Nicholson)'
```

The generated constructor will be roughly like this:

```
public Person(Map args) {
    if (args.containsKey('firstName')) {
        this.firstName = args.get('firstName')
    }
    if (args.containsKey('lastName')) {
        this.lastName = args.get('lastName')
    }
}
```

`@groovy.transform.Canonical`

The `@Canonical` meta-annotation combines the @ToString, @EqualsAndHashCode and @TupleConstructor annotations:

```
import groovy.transform.Canonical

@Canonical
class Person {
    String firstName
    String lastName
}
def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
assert p1.toString() == 'Person(Jack, Nicholson)' // Effect of @ToString

def p2 = new Person('Jack','Nicholson') // Effect of @TupleConstructor
assert p2.toString() == 'Person(Jack, Nicholson)'

assert p1==p2 // Effect of @EqualsAndHashCode
assert p1.hashCode()==p2.hashCode() // Effect of @EqualsAndHashCode
```

A similar immutable class can be generated using the @Immutable meta-annotation instead. The `@Canonical` meta-annotation supports the configuration options found in the annotations it aggregates. See those annotations for more details.

```
import groovy.transform.Canonical

@Canonical(excludes=['lastName'])
class Person {
    String firstName
    String lastName
}
def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
assert p1.toString() == 'Person(Jack)' // Effect of @ToString(excludes=['lastName'])

def p2 = new Person('Jack') // Effect of @TupleConstructor(excludes=['lastName'])
assert p2.toString() == 'Person(Jack)'

assert p1==p2 // Effect of @EqualsAndHashCode(excludes=['lastName'])
```

```
assert p1.hashCode()==p2.hashCode() // Effect of
@EqualsAndHashCode(excludes=['lastName'])
```

The `@Canonical` meta-annotation can be used in conjunction with an explicit use one or more of its component annotations, like this:

```
import groovy.transform.Canonical

@Canonical(excludes=['lastName'])
class Person {
    String firstName
    String lastName
}
def p1 = new Person(firstName: 'Jack', lastName: 'Nicholson')
assert p1.toString() == 'Person(Jack)' // Effect of @ToString(excludes=['lastName'])

def p2 = new Person('Jack') // Effect of @TupleConstructor(excludes=['lastName'])
assert p2.toString() == 'Person(Jack)'

assert p1==p2 // Effect of @EqualsAndHashCode(excludes=['lastName'])
assert p1.hashCode()==p2.hashCode() // Effect of
@EqualsAndHashCode(excludes=['lastName'])
```

Any applicable annotation attributes from `@Canonical` are passed along to the explicit annotation but attributes already existing in the explicit annotation take precedence.

`@groovy.transform.InheritConstructors`

The `@InheritConstructor` AST transformation aims at generating constructors matching super constructors for you. This is in particular useful when overriding exception classes:

```
import groovy.transform.InheritConstructors

@InheritConstructors
class CustomException extends Exception {}

// all those are generated constructors
new CustomException()
new CustomException("A custom message")
new CustomException("A custom message", new RuntimeException())
new CustomException(new RuntimeException())

// Java 7 only
// new CustomException("A custom message", new RuntimeException(), false, true)
```

The `@InheritConstructor` AST transformation supports the following configuration options:

Attribute	Default value	Description	Example

constructorAnnotations	False	Whether to carry over annotations from the constructor during copying	`@Retention(RetentionPolicy.RUNTIME)`
			`@Target([ElementType.CONSTRUCTOR])`
			`public @interface ConsAnno {}`
			
			`class Base {`
			`  @ConsAnno Base() {}`
			`}`
			
			`@InheritConstructors(constructorAnnotations=true)`
			`class Child extends Base {}`
			
			`assert Child.constructors[0].annotations[0].annotationType().name == 'groovy.transform.Generated'`
			`assert Child.constructors[0].annotations[1].annotationType().name == 'ConsAnno'`

parameterAnnotations	False	Whether to carry over annotations from the constructor parameters when copying the constructor	`@Retention(RetentionPolicy.RUNTIME)`
			`@Target([ElementType.PARAMETER])`
			`public @interface ParamAnno {}`
			
			`class Base {`
			`  Base(@ParamAnno String name) {}`
			`}`
			
			`@InheritConstructors(parameterAnnotations=true)`
			`class Child extends Base {}`
			
			`assert Child.constructors[0].parameterAnnotations[0][0].annotationType().name == 'ParamAnno'`

`@groovy.lang.Category`

The `@Category` AST transformation simplifies the creation of Groovy categories. Historically, a Groovy category was written like this:

```
class TripleCategory {
    public static Integer triple(Integer self) {
        3*self
    }
}
use (TripleCategory) {
    assert 9 == 3.triple()
}
```

The `@Category` transformation lets you write the same using an instance-style class, rather than a static class style. This removes the need for having the first argument of each method being the receiver. The category can be written like this:

```
@Category(Integer)
class TripleCategory {
    public Integer triple() { 3*this }
}
use (TripleCategory) {
    assert 9 == 3.triple()
}
```

Note that the mixed in class can be referenced using `this` instead. It's also worth noting that using instance fields in a category class is inherently unsafe: categories are not stateful (like traits).

`@groovy.transform.IndexedProperty`

The `@IndexedProperty` annotation aims at generating indexed getters/setters for properties of list/array types. This is in particular useful if you want to use a Groovy class from Java. While Groovy supports GPath to access properties, this is not available from Java. The `@IndexedProperty` annotation will generate indexed properties of the following form:

```
class SomeBean {
    @IndexedProperty String[] someArray = new String[2]
    @IndexedProperty List someList = []
}

def bean = new SomeBean()
bean.setSomeArray(0, 'value')
bean.setSomeList(0, 123)

assert bean.someArray[0] == 'value'
assert bean.someList == [123]
```

`@groovy.lang.Lazy`

The `@Lazy` AST transformation implements lazy initialization of fields. For example, the following code:

```
class SomeBean {
    @Lazy LinkedList myField
}
```

will produce the following code:

```
List $myField
List getMyField() {
    if ($myField!=null) { return $myField }
    else {
        $myField = new LinkedList()
        return $myField
    }
}
```

The default value which is used to initialize the field is the default constructor of the declaration type. It is possible to define a default value by using a closure on the right hand side of the property assignment, as in the following example:

```
class SomeBean {
    @Lazy LinkedList myField = { ['a','b','c']}()
}
```

In that case, the generated code looks like the following:

```
List $myField
List getMyField() {
    if ($myField!=null) { return $myField }
    else {
        $myField = { ['a','b','c']}()
        return $myField
    }
}
```

If the field is declared volatile then initialization will be synchronized using the double-checked locking pattern.

Using the `soft=true` parameter, the helper field will use a `SoftReference` instead, providing a simple way to implement caching. In that case, if the garbage collector decides to collect the reference, initialization will occur the next time the field is accessed.

`@groovy.lang.Newify`

The `@Newify` AST transformation is used to bring alternative syntaxes to construct objects:

- Using the `Python` style:

```
@Newify([Tree,Leaf])
class TreeBuilder {
    Tree tree = Tree(Leaf('A'),Leaf('B'),Tree(Leaf('C')))
}
```

- or using the Ruby style:

```
@Newify([Tree,Leaf])
class TreeBuilder {
    Tree tree = Tree.new(Leaf.new('A'),Leaf.new('B'),Tree.new(Leaf.new('C')))
}
```

The Ruby version can be disabled by setting the auto flag to false.

@groovy.transform.Sortable

The @Sortable AST transformation is used to help write classes that are Comparable and easily sorted typically by numerous properties. It is easy to use as shown in the following example where we annotate the Person class:

```
import groovy.transform.Sortable

@Sortable class Person {
    String first
    String last
    Integer born
}
```

The generated class has the following properties:

- it implements the Comparable interface
- it contains a compareTo method with an implementation based on the natural ordering of the first, last and born properties
- it has three methods returning comparators: comparatorByFirst, comparatorByLast and comparatorByBorn.

The generated compareTo method will look like this:

```
public int compareTo(java.lang.Object obj) {
    if (this.is(obj)) {
        return 0
    }
    if (!(obj instanceof Person)) {
        return -1
    }
    java.lang.Integer value = this.first <=> obj.first
```

```
    if (value != 0) {
        return value
    }
    value = this.last <=> obj.last
    if (value != 0) {
        return value
    }
    value = this.born <=> obj.born
    if (value != 0) {
        return value
    }
    return 0
}
```

As an example of the generated comparators, the `comparatorByFirst` comparator will have a `compare` method that looks like this:

```
public int compare(java.lang.Object arg0, java.lang.Object arg1) {
    if (arg0 == arg1) {
        return 0
    }
    if (arg0 != null && arg1 == null) {
        return -1
    }
    if (arg0 == null && arg1 != null) {
        return 1
    }
    return arg0.first <=> arg1.first
}
```

The `Person` class can be used wherever a `Comparable` is expected and the generated comparators wherever a `Comparator` is expected as shown by these examples:

```
def people = [
    new Person(first: 'Johnny', last: 'Depp', born: 1963),
    new Person(first: 'Keira', last: 'Knightley', born: 1985),
    new Person(first: 'Geoffrey', last: 'Rush', born: 1951),
    new Person(first: 'Orlando', last: 'Bloom', born: 1977)
]

assert people[0] > people[2]
assert people.sort()*.last == ['Rush', 'Depp', 'Knightley', 'Bloom']
assert people.sort(false, Person.comparatorByFirst())*.first == ['Geoffrey', 'Johnny',
'Keira', 'Orlando']
assert people.sort(false, Person.comparatorByLast())*.last == ['Bloom', 'Depp',
'Knightley', 'Rush']
assert people.sort(false, Person.comparatorByBorn())*.last == ['Rush', 'Depp',
'Bloom', 'Knightley']
```

Normally, all properties are used in the generated `compareTo` method in the priority order in which they are defined. You can include or exclude certain properties from the generated `compareTo` method by giving a list of property names in the `includes` or `excludes` annotation attributes. If using `includes`, the order of the property names given will determine the priority of properties when comparing. To illustrate, consider the following `Person` class definition:

```
@Sortable(includes='first,born') class Person {
    String last
    int born
    String first
}
```

It will have two comparator methods `comparatorByFirst` and `comparatorByBorn` and the generated `compareTo` method will look like this:

```
public int compareTo(java.lang.Object obj) {
    if (this.is(obj)) {
        return 0
    }
    if (!(obj instanceof Person)) {
        return -1
    }
    java.lang.Integer value = this.first <=> obj.first
    if (value != 0) {
        return value
    }
    value = this.born <=> obj.born
    if (value != 0) {
        return value
    }
    return 0
}
```

This `Person` class can be used as follows:

```
def people = [
    new Person(first: 'Ben', last: 'Affleck', born: 1972),
    new Person(first: 'Ben', last: 'Stiller', born: 1965)
]

assert people.sort()*.last == ['Stiller', 'Affleck']
```

The behavior of the `@Sortable` AST transformation can be further changed using the following additional parameters:

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>allProperties</td><td>True</td><td>Should JavaBean properties (ordered after native properties) be used</td><td>

```
import groovy.transform.*

@Canonical(includeFields = true)
@Sortable(allProperties = true,
includes = 'nameSize')
class Player {
  String name
  int getNameSize() { name.size()
}
}

def finalists = [
  new Player('Serena'),
  new Player('Venus'),
  new Player('CoCo'),
  new Player('Mirjana')
]

assert finalists.sort()*.name ==
['CoCo', 'Venus', 'Serena',
'Mirjana']
```

</td></tr>
<tr><td>allNames</td><td>False</td><td>Should properties with "internal" names be used</td><td>

```
import groovy.transform.*

@Canonical(allNames = true)
@Sortable(allNames = false)
class Player {
  String $country
  String name
}

def finalists = [
  new Player('USA', 'Serena'),
  new Player('USA', 'Venus'),
  new Player('USA', 'CoCo'),
  new Player('Croatian',
'Mirjana')
]

assert finalists.sort()*.name ==
['Mirjana', 'CoCo', 'Serena',
'Venus']
```

</td></tr>
</table>

Attribute	Default value	Description	Example

includeSuperProperties	False	Should super properties also be used (ordered first)	`class Person {`
			`  String name`
			`}`
			
			`@Canonical(includeSuperProperties = true)`
			`@Sortable(includeSuperProperties = true)`
			`class Citizen extends Person {`
			`  String country`
			`}`
			
			`def people = [`
			`  new Citizen('Bob', 'Italy'),`
			`  new Citizen('Cathy', 'Hungary'),`
			`  new Citizen('Cathy', 'Egypt'),`
			`  new Citizen('Bob', 'Germany'),`
			`  new Citizen('Alan', 'France')`
			`]`
			
			`assert people.sort()*.name == ['Alan', 'Bob', 'Bob', 'Cathy', 'Cathy']`
			`assert people.sort()*.country == ['France', 'Germany', 'Italy', 'Egypt', 'Hungary']`

`@groovy.transform.builder.Builder`

The `@Builder` AST transformation is used to help write classes that can be created using *fluent* api calls. The transform supports multiple building strategies to cover a range of cases and there are a number of configuration options to customize the building process. If you're an AST hacker, you can also define your own strategy class. The following table lists the available strategies that are bundled with Groovy and the configuration options each strategy supports.

Strategy	Description	builderClassName	builderMethodName	buildMethodName	prefix	includes/excludes	includeSuperProperties	allNames
`SimpleStrategy`	chained setters	n/a	n/a	n/a	yes, default "set"	yes	n/a	yes, default `false`

`ExternalStrategy`	explicit builder class, class being built untouched	n/a	n/a	yes, default "build"	yes, default ""	yes	yes, default `false`	yes, default `false`
`DefaultStrategy`	creates a nested helper class	yes, default <*TypeName*>Builder	yes, default "builder"	yes, default "build"	yes, default ""	yes	yes, default `false`	yes, default `false`
`InitializerStrategy`	creates a nested helper class providing type-safe fluent creation	yes, default <*TypeName*>Initializer	yes, default "createInitializer"	yes, default "create" but usually only used internally	yes, default ""	yes	yes, default `false`	yes, default `false`

SimpleStrategy

To use the `SimpleStrategy`, annotate your Groovy class using the `@Builder` annotation, and specify the strategy as shown in this example:

```
import groovy.transform.builder.*

@Builder(builderStrategy=SimpleStrategy)
class Person {
    String first
    String last
    Integer born
}
```

Then, just call the setters in a chained fashion as shown here:

```
def p1 = new Person().setFirst('Johnny').setLast('Depp').setBorn(1963)
assert "$p1.first $p1.last" == 'Johnny Depp'
```

For each property, a generated setter will be created which looks like this:

```
public Person setFirst(java.lang.String first) {
    this.first = first
    return this
```

```
}
```

You can specify a prefix as shown in this example:

```
import groovy.transform.builder.*

@Builder(builderStrategy=SimpleStrategy, prefix="")
class Person {
    String first
    String last
    Integer born
}
```

And calling the chained setters would look like this:

```
def p = new Person().first('Johnny').last('Depp').born(1963)
assert "$p.first $p.last" == 'Johnny Depp'
```

You can use the `SimpleStrategy` in conjunction with `@TupleConstructor`. If your `@Builder` annotation doesn't have explicit `includes` or `excludes` annotation attributes but your `@TupleConstructor` annotation does, the ones from `@TupleConstructor` will be re-used for `@Builder`. The same applies for any annotation aliases which combine `@TupleConstructor` such as `@Canonical`.

The annotation attribute `useSetters` can be used if you have a setter which you want called as part of the construction process. See the JavaDoc for details.

The annotation attributes `builderClassName`, `buildMethodName`, `builderMethodName`, `forClass` and `includeSuperProperties` are not supported for this strategy.

NOTE Groovy already has built-in building mechanisms. Don't rush to using `@Builder` if the built-in mechanisms meet your needs. Some examples:

```
def p2 = new Person(first: 'Keira', last: 'Knightley', born: 1985)
def p3 = new Person().tap {
    first = 'Geoffrey'
    last = 'Rush'
    born = 1951
}
```

ExternalStrategy

To use the `ExternalStrategy`, create and annotate a Groovy builder class using the `@Builder` annotation, specify the class the builder is for using `forClass` and indicate use of the `ExternalStrategy`. Suppose you have the following class you would like a builder for:

```
class Person {
```

```
    String first
    String last
    int born
}
```

you explicitly create and use your builder class as follows:

```
import groovy.transform.builder.*

@Builder(builderStrategy=ExternalStrategy, forClass=Person)
class PersonBuilder { }

def p = new PersonBuilder().first('Johnny').last('Depp').born(1963).build()
assert "$p.first $p.last" == 'Johnny Depp'
```

Note that the (normally empty) builder class you provide will be filled in with appropriate setters and a build method. The generated build method will look something like:

```
public Person build() {
    Person _thePerson = new Person()
    _thePerson.first = first
    _thePerson.last = last
    _thePerson.born = born
    return _thePerson
}
```

The class you are creating the builder for can be any Java or Groovy class following the normal JavaBean conventions, e.g. a no-arg constructor and setters for the properties. Here is an example using a Java class:

```
import groovy.transform.builder.*

@Builder(builderStrategy=ExternalStrategy, forClass=javax.swing.DefaultButtonModel)
class ButtonModelBuilder {}

def model = new ButtonModelBuilder().enabled(true).pressed(true).armed(true).rollover
(true).selected(true).build()
assert model.isArmed()
assert model.isPressed()
assert model.isEnabled()
assert model.isSelected()
assert model.isRollover()
```

The generated builder can be customised using the `prefix`, `includes`, `excludes` and `buildMethodName` annotation attributes. Here is an example illustrating various customisations:

```
import groovy.transform.builder.*
import groovy.transform.Canonical

@Canonical
class Person {
    String first
    String last
    int born
}

@Builder(builderStrategy=ExternalStrategy, forClass=Person, includes=['first',
'last'], buildMethodName='create', prefix='with')
class PersonBuilder { }

def p = new PersonBuilder().withFirst('Johnny').withLast('Depp').create()
assert "$p.first $p.last" == 'Johnny Depp'
```

The `builderMethodName` and `builderClassName` annotation attributes for `@Builder` aren't applicable for this strategy.

You can use the `ExternalStrategy` in conjunction with `@TupleConstructor`. If your `@Builder` annotation doesn't have explicit `includes` or `excludes` annotation attributes but the `@TupleConstructor` annotation of the class you are creating the builder for does, the ones from `@TupleConstructor` will be re-used for `@Builder`. The same applies for any annotation aliases which combine `@TupleConstructor` such as `@Canonical`.

DefaultStrategy

To use the `DefaultStrategy`, annotate your Groovy class using the `@Builder` annotation as shown in this example:

```
import groovy.transform.builder.Builder

@Builder
class Person {
    String firstName
    String lastName
    int age
}

def person = Person.builder().firstName("Robert").lastName("Lewandowski").age(21
).build()
assert person.firstName == "Robert"
assert person.lastName == "Lewandowski"
assert person.age == 21
```

If you want, you can customize various aspects of the building process using the `builderClassName`, `buildMethodName`, `builderMethodName`, `prefix`, `includes` and `excludes` annotation attributes, some of which are used in the example here:

```
import groovy.transform.builder.Builder

@Builder(buildMethodName='make', builderMethodName='maker', prefix='with', excludes
='age')
class Person {
    String firstName
    String lastName
    int age
}

def p = Person.maker().withFirstName("Robert").withLastName("Lewandowski").make()
assert "$p.firstName $p.lastName" == "Robert Lewandowski"
```

This strategy also supports annotating static methods and constructors. In this case, the static method or constructor parameters become the properties to use for building purposes and in the case of static methods, the return type of the method becomes the target class being built. If you have more than one `@Builder` annotation used within a class (at either the class, method or constructor positions) then it is up to you to ensure that the generated helper classes and factory methods have unique names (i.e. no more than one can use the default name values). Here is an example highlighting method and constructor usage (and also illustrating the renaming required for unique names).

```
import groovy.transform.builder.*
import groovy.transform.*

@ToString
@Builder
class Person {
  String first, last
  int born

  Person(){}

  @Builder(builderClassName='MovieBuilder', builderMethodName='byRoleBuilder')
  Person(String roleName) {
     if (roleName == 'Jack Sparrow') {
         this.first = 'Johnny'; this.last = 'Depp'; this.born = 1963
     }
  }

  @Builder(builderClassName='NameBuilder', builderMethodName='nameBuilder', prefix
='having', buildMethodName='fullName')
  static String join(String first, String last) {
      first + ' ' + last
  }

  @Builder(builderClassName='SplitBuilder', builderMethodName='splitBuilder')
  static Person split(String name, int year) {
      def parts = name.split(' ')
```

```
        new Person(first: parts[0], last: parts[1], born: year)
    }
}

assert Person.splitBuilder().name("Johnny Depp").year(1963).build().toString() ==
'Person(Johnny, Depp, 1963)'
assert Person.byRoleBuilder().roleName("Jack Sparrow").build().toString() ==
'Person(Johnny, Depp, 1963)'
assert Person.nameBuilder().havingFirst('Johnny').havingLast('Depp').fullName() ==
'Johnny Depp'
assert Person.builder().first("Johnny").last('Depp').born(1963).build().toString() ==
'Person(Johnny, Depp, 1963)'
```

The `forClass` annotation attribute is not supported for this strategy.

InitializerStrategy

To use the `InitializerStrategy`, annotate your Groovy class using the `@Builder` annotation, and specify the strategy as shown in this example:

```
import groovy.transform.builder.*
import groovy.transform.*

@ToString
@Builder(builderStrategy=InitializerStrategy)
class Person {
    String firstName
    String lastName
    int age
}
```

Your class will be locked down to have a single public constructor taking a "fully set" initializer. It will also have a factory method to create the initializer. These are used as follows:

```
@CompileStatic
def firstLastAge() {
    assert new Person(Person.createInitializer().firstName("John").lastName("Smith"
).age(21)).toString() == 'Person(John, Smith, 21)'
}
firstLastAge()
```

Any attempt to use the initializer which doesn't involve setting all the properties (though order is not important) will result in a compilation error. If you don't need this level of strictness, you don't need to use `@CompileStatic`.

You can use the `InitializerStrategy` in conjunction with `@Canonical` and `@Immutable`. If your `@Builder` annotation doesn't have explicit `includes` or `excludes` annotation attributes but your `@Canonical` annotation does, the ones from `@Canonical` will be re-used for `@Builder`. Here is an example using

`@Builder` with `@Immutable`:

```
import groovy.transform.builder.*
import groovy.transform.*
import static groovy.transform.options.Visibility.PRIVATE

@Builder(builderStrategy=InitializerStrategy)
@Immutable
@VisibilityOptions(PRIVATE)
class Person {
    String first
    String last
    int born
}

def publicCons = Person.constructors
assert publicCons.size() == 1

@CompileStatic
def createFirstLastBorn() {
  def p = new Person(Person.createInitializer().first('Johnny').last('Depp').born(
1963))
  assert "$p.first $p.last $p.born" == 'Johnny Depp 1963'
}

createFirstLastBorn()
```

The annotation attribute `useSetters` can be used if you have a setter which you want called as part of the construction process. See the JavaDoc for details.

This strategy also supports annotating static methods and constructors. In this case, the static method or constructor parameters become the properties to use for building purposes and in the case of static methods, the return type of the method becomes the target class being built. If you have more than one `@Builder` annotation used within a class (at either the class, method or constructor positions) then it is up to you to ensure that the generated helper classes and factory methods have unique names (i.e. no more than one can use the default name values). For an example of method and constructor usage but using the `DefaultStrategy` strategy, consult that strategy's documentation.

The annotation attribute `forClass` is not supported for this strategy.

`@groovy.transform.AutoImplement`

The `@AutoImplement` AST transformation supplies dummy implementations for any found abstract methods from superclasses or interfaces. The dummy implementation is the same for all abstract methods found and can be:

- essentially empty (exactly true for void methods and for methods with a return type, returns the default value for that type)

- a statement that throws a specified exception (with optional message)
- some user supplied code

The first example illustrates the default case. Our class is annotated with `@AutoImplement`, has a superclass and a single interface as can be seen here:

```
import groovy.transform.AutoImplement

@AutoImplement
class MyNames extends AbstractList<String> implements Closeable { }
```

A `void close()` method from the `Closeable` interface is supplied and left empty. Implementations are also supplied for the three abstract methods from the super class. The `get`, `addAll` and `size` methods have return types of `String`, `boolean` and `int` respectively with default values `null`, `false` and `0`. We can use our class (and check the expected return type for one of the methods) using the following code:

```
assert new MyNames().size() == 0
```

It is also worthwhile examining the equivalent generated code:

```
class MyNames implements Closeable extends AbstractList<String> {

    String get(int param0) {
        return null
    }

    boolean addAll(Collection<? extends String> param0) {
        return false
    }

    void close() throws Exception {
    }

    int size() {
        return 0
    }

}
```

The second example illustrates the simplest exception case. Our class is annotated with `@AutoImplement`, has a superclass and an annotation attribute indicates that an `IOException` should be thrown if any of our "dummy" methods are called. Here is the class definition:

```
@AutoImplement(exception=IOException)
```

```
class MyWriter extends Writer { }
```

We can use the class (and check the expected exception is thrown for one of the methods) using the following code:

```
import static groovy.test.GroovyAssert.shouldFail

shouldFail(IOException) {
  new MyWriter().flush()
}
```

It is also worthwhile examining the equivalent generated code where three void methods have been provided all of which throw the supplied exception:

```
class MyWriter extends Writer {

    void flush() throws IOException {
        throw new IOException()
    }

    void write(char[] param0, int param1, int param2) throws IOException {
        throw new IOException()
    }

    void close() throws Exception {
        throw new IOException()
    }

}
```

The third example illustrates the exception case with a supplied message. Our class is annotated with `@AutoImplement`, implements an interface, and has annotation attributes to indicate that an `UnsupportedOperationException` with `Not supported by MyIterator` as the message should be thrown for any supplied methods. Here is the class definition:

```
@AutoImplement(exception=UnsupportedOperationException, message='Not supported by
MyIterator')
class MyIterator implements Iterator<String> { }
```

We can use the class (and check the expected exception is thrown and has the correct message for one of the methods) using the following code:

```
def ex = shouldFail(UnsupportedOperationException) {
     new MyIterator().hasNext()
}
```

```
assert ex.message == 'Not supported by MyIterator'
```

It is also worthwhile examining the equivalent generated code where three void methods have been provided all of which throw the supplied exception:

```
class MyIterator implements Iterator<String> {

    boolean hasNext() {
        throw new UnsupportedOperationException('Not supported by MyIterator')
    }

    String next() {
        throw new UnsupportedOperationException('Not supported by MyIterator')
    }

}
```

The fourth example illustrates the case of user supplied code. Our class is annotated with `@AutoImplement`, implements an interface, has an explicitly overridden `hasNext` method, and has an annotation attribute containing the supplied code for any supplied methods. Here is the class definition:

```
@AutoImplement(code = { throw new UnsupportedOperationException('Should never be
called but was called on ' + new Date()) })
class EmptyIterator implements Iterator<String> {
    boolean hasNext() { false }
}
```

We can use the class (and check the expected exception is thrown and has a message of the expected form) using the following code:

```
def ex = shouldFail(UnsupportedOperationException) {
     new EmptyIterator().next()
}
assert ex.message.startsWith('Should never be called but was called on ')
```

It is also worthwhile examining the equivalent generated code where the `next` method has been supplied:

```
class EmptyIterator implements java.util.Iterator<String> {

    boolean hasNext() {
        false
    }

    String next() {
```

```
        throw new UnsupportedOperationException('Should never be called but was called
on ' + new Date())
    }

}
```

@groovy.transform.NullCheck

The `@NullCheck` AST transformation adds null-check guard statements to constructors and methods which cause those methods to fail early when supplied with null arguments. It can be seen as a form of defensive programming. The annotation can be added to individual methods or constructors, or to the class in which case it will apply to all methods/constructors.

```
@NullCheck
String longerOf(String first, String second) {
    first.size() >= second.size() ? first : second
}

assert longerOf('cat', 'canary') == 'canary'
def ex = shouldFail(IllegalArgumentException) {
    longerOf('cat', null)
}
assert ex.message == 'second cannot be null'
```

Class design annotations

This category of annotations are aimed at simplifying the implementation of well-known design patterns (delegation, singleton, …) by using a declarative style.

@groovy.transform.BaseScript

`@BaseScript` is used within scripts to indicate that the script should extend from a custom script base class rather than `groovy.lang.Script`. See the documentation for domain specific languages for further details.

@groovy.lang.Delegate

The `@Delegate` AST transformation aims at implementing the delegation design pattern. In the following class:

```
class Event {
    @Delegate Date when
    String title
}
```

The `when` property is annotated with `@Delegate`, meaning that the `Event` class will delegate calls to `Date` methods to the `when` property. In this case, the generated code looks like this:

```
class Event {
    Date when
    String title
    boolean before(Date other) {
        when.before(other)
    }
    // ...
}
```

Then you can call the `before` method, for example, directly on the `Event` class:

```
def ev = new Event(title:'Groovy keynote', when: Date.parse('yyyy/MM/dd',
'2013/09/10'))
def now = new Date()
assert ev.before(now)
```

Instead of annotating a property (or field), you can also annotate a method. In this case, the method can be thought of as a getter or factory method for the delegate. As an example, here is a class which (rather unusually) has a pool of delegates which are accessed in a round-robin fashion:

```
class Test {
    private int robinCount = 0
    private List<List> items = [[0], [1], [2]]

    @Delegate
    List getRoundRobinList() {
        items[robinCount++ % items.size()]
    }

    void checkItems(List<List> testValue) {
        assert items == testValue
    }
}
```

Here is an example usage of that class:

```
def t = new Test()
t << 'fee'
t << 'fi'
t << 'fo'
t << 'fum'
t.checkItems([[0, 'fee', 'fum'], [1, 'fi'], [2, 'fo']])
```

Using a standard list in this round-robin fashion would violate many expected properties of lists, so don’t expect the above class to do anything useful beyond this trivial example.

The behavior of the `@Delegate` AST transformation can be changed using the following parameters:

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>interfaces</td><td>True</td><td>Should the interfaces implemented by the field be implemented by the class too</td><td><pre><code>interface Greeter { void sayHello() }
class MyGreeter implements Greeter { void sayHello() { println 'Hello!'} }

class DelegatingGreeter { // no explicit interface
    @Delegate MyGreeter greeter = new MyGreeter()
}
def greeter = new DelegatingGreeter()
assert greeter instanceof Greeter // interface was added transparently</code></pre></td></tr>
<tr><td>deprecated</td><td>false</td><td>If true, also delegates methods annotated with @Deprecated</td><td><pre><code>class WithDeprecation {
    @Deprecated
    void foo() {}
}
class WithoutDeprecation {
    @Deprecated
    void bar() {}
}
class Delegating {
    @Delegate(deprecated=true) WithDeprecation with = new WithDeprecation()
    @Delegate WithoutDeprecation without = new WithoutDeprecation()
}
def d = new Delegating()
d.foo() // passes thanks to deprecated=true
d.bar() // fails because of @Deprecated</code></pre></td></tr>
</table>

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>methodAnnotations</td><td>False</td><td>Whether to carry over annotations from the methods of the delegate to your delegating method.</td><td><pre><code>class WithAnnotations {
    @Transactional
    void method() {
    }
}
class DelegatingWithoutAnnotations {
    @Delegate WithAnnotations delegate
}
class DelegatingWithAnnotations {
    @Delegate(methodAnnotations = true) WithAnnotations delegate
}
def d1 = new DelegatingWithoutAnnotations()
def d2 = new DelegatingWithAnnotations()
assert d1.class.getDeclaredMethod('method').annotations.length==1
assert d2.class.getDeclaredMethod('method').annotations.length==2</code></pre></td></tr>
</table>

Attribute	Default value	Description	Example

parameterAnnotations	False	Whether to carry over annotations from the method parameters of the delegate to your delegating method.	`class WithAnnotations {`
			`    void method(@NotNull String str) {`
			`    }`
			`}`
			`class DelegatingWithoutAnnotations {`
			`    @Delegate WithAnnotations delegate`
			`}`
			`class DelegatingWithAnnotations {`
			`    @Delegate(parameterAnnotations = true) WithAnnotations delegate`
			`}`
			`def d1 = new DelegatingWithoutAnnotations()`
			`def d2 = new DelegatingWithAnnotations()`
			`assert d1.class.getDeclaredMethod('method',String).parameterAnnotations[0].length==0`
			`assert d2.class.getDeclaredMethod('method',String).parameterAnnotations[0].length==1`

excludes	Empty array	A list of methods to be excluded from delegation. For more fine-grained control, see also `excludeTypes`.	`class Worker {`
			`    void task1() {}`
			`    void task2() {}`
			`}`
			`class Delegating {`
			`    @Delegate(excludes=['task2']) Worker worker = new Worker()`
			`}`
			`def d = new Delegating()`
			`d.task1() // passes`
			`d.task2() // fails because method is excluded`

<table>
<thead>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
</thead>
<tbody>
<tr>
<td>includes</td>
<td>Undefined marker array (indicates all methods)</td>
<td>A list of methods to be included in delegation. For more fine-grained control, see also <code>includeTypes</code>.</td>
<td><pre><code>class Worker {
    void task1() {}
    void task2() {}
}
class Delegating {
    @Delegate(includes=['task1'])
Worker worker = new Worker()
}
def d = new Delegating()
d.task1() // passes
d.task2() // fails because method is not included</code></pre></td>
</tr>
<tr>
<td>excludeTypes</td>
<td>Empty array</td>
<td>A list of interfaces containing method signatures to be excluded from delegation</td>
<td><pre><code>interface AppendStringSelector {
    StringBuilder append(String str)
}
class UpperStringBuilder {
    @Delegate(excludeTypes=AppendStringSelector)
    StringBuilder sb1 = new StringBuilder()

    @Delegate(includeTypes=AppendStringSelector)
    StringBuilder sb2 = new StringBuilder()

    String toString() { sb1.toString() + sb2.toString().toUpperCase() }
}
def usb = new UpperStringBuilder()
usb.append(3.5d)
usb.append('hello')
usb.append(true)
assert usb.toString() == '3.5trueHELLO'</code></pre></td>
</tr>
</tbody>
</table>

Attribute	Default value	Description	Example

includeTypes	Undefined marker array (indicates no list be default)	A list of interfaces containing method signatures to be included in delegation	`interface AppendBooleanSelector {`
			`    StringBuilder append(boolean b)`
			`}`
			`interface AppendFloatSelector {`
			`    StringBuilder append(float b)`
			`}`
			`class NumberBooleanBuilder {`
			`    @Delegate(includeTypes=AppendBooleanSelector, interfaces=false)`
			`    StringBuilder nums = new StringBuilder()`
			`    @Delegate(includeTypes=[AppendFloatSelector], interfaces=false)`
			`    StringBuilder bools = new StringBuilder()`
			`    String result() { "${nums.toString()} ~ ${bools.toString()}" }`
			`}`
			`def b = new NumberBooleanBuilder()`
			`b.append(true)`
			`b.append(3.14f)`
			`b.append(false)`
			`b.append(0.0f)`
			`assert b.result() == "truefalse ~ 3.140.0"`
			`b.append(3.5d) // would fail because we didn't include append(double)`

allNames	False	Should the delegate pattern be also applied to methods with internal names	`class Worker {`
			`    void task$() {}`
			`}`
			`class Delegating {`
			`    @Delegate(allNames=true) Worker worker = new Worker()`
			`}`
			`def d = new Delegating()`
			`d.task$() //passes`

`@groovy.transform.Immutable`

The `@Immutable` meta-annotation combines the following annotations:

- @ToString
- @EqualsAndHashCode
- @TupleConstructor
- @MapConstructor
- @Final
- @ImmutableBase
- @ImmutableOptions
- @PropertyOptions
- @KnownImmutable

The `@Immutable` meta-annotation simplifies the creation of immutable classes. Immutable classes are useful since they are often easier to reason about and are inherently thread-safe. See Effective Java, Minimize Mutability for all the details about how to achieve immutable classes in Java. The `@Immutable` meta-annotation does most of the things described in *Effective Java* for you automatically. To use the meta-annotation, all you have to do is annotate the class like in the following example:

```
import groovy.transform.Immutable

@Immutable
class Point {
    int x
    int y
}
```

One of the requirements for immutable classes is that there is no way to modify any state information within the class. One requirement to achieve this is to use immutable classes for each property or alternatively perform special coding such as defensive copy in and defensive copy out for any mutable properties within the constructors and property getters. Between `@ImmutableBase`, `@MapConstructor` and `@TupleConstructor` properties are either identified as immutable or the special coding for numerous known cases is handled automatically. Various mechanisms are provided for you to extend the handled property types which are allowed. See `@ImmutableOptions` and `@KnownImmutable` for details.

The results of applying `@Immutable` to a class are pretty similar to those of applying the @Canonical meta-annotation but the generated class will have extra logic to handle immutability. You will observe this by, for instance, trying to modify a property which will result in a `ReadOnlyPropertyException` being thrown since the backing field for the property will have been automatically made final.

The `@Immutable` meta-annotation supports the configuration options found in the annotations it aggregates. See those annotations for more details.

`@groovy.transform.ImmutableBase`

Immutable classes generated with `@ImmutableBase` are automatically made final. Also, the type of each property is checked and various checks are made on the class, for example, public instance fields currently aren't allowed. It also generates a `copyWith` constructor if desired.

The following annotation attribute is supported:

Attribute	Default value	Description	Example

copyWith	false	A boolean whether to generate a `copyWith( Map )` method.	`import groovy.transform.Immutable`
			
			`@Immutable( copyWith=true )`
			`class User {`
			`    String  name`
			`    Integer age`
			`}`
			
			`def bob   = new User( 'bob', 43 )`
			`def alice = bob.copyWith(`
			`name:'alice' )`
			`assert alice.name == 'alice'`
			`assert alice.age  == 43`

`@groovy.transform.PropertyOptions`

This annotation allows you to specify a custom property handler to be used by transformations during class construction. It is ignored by the main Groovy compiler but is referenced by other transformations like `@TupleConstructor`, `@MapConstructor`, and `@ImmutableBase`. It is frequently used behind the scenes by the `@Immutable` meta-annotation.

`@groovy.transform.VisibilityOptions`

This annotation allows you to specify a custom visibility for a construct generated by another transformation. It is ignored by the main Groovy compiler but is referenced by other transformations like `@TupleConstructor`, `@MapConstructor`, and `@NamedVariant`.

`@groovy.transform.ImmutableOptions`

Groovy's immutability support relies on a predefined list of known immutable classes (like `java.net.URI` or `java.lang.String` and fails if you use a type which is not in that list, you are allowed to add to the list of known immutable types thanks to the following annotation attributes of the `@ImmutableOptions` annotation:

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>knownImmutableClasses</td><td>Empty list</td><td>A list of classes which are deemed immutable.</td><td>

```
import groovy.transform.Immutable
import
groovy.transform.TupleConstructor

@TupleConstructor
final class Point {
    final int x
    final int y
    public String toString() {
"($x,$y)" }
}

@Immutable(knownImmutableClasses=
[Point])
class Triangle {
    Point a,b,c
}
```

</td></tr>
<tr><td>knownImmutables</td><td>Empty list</td><td>A list of property names which are deemed immutable.</td><td>

```
import groovy.transform.Immutable
import
groovy.transform.TupleConstructor

@TupleConstructor
final class Point {
    final int x
    final int y
    public String toString() {
"($x,$y)" }
}

@Immutable(knownImmutables=['a','
b','c'])
class Triangle {
    Point a,b,c
}
```

</td></tr>
</table>

If you deem a type as immutable and it isn't one of the ones automatically handled, then it is up to you to correctly code that class to ensure immutability.

`@groovy.transform.KnownImmutable`

The `@KnownImmutable` annotation isn't actually one that triggers any AST transformations. It is simply a marker annotation. You can annotate your classes with the annotation (including Java classes) and they will be recognized as acceptable types for members within an immutable class. This saves you having to explicitly use the `knownImmutables` or `knownImmutableClasses` annotation attributes from `@ImmutableOptions`.

`@groovy.transform.Memoized`

The `@Memoized` AST transformations simplifies the implementation of caching by allowing the result of method calls to be cached just by annotating the method with `@Memoized`. Let's imagine the following method:

```
long longComputation(int seed) {
    // slow computation
    Thread.sleep(100*seed)
    System.nanoTime()
}
```

This emulates a long computation, based on the actual parameters of the method. Without `@Memoized`, each method call would take several seconds plus it would return a random result:

```
def x = longComputation(1)
def y = longComputation(1)
assert x!=y
```

Adding `@Memoized` changes the semantics of the method by adding caching, based on the parameters:

```
@Memoized
long longComputation(int seed) {
    // slow computation
    Thread.sleep(100*seed)
    System.nanoTime()
}

def x = longComputation(1) // returns after 100 milliseconds
def y = longComputation(1) // returns immediately
def z = longComputation(2) // returns after 200 milliseconds
assert x==y
assert x!=z
```

The size of the cache can be configured using two optional parameters:

- *protectedCacheSize*: the number of results which are guaranteed not to be cleared after garbage collection
- *maxCacheSize*: the maximum number of results that can be kept in memory

By default, the size of the cache is unlimited and no cache result is protected from garbage collection. Setting a *protectedCacheSize>0* would create an unlimited cache with some results protected. Setting *maxCacheSize>0* would create a limited cache but without any protection from garbage protection. Setting both would create a limited, protected cache.

@groovy.transform.TailRecursive

The @TailRecursive annotation can be used to automatically transform a recursive call at the end of a method into an equivalent iterative version of the same code. This avoids stack overflow due to too many recursive calls. Below is an example of use when calculating factorial:

```
import groovy.transform.CompileStatic
import groovy.transform.TailRecursive

@CompileStatic
class Factorial {

    @TailRecursive
    static BigInteger factorial( BigInteger i, BigInteger product = 1) {
        if( i == 1) {
            return product
        }
        return factorial(i-1, product*i)
    }
}

assert Factorial.factorial(1) == 1
assert Factorial.factorial(3) == 6
assert Factorial.factorial(5) == 120
assert Factorial.factorial(50000).toString().size() == 213237 // Big number and no
Stack Overflow
```

Currently, the annotation will only work for self-recursive method calls, i.e. a single recursive call to the exact same method again. Consider using Closures and trampoline() if you have a scenario involving simple mutual recursion. Also note that only non-void methods are currently handled (void calls will result in a compilation error).

CAUTION	Currently, some forms of method overloading can trick the compiler, and some non-tail recursive calls are erroneously treated as tail recursive.

@groovy.lang.Singleton

The @Singleton annotation can be used to implement the singleton design pattern on a class. The singleton instance is defined eagerly by default, using class initialization, or lazily, in which case the field is initialized using double-checked locking.

```
@Singleton
class GreetingService {
    String greeting(String name) { "Hello, $name!" }
}
assert GreetingService.instance.greeting('Bob') == 'Hello, Bob!'
```

By default, the singleton is created eagerly when the class is initialized and available through the instance property. It is possible to change the name of the singleton using the property parameter:

```
@Singleton(property='theOne')
class GreetingService {
    String greeting(String name) { "Hello, $name!" }
}

assert GreetingService.theOne.greeting('Bob') == 'Hello, Bob!'
```

And it is also possible to make initialization lazy using the lazy parameter:

```
class Collaborator {
    public static boolean init = false
}
@Singleton(lazy=true,strict=false)
class GreetingService {
    static void init() {}
    GreetingService() {
        Collaborator.init = true
    }
    String greeting(String name) { "Hello, $name!" }
}
GreetingService.init() // make sure class is initialized
assert Collaborator.init == false
GreetingService.instance
assert Collaborator.init == true
assert GreetingService.instance.greeting('Bob') == 'Hello, Bob!'
```

In this example, we also set the strict parameter to false, which allows us to define our own constructor.

@groovy.lang.Mixin

Deprecated. Consider using traits instead.

Logging improvements

Groovy provides a family of AST transformations that help with integration of the most widely used logging frameworks. There is a transform and associated annotation for each of the common frameworks. These transforms provide a streamlined declarative approach to using the logging framework. In each case, the transform will:

- add a static final log field to the annotated class corresponding to the logger
- wrap all calls to log.level() into the appropriate log.isLevelEnabled guard, depending on the underlying framework

Those transformations support two parameters:

- value (default log) corresponds to the name of the logger field

* `category` (defaults to the class name) is the name of the logger category

It's worth noting that annotating a class with one of those annotations doesn't prevent you from using the logging framework using the normal long-hand approach.

`@groovy.util.logging.Log`

The first logging AST transformation available is the `@Log` annotation which relies on the JDK logging framework. Writing:

```
@groovy.util.logging.Log
class Greeter {
    void greet() {
        log.info 'Called greeter'
        println 'Hello, world!'
    }
}
```

is equivalent to writing:

```
import java.util.logging.Level
import java.util.logging.Logger

class Greeter {
    private static final Logger log = Logger.getLogger(Greeter.name)
    void greet() {
        if (log.isLoggable(Level.INFO)) {
            log.info 'Called greeter'
        }
        println 'Hello, world!'
    }
}
```

`@groovy.util.logging.Commons`

Groovy supports the Apache Commons Logging framework using the `@Commons` annotation. Writing:

```
@groovy.util.logging.Commons
class Greeter {
    void greet() {
        log.debug 'Called greeter'
        println 'Hello, world!'
    }
}
```

is equivalent to writing:

```
import org.apache.commons.logging.LogFactory
import org.apache.commons.logging.Log

class Greeter {
    private static final Log log = LogFactory.getLog(Greeter)
    void greet() {
        if (log.isDebugEnabled()) {
            log.debug 'Called greeter'
        }
        println 'Hello, world!'
    }
}
```

You still need to add the appropriate commons-logging jar to your classpath.

`@groovy.util.logging.Log4j`

Groovy supports the Apache Log4j 1.x framework using the `@Log4j` annotation. Writing:

```
@groovy.util.logging.Log4j
class Greeter {
    void greet() {
        log.debug 'Called greeter'
        println 'Hello, world!'
    }
}
```

is equivalent to writing:

```
import org.apache.log4j.Logger

class Greeter {
    private static final Logger log = Logger.getLogger(Greeter)
    void greet() {
        if (log.isDebugEnabled()) {
            log.debug 'Called greeter'
        }
        println 'Hello, world!'
    }
}
```

You still need to add the appropriate log4j jar to your classpath. This annotation can also be used with the compatible reload4j log4j drop-in replacement, just use the jar from that project instead of a log4j jar.

`@groovy.util.logging.Log4j2`

Groovy supports the Apache Log4j 2.x framework using the `@Log4j2` annotation. Writing:

```
@groovy.util.logging.Log4j2
class Greeter {
    void greet() {
        log.debug 'Called greeter'
        println 'Hello, world!'
    }
}
```

is equivalent to writing:

```
import org.apache.logging.log4j.LogManager
import org.apache.logging.log4j.Logger

class Greeter {
    private static final Logger log = LogManager.getLogger(Greeter)
    void greet() {
        if (log.isDebugEnabled()) {
            log.debug 'Called greeter'
        }
        println 'Hello, world!'
    }
}
```

You still need to add the appropriate log4j2 jar to your classpath.

`@groovy.util.logging.Slf4j`

Groovy supports the Simple Logging Facade for Java (SLF4J) framework using the `@Slf4j` annotation. Writing:

```
@groovy.util.logging.Slf4j
class Greeter {
    void greet() {
        log.debug 'Called greeter'
        println 'Hello, world!'
    }
}
```

is equivalent to writing:

```
import org.slf4j.LoggerFactory
import org.slf4j.Logger

class Greeter {
    private static final Logger log = LoggerFactory.getLogger(Greeter)
    void greet() {
        if (log.isDebugEnabled()) {
```

```
            log.debug 'Called greeter'
        }
        println 'Hello, world!'
    }
}
```

You still need to add the appropriate slf4j jar(s) to your classpath.

`@groovy.util.logging.PlatformLog`

Groovy supports the Java Platform Logging API and Service framework using the `@PlatformLog` annotation. Writing:

```
@groovy.util.logging.PlatformLog
class Greeter {
    void greet() {
        log.info 'Called greeter'
        println 'Hello, world!'
    }
}
```

is equivalent to writing:

```
import java.lang.System.Logger
import java.lang.System.LoggerFinder
import static java.lang.System.Logger.Level.INFO

class Greeter {
    private static final transient Logger log =
        LoggerFinder.loggerFinder.getLogger(Greeter.class.name, Greeter.class.module)
    void greet() {
        log.log INFO, 'Called greeter'
        println 'Hello, world!'
    }
}
```

You need to be using JDK 9+ to use this capability.

Declarative concurrency

The Groovy language provides a set of annotations aimed at simplifying common concurrency patterns in a declarative approach.

`@groovy.transform.Synchronized`

The `@Synchronized` AST transformations works in a similar way to the `synchronized` keyword but locks on different objects for safer concurrency. It can be applied on any method or static method:

```
import groovy.transform.Synchronized

import java.util.concurrent.Executors
import java.util.concurrent.TimeUnit

class Counter {
    int cpt
    @Synchronized
    int incrementAndGet() {
        cpt++
    }
    int get() {
        cpt
    }
}
```

Writing this is equivalent to creating a lock object and wrapping the whole method into a synchronized block:

```
class Counter {
    int cpt
    private final Object $lock = new Object()

    int incrementAndGet() {
        synchronized($lock) {
            cpt++
        }
    }
    int get() {
        cpt
    }

}
```

By default, `@Synchronized` creates a field named `$lock` (or `$LOCK` for a static method) but you can make it use any field you want by specifying the value attribute, like in the following example:

```
import groovy.transform.Synchronized

import java.util.concurrent.Executors
import java.util.concurrent.TimeUnit

class Counter {
    int cpt
    private final Object myLock = new Object()

    @Synchronized('myLock')
    int incrementAndGet() {
```

```
        cpt++
    }
    int get() {
        cpt
    }
}
```

`@groovy.transform.WithReadLock` and `@groovy.transform.WithWriteLock`

The `@WithReadLock` AST transformation works in conjunction with the `@WithWriteLock` transformation to provide read/write synchronization using the `ReentrantReadWriteLock` facility that the JDK provides. The annotation can be added to a method or a static method. It will transparently create a `$reentrantLock` final field (or `$REENTRANTLOCK` for a static method) and proper synchronization code will be added. For example, the following code:

```
import groovy.transform.WithReadLock
import groovy.transform.WithWriteLock

class Counters {
    public final Map<String,Integer> map = [:].withDefault { 0 }

    @WithReadLock
    int get(String id) {
        map.get(id)
    }

    @WithWriteLock
    void add(String id, int num) {
        Thread.sleep(200) // emulate long computation
        map.put(id, map.get(id)+num)
    }
}
```

is equivalent to this:

```
import groovy.transform.WithReadLock as WithReadLock
import groovy.transform.WithWriteLock as WithWriteLock

public class Counters {

    private final Map<String, Integer> map
    private final java.util.concurrent.locks.ReentrantReadWriteLock $reentrantlock

    public int get(java.lang.String id) {
        $reentrantlock.readLock().lock()
        try {
            map.get(id)
        }
```

```
        finally {
            $reentrantlock.readLock().unlock()
        }
    }

    public void add(java.lang.String id, int num) {
        $reentrantlock.writeLock().lock()
        try {
            java.lang.Thread.sleep(200)
            map.put(id, map.get(id) + num )
        }
        finally {
            $reentrantlock.writeLock().unlock()
        }
    }
}
```

Both `@WithReadLock` and `@WithWriteLock` support specifying an alternative lock object. In that case, the referenced field must be declared by the user, like in the following alternative:

```
import groovy.transform.WithReadLock
import groovy.transform.WithWriteLock

import java.util.concurrent.locks.ReentrantReadWriteLock

class Counters {
    public final Map<String,Integer> map = [:].withDefault { 0 }
    private final ReentrantReadWriteLock customLock = new ReentrantReadWriteLock()

    @WithReadLock('customLock')
    int get(String id) {
        map.get(id)
    }

    @WithWriteLock('customLock')
    void add(String id, int num) {
        Thread.sleep(200) // emulate long computation
        map.put(id, map.get(id)+num)
    }
}
```

For details

- See Javadoc for groovy.transform.WithReadLock
- See Javadoc for groovy.transform.WithWriteLock

Easier cloning and externalizing

Groovy provides two annotations aimed at facilitating the implementation of `Cloneable` and

`Externalizable` interfaces, respectively named `@AutoClone` and `@AutoExternalize`.

`@groovy.transform.AutoClone`

The `@AutoClone` annotation is aimed at implementing the `@java.lang.Cloneable` interface using various strategies, thanks to the `style` parameter:

- the default `AutoCloneStyle.CLONE` strategy calls `super.clone()` first then `clone()` on each cloneable property
- the `AutoCloneStyle.SIMPLE` strategy uses a regular constructor call and copies properties from the source to the clone
- the `AutoCloneStyle.COPY_CONSTRUCTOR` strategy creates and uses a copy constructor
- the `AutoCloneStyle.SERIALIZATION` strategy uses serialization (or externalization) to clone the object

Each of those strategies have pros and cons which are discussed in the Javadoc for groovy.transform.AutoClone and groovy.transform.AutoCloneStyle .

For example, the following example:

```
import groovy.transform.AutoClone

@AutoClone
class Book {
    String isbn
    String title
    List<String> authors
    Date publicationDate
}
```

is equivalent to this:

```
class Book implements Cloneable {
    String isbn
    String title
    List<String> authors
    Date publicationDate

    public Book clone() throws CloneNotSupportedException {
        Book result = super.clone()
        result.authors = authors instanceof Cloneable ? (List) authors.clone() :
authors
        result.publicationDate = publicationDate.clone()
        result
    }
}
```

Note that the String properties aren't explicitly handled because Strings are immutable and the `clone()` method from `Object` will copy the String references. The same would apply to primitive fields and most of the concrete subclasses of `java.lang.Number`.

In addition to cloning styles, `@AutoClone` supports multiple options:

Attribute	Default value	Description	Example

excludes	Empty list	A list of property or field names that need to be excluded from cloning. A string consisting of a comma-separated field/property names is also allowed. See groovy.transform.AutoClone#excludes for details	`import groovy.transform.AutoClone`
			`import groovy.transform.AutoCloneStyle`
			
			`@AutoClone(style=AutoCloneStyle.SIMPLE,excludes='authors')`
			`class Book {`
			`    String isbn`
			`    String title`
			`    List authors`
			`    Date publicationDate`
			`}`

includeFields	false	By default, only properties are cloned. Setting this flag to true will also clone fields.	`import groovy.transform.AutoClone`
			`import groovy.transform.AutoCloneStyle`
			
			`@AutoClone(style=AutoCloneStyle.SIMPLE,includeFields=true)`
			`class Book {`
			`    String isbn`
			`    String title`
			`    List authors`
			`    protected Date publicationDate`
			`}`

`@groovy.transform.AutoExternalize`

The `@AutoExternalize` AST transformation will assist in the creation of `java.io.Externalizable` classes. It will automatically add the interface to the class and generate the `writeExternal` and `readExternal` methods. For example, this code:

```
import groovy.transform.AutoExternalize

@AutoExternalize
class Book {
    String isbn
    String title
```

```
    float price
}
```

will be converted into:

```
class Book implements java.io.Externalizable {
    String isbn
    String title
    float price

    void writeExternal(ObjectOutput out) throws IOException {
        out.writeObject(isbn)
        out.writeObject(title)
        out.writeFloat( price )
    }

    public void readExternal(ObjectInput oin) {
        isbn = (String) oin.readObject()
        title = (String) oin.readObject()
        price = oin.readFloat()
    }

}
```

The `@AutoExternalize` annotation supports two parameters which will let you slightly customize its behavior:

Attribute	Default value	Description	Example

excludes	Empty list	A list of property or field names that need to be excluded from externalizing. A string consisting of a comma-separated field/property names is also allowed. See groovy.transform.AutoExternalize#excludes for details	`import groovy.transform.AutoExternalize`
			
			`@AutoExternalize(excludes='price')`
			`class Book {`
			`    String isbn`
			`    String title`
			`    float price`
			`}`

Attribute	Default value	Description	Example

includeFields	false	By default, only properties are externalized. Setting this flag to true will also clone fields.	`import groovy.transform.AutoExternalize`
			
			`@AutoExternalize(includeFields=true)`
			`class Book {`
			`    String isbn`
			`    String title`
			`    protected float price`
			`}`

Safer scripting

The Groovy language makes it easy to execute user scripts at runtime (for example using groovy.lang.GroovyShell), but how do you make sure that a script won't eat all CPU (infinite loops) or that concurrent scripts won't slowly consume all available threads of a thread pool? Groovy provides several annotations which are aimed towards safer scripting, generating code which will for example allow you to interrupt execution automatically.

`@groovy.transform.ThreadInterrupt`

One complicated situation in the JVM world is when a thread can't be stopped. The `Thread#stop` method exists but is deprecated (and isn't reliable) so your only chance lies in `Thread#interrupt`. Calling the latter will set the `interrupt` flag on the thread, but it will **not** stop the execution of the thread. This is problematic because it's the responsibility of the code executing in the thread to check the interrupt flag and properly exit. This makes sense when you, as a developer, know that the code you are executing is meant to be run in an independent thread, but in general, you don't know it. It's even worse with user scripts, who might not even know what a thread is (think of DSLs).

`@ThreadInterrupt` simplifies this by adding thread interruption checks at critical places in the code:

- loops (for, while)
- first instruction of a method
- first instruction of a closure body

Let's imagine the following user script:

```
while (true) {
    i++
}
```

This is an obvious infinite loop. If this code executes in its own thread, interrupting wouldn't help: if you `join` on the thread, then the calling code would be able to continue, but the thread would still be alive, running in background without any ability for you to stop it, slowly causing thread starvation.

One possibility to work around this is to set up your shell this way:

```
def config = new CompilerConfiguration()
config.addCompilationCustomizers(
        new ASTTransformationCustomizer(ThreadInterrupt)
)
def binding = new Binding(i:0)
def shell = new GroovyShell(binding,config)
```

The shell is then configured to automatically apply the `@ThreadInterrupt` AST transformations on all scripts. This allows you to execute user scripts this way:

```
def t = Thread.start {
    shell.evaluate(userCode)
}
t.join(1000) // give at most 1000ms for the script to complete
if (t.alive) {
    t.interrupt()
}
```

The transformation automatically modified user code like this:

```
while (true) {
    if (Thread.currentThread().interrupted) {
        throw new InterruptedException('The current thread has been interrupted.')
    }
    i++
}
```

The check which is introduced inside the loop guarantees that if the `interrupt` flag is set on the current thread, an exception will be thrown, interrupting the execution of the thread.

`@ThreadInterrupt` supports multiple options that will let you further customize the behavior of the transformation:

Attribute	Default value	Description	Example

thrown	`java.lang.InterruptedException`	Specifies the type of exception which is thrown if the thread is interrupted.	`class BadException extends Exception {`
			`    BadException(String message) { super(message) }`
			`}`
			
			`def config = new CompilerConfiguration()`
			`config.addCompilationCustomizers(`
			`        new ASTTransformationCustomizer(thrown:BadException, ThreadInterrupt)`
			`)`
			`def binding = new Binding(i:0)`
			`def shell = new GroovyShell(this.class.classLoader,binding,config)`
			
			`def userCode = """`
			`try {`
			`    while (true) {`
			`        i++`
			`    }`
			`} catch (BadException e) {`
			`    i = -1`
			`}`
			`"""`
			
			`def t = Thread.start {`
			`    shell.evaluate(userCode)`
			`}`
			`t.join(1000) // give at most 1s for the script to complete`
			`assert binding.i > 0`
			`if (t.alive) {`
			`    t.interrupt()`
			`}`
			`Thread.sleep(500)`
			`assert binding.i == -1'''`

checkOnMethodStart	true	Should an interruption check be inserted at the beginning of each method body. See groovy.transform.ThreadInterrupt for details.	`@ThreadInterrupt(checkOnMethodStart=false)`

Attribute	Default value	Description	Example

applyToAllClasses	true	Should the transformation be applied on all classes of the same source unit (in the same source file). See groovy.transform.ThreadInterrupt for details.	`@ThreadInterrupt(applyToAllClasses=false)`
			`class A { ... } // interrupt checks added`
			`class B { ... } // no interrupt checks`

applyToAllMembers	true	Should the transformation be applied on all members of class. See groovy.transform.ThreadInterrupt for details.	`class A {`
			`    @ThreadInterrupt(applyToAllMembers=false)`
			`    void method1() { ... } // interrupt checked added`
			`    void method2() { ... } // no interrupt checks`
			`}`

`@groovy.transform.TimedInterrupt`

The `@TimedInterrupt` AST transformation tries to solve a slightly different problem from `@groovy.transform.ThreadInterrupt`: instead of checking the `interrupt` flag of the thread, it will automatically throw an exception if the thread has been running for too long.

NOTE	This annotation does **not** spawn a monitoring thread. Instead, it works in a similar manner as `@ThreadInterrupt` by placing checks at appropriate places in the code. This means that if you have a thread blocked by I/O, it will **not** be interrupted.

Imagine the following user code:

```
def fib(int n) { n<2?n:fib(n-1)+fib(n-2) }

result = fib(600)
```

The implementation of the famous Fibonacci number computation here is far from optimized. If it is called with a high `n` value, it can take minutes to answer. With `@TimedInterrupt`, you can choose how long a script is allowed to run. The following setup code will allow the user script to run for 1 second at max:

```
def config = new CompilerConfiguration()
config.addCompilationCustomizers(
        new ASTTransformationCustomizer(value:1, TimedInterrupt)
)
def binding = new Binding(result:0)
```

```
def shell = new GroovyShell(this.class.classLoader, binding,config)
```

This code is equivalent to annotating a class with `@TimedInterrupt` like this:

```
@TimedInterrupt(value=1, unit=TimeUnit.SECONDS)
class MyClass {
    def fib(int n) {
        n<2?n:fib(n-1)+fib(n-2)
    }
}
```

`@TimedInterrupt` supports multiple options that will let you further customize the behavior of the transformation:

Attribute	Default value	Description	Example
value	Long.MAX_VALUE	Used in combination with `unit` to specify after how long execution times out.	`@TimedInterrupt(value=500L, unit= TimeUnit.MILLISECONDS, applyToAllClasses = false) class Slow { def fib(n) { n<2?n:fib(n-1 )+fib(n-2) } } def result def t = Thread.start { result = new Slow().fib(500) } t.join(5000) assert result == null assert !t.alive`
unit	TimeUnit.SECONDS	Used in combination with `value` to specify after how long execution times out.	`@TimedInterrupt(value=500L, unit= TimeUnit.MILLISECONDS, applyToAllClasses = false) class Slow { def fib(n) { n<2?n:fib(n-1 )+fib(n-2) } } def result def t = Thread.start { result = new Slow().fib(500) } t.join(5000) assert result == null assert !t.alive`

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>thrown</td><td><code>java.util.concurrent.TimeoutException</code></td><td>Specifies the type of exception which is thrown if timeout is reached.</td><td><pre><code>@TimedInterrupt(thrown=TooLongException, applyToAllClasses = false, value=1L)
class Slow {
    def fib(n) { Thread.sleep(100); n<2?n:fib(n-1)+fib(n-2) }
}
def result
def t = Thread.start {
    try {
        result = new Slow().fib(50)
    } catch (TooLongException e) {
        result = -1
    }
}
t.join(5000)
assert result == -1</code></pre></td></tr>
<tr><td>checkOnMethodStart</td><td>true</td><td>Should an interruption check be inserted at the beginning of each method body. See groovy.transform.TimedInterrupt for details.</td><td><pre><code>@TimedInterrupt(checkOnMethodStart=false)</code></pre></td></tr>
<tr><td>applyToAllClasses</td><td>true</td><td>Should the transformation be applied on all classes of the same source unit (in the same source file). See groovy.transform.TimedInterrupt for details.</td><td><pre><code>@TimedInterrupt(applyToAllClasses=false)
class A { ... } // interrupt checks added
class B { ... } // no interrupt checks</code></pre></td></tr>
<tr><td>applyToAllMembers</td><td>true</td><td>Should the transformation be applied on all members of class. See groovy.transform.TimedInterrupt for details.</td><td><pre><code>class A {
    @TimedInterrupt(applyToAllMembers=false)
    void method1() { ... } // interrupt checked added
    void method2() { ... } // no interrupt checks
}</code></pre></td></tr>
</table>

WARNING	`@TimedInterrupt` is currently not compatible with static methods!

`@groovy.transform.ConditionalInterrupt`

The last annotation for safer scripting is the base annotation when you want to interrupt a script using a custom strategy. In particular, this is the annotation of choice if you want to use resource management (limit the number of calls to an API, …). In the following example, user code is using an infinite loop, but `@ConditionalInterrupt` will allow us to check a quota manager and interrupt automatically the script:

```
@ConditionalInterrupt({Quotas.disallow('user')})
class UserCode {
    void doSomething() {
        int i=0
        while (true) {
            println "Consuming resources ${++i}"
        }
    }
}
```

The quota checking is very basic here, but it can be any code:

```
class Quotas {
    static def quotas = [:].withDefault { 10 }
    static boolean disallow(String userName) {
        println "Checking quota for $userName"
        (quotas[userName]--)<0
    }
}
```

We can make sure `@ConditionalInterrupt` works properly using this test code:

```
assert Quotas.quotas['user'] == 10
def t = Thread.start {
    new UserCode().doSomething()
}
t.join(5000)
assert !t.alive
assert Quotas.quotas['user'] < 0
```

Of course, in practice, it is unlikely that `@ConditionalInterrupt` will be itself added by hand on user code. It can be injected in a similar manner as the example shown in the ThreadInterrupt section, using the org.codehaus.groovy.control.customizers.ASTTransformationCustomizer :

```
def config = new CompilerConfiguration()
def checkExpression = new ClosureExpression(
```

```
        Parameter.EMPTY_ARRAY,
        new ExpressionStatement(
                new MethodCallExpression(new ClassExpression(ClassHelper.make(
Quotas)), 'disallow', new ConstantExpression('user'))
        )
)
config.addCompilationCustomizers(
        new ASTTransformationCustomizer(value: checkExpression, ConditionalInterrupt)
)

def shell = new GroovyShell(this.class.classLoader,new Binding(),config)

def userCode = """
        int i=0
        while (true) {
            println "Consuming resources \\${++i}"
        }
"""

assert Quotas.quotas['user'] == 10
def t = Thread.start {
    shell.evaluate(userCode)
}
t.join(5000)
assert !t.alive
assert Quotas.quotas['user'] < 0
```

`@ConditionalInterrupt` supports multiple options that will let you further customize the behavior of the transformation:

Attribute	Default value	Description	Example
value		The closure which will be called to check if execution is allowed. If the closure returns false, execution is allowed. If it returns true, then an exception will be thrown.	`@ConditionalInterrupt({ ... })`

<table>
<tr><th>Attribute</th><th>Default value</th><th>Description</th><th>Example</th></tr>
<tr><td>thrown</td><td><code>java.lang.InterruptedException</code></td><td>Specifies the type of exception which is thrown if execution should be aborted.</td><td><pre>config.addCompilationCustomizers(
        new
ASTTransformationCustomizer(thrown: QuotaExceededException,value:
checkExpression,
ConditionalInterrupt)
)
assert Quotas.quotas['user'] ==
10
def t = Thread.start {
    try {
        shell.evaluate(userCode)
    } catch
(QuotaExceededException) {
        Quotas.quotas['user'] =
'Quota exceeded'
    }
}
t.join(5000)
assert !t.alive
assert Quotas.quotas['user'] ==
'Quota exceeded'</pre></td></tr>
<tr><td>checkOnMethodStart</td><td>true</td><td>Should an interruption check be inserted at the beginning of each method body. See groovy.transform.ConditionalInterrupt for details.</td><td><pre>@ConditionalInterrupt(checkOnMethodStart=false)</pre></td></tr>
<tr><td>applyToAllClasses</td><td>true</td><td>Should the transformation be applied on all classes of the same source unit (in the same source file). See groovy.transform.ConditionalInterrupt for details.</td><td><pre>@ConditionalInterrupt(applyToAllClasses=false)
class A { ... } // interrupt
checks added
class B { ... } // no interrupt
checks</pre></td></tr>
</table>

Attribute	Default value	Description	Example
applyToAllMembers	true	Should the transformation be applied on all members of class. See groovy.transform.ConditionalInterrupt for details.	`class A { @ConditionalInterrupt (applyToAllMembers=false) void method1() { ... } // interrupt checked added void method2() { ... } // no interrupt checks }`

Compiler directives

This category of AST transformations groups annotations which have a direct impact on the semantics of the code, rather than focusing on code generation. With that regards, they can be seen as compiler directives that either change the behavior of a program at compile time or runtime.

`@groovy.transform.Field`

The `@Field` annotation only makes sense in the context of a script and aims at solving a common scoping error with scripts. The following example will for example fail at runtime:

```
def x

String line() {
    "="*x
}

x=3
assert "===" == line()
x=5
assert "=====" == line()
```

The error that is thrown may be difficult to interpret: groovy.lang.MissingPropertyException: No such property: x. The reason is that scripts are compiled to classes and the script body is itself compiled as a single *run()* method. Methods which are defined in the scripts are independent, so the code above is equivalent to this:

```
class MyScript extends Script {

    String line() {
        "="*x
    }

    public def run() {
        def x
```

```
        x=3
        assert "===" == line()
        x=5
        assert "=====" == line()
    }
}
```

So `def x` is effectively interpreted as a local variable, outside of the scope of the `line` method. The `@Field` AST transformation aims at fixing this by changing the scope of the variable to a field of the enclosing script:

```
@Field def x

String line() {
    "="*x
}

x=3
assert "===" == line()
x=5
assert "=====" == line()
```

The resulting, equivalent, code is now:

```
class MyScript extends Script {

    def x

    String line() {
        "="*x
    }

    public def run() {
        x=3
        assert "===" == line()
        x=5
        assert "=====" == line()
    }
}
```

`@groovy.transform.PackageScope`

By default, Groovy visibility rules imply that if you create a field without specifying a modifier, then the field is interpreted as a property:

```
class Person {
    String name // this is a property
```

```
}
```

Should you want to create a package private field instead of a property (private field+getter/setter), then annotate your field with `@PackageScope`:

```
class Person {
    @PackageScope String name // not a property anymore
}
```

The `@PackageScope` annotation can also be used for classes, methods and constructors. In addition, by specifying a list of `PackageScopeTarget` values as the annotation attribute at the class level, all members within that class that don't have an explicit modifier and match the provided `PackageScopeTarget` will remain package protected. For example to apply to fields within a class use the following annotation:

```
import static groovy.transform.PackageScopeTarget.FIELDS
@PackageScope(FIELDS)
class Person {
  String name     // not a property, package protected
  Date dob        // not a property, package protected
  private int age // explicit modifier, so won't be touched
}
```

The `@PackageScope` annotation is seldom used as part of normal Groovy conventions but is sometimes useful for factory methods that should be visible internally within a package or for methods or constructors provided for testing purposes, or when integrating with third-party libraries which require such visibility conventions.

`@groovy.transform.Final`

`@Final` is essentially an alias for the `final` modifier. The intention is that you would almost never use the `@Final` annotation directly (just use `final`). However, when creating meta-annotations that should apply the final modifier to the node being annotated, you can mix in `@Final`, e.g..

```
@AnnotationCollector([Singleton,Final]) @interface MySingleton {}

@MySingleton
class GreetingService {
    String greeting(String name) { "Hello, $name!" }
}
assert GreetingService.instance.greeting('Bob') == 'Hello, Bob!'
assert Modifier.isFinal(GreetingService.modifiers)
```

`@groovy.transform.AutoFinal`

The `@AutoFinal` annotation instructs the compiler to automatically insert the final modifier in numerous places within the annotated node. If applied on a method (or constructor), the parameters for that method (or constructor) will be marked as final. If applied on a class definition, the same treatment will occur for all declared methods and constructors within that class.

It is often considered bad practice to reassign parameters of a method or constructor with its body. By adding the final modifier to all parameter declarations you can avoid this practice entirely. Some programmers feel that adding final everywhere increases the amount of boilerplate code and makes the method signatures somewhat noisy. An alternative might instead be to use a code review process or apply a codenarc rule to give warnings if that practice is observed but these alternatives might lead to delayed feedback during quality checking rather than within the IDE or during compilation. The `@AutoFinal` annotation aims to maximise compiler/IDE feedback while retaining succinct code with minimum boilerplate noise.

The following example illustrates applying the annotation at the class level:

```
import groovy.transform.AutoFinal

@AutoFinal
class Person {
    private String first, last

    Person(String first, String last) {
        this.first = first
        this.last = last
    }

    String fullName(String separator) {
        "$first$separator$last"
    }

    String greeting(String salutation) {
        "$salutation, $first"
    }
}
```

In this example, the two parameters for the constructor and the single parameter for both the `fullname` and `greeting` methods will be final. Attempts to modify those parameters within the constructor or method bodies will be flagged by the compiler.

The following example illustrates applying the annotation at the method level:

```
class Calc {
    @AutoFinal
    int add(int a, int b) { a + b }

    int mult(int a, int b) { a * b }
}
```

Here, the `add` method will have final parameters but the `mult` method will remain unchanged.

@groovy.transform.AnnotationCollector

`@AnnotationCollector` allows the creation of meta-annotations, which are described in a dedicated section.

@groovy.transform.TypeChecked

`@TypeChecked` activates compile-time type checking on your Groovy code. See section on type checking for details.

@groovy.transform.CompileStatic

`@CompileStatic` activates static compilation on your Groovy code. See section on type checking for details.

@groovy.transform.CompileDynamic

`@CompileDynamic` disables static compilation on parts of your Groovy code. See section on type checking for details.

@groovy.lang.DelegatesTo

`@DelegatesTo` is not, technically speaking, an AST transformation. It is aimed at documenting code and helping the compiler in case you are using type checking or static compilation. The annotation is described thoroughly in the DSL section of this guide.

@groovy.transform.SelfType

`@SelfType` is not an AST transformation but rather a marker interface used with traits. See the traits documentation for further details.

Swing patterns

@groovy.beans.Bindable

`@Bindable` is an AST transformation that transforms a regular property into a bound property (according to the JavaBeans specification). The `@Bindable` annotation can be placed on a property or a class. To convert all properties of a class into bound properties, on can annotate the class like in this example:

```
import groovy.beans.Bindable

@Bindable
class Person {
    String name
    int age
}
```

This is equivalent to writing this:

```
import java.beans.PropertyChangeListener
```

```
import java.beans.PropertyChangeSupport

class Person {
    final private PropertyChangeSupport this$propertyChangeSupport

    String name
    int age

    public void addPropertyChangeListener(PropertyChangeListener listener) {
        this$propertyChangeSupport.addPropertyChangeListener(listener)
    }

    public void addPropertyChangeListener(String name, PropertyChangeListener
listener) {
        this$propertyChangeSupport.addPropertyChangeListener(name, listener)
    }

    public void removePropertyChangeListener(PropertyChangeListener listener) {
        this$propertyChangeSupport.removePropertyChangeListener(listener)
    }

    public void removePropertyChangeListener(String name, PropertyChangeListener
listener) {
        this$propertyChangeSupport.removePropertyChangeListener(name, listener)
    }

    public void firePropertyChange(String name, Object oldValue, Object newValue) {
        this$propertyChangeSupport.firePropertyChange(name, oldValue, newValue)
    }

    public PropertyChangeListener[] getPropertyChangeListeners() {
        return this$propertyChangeSupport.getPropertyChangeListeners()
    }

    public PropertyChangeListener[] getPropertyChangeListeners(String name) {
        return this$propertyChangeSupport.getPropertyChangeListeners(name)
    }
}
```

`@Bindable` therefore removes a lot of boilerplate from your class, dramatically increasing readability. If the annotation is put on a single property, only that property is bound:

```
import groovy.beans.Bindable

class Person {
    String name
    @Bindable int age
}
```

@groovy.beans.ListenerList

The @ListenerList AST transformation generates code for adding, removing and getting the list of listeners to a class, just by annotating a collection property:

```
import java.awt.event.ActionListener
import groovy.beans.ListenerList

class Component {
    @ListenerList
    List<ActionListener> listeners;
}
```

The transform will generate the appropriate add/remove methods based on the generic type of the list. In addition, it will also create fireXXX methods based on the public methods declared on the class:

```
import java.awt.event.ActionEvent
import java.awt.event.ActionListener as ActionListener
import groovy.beans.ListenerList as ListenerList

public class Component {

    @ListenerList
    private List<ActionListener> listeners

    public void addActionListener(ActionListener listener) {
        if ( listener == null) {
            return
        }
        if ( listeners == null) {
            listeners = []
        }
        listeners.add(listener)
    }

    public void removeActionListener(ActionListener listener) {
        if ( listener == null) {
            return
        }
        if ( listeners == null) {
            listeners = []
        }
        listeners.remove(listener)
    }

    public ActionListener[] getActionListeners() {
        Object __result = []
        if ( listeners != null) {
            __result.addAll(listeners)
```

```
        }
        return (( __result ) as ActionListener[])
    }

    public void fireActionPerformed(ActionEvent param0) {
        if ( listeners != null) {
            ArrayList<ActionListener> __list = new ArrayList<ActionListener>(
listeners)
            for (def listener : __list ) {
                listener.actionPerformed(param0)
            }
        }
    }
}
```

`@Bindable` supports multiple options that will let you further customize the behavior of the transformation:

Attribute	Default value	Description	Example
name	Generic type name	By default, the suffix which will be appended to add/remove/... methods is the simple class name of the generic type of the list.	`class Component { @ListenerList(name='item') List<ActionListener> listeners; }`
synchronize	false	If set to true, generated methods will be synchronized	`class Component { @ListenerList(synchronize = true) List<ActionListener> listeners; }`

`@groovy.beans.Vetoable`

The `@Vetoable` annotation works in a similar manner to `@Bindable` but generates constrained property according to the JavaBeans specification, instead of bound properties. The annotation can be placed on a class, meaning that all properties will be converted to constrained properties, or on a single property. For example, annotating this class with `@Vetoable`:

```
import groovy.beans.Vetoable

import java.beans.PropertyVetoException
import java.beans.VetoableChangeListener

@Vetoable
class Person {
```

```
    String name
    int age
}
```

is equivalent to writing this:

```
public class Person {

    private String name
    private int age
    final private java.beans.VetoableChangeSupport this$vetoableChangeSupport

    public void addVetoableChangeListener(VetoableChangeListener listener) {
        this$vetoableChangeSupport.addVetoableChangeListener(listener)
    }

    public void addVetoableChangeListener(String name, VetoableChangeListener
listener) {
        this$vetoableChangeSupport.addVetoableChangeListener(name, listener)
    }

    public void removeVetoableChangeListener(VetoableChangeListener listener) {
        this$vetoableChangeSupport.removeVetoableChangeListener(listener)
    }

    public void removeVetoableChangeListener(String name, VetoableChangeListener
listener) {
        this$vetoableChangeSupport.removeVetoableChangeListener(name, listener)
    }

    public void fireVetoableChange(String name, Object oldValue, Object newValue)
throws PropertyVetoException {
        this$vetoableChangeSupport.fireVetoableChange(name, oldValue, newValue)
    }

    public VetoableChangeListener[] getVetoableChangeListeners() {
        return this$vetoableChangeSupport.getVetoableChangeListeners()
    }

    public VetoableChangeListener[] getVetoableChangeListeners(String name) {
        return this$vetoableChangeSupport.getVetoableChangeListeners(name)
    }

    public void setName(String value) throws PropertyVetoException {
        this.fireVetoableChange('name', name, value)
        name = value
    }

    public void setAge(int value) throws PropertyVetoException {
        this.fireVetoableChange('age', age, value)
```

```
        age = value
    }
}
```

If the annotation is put on a single property, only that property is made vetoable:

```
import groovy.beans.Vetoable

class Person {
    String name
    @Vetoable int age
}
```

Test assistance

@groovy.test.NotYetImplemented

`@NotYetImplemented` is used to invert the result of a JUnit 3/4 test case. It is in particular useful if a feature is not yet implemented but the test is. In that case, it is expected that the test fails. Marking it with `@NotYetImplemented` will inverse the result of the test, like in this example:

```
import groovy.test.GroovyTestCase
import groovy.test.NotYetImplemented

class Maths {
    static int fib(int n) {
        // todo: implement later
    }
}

class MathsTest extends GroovyTestCase {
    @NotYetImplemented
    void testFib() {
        def dataTable = [
                1:1,
                2:1,
                3:2,
                4:3,
                5:5,
                6:8,
                7:13
        ]
        dataTable.each { i, r ->
            assert Maths.fib(i) == r
        }
    }
}
```

Another advantage of using this technique is that you can write test cases for bugs before knowing how to fix them. If some time in the future, a modification in the code fixes a bug by side effect, you'll be notified because a test which was expected to fail passed.

`@groovy.transform.ASTTest`

`@ASTTest` is a special AST transformation meant to help debugging other AST transformations or the Groovy compiler itself. It will let the developer "explore" the AST during compilation and perform assertions on the AST rather than on the result of compilation. This means that this AST transformations gives access to the AST before the bytecode is produced. `@ASTTest` can be placed on any annotable node and requires two parameters:

- *phase*: sets at which phase at which `@ASTTest` will be triggered. The test code will work on the AST tree at the end of this phase.
- *value*: the code which will be executed once the phase is reached, on the annotated node

TIP Compile phase has to be chosen from one of org.codehaus.groovy.control.CompilePhase . However, since it is not possible to annotate a node twice with the same annotation, you will not be able to use `@ASTTest` on the same node at two distinct compile phases.

`value` is a closure expression which has access to a special variable `node` corresponding to the annotated node, and a helper `lookup` method which will be discussed here. For example, you can annotate a class node like this:

```
import groovy.transform.ASTTest
import org.codehaus.groovy.ast.ClassNode

@ASTTest(phase=CONVERSION, value={   ①
    assert node instanceof ClassNode ②
    assert node.name == 'Person'     ③
})
class Person {
}
```

① we're checking the state of the Abstract Syntax Tree after the CONVERSION phase

② node refers to the AST node which is annotated by @ASTTest

③ it can be used to perform assertions at compile time

One interesting feature of `@ASTTest` is that if an assertion fails, then **compilation will fail**. Now imagine that we want to check the behavior of an AST transformation at compile time. We will take `@PackageScope` here, and we will want to verify that a property annotated with `@PackageScope` becomes a package private field. For this, we have to know at which phase the transform runs, which can be found in org.codehaus.groovy.transform.PackageScopeASTTransformation : semantic analysis. Then a test can be written like this:

```
import groovy.transform.ASTTest
```

```
import groovy.transform.PackageScope

@ASTTest(phase=SEMANTIC_ANALYSIS, value={
    def nameNode = node.properties.find { it.name == 'name' }
    def ageNode = node.properties.find { it.name == 'age' }
    assert nameNode
    assert ageNode == null // shouldn't be a property anymore
    def ageField = node.getDeclaredField 'age'
    assert ageField.modifiers == 0
})
class Person {
    String name
    @PackageScope int age
}
```

The `@ASTTest` annotation can only be placed wherever the grammar allows it. Sometimes, you would like to test the contents of an AST node which is not annotable. In this case, `@ASTTest` provides a convenient `lookup` method which will search the AST for nodes which are labelled with a special token:

```
def list = lookup('anchor') ①
Statement stmt = list[0] ②
```

① returns the list of AST nodes which label is 'anchor'

② it is always necessary to choose which element to process since lookup always returns a list

Imagine, for example, that you want to test the declared type of a for loop variable. Then you can do it like this:

```
import groovy.transform.ASTTest
import groovy.transform.PackageScope
import org.codehaus.groovy.ast.ClassHelper
import org.codehaus.groovy.ast.expr.DeclarationExpression
import org.codehaus.groovy.ast.stmt.ForStatement

class Something {
    @ASTTest(phase=SEMANTIC_ANALYSIS, value={
        def forLoop = lookup('anchor')[0]
        assert forLoop instanceof ForStatement
        def decl = forLoop.collectionExpression.expressions[0]
        assert decl instanceof DeclarationExpression
        assert decl.variableExpression.name == 'i'
        assert decl.variableExpression.originType == ClassHelper.int_TYPE
    })
    void someMethod() {
        int x = 1;
        int y = 10;
        anchor: for (int i=0; i<x+y; i++) {
```

```
            println "$i"
        }
    }
}
```

`@ASTTest` also exposes those variables inside the test closure:

- `node` corresponds to the annotated node, as usual
- `compilationUnit` gives access to the current `org.codehaus.groovy.control.CompilationUnit`
- `compilePhase` returns the current compile phase (`org.codehaus.groovy.control.CompilePhase`)

The latter is interesting if you don't specify the `phase` attribute. In that case, the closure will be executed after each compile phase after (and including) `SEMANTIC_ANALYSIS`. The context of the transformation is kept after each phase, giving you a chance to check what changed between two phases.

As an example, here is how you could dump the list of AST transformations registered on a class node:

```
import groovy.transform.ASTTest
import groovy.transform.CompileStatic
import groovy.transform.Immutable
import org.codehaus.groovy.ast.ClassNode
import org.codehaus.groovy.control.CompilePhase

@ASTTest(value={
    System.err.println "Compile phase: $compilePhase"
    ClassNode cn = node
    System.err.println "Global AST xforms:
${compilationUnit?.ASTTransformationsContext?.globalTransformNames}"
    CompilePhase.values().each {
        def transforms = cn.getTransforms(it)
        if (transforms) {
            System.err.println "Ast xforms for phase $it:"
            transforms.each { map ->
                System.err.println(map)
            }
        }
    }
})
@CompileStatic
@Immutable
class Foo {
}
```

And here is how you can memorize variables for testing between two phases:

```
import groovy.transform.ASTTest
```

```groovy
import groovy.transform.ToString
import org.codehaus.groovy.ast.ClassNode
import org.codehaus.groovy.control.CompilePhase

@ASTTest(value={
    if (compilePhase == CompilePhase.INSTRUCTION_SELECTION) {           ①
        println "toString() was added at phase: ${added}"
        assert added == CompilePhase.CANONICALIZATION                   ②
    } else {
        if (node.getDeclaredMethods('toString') && added == null) {     ③
            added = compilePhase                                        ④
        }
    }
})
@ToString
class Foo {
    String name
}
```

① if the current compile phase is instruction selection

② then we want to make sure `toString` was added at `CANONICALIZATION`

③ otherwise, if `toString` exists and that the variable from the context, `added` is null

④ then it means that this compile phase is the one where `toString` was added

Grape handling

`@groovy.lang.Grab`

`@groovy.lang.GrabConfig`

`@groovy.lang.GrabExclude`

`@groovy.lang.GrabResolver`

`@groovy.lang.Grapes`

`Grape` is a dependency management engine embedded into Groovy, relying on several annotations which are described thoroughly in this section of the guide.

Developing AST transformations

There are two kinds of transformations: global and local transformations.

- Global transformations are applied by the compiler on the code being compiled, wherever the transformation applies. Compiled classes that implement global transformations are in a JAR added to the classpath of the compiler and contain service locator file `META-INF/services/org.codehaus.groovy.transform.ASTTransformation` with a line with the name of the transformation class. The transformation class must have a no-arg constructor and implement the `org.codehaus.groovy.transform.ASTTransformation` interface. It will be run against **every source in the compilation**, so if you want fast compilation times, don't create transformations which scan all the AST in an expansive and time-consuming manner.

- Local transformations are transformations applied locally by annotating code elements you want to transform. For this, we reuse the annotation notation, and those annotations should implement `org.codehaus.groovy.transform.ASTTransformation`. The compiler will discover them and apply the transformation on these code elements.

Compilation phases guide

Groovy AST transformations must be performed in one of the nine defined compilation phases (org.codehaus.groovy.control.CompilePhase).

Global transformations may be applied in any phase, but local transformations may only be applied in the semantic analysis phase or later. Briefly, the compiler phases are:

- *Initialization*: source files are opened and environment configured
- *Parsing*: the grammar is used to produce tree of tokens representing the source code
- *Conversion*: An abstract syntax tree (AST) is created from token trees.
- *Semantic Analysis*: Performs consistency and validity checks that the grammar can't check for, and resolves classes.
- *Canonicalization*: Complete building the AST
- *Instruction Selection*: instruction set is chosen, for example Java 6 or Java 7 bytecode level
- *Class Generation*: creates the bytecode of the class in memory
- *Output*: write the binary output to the file system
- *Finalization*: Perform any last cleanup

Generally speaking, there is more type information available later in the phases. If your transformation is concerned with reading the AST, then a later phase where information is more plentiful might be a good choice. If your transformation is concerned with writing AST, then an earlier phase where the tree is more sparse might be more convenient.

Local transformations

Local AST transformations are relative to the context they are applied to. In most cases, the context is defined by an annotation that will define the scope of the transform. For example, annotating a field would mean that the transformation *applies to* the field, while annotating the class would mean that the transformation *applies to* the whole class.

As a naive and simple example, consider wanting to write a `@WithLogging` transformation that would add console messages at the start and end of a method invocation. So the following "Hello World" example would actually print "Hello World" along with a start and stop message:

Poor man's aspect oriented programming

```
@WithLogging
def greet() {
    println "Hello World"
}
```

```
greet()
```

A local AST transformation is an easy way to do this. It requires two things:

- a definition of the `@WithLogging` annotation
- an implementation of org.codehaus.groovy.transform.ASTTransformation that adds the logging expressions to the method

An `ASTTransformation` is a callback that gives you access to the org.codehaus.groovy.control.SourceUnit, through which you can get a reference to the org.codehaus.groovy.ast.ModuleNode (AST).

The AST (Abstract Syntax Tree) is a tree structure consisting mostly of org.codehaus.groovy.ast.expr.Expression (expressions) or org.codehaus.groovy.ast.expr.Statement (statements). An easy way to learn about the AST is to explore it in a debugger. Once you have the AST, you can analyze it to find out information about the code or rewrite it to add new functionality.

The local transformation annotation is the simple part. Here is the `@WithLogging` one:

```
import org.codehaus.groovy.transform.GroovyASTTransformationClass

import java.lang.annotation.ElementType
import java.lang.annotation.Retention
import java.lang.annotation.RetentionPolicy
import java.lang.annotation.Target

@Retention(RetentionPolicy.SOURCE)
@Target([ElementType.METHOD])
@GroovyASTTransformationClass(["gep.WithLoggingASTTransformation"])
public @interface WithLogging {
}
```

The annotation retention can be `SOURCE` because you won't need the annotation past that. The element type here is `METHOD`, the `@WithLogging` because the annotation applies to methods.

But the most important part is the `@GroovyASTTransformationClass` annotation. This links the `@WithLogging` annotation to the `ASTTransformation` class you will write. `gep.WithLoggingASTTransformation` is the fully qualified class name of the `ASTTransformation` we are going to write. This line wires the annotation to the transformation.

With this in place, the Groovy compiler is going to invoke `gep.WithLoggingASTTransformation` every time an `@WithLogging` is found in a source unit. Any breakpoint set within `LoggingASTTransformation` will now be hit within the IDE when running the sample script.

The `ASTTransformation` class is a little more complex. Here is the very simple, and very naive, transformation to add a method start and stop message for `@WithLogging`:

```groovy
@CompileStatic                                                                    ①
@GroovyASTTransformation(phase=CompilePhase.SEMANTIC_ANALYSIS)                    ②
class WithLoggingASTTransformation implements ASTTransformation {                 ③

    @Override
    void visit(ASTNode[] nodes, SourceUnit sourceUnit) {                          ④
        MethodNode method = (MethodNode) nodes[1]                                 ⑤

        def startMessage = createPrintlnAst("Starting $method.name")              ⑥
        def endMessage = createPrintlnAst("Ending $method.name")                  ⑦

        def existingStatements = ((BlockStatement)method.code).statements         ⑧
        existingStatements.add(0, startMessage)                                   ⑨
        existingStatements.add(endMessage)                                        ⑩

    }

    private static Statement createPrintlnAst(String message) {                   ⑪
        new ExpressionStatement(
            new MethodCallExpression(
                new VariableExpression("this"),
                new ConstantExpression("println"),
                new ArgumentListExpression(
                    new ConstantExpression(message)
                )
            )
        )
    }
}
```

① even if not mandatory, if you write an AST transformation in Groovy, it is highly recommended to use `CompileStatic` because it will improve performance of the compiler.

② annotate with org.codehaus.groovy.transform.GroovyASTTransformation to tell at which compilation phase the transform needs to run. Here, it's at the *semantic analysis* phase.

③ implement the `ASTTransformation` interface

④ which only has a single `visit` method

⑤ the `nodes` parameter is a 2 AST node array, for which the first one is the annotation node (`@WithLogging`) and the second one is the annotated node (the method node)

⑥ create a statement that will print a message when we enter the method

⑦ create a statement that will print a message when we exit the method

⑧ get the method body, which in this case is a `BlockStatement`

⑨ add the enter method message before the first statement of existing code

⑩ append the exit method message after the last statement of existing code

⑪ creates an `ExpressionStatement` wrapping a `MethodCallExpression` corresponding to `this.println("message")`

It is important to notice that for the brevity of this example, we didn't make the necessary checks, such as checking that the annotated node is really a `MethodNode`, or that the method body is an instance of `BlockStatement`. This exercise is left to the reader.

Note the creation of the new println statements in the `createPrintlnAst(String)` method. Creating AST for code is not always simple. In this case we need to construct a new method call, passing in the receiver/variable, the name of the method, and an argument list. When creating AST, it might be helpful to write the code you're trying to create in a Groovy file and then inspect the AST of that code in the debugger to learn what to create. Then write a function like `createPrintlnAst` using what you learned through the debugger.

In the end:

```
@WithLogging
def greet() {
    println "Hello World"
}

greet()
```

Produces:

```
Starting greet
Hello World
Ending greet
```

NOTE	It is important to note that an AST transformation participates directly in the compilation process. A common error by beginners is to have the AST transformation code in the same source tree as a class that uses the transformation. Being in the same source tree in general means that they are compiled at the same time. Since the transformation itself is going to be compiled in phases and that each compile phase processes all files of the same source unit before going to the next one, there's a direct consequence: the transformation will not be compiled before the class that uses it! In conclusion, AST transformations need to be precompiled before you can use them. In general, it is as easy as having them in a separate source tree.

Global transformations

Global AST transformation are similar to local one with a major difference: they do not need an annotation, meaning that they are applied *globally*, that is to say on each class being compiled. It is therefore very important to limit their use to last resort, because it can have a significant impact on the compiler performance.

Following the example of the local AST transformation, imagine that we would like to trace all methods, and not only those which are annotated with `@WithLogging`. Basically, we need this code to behave the same as the one annotated with `@WithLogging` before:

```
def greet() {
    println "Hello World"
}

greet()
```

To make this work, there are two steps:

1. create the `org.codehaus.groovy.transform.ASTTransformation` descriptor inside the `META-INF/services` directory
2. create the `ASTTransformation` implementation

The descriptor file is required and must be found on classpath. It will contain a single line:

META-INF/services/org.codehaus.groovy.transform.ASTTransformation

```
gep.WithLoggingASTTransformation
```

The code for the transformation looks similar to the local case, but instead of using the `ASTNode[]` parameter, we need to use the `SourceUnit` instead:

gep/WithLoggingASTTransformation.groovy

```
@CompileStatic                                                                    ①
@GroovyASTTransformation(phase=CompilePhase.SEMANTIC_ANALYSIS)                    ②
class WithLoggingASTTransformation implements ASTTransformation {                 ③

    @Override
    void visit(ASTNode[] nodes, SourceUnit sourceUnit) {                          ④
        def methods = sourceUnit.AST.methods                                      ⑤
        methods.each { method ->                                                  ⑥
            def startMessage = createPrintlnAst("Starting $method.name")          ⑦
            def endMessage = createPrintlnAst("Ending $method.name")              ⑧

            def existingStatements = ((BlockStatement)method.code).statements     ⑨
            existingStatements.add(0, startMessage)                               ⑩
            existingStatements.add(endMessage)                                    ⑪
        }
    }

    private static Statement createPrintlnAst(String message) {                   ⑫
        new ExpressionStatement(
            new MethodCallExpression(
                new VariableExpression("this"),
                new ConstantExpression("println"),
                new ArgumentListExpression(
                    new ConstantExpression(message)
                )
            )
```

```
        )
    }
}
```

① even if not mandatory, if you write an AST transformation in Groovy, it is highly recommended to use `CompileStatic` because it will improve performance of the compiler.

② annotate with org.codehaus.groovy.transform.GroovyASTTransformation to tell at which compilation phase the transform needs to run. Here, it's at the *semantic analysis* phase.

③ implement the `ASTTransformation` interface

④ which only has a single `visit` method

⑤ the `sourceUnit` parameter gives access to the source being compiled, so we get the AST of the current source and retrieve the list of methods from this file

⑥ we iterate on each method from the source file

⑦ create a statement that will print a message when we enter the method

⑧ create a statement that will print a message when we exit the method

⑨ get the method body, which in this case is a `BlockStatement`

⑩ add the enter method message before the first statement of existing code

⑪ append the exit method message after the last statement of existing code

⑫ creates an `ExpressionStatement` wrapping a `MethodCallExpression` corresponding to `this.println("message")`

AST API guide

AbstractASTTransformation

While you have seen that you can directly implement the `ASTTransformation` interface, in almost all cases you will not do this but extend the org.codehaus.groovy.transform.AbstractASTTransformation class. This class provides several utility methods that make AST transformations easier to write. Almost all AST transformations included in Groovy extend this class.

ClassCodeExpressionTransformer

It is a common use case to be able to transform an expression into another. Groovy provides a class which makes it very easy to do this: org.codehaus.groovy.ast.ClassCodeExpressionTransformer

To illustrate this, let's create a `@Shout` transformation that will transform all `String` constants in method call arguments into their uppercase version. For example:

```
@Shout
def greet() {
    println "Hello World"
}
```

```
greet()
```

should print:

```
HELLO WORLD
```

Then the code for the transformation can use the ClassCodeExpressionTransformer to make this easier:

```
@CompileStatic
@GroovyASTTransformation(phase=CompilePhase.SEMANTIC_ANALYSIS)
class ShoutASTTransformation implements ASTTransformation {

    @Override
    void visit(ASTNode[] nodes, SourceUnit sourceUnit) {
        ClassCodeExpressionTransformer trn = new ClassCodeExpressionTransformer() {
①
            private boolean inArgList = false
            @Override
            protected SourceUnit getSourceUnit() {
                sourceUnit
②
            }

            @Override
            Expression transform(final Expression exp) {
                if (exp instanceof ArgumentListExpression) {
                    inArgList = true
                } else if (inArgList &&
                    exp instanceof ConstantExpression && exp.value instanceof String)
{
                    return new ConstantExpression(exp.value.toUpperCase())
③
                }
                def trn = super.transform(exp)
                inArgList = false
                trn
            }
        }
        trn.visitMethod((MethodNode)nodes[1])
④
    }
}
```

① Internally the transformation creates a ClassCodeExpressionTransformer

② The transformer needs to return the source unit

③ if a constant expression of type string is detected inside an argument list, transform it into its upper case version

④ call the transformer on the method being annotated

AST Nodes

WARNING	Writing an AST transformation requires a deep knowledge of the internal Groovy API. In particular it requires knowledge about the AST classes. Since those classes are internal, there are chances that the API will change in the future, meaning that your transformations *could* break. Despite that warning, the AST has been very stable over time and such a thing rarely happens.

Classes of the Abstract Syntax Tree belong to the `org.codehaus.groovy.ast` package. It is recommended to the reader to use the Groovy Console, in particular the AST browser tool, to gain knowledge about those classes. Another resource for learning is the AST Builder test suite.

Macros

Introduction

Until version 2.5.0, when developing AST transformations, developers should have a deep knowledge about how the AST (Abstract Syntax Tree) was built by the compiler in order to know how to add new expressions or statements during compile time.

Although the use of `org.codehaus.groovy.ast.tool.GeneralUtils` static methods could mitigate the burden of creating expressions and statements, it's still a low-level way of writing those AST nodes directly. We needed something to abstract us from writing the AST directly and that's exactly what Groovy macros were made for. They allow you to directly add code during compilation, without having to translate the code you had in mind to the `org.codehaus.groovy.ast.*` node related classes.

Statements and expressions

Let's see an example, lets create a local AST transformation: `@AddMessageMethod`. When applied to a given class it will add a new method called `getMessage` to that class. The method will return "42". The annotation is pretty straight forward:

```
@Retention(RetentionPolicy.SOURCE)
@Target([ElementType.TYPE])
@GroovyASTTransformationClass(["metaprogramming.AddMethodASTTransformation"])
@interface AddMethod { }
```

What would the AST transformation look like without the use of a macro ? Something like this:

```
@GroovyASTTransformation(phase = CompilePhase.INSTRUCTION_SELECTION)
class AddMethodASTTransformation extends AbstractASTTransformation {
    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        ClassNode classNode = (ClassNode) nodes[1]
```

```
        ReturnStatement code =
                new ReturnStatement(                            ①
                        new ConstantExpression("42"))           ②

        MethodNode methodNode =
                new MethodNode(
                        "getMessage",
                        ACC_PUBLIC,
                        ClassHelper.make(String),
                        [] as Parameter[],
                        [] as ClassNode[],
                        code)                                   ③

        classNode.addMethod(methodNode)                         ④
    }
}
```

① Create a return statement

② Create a constant expression "42"

③ Adding the code to the new method

④ Adding the new method to the annotated class

If you're not used to the AST API, that definitely doesn't look like the code you had in mind. Now look how the previous code simplifies with the use of macros.

```
@GroovyASTTransformation(phase = CompilePhase.INSTRUCTION_SELECTION)
class AddMethodWithMacrosASTTransformation extends AbstractASTTransformation {
    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        ClassNode classNode = (ClassNode) nodes[1]

        ReturnStatement simplestCode = macro { return "42" }   ①

        MethodNode methodNode =
                new MethodNode(
                        "getMessage",
                        ACC_PUBLIC,
                        ClassHelper.make(String),
                        [] as Parameter[],
                        [] as ClassNode[],
                        simplestCode)                          ②

        classNode.addMethod(methodNode)                        ③
    }
}
```

① Much simpler. You wanted to add a return statement that returned "42" and that's exactly what you can read inside the `macro` utility method. Your plain code will be translated for you to a org.codehaus.groovy.ast.stmt.ReturnStatement

② Adding the return statement to the new method

③ Adding the new code to the annotated class

Although the `macro` method is used in this example to create a **statement** the `macro` method could also be used to create **expressions** as well, it depends on which `macro` signature you use:

- `macro(Closure)`: Create a given statement with the code inside the closure.
- `macro(Boolean,Closure)`: if **true** wrap expressions inside the closure inside a statement, if **false** then return an expression
- `macro(CompilePhase, Closure)`: Create a given statement with the code inside the closure in a specific compile phase
- `macro(CompilePhase, Boolean, Closure)`: Create a statement or an expression (true == statement, false == expression) in a specific compilation phase.

NOTE All these signatures can be found at `org.codehaus.groovy.macro.runtime.MacroGroovyMethods`

Sometimes we could be only interested in creating a given expression, not the whole statement, in order to do that we should use any of the `macro` invocations with a boolean parameter:

```
@GroovyASTTransformation(phase = CompilePhase.INSTRUCTION_SELECTION)
class AddGetTwoASTTransformation extends AbstractASTTransformation {

    BinaryExpression onePlusOne() {
        return macro(false) { 1 + 1 }                                    ①
    }

    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        ClassNode classNode = nodes[1]
        BinaryExpression expression = onePlusOne()                       ②
        ReturnStatement returnStatement = GeneralUtils.returnS(expression) ③

        MethodNode methodNode =
                new MethodNode("getTwo",
                        ACC_PUBLIC,
                        ClassHelper.Integer_TYPE,
                        [] as Parameter[],
                        [] as ClassNode[],
                        returnStatement                                  ④
                )

        classNode.addMethod(methodNode)                                  ⑤
    }
}
```

① We're telling macro not to wrap the expression in a statement, we're only interested in the expression

② Assigning the expression

③ Creating a `ReturnStatement` using a method from `GeneralUtils` and returning the expression

④ Adding the code to the new method

⑤ Adding the method to the class

Variable substitution

Macros are great but we can't create anything useful or reusable if our macros couldn't receive parameters or resolve surrounding variables.

In the following example we're creating an AST transformation `@MD5` that when applied to a given String field will add a method returning the MD5 value of that field.

```
@Retention(RetentionPolicy.SOURCE)
@Target([ElementType.FIELD])
@GroovyASTTransformationClass(["metaprogramming.MD5ASTTransformation"])
@interface MD5 { }
```

And the transformation:

```
@GroovyASTTransformation(phase = CompilePhase.CANONICALIZATION)
class MD5ASTTransformation extends AbstractASTTransformation {

    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        FieldNode fieldNode = nodes[1]
        ClassNode classNode = fieldNode.declaringClass
        String capitalizedName = fieldNode.name.capitalize()
        MethodNode methodNode = new MethodNode(
                "get${capitalizedName}MD5",
                ACC_PUBLIC,
                ClassHelper.STRING_TYPE,
                [] as Parameter[],
                [] as ClassNode[],
                buildMD5MethodCode(fieldNode))

        classNode.addMethod(methodNode)
    }

    BlockStatement buildMD5MethodCode(FieldNode fieldNode) {
        VariableExpression fieldVar = GeneralUtils.varX(fieldNode.name) ①

        return macro(CompilePhase.SEMANTIC_ANALYSIS, true) {          ②
            return java.security.MessageDigest
                    .getInstance('MD5')
```

```
                        .digest($v { fieldVar }.getBytes())                ③
                        .encodeHex()
                        .toString()
            }
        }
    }
```

① We need a reference to a variable expression

② If using a class outside the standard packages we should add any needed imports or use the qualified name. When using the qualified name of a given static method you need to make sure it's resolved in the proper compile phase. In this particular case we're instructing the macro to resolve it at the SEMANTIC_ANALYSIS phase, which is the first compile phase with type information.

③ In order to substitute any `expression` inside the macro we need to use the `$v` method. `$v` receives a closure as an argument, and the closure is only allowed to substitute expressions, meaning classes inheriting `org.codehaus.groovy.ast.expr.Expression`.

MacroClass

As we mentioned earlier, the `macro` method is only capable of producing `statements` and `expressions`. But what if we want to produce other types of nodes, such as a method, a field and so on?

`org.codehaus.groovy.macro.transform.MacroClass` can be used to create **classes** (ClassNode instances) in our transformations the same way we created statements and expressions with the `macro` method before.

The next example is a local transformation `@Statistics`. When applied to a given class, it will add two methods **getMethodCount()** and **getFieldCount()** which return how many methods and fields within the class respectively. Here is the marker annotation.

```
@Retention(RetentionPolicy.SOURCE)
@Target([ElementType.TYPE])
@GroovyASTTransformationClass(["metaprogramming.StatisticsASTTransformation"])
@interface Statistics {}
```

And the AST transformation:

```
@CompileStatic
@GroovyASTTransformation(phase = CompilePhase.INSTRUCTION_SELECTION)
class StatisticsASTTransformation extends AbstractASTTransformation {

    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        ClassNode classNode = (ClassNode) nodes[1]
        ClassNode templateClass = buildTemplateClass(classNode)  ①

        templateClass.methods.each { MethodNode node ->          ②
            classNode.addMethod(node)
```

```
        }
    }

    @CompileDynamic
    ClassNode buildTemplateClass(ClassNode reference) {           ③
        def methodCount = constX(reference.methods.size())        ④
        def fieldCount = constX(reference.fields.size())          ⑤

        return new MacroClass() {
            class Statistics {
                java.lang.Integer getMethodCount() {              ⑥
                    return $v { methodCount }
                }

                java.lang.Integer getFieldCount() {               ⑦
                    return $v { fieldCount }
                }
            }
        }
    }
}
```

① Creating a template class

② Adding template class methods to the annotated class

③ Passing the reference class

④ Extracting reference class method count value expression

⑤ Extracting reference class field count value expression

⑥ Building the **getMethodCount()** method using reference's method count value expression

⑦ Building the **getFieldCount()** method using reference's field count value expression

Basically we've created the **Statistics** class as a template to avoid writing low level AST API, then we copied methods created in the template class to their final destination.

NOTE	Types inside the `MacroClass` implementation should be resolved inside, that's why we had to write `java.lang.Integer` instead of simply writing `Integer`.

IMPORTANT	Notice that we're using `@CompileDynamic`. That's because the way we use `MacroClass` is like we were actually implementing it. So if you were using `@CompileStatic` it will complain because an implementation of an abstract class can't be another different class.

@Macro methods

You have seen that by using `macro` you can save yourself a lot of work but you might wonder where that method came from. You didn't declare it or static import it. You can think of it as a special global method (or if you prefer, a method on every `Object`). This is much like how the `println` extension method is defined. But unlike `println` which becomes a method selected for execution later in the compilation process, macro expansion is done early in the compilation process. The declaration of macro as one of the available methods for this early expansion is done by annotating a macro method definition with the @Macro annotation and making that method available using a similar mechanism for extension modules. Such methods are known as *macro* methods and the good news is you can define your own.

To define your own macro method, create a class in a similar way to an extension module and add a method such as:

```
public class ExampleMacroMethods {

    @Macro
    public static Expression safe(MacroContext macroContext, MethodCallExpression
callExpression) {
        return ternaryX(
                notNullX(callExpression.getObjectExpression()),
                callExpression,
                constX(null)
        );
    }
    ...
}
```

Now you would register this as an extension module using a org.codehaus.groovy.runtime.ExtensionModule file within the META-INF/groovy directory.

Now, assuming that the class and meta info file are on your classpath, you can use the macro method in the following way:

```
def nullObject = null
assert null == safe(safe(nullObject.hashcode()).toString())
```

Testing AST transformations

Separating source trees

This section is about good practices in regard to testing AST transformations. Previous sections highlighted the fact that to be able to execute an AST transformation, it has to be precompiled. It might sound obvious but a lot of people get caught on this, trying to use an AST transformation in the same source tree as where it is defined.

The first tip for testing AST transformation is therefore to separate test sources from the sources of the transform. Again, this is nothing but best practices, but you must make sure that your build too does actually compile them separately. This is the case by default with both Apache Maven and Gradle.

Debugging AST transformations

It is very handy to be able to put a breakpoint in an AST transformation, so that you can debug your code in the IDE. However, you might be surprised to see that your IDE doesn't stop on the breakpoint. The reason is actually simple: if your IDE uses the Groovy compiler to compile the unit tests for your AST transformation, then the compilation is triggered from the IDE, but the process which will compile the files doesn't have debugging options. It's only when the test case is executed that the debugging options are set on the virtual machine. In short: it is too late, the class has been compiled already, and your transformation is already applied.

A very easy workaround is to use the `GroovyTestCase` class which provides an `assertScript` method. This means that instead of writing this in a test case:

```
static class Subject {
    @MyTransformToDebug
    void methodToBeTested() {}
}

void testMyTransform() {
    def c = new Subject()
    c.methodToBeTested()
}
```

You should write:

```
void testMyTransformWithBreakpoint() {
    assertScript '''
        import metaprogramming.MyTransformToDebug

        class Subject {
            @MyTransformToDebug
            void methodToBeTested() {}
        }
        def c = new Subject()
        c.methodToBeTested()
    '''
}
```

The difference is that when you use `assertScript`, the code in the `assertScript` block is compiled **when the unit test is executed**. That is to say that this time, the `Subject` class will be compiled with debugging active, and the breakpoint is going to be hit.

ASTMatcher

Sometimes you may want to make assertions over AST nodes; perhaps to filter the nodes, or to make sure a given transformation has built the expected AST node.

Filtering nodes

For instance if you would like to apply a given transformation only to a specific set of AST nodes, you could use **ASTMatcher** to filter these nodes. The following example shows how to transform a given expression to another. Using **ASTMatcher** it looks for a specific expression `1 + 1` and it transforms it to `3`. That's why we called it the `@Joking` example.

First we create the `@Joking` annotation that only can be applied to methods:

```
@Retention(RetentionPolicy.SOURCE)
@Target([ElementType.METHOD])
@GroovyASTTransformationClass(["metaprogramming.JokingASTTransformation"])
@interface Joking { }
```

Then the transformation, that only applies an instance of `org.codehaus.groovy.ast.ClassCodeExpressionTransformer` to all the expressions within the method code block.

```
@CompileStatic
@GroovyASTTransformation(phase = CompilePhase.INSTRUCTION_SELECTION)
class JokingASTTransformation extends AbstractASTTransformation {
    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        MethodNode methodNode = (MethodNode) nodes[1]

        methodNode
            .getCode()
            .visit(new ConvertOnePlusOneToThree(source))  ①
    }
}
```

① Get the method's code statement and apply the expression transformer

And this is when the **ASTMatcher** is used to apply the transformation only to those expressions matching the expression `1 + 1`.

```
class ConvertOnePlusOneToThree extends ClassCodeExpressionTransformer {
    SourceUnit sourceUnit

    ConvertOnePlusOneToThree(SourceUnit sourceUnit) {
        this.sourceUnit = sourceUnit
    }

    @Override
    Expression transform(Expression exp) {
        Expression ref = macro { 1 + 1 }     ①

        if (ASTMatcher.matches(ref, exp)) {  ②
            return macro { 3 }               ③
        }
```

```
        return super.transform(exp)
    }
}
```

① Builds the expression used as reference pattern

② Checks the current expression evaluated matches the reference expression

③ If it matches then replaces the current expression with the expression built with `macro`

Then you could test the implementation as follows:

```
package metaprogramming

class Something {
    @Joking
    Integer getResult() {
        return 1 + 1
    }
}

assert new Something().result == 3
```

Unit testing AST transforms

Normally we test AST transformations just checking that the final use of the transformation does what we expect. But it would be great if we could have an easy way to check, for example, that the nodes the transformation adds are what we expected from the beginning.

The following transformation adds a new method `giveMeTwo` to an annotated class.

```
@GroovyASTTransformation(phase = CompilePhase.INSTRUCTION_SELECTION)
class TwiceASTTransformation extends AbstractASTTransformation {

    static final String VAR_X = 'x'

    @Override
    void visit(ASTNode[] nodes, SourceUnit source) {
        ClassNode classNode = (ClassNode) nodes[1]
        MethodNode giveMeTwo = getTemplateClass(sumExpression)
            .getDeclaredMethods('giveMeTwo')
            .first()

        classNode.addMethod(giveMeTwo)                  ①
    }

    BinaryExpression getSumExpression() {               ②
        return macro {
            $v{ varX(VAR_X) } +
```

```
            $v{ varX(VAR_X) }
        }
    }

    ClassNode getTemplateClass(Expression expression) { ③
        return new MacroClass() {
            class Template {
                java.lang.Integer giveMeTwo(java.lang.Integer x) {
                    return $v { expression }
                }
            }
        }
    }
}
```

① Adding the method to the annotated class

② Building a binary expression. The binary expression uses the same variable expression in both sides of the `+` token (check `varX` method at **org.codehaus.groovy.ast.tool.GeneralUtils**).

③ Builds a new **ClassNode** with a method called `giveMeTwo` which returns the result of an expression passed as parameter.

Now instead of creating a test executing the transformation over a given sample code. I would like to check that the construction of the binary expression is done properly:

```
void testTestingSumExpression() {
    use(ASTMatcher) {                 ①
        TwiceASTTransformation sample = new TwiceASTTransformation()
        Expression referenceNode = macro {
            a + a                     ②
        }.withConstraints {           ③
            placeholder 'a'           ④
        }

        assert sample
            .sumExpression
            .matches(referenceNode)   ⑤
    }
}
```

① Using ASTMatcher as a category

② Build a template node

③ Apply some constraints to that template node

④ Tells compiler that `a` is a placeholder.

⑤ Asserts reference node and current node are equal

Of course you can/should always check the actual execution:

```
void testASTBehavior() {
    assertScript '''
    package metaprogramming

    @Twice
    class AAA {

    }

    assert new AAA().giveMeTwo(1) == 2
    '''
}
```

ASTTest

Last but not least, testing an AST transformation is also about testing the state of the AST **during compilation**. Groovy provides a tool named `@ASTTest` for this: it is an annotation that will let you add assertions on an abstract syntax tree. Please check the documentation for ASTTest for more details.

External references

If you are interested in a step-by-step tutorial about writing AST transformations, you can follow this workshop.

Dependency management with Grape

Quick start

Add a Dependency

Grape is a JAR dependency manager embedded into Groovy. Grape lets you quickly add maven repository dependencies to your classpath, making scripting even easier. The simplest use is as simple as adding an annotation to your script:

```
@Grab(group='org.springframework', module='spring-orm', version='5.2.8.RELEASE')
import org.springframework.jdbc.core.JdbcTemplate
```

`@Grab` also supports a shorthand notation:

```
@Grab('org.springframework:spring-orm:5.2.8.RELEASE')
import org.springframework.jdbc.core.JdbcTemplate
```

Note that we are using an annotated import here, which is the recommended way. You can also search for dependencies on mvnrepository.com and it will provide you the `@Grab` annotation form of the `pom.xml` entry.

Specify Additional Repositories

Not all dependencies are in maven central. You can add new ones like this:

```
@GrabResolver(name='restlet', root='http://maven.restlet.org/')
@Grab(group='org.restlet', module='org.restlet', version='1.1.6')
```

Maven Classifiers

Some maven dependencies need classifiers in order to be able to resolve. You can fix that like this:

```
@Grab(group='net.sf.json-lib', module='json-lib', version='2.2.3', classifier='jdk15')
```

Excluding Transitive Dependencies

Sometimes you will want to exclude transitive dependencies as you might be already using a slightly different but compatible version of some artifact. You can do this as follows:

```
@Grab('net.sourceforge.htmlunit:htmlunit:2.8')
@GrabExclude('xml-apis:xml-apis')
```

JDBC Drivers

Because of the way JDBC drivers are loaded, you'll need to configure Grape to attach JDBC driver dependencies to the system class loader. I.e:

```
@GrabConfig(systemClassLoader=true)
@Grab(group='mysql', module='mysql-connector-java', version='5.1.6')
```

Using Grape From the Groovy Shell

From groovysh use the method call variant:

```
groovy.grape.Grape.grab(group:'org.springframework', module:'spring', version:'2.5.6')
```

Proxy settings

If you are behind a firewall and/or need to use Groovy/Grape through a proxy server, you can specify those settings on the command like via the `http.proxyHost` and `http.proxyPort` system properties:

```
groovy -Dhttp.proxyHost=yourproxy -Dhttp.proxyPort=8080 yourscript.groovy
```

Or you can make this system-wide by adding these properties to your JAVA_OPTS environment variable:

```
JAVA_OPTS = -Dhttp.proxyHost=yourproxy -Dhttp.proxyPort=8080
```

Logging

If you want to see what Grape is doing set the system property `groovy.grape.report.downloads` to `true` (e.g. add `-Dgroovy.grape.report.downloads=true` to invocation or JAVA_OPTS) and Grape will print the following infos to System.error:

- Starting resolve of a dependency
- Starting download of an artifact
- Retrying download of an artifact
- Download size and time for downloaded artifacts

To log with even more verbosity, increase the Ivy log level (defaults to `-1`). For example `-Divy.message.logger.level=4`.

Detail

Grape (The *Groovy Adaptable Packaging Engine* or *Groovy Advanced Packaging Engine*) is the infrastructure enabling the grab() calls in Groovy, a set of classes leveraging Ivy to allow for a repository driven module system for Groovy. This allows a developer to write a script with an essentially arbitrary library requirement, and ship just the script. Grape will, at runtime, download as needed and link the named libraries and all dependencies forming a transitive closure when the script is run from existing repositories such as Maven Central.

Grape follows the Ivy conventions for module version identification, with naming change.

- `group` - Which module group the module comes from. Translates directly to a Maven groupId or an Ivy Organization. Any group matching `/groovy[x][\..*]^/` is reserved and may have special meaning to the groovy endorsed modules.
- `module` - The name of the module to load. Translated directly to a Maven artifactId or an Ivy artifact.
- `version` - The version of the module to use. Either a literal version `1.1-RC3' or an Ivy Range `[2.2.1,)' meaning 2.2.1 or any greater version).
- `classifier` - The optional classifier to use (for example, *jdk15*)

The downloaded modules will be stored according to Ivy's standard mechanism with a cache root of `~/.groovy/grapes`

Usage

Annotation

One or more `groovy.lang.Grab` annotations can be added at any place that annotations are accepted to tell the compiler that this code relies on the specific library. This will have the effect of adding the library to the classloader of the groovy compiler. This annotation is detected and evaluated before any other resolution of classes in the script, so imported classes can be properly resolved by a `@Grab` annotation.

```
import com.jidesoft.swing.JideSplitButton
@Grab(group='com.jidesoft', module='jide-oss', version='[2.2.1,2.3.0)')
public class TestClassAnnotation {
    public static String testMethod () {
        return JideSplitButton.class.name
    }
}
```

An appropriate `grab(…)` call will be added to the static initializer of the class of the containing class (or script class in the case of an annotated script element).

Multiple Grape Annotations

In early versions of Groovy, if you wanted to use a Grab annotation multiple times on the same node you had to use the `@Grapes` annotation, e.g.:

```
@Grapes([
   @Grab(group='commons-primitives', module='commons-primitives', version='1.0'),
   @Grab(group='org.ccil.cowan.tagsoup', module='tagsoup', version='0.9.7')])
class Example {
// ...
}
```

Otherwise you'd encounter the following error:

```
Cannot specify duplicate annotation on the same member
```

But in recent versions, @Grapes is purely optional.

Technical notes:

- Originally, Groovy stored the Grab annotations for access at runtime and duplicates aren't allowed in the bytecode. In current versions, @Grab has only SOURCE retention, so the multiple occurrences aren't an issue.
- Future versions of Grape may support using the Grapes annotation to provide a level of structuring, e.g. allowing a GrabExclude or GrabResolver annotation to apply to only a subset of the Grab annotations.

Method call

Typically a call to grab will occur early in the script or in class initialization. This is to ensure that the libraries are made available to the ClassLoader before the groovy code relies on the code. A couple of typical calls may appear as follows:

```
import groovy.grape.Grape
// random maven library
Grape.grab(group:'com.jidesoft', module:'jide-oss', version:'[2.2.0,)')
Grape.grab([group:'org.apache.ivy', module:'ivy', version:'2.0.0-beta1', conf:
['default', 'optional']],
     [group:'org.apache.ant', module:'ant', version:'1.7.0'])
```

- Multiple calls to grab in the same context with the same parameters should be idempotent. However, if the same code is called with a different `ClassLoader` context then resolution may be re-run.
- If the `args` map passed into the `grab` call has an attribute `noExceptions` that evaluates true no exceptions will be thrown.
- `grab` requires that a `RootLoader` or `GroovyClassLoader` be specified or be in the `ClassLoader` chain of the calling class. By default failure to have such a `ClassLoader` available will result in module resolution and an exception being thrown
  - The ClassLoader passed in via the `classLoader:` argument and its parent classloaders.
  - The ClassLoader of the object passed in as the `referenceObject:` argument, and its parent classloaders.
  - The ClassLoader of the class issuing the call to `grab`

grab(HashMap) Parameters

- `group:` - <String> - Which module group the module comes from. Translates directly to a Maven groupId. Any group matching `/groovy(|\..|x|x\..)/` is reserved and may have special meaning to the groovy endorsed modules.
- `module:` - <String> - The name of the module to load. Translated directly to a Maven artifactId.
- `version:` - <String> and possibly <Range> - The version of the module to use. Either a literal version `1.1-RC3' or an Ivy Range `[2.2.1,)' meaning 2.2.1 or any greater version).
- `classifier:` - <String> - The Maven classifier to resolve by.
- `conf:` - <String>, default ``default' - The configuration or scope of the module to download. The default conf is `default:`` which maps to the maven `runtime` and `master` scopes.
- `force:`- <boolean>, defaults true - Used to indicate that this revision must be used in case of conflicts, independently of
- conflicts manager
- `changing:` - <boolean>, default false - Whether the artifact can change without its version designation changing.
- `transitive:` - <boolean>, default true - Whether to resolve other dependencies this module has or not.

There are two principal variants of `grab`, one with a single Map and one with an arguments Map and multiple dependencies map. A call to the single map grab is the same as calling grab with the same map passed in twice, so grab arguments and dependencies can be mixed in the same map, and grab can be called as a single method with named parameters.

There are synonyms for these parameters. Submitting more than one is a runtime exception.

- `group:`, `groupId:`, `organisation:`, `organization:`, `org:`
- `module:`, `artifactId:`, `artifact:`
- `version:`, `revision:`, `rev:`
- `conf:`, `scope:`, `configuration:`

Arguments Map arguments

- `classLoader:` - <GroovyClassLoader> or <RootClassLoader> - The ClassLoader to add resolved Jars to
- `refObject:` - <Object> - The closest parent ClassLoader for the object's class will be treated as though it were passed in as `classLoader:`
- `validate:` - <boolean>, default false - Should poms or ivy files be validated (true), or should we trust the cache (false).
- `noExceptions:` - <boolean>, default false - If ClassLoader resolution or repository querying fails, should we throw an exception (false) or fail silently (true).

Command Line Tool

Grape added a command line executable `grape' that allows for the inspection and management of the local grape cache.

```
grape install [-hv] <group> <module> [<version>] [<classifier>]
```

This installs the specified groovy module or maven artifact. If a version is specified that specific version will be installed, otherwise the most recent version will be used (as if `*' we passed in).

```
grape list
```

Lists locally installed modules (with their full maven name in the case of groovy modules) and versions.

```
grape resolve [-adhisv] (<groupId> <artifactId> <version>)+
```

This returns the file locations of the jars representing the artifacts for the specified module(s) and the respective transitive dependencies. You may optionally pass in -ant, -dos, or -shell to get the dependencies expressed in a format applicable for an ant script, windows batch file, or unix shell script respectively. -ivy may be passed to see the dependencies expressed in an ivy like format.

```
grape uninstall [-hv] <group> <module> <version>
```

This uninstalls a particular grape: it non-transitively removes the respective jar file from the grape cache.

Advanced configuration

Repository Directory

If you need to change the directory grape uses for downloading libraries you can specify the grape.root system property to change the default (which is ~/.groovy/grapes)

```
groovy -Dgrape.root=/repo/grapes yourscript.groovy
```

Customize Ivy settings

You can customize the ivy settings that Grape uses by creating a ~/.groovy/grapeConfig.xml file. If no such file exists, here are the default settings used by Grape.

For more information on how to customize these settings, please refer to the Ivy documentation.

More Examples

Using Apache Commons Collections:

```
// create and use a primitive array list
@Grab(group='commons-primitives', module='commons-primitives', version='1.0')
import org.apache.commons.collections.primitives.ArrayIntList

def createEmptyInts() { new ArrayIntList() }

def ints = createEmptyInts()
ints.add(0, 42)
assert ints.size() == 1
assert ints.get(0) == 42
```

Using TagSoup:

```
// find the PDF links of the Java specifications
@Grab(group='org.ccil.cowan.tagsoup', module='tagsoup', version='1.2.1')
def getHtml() {
    def parser = new XmlParser(new org.ccil.cowan.tagsoup.Parser())
    parser.parse("https://docs.oracle.com/javase/specs/")
}
html.body.'**'.a.@href.grep(~/.*\.pdf/).each{ println it }
```

Using Google Collections:

```
import com.google.common.collect.HashBiMap
@Grab(group='com.google.code.google-collections', module='google-collect', version
='snapshot-20080530')
def getFruit() { [grape:'purple', lemon:'yellow', orange:'orange'] as HashBiMap }
assert fruit.lemon == 'yellow'
assert fruit.inverse().yellow == 'lemon'
```

Launching a Jetty server to serve Groovy templates:

```
@Grab('org.eclipse.jetty.aggregate:jetty-server:8.1.19.v20160209')
@Grab('org.eclipse.jetty.aggregate:jetty-servlet:8.1.19.v20160209')
@Grab('javax.servlet:javax.servlet-api:3.0.1')
import org.eclipse.jetty.server.Server
import org.eclipse.jetty.servlet.ServletContextHandler
import groovy.servlet.TemplateServlet

def runServer(duration) {
    def server = new Server(8080)
    def context = new ServletContextHandler(server, "/", ServletContextHandler
.SESSIONS)
    context.resourceBase = "."
    context.addServlet(TemplateServlet, "*.gsp")
    server.start()
    sleep duration
    server.stop()
}

runServer(10000)
```

Grape will download Jetty and its dependencies on first launch of this script, and cache them. We create a new Jetty Server on port 8080, then expose Groovy's TemplateServlet at the root of the context — Groovy comes with its own powerful template engine mechanism. We start the server and let it run for a certain duration. Each time someone will hit http://localhost:8080/somepage.gsp, it will display the somepage.gsp template to the user — those template pages should be situated in the same directory as this server script.

Testing Guide

Introduction

The Groovy programming language comes with great support for writing tests. In addition to the language features and test integration with state-of-the-art testing libraries and frameworks, the Groovy ecosystem has born a rich set of testing libraries and frameworks.

This chapter will start with language specific testing features and continue with a closer look at

JUnit integration, Spock for specifications, and Geb for functional tests. Finally, we'll do an overview of other testing libraries known to be working with Groovy.

Language Features

Besides integrated support for JUnit, the Groovy programming language comes with features that have proven to be very valuable for test-driven development. This section gives insight on them.

Power Assertions

Writing tests means formulating assumptions by using assertions. In Java this can be done by using the `assert` keyword that has been added in J2SE 1.4. In Java, `assert` statements can be enabled via the JVM parameters `-ea` (or `-enableassertions`) and `-da` (or `-disableassertions`). Assertion statements in Java are disabled by default.

Groovy comes with a rather *powerful variant* of `assert` also known as *power assertion statement*. Groovy's power `assert` differs from the Java version in its output given the boolean expression validates to `false`:

```
def x = 1
assert x == 2

// Output:              ①
//
// Assertion failed:
// assert x == 2
//        | |
//        1 false
```

① This section shows the std-err output

The `java.lang.AssertionError` that is thrown whenever the assertion can not be validated successfully, contains an extended version of the original exception message. The power assertion output shows evaluation results from the outer to the inner expression.

The power assertion statements true power unleashes in complex Boolean statements, or statements with collections or other `toString`-enabled classes:

```
def x = [1,2,3,4,5]
assert (x << 6) == [6,7,8,9,10]

// Output:
//
// Assertion failed:
// assert (x << 6) == [6,7,8,9,10]
//         | |     |
//         | |     false
//         | [1, 2, 3, 4, 5, 6]
```

```
//          [1, 2, 3, 4, 5, 6]
```

Another important difference from Java is that in Groovy assertions are *enabled by default*. It has been a language design decision to remove the possibility to deactivate assertions. Or, as Bertrand Meyer stated, `it makes no sense to take off your swim ring if you put your feet into real water`.

One thing to be aware of are methods with side effects inside Boolean expressions in power assertion statements. As the internal error message construction mechanism does only store references to instances under target, it happens that the error message text is invalid at rendering time in case of side-effecting methods involved:

```
assert [[1,2,3,3,3,3,4]].first().unique() == [1,2,3]

// Output:
//
// Assertion failed:
// assert [[1,2,3,3,3,3,4]].first().unique() == [1,2,3]
//                          |       |        |
//                          |       |        false
//                          |       [1, 2, 3, 4]
//                          [1, 2, 3, 4]           ①
```

① The error message shows the actual state of the collection, not the state before the `unique` method was applied

NOTE If you choose to provide a custom assertion error message this can be done by using the Java syntax `assert expression1 : expression2` where `expression1` is the Boolean expression and `expression2` is the custom error message. Be aware though that this will disable the power assert and will fully fall back to custom error messages on assertion errors.

Mocking and Stubbing

Groovy has excellent built-in support for a range of mocking and stubbing alternatives. When using Java, dynamic mocking frameworks are very popular. A key reason for this is that it is hard work creating custom hand-crafted mocks using Java. Such frameworks can be used easily with Groovy if you choose but creating custom mocks is much easier in Groovy. You can often get away with simple maps or closures to build your custom mocks.

The following sections show ways to create mocks and stubs with Groovy language features only.

Map Coercion

By using maps or expandos, we can incorporate desired behaviour of a collaborator very easily as shown here:

```
class TranslationService {
    String convert(String key) {
```

```
        return "test"
    }
}

def service = [convert: { String key -> 'some text' }] as TranslationService
assert 'some text' == service.convert('key.text')
```

The `as` operator can be used to coerce a map to a particular class. The given map keys are interpreted as method names and the values, being `groovy.lang.Closure` blocks, are interpreted as method code blocks.

NOTE Be aware that map coercion can get into the way if you deal with custom `java.util.Map` descendant classes in combination with the `as` operator. The map coercion mechanism is targeted directly at certain collection classes, it doesn't take custom classes into account.

Closure Coercion

The 'as' operator can be used with closures in a neat way which is great for developer testing in simple scenarios. We haven't found this technique to be so powerful that we want to do away with dynamic mocking, but it can be very useful in simple cases none-the-less.

Classes or interfaces holding a single method, including SAM (single abstract method) classes, can be used to coerce a closure block to be an object of the given type. Be aware that for doing this, Groovy internally create a proxy object descending for the given class. So the object will not be a direct instance of the given class. This important if, for example, the generated proxy object's metaclass is altered afterwards.

Let's have an example on coercing a closure to be of a specific type:

```
def service = { String key -> 'some text' } as TranslationService
assert 'some text' == service.convert('key.text')
```

Groovy supports a feature called implicit SAM coercion. This means that the `as` operator is not necessary in situations where the runtime can infer the target SAM type. This type of coercion might be useful in tests to mock entire SAM classes:

```
abstract class BaseService {
    abstract void doSomething()
}

BaseService service = { -> println 'doing something' }
service.doSomething()
```

MockFor and StubFor

The Groovy mocking and stubbing classes can be found in the `groovy.mock.interceptor` package.

The MockFor class supports (typically unit) testing of classes in isolation by allowing a *strictly ordered* expectation of the behavior of collaborators to be defined. A typical test scenario involves a class under test and one or more collaborators. In such a scenario it is often desirable to just test the business logic of the class under test. One strategy for doing that is to replace the collaborator instances with simplified mock objects to help isolate out the logic in the test target. MockFor allows such mocks to be created using meta-programming. The desired behavior of collaborators is defined as a behavior specification. The behavior is enforced and checked automatically.

Let's assume our target classes looked like this:

```
class Person {
    String first, last
}

class Family {
    Person father, mother
    def nameOfMother() { "$mother.first $mother.last" }
}
```

With MockFor, a mock expectation is always sequence dependent and its use automatically ends with a call to verify:

```
def mock = new MockFor(Person)       ①
mock.demand.getFirst{ 'dummy' }
mock.demand.getLast{ 'name' }
mock.use {                           ②
    def mary = new Person(first:'Mary', last:'Smith')
    def f = new Family(mother:mary)
    assert f.nameOfMother() == 'dummy name'
}
mock.expect.verify()                 ③
```

① a new mock is created by a new instance of MockFor

② a Closure is passed to use which enables the mocking functionality

③ a call to verify checks whether the sequence and number of method calls is as expected

The StubFor class supports (typically unit) testing of classes in isolation by allowing a *loosely-ordered* expectation of the behavior of collaborators to be defined. A typical test scenario involves a class under test and one or more collaborators. In such a scenario it is often desirable to just test the business logic of the CUT. One strategy for doing that is to replace the collaborator instances with simplified stub objects to help isolate out the logic in the target class. StubFor allows such stubs to be created using meta-programming. The desired behavior of collaborators is defined as a behavior specification.

In contrast to MockFor the stub expectation checked with verify is sequence independent and its use is optional:

```
def stub = new StubFor(Person)      ①
stub.demand.with {                  ②
    getLast{ 'name' }
    getFirst{ 'dummy' }
}
stub.use {                          ③
    def john = new Person(first:'John', last:'Smith')
    def f = new Family(father:john)
    assert f.father.first == 'dummy'
    assert f.father.last == 'name'
}
stub.expect.verify()                ④
```

① a new stub is created by a new instance of `StubFor`

② the `with` method is used for delegating all calls inside the closure to the `StubFor` instance

③ a `Closure` is passed to `use` which enables the stubbing functionality

④ a call to `verify` (optional) checks whether the number of method calls is as expected

`MockFor` and `StubFor` can not be used to test statically compiled classes e.g. for Java classes or Groovy classes that make use of `@CompileStatic`. To stub and/or mock these classes you can use Spock or one of the Java mocking libraries.

Expando Meta-Class (EMC)

Groovy includes a special `MetaClass` the so-called `ExpandoMetaClass` (EMC). It allows to dynamically add methods, constructors, properties and static methods using a neat closure syntax.

Every `java.lang.Class` is supplied with a special `metaClass` property that will give a reference to an `ExpandoMetaClass` instance. The expando metaclass is not restricted to custom classes, it can be used for JDK classes like for example `java.lang.String` as well:

```
String.metaClass.swapCase = {->
    def sb = new StringBuffer()
    delegate.each {
        sb << (Character.isUpperCase(it as char) ? Character.toLowerCase(it as char) :
            Character.toUpperCase(it as char))
    }
    sb.toString()
}

def s = "heLLo, worLD!"
assert s.swapCase() == 'HEllO, WORld!'
```

The `ExpandoMetaClass` is a rather good candidate for mocking functionality as it allows for more advanced stuff like mocking static methods

```
class Book {
```

```
    String title
}

Book.metaClass.static.create << { String title -> new Book(title:title) }

def b = Book.create("The Stand")
assert b.title == 'The Stand'
```

or even constructors

```
Book.metaClass.constructor << { String title -> new Book(title:title) }

def b = new Book("The Stand")
assert b.title == 'The Stand'
```

> **NOTE** Mocking constructors might seem like a hack that's better not even to be considered but even there might be valid use cases. An example can be found in Grails where domain class constructors are added at run-time with the help of `ExpandoMetaClass`. This lets the domain object register itself in the Spring application context and allows for injection of services or other beans controlled by the dependency-injection container.

If you want to change the `metaClass` property on a per test method level you need to remove the changes that were done to the metaclass, otherwise those changes would be persistent across test method calls. Changes are removed by replacing the metaclass in the `GroovyMetaClassRegistry`:

```
GroovySystem.metaClassRegistry.removeMetaClass(String)
```

Another alternative is to register a `MetaClassRegistryChangeEventListener`, track the changed classes and remove the changes in the cleanup method of your chosen testing runtime. A good example can be found in the Grails web development framework.

Besides using the `ExpandoMetaClass` on a class-level, there is also support for using the metaclass on a per-object level:

```
def b = new Book(title: "The Stand")
b.metaClass.getTitle {-> 'My Title' }

assert b.title == 'My Title'
```

In this case the metaclass change is related to the instance only. Depending on the test scenario this might be a better fit than the global metaclass change.

GDK Methods

The following section gives a brief overview on GDK methods that can be leveraged in test case scenarios, for example for test data generation.

Iterable#combinations

The `combinations` method that is added on `java.lang.Iterable` compliant classes can be used to get a list of combinations from a list containing two or more sub-lists:

```
void testCombinations() {
    def combinations = [[2, 3],[4, 5, 6]].combinations()
    assert combinations == [[2, 4], [3, 4], [2, 5], [3, 5], [2, 6], [3, 6]]
}
```

The method could be used in test case scenarios to generate all possible argument combinations for a specific method call.

Iterable#eachCombination

The `eachCombination` method that is added on `java.lang.Iterable` can be used to apply a function (or in this case a `groovy.lang.Closure`) to each if the combinations that has been built by the `combinations` method:

`eachCombination` is a GDK method that is added to all classes conforming to the `java.lang.Iterable` interface. It applies a function on each combination of the input lists:

```
void testEachCombination() {
    [[2, 3],[4, 5, 6]].eachCombination { println it[0] + it[1] }
}
```

The method could be used in the testing context to call methods with each of the generated combinations.

Tool Support

Test Code Coverage

Code coverage is a useful measure of the effectiveness of (unit) tests. A program with high code coverage has a lower chance to hold critical bugs than a program with no or low coverage. To get code coverage metrics, the generated byte-code usually needs to be instrumented before the tests are executed. One tool with Groovy support for this task is Cobertura.

The following code listing shows an example on how to enable Cobertura test coverage reports in a Gradle build script from a Groovy project:

```
def pluginVersion = '<plugin version>'
def groovyVersion = '<groovy version>'
def junitVersion = '<junit version>'

buildscript {
```

```
    repositories {
        mavenCentral()
    }
    dependencies {
        classpath 'com.eriwen:gradle-cobertura-plugin:${pluginVersion}'
    }
}

apply plugin: 'groovy'
apply plugin: 'cobertura'

repositories {
    mavenCentral()
}

dependencies {
    compile "org.codehaus.groovy:groovy-all:${groovyVersion}"
    testCompile "junit:junit:${junitVersion}"
}

cobertura {
    format = 'html'
    includes = ['**/*.java', '**/*.groovy']
    excludes = ['com/thirdparty/**/*.*']
}
```

Several output formats can be chosen for Cobertura coverage reports and test code coverage reports can be added to continuous integration build tasks.

Testing with JUnit

Groovy simplifies JUnit testing in the following ways:

- You use the same overall practices as you would when testing with Java but you can adopt much of Groovy's concise syntax in your tests making them succinct. You can even use the capabilities for writing testing domain specific languages (DSLs) if you feel so inclined.
- There are numerous helper classes that simplify many testing activities. The details differ in some cases depending on the version of JUnit you are using. We'll cover those details shortly.
- Groovy's PowerAssert mechanism is wonderful to use in your tests
- Groovy deems that tests are so important you should be able to run them as easily as scripts or classes. This is why Groovy includes an automatic test runner when using the `groovy` command or the GroovyConsole. This gives you some additional options over and above running your tests

In the following sections we will have a closer look at JUnit 3, 4 and 5 Groovy integration.

JUnit 3

Maybe one of the most prominent Groovy classes supporting JUnit 3 tests is the `GroovyTestCase` class. Being derived from `junit.framework.TestCase` it offers a bunch of additional methods that make testing in Groovy a breeze.

NOTE Although `GroovyTestCase` inherits from `TestCase` doesn't mean you can't use JUnit 4 features in your project. In fact, the most recent Groovy versions come with a bundled JUnit 4 and that comes with a backwards compatible `TestCase` implementation. There have been some discussion on the Groovy mailing-list on whether to use `GroovyTestCase` or JUnit 4 with the result that it is mostly a matter of taste, but with `GroovyTestCase` you get a bunch of methods for free that make certain types of tests easier to write.

In this section, we will have a look at some of the methods provided by `GroovyTestCase`. A full list of these can be found in the JavaDoc documentation for groovy.test.GroovyTestCase , don't forget it is inherited from `junit.framework.TestCase` which inherits all the `assert*` methods.

Assertion Methods

`GroovyTestCase` is inherited from `junit.framework.TestCase` therefore it inherits a large number of assertion methods being available to be called in every test method:

```
class MyTestCase extends GroovyTestCase {

    void testAssertions() {
        assertTrue(1 == 1)
        assertEquals("test", "test")

        def x = "42"
        assertNotNull "x must not be null", x
        assertNull null

        assertSame x, x
    }

}
```

As can be seen above, in contrast to Java it is possible to leave out the parenthesis in most situations which leads to even more readability of JUnit assertion method call expressions.

An interesting assertion method that is added by `GroovyTestCase` is `assertScript`. It ensures that the given Groovy code string succeeds without any exception:

```
void testScriptAssertions() {
    assertScript '''
        def x = 1
        def y = 2
```

```
        assert x + y == 3
    '''
}
```

shouldFail Methods

`shouldFail` can be used to check whether the given code block fails or not. In case it fails, the assertion does hold, otherwise the assertion fails:

```
void testInvalidIndexAccess1() {
    def numbers = [1,2,3,4]
    shouldFail {
        numbers.get(4)
    }
}
```

The example above uses the basic `shouldFail` method interface that takes a `groovy.lang.Closure` as a single argument. The `Closure` instance holds the code that is supposed to be breaking during run-time.

If we wanted to assert `shouldFail` on a specific `java.lang.Exception` type we could have done so by using the `shouldFail` implementation that takes the `Exception` class as first argument and the `Closure` as second argument:

```
void testInvalidIndexAccess2() {
    def numbers = [1,2,3,4]
    shouldFail IndexOutOfBoundsException, {
        numbers.get(4)
    }
}
```

If anything other than `IndexOutOfBoundsException` (or a descendant class of it) is thrown, the test case will fail.

A pretty nice feature of `shouldFail` hasn't been visible so far: it returns the exception message. This is really useful if you want to assert on the exception error message:

```
void testInvalidIndexAccess3() {
    def numbers = [1,2,3,4]
    def msg = shouldFail IndexOutOfBoundsException, {
        numbers.get(4)
    }
    assert msg.contains('Index: 4, Size: 4') ||
        msg.contains('Index 4 out-of-bounds for length 4') ||
        msg.contains('Index 4 out of bounds for length 4')
}
```

notYetImplemented Method

The notYetImplemented method has been greatly influenced by HtmlUnit. It allows to write a test method but mark it as not yet implemented. As long as the test method fails and is marked with notYetImplemented the test goes green:

```
void testNotYetImplemented1() {
    if (notYetImplemented()) return   ①

    assert 1 == 2                    ②
}
```

① a call to notYetImplemented is necessary for GroovyTestCase to get the current method stack.

② as long as the test evaluates to false the test execution will be successful.

An alternative to the notYetImplemented method is the @NotYetImplemented annotation. It allows for annotating a method as not yet implemented, with the exact same behavior as GroovyTestCase#notYetImplemented but without the need for the notYetImplemented method call:

```
@NotYetImplemented
void testNotYetImplemented2() {
    assert 1 == 2
}
```

JUnit 4

Groovy can be used to write JUnit 4 test cases without any restrictions. The groovy.test.GroovyAssert holds various static methods that can be used as replacement for the GroovyTestCase methods in JUnit 4 tests:

```
import org.junit.Test

import static groovy.test.GroovyAssert.shouldFail

class JUnit4ExampleTests {

    @Test
    void indexOutOfBoundsAccess() {
        def numbers = [1,2,3,4]
        shouldFail {
            numbers.get(4)
        }
    }

}
```

As can be seen in the example above, the static methods found in GroovyAssert are imported at the beginning of the class definition thus `shouldFail` can be used the same way it can be used in a `GroovyTestCase`.

NOTE `groovy.test.GroovyAssert` descends from `org.junit.Assert` that means it inherits all JUnit assertion methods. However, with the introduction of the power assertion statement, it turned out to be *good practice to rely on assertion statements* instead of using the JUnit assertion methods with the improved message being the main reason.

It is worth mentioning that `GroovyAssert.shouldFail` is not absolutely identical to `GroovyTestCase.shouldFail`. While `GroovyTestCase.shouldFail` returns the exception message, `GroovyAssert.shouldFail` returns the exception itself. It takes a few more keystrokes to get the message, but in return you can access other properties and methods of the exception:

```
@Test
void shouldFailReturn() {
    def e = shouldFail {
        throw new RuntimeException('foo',
                                   new RuntimeException('bar'))
    }
    assert e instanceof RuntimeException
    assert e.message == 'foo'
    assert e.cause.message == 'bar'
}
```

JUnit 5

Much of the approach and helper classes described under JUnit4 apply when using JUnit5 however JUnit5 uses some slightly different class annotations when writing your tests. See the JUnit5 documentation for more details.

Create your test classes as per normal JUnit5 guidelines as shown in this example:

```
class MyTest {
  @Test
  void streamSum() {
    assertTrue(Stream.of(1, 2, 3)
      .mapToInt(i -> i)
      .sum() > 5, () -> "Sum should be greater than 5")
  }

  @RepeatedTest(value=2, name = "{displayName}
{currentRepetition}/{totalRepetitions}")
  void streamSumRepeated() {
    assert Stream.of(1, 2, 3).mapToInt(i -> i).sum() == 6
  }

  private boolean isPalindrome(s) { s == s.reverse()  }
```

```
  @ParameterizedTest                                                          ①
  @ValueSource(strings = [ "racecar", "radar", "able was I ere I saw elba" ])
  void palindromes(String candidate) {
    assert isPalindrome(candidate)
  }

  @TestFactory
  def dynamicTestCollection() {[
    dynamicTest("Add test") { -> assert 1 + 1 == 2 },
    dynamicTest("Multiply Test", () -> { assert 2 * 3 == 6 })
  ]}
}
```

① This test requires the additional `org.junit.jupiter:junit-jupiter-params` dependency if not already in your project.

You can run the tests in your IDE or build tool if it supports and is configured for JUnit5. If you run the above test in the GroovyConsole or via the `groovy` command, you will see a short text summary of the result of running the test:

```
JUnit5 launcher: passed=8, failed=0, skipped=0, time=246ms
```

More detailed information is available at the `FINE` logging level. You can configure your logging to display such information or do it programmatically as follows:

```
@BeforeAll
static void init() {
  def logger = Logger.getLogger(LoggingListener.name)
  logger.level = Level.FINE
  logger.addHandler(new ConsoleHandler(level: Level.FINE))
}
```

Testing with Spock

Spock is a testing and specification framework for Java and Groovy applications. What makes it stand out from the crowd is its beautiful and highly expressive specification DSL. In practice, Spock specifications are written as Groovy classes. Although written in Groovy they can be used to test Java classes. Spock can be used for unit, integration or BDD (behavior-driven-development) testing, it doesn't put itself into a specific category of testing frameworks or libraries.

NOTE Beside these awesome features Spock is a good example on how to leverage advanced Groovy programming language features in third party libraries, for example, by using Groovy AST transformations.

NOTE This section should not serve as detailed guide on how to use Spock, it should rather give an impression what Spock is about and how it can be leveraged for unit, integration, functional or any other type of testing.

The next section we will have a first look at the anatomy of a Spock specification. It should give a pretty good feeling on what Spock is up to.

Specifications

Spock lets you write specifications that describe features (properties, aspects) exhibited by a system of interest. The "system" can be anything between a single class and an entire application, a more advanced term for it is *system under specification*. The *feature description* starts from a specific snapshot of the system and its collaborators, this snapshot is called the *feature's fixture*.

Spock specification classes are derived from `spock.lang.Specification`. A concrete specification class might consist of fields, fixture methods, features methods and helper methods.

Let's have a look at a simple specification with a single feature method for an imaginary `Stack` class:

```
class StackSpec extends Specification {

    def "adding an element leads to size increase"() {  ①
        setup: "a new stack instance is created"        ②
            def stack = new Stack()

        when:                                           ③
            stack.push 42

        then:                                           ④
            stack.size() == 1
    }
}
```

① Feature method, is by convention named with a String literal.

② Setup block, here is where any setup work for this feature needs to be done.

③ When block describes a stimulus, a certain action under target by this feature specification.

④ Then block any expressions that can be used to validate the result of the code that was triggered by the when block.

Spock feature specifications are defined as methods inside a `spock.lang.Specification` class. They describe the feature by using a String literal instead of a method name.

A feature method holds multiple blocks, in our example we used `setup`, `when` and `then`. The `setup` block is special in that it is optional and allows to configure local variables visible inside the feature method. The `when` block defines the stimulus and is a companion of the `then` block which describes the response to the stimulus.

Note that the `setup` method in the `StackSpec` above additionally has a description String. Description Strings are optional and can be added after block labels (like `setup`, `when`, `then`).

More Spock

Spock provides much more features like data tables or advanced mocking capabilities. Feel free to consult the Spock GitHub page for more documentation and download information.

Functional Tests with Geb

Geb is a functional web testing and scraper library that integrates with JUnit and Spock. It is based upon the Selenium web drivers and, like Spock, provides a Groovy DSL to write functional tests for web applications.

Geb has great features that make it a good fit for a functional testing library:

- DOM access via a JQuery-like `$` function
- implements the *page pattern*
- support for modularization of certain web components (e.g. menu-bars, etc.) with *modules*
- integration with JavaScript via the JS variable

NOTE This section should not serve as detailed guide on how to use Geb, it should rather give an impression what Geb is about and how it can be leveraged functional testing.

The next section will give an example on how Geb can be used to write a functional test for a simple web page with a single search field.

A Geb Script

Although Geb can be used standalone in a Groovy script, in many scenarios it's used in combination with other testing frameworks. Geb comes with various base classes that can be used in JUnit 3, 4, TestNG or Spock tests. The base classes are part of additional Geb modules that need to be added as a dependency.

For example, the following `@Grab` dependencies can be used to run Geb with the Selenium Firefox driver in JUnit4 tests. The module that is needed for JUnit 3/4 support is `geb-junit4`:

```
@Grab('org.gebish:geb-core:0.9.2')
@Grab('org.gebish:geb-junit4:0.9.2')
@Grab('org.seleniumhq.selenium:selenium-firefox-driver:2.26.0')
@Grab('org.seleniumhq.selenium:selenium-support:2.26.0')
```

The central class in Geb is the `geb.Browser` class. As its name implies it is used to browse pages and access DOM elements:

```
import geb.Browser
import org.openqa.selenium.firefox.FirefoxDriver

def browser = new Browser(driver: new FirefoxDriver(), baseUrl:
```

```
'http://myhost:8080/myapp')  ①
browser.drive {
    go "/login"                 ②

    $("#username").text = 'John'      ③
    $("#password").text = 'Doe'

    $("#loginButton").click()

    assert title == "My Application - Dashboard"
}
```

① A new `Browser` instance is created. In this case it uses the Selenium `FirefoxDriver` and sets the `baseUrl`.

② `go` is used to navigate to a URL or relative URI

③ `$` together with CSS selectors is used to access the `username` and `password` DOM fields.

The `Browser` class comes with a `drive` method that delegates all method/property calls to the current `browser` instance. The `Browser` configuration must not be done inline, it can also be externalized in a `GebConfig.groovy` configuration file for example. In practice, the usage of the `Browser` class is mostly hidden by Geb test base classes. They delegate all missing properties and method calls to the current `browser` instance that exists in the background:

```
class SearchTests extends geb.junit4.GebTest {

    @Test
    void executeSeach() {
        go 'http://somehost/mayapp/search'              ①
        $('#searchField').text = 'John Doe'             ②
        $('#searchButton').click()                      ③

        assert $('.searchResult a').first().text() == 'Mr. John Doe' ④
    }
}
```

① `Browser#go` takes a relative or absolute link and calls the page.

② `Browser#$` is used to access DOM content. Any CSS selectors supported by the underlying Selenium drivers are allowed

③ `click` is used to click a button.

④ `$` is used to get the first link out of the `searchResult` block

The example above shows a simple Geb web test with the JUnit 4 base class `geb.junit4.GebTest`. Note that in this case the `Browser` configuration is externalized. `GebTest` delegates methods like `go` and `$` to the underlying `browser` instance.

More Geb

In the previous section we only scratched the surface of the available Geb features. More information on Geb can be found at the project homepage.

Tune parsing performance of Parrot parser

The Parrot parser is based on antlr4 and introduced since Groovy 3.0.0. It provides the following options to tune parsing performance:

Option	Description	Default	Version	Example
groovy.parallel.parse	Parsing groovy source files in parallel.	`false` util Groovy 4.0.0	3.0.5+	-Dgroovy.parallel.parse=true

Option	Description	Default	Version	Example
groovy.antlr4.cache.threshold	antlr4 relies on DFA cache heavily for better performance, so antlr4 will not clear DFA cache, thus OutOfMemoryError will probably occur. Groovy trades off parsing performance and memory usage, when the count of Groovy source files parsed hits the cache threshold, the DFA cache will be cleared. **Note:** `0` means managing the DFA cache automatically since Groovy 5.0.0, `-1` means never clearing DFA cache, so requiring bigger JVM heap size. Or set a greater value, e.g. 200 to clear DFA cache if threshold hits. **Note:** the threshold specified is the count of groovy source files	`64`; `0` since Groovy 5.0.0	3.0.5+	-Dgroovy.antlr4.cache.threshold=200

Option	Description	Default	Version	Example
groovy.antlr4.sll.threshold	Parrot parser will try SLL mode and then try LL mode if SLL failed. But the more tokens to parse, the more likely SLL will fail. If SLL threshold hits, SLL will be skipped. Setting the threshold to `0` means never trying SLL mode, which is not recommended at most cases because SLL is the fastest mode though SLL is less powerful than LL. **Note:** the threshold specified is the token count	`-1` (disabled by default)	3.0.9+	-Dgroovy.antlr4.sll.threshold=1000
groovy.antlr4.clear.lexer.dfa.cache	Clear the DFA cache for lexer. The DFA cache for lexer is always small and important for parsing performance, so it's strongly recommended to leave it as it is until OutOfMemoryError will truly occur	`false`	3.0.9+	-Dgroovy.antlr4.clear.lexer.dfa.cache=true

Processing JSON

Groovy comes with integrated support for converting between Groovy objects and JSON. The classes dedicated to JSON serialisation and parsing are found in the `groovy.json` package.

JsonSlurper

JsonSlurper is a class that parses JSON text or reader content into Groovy data structures (objects) such as maps, lists and primitive types like Integer, Double, Boolean and String.

The class comes with a bunch of overloaded parse methods plus some special methods such as parseText, parseFile and others. For the next example we will use the parseText method. It parses a JSON String and recursively converts it to a list or map of objects. The other parse* methods are similar in that they return a JSON String but for different parameter types.

```
def jsonSlurper = new JsonSlurper()
def object = jsonSlurper.parseText('{ "name": "John Doe" } /* some comment */')

assert object instanceof Map
assert object.name == 'John Doe'
```

Notice the result is a plain map and can be handled like a normal Groovy object instance. JsonSlurper parses the given JSON as defined by the ECMA-404 JSON Interchange Standard plus support for JavaScript comments and dates.

In addition to maps JsonSlurper supports JSON arrays which are converted to lists.

```
def jsonSlurper = new JsonSlurper()
def object = jsonSlurper.parseText('{ "myList": [4, 8, 15, 16, 23, 42] }')

assert object instanceof Map
assert object.myList instanceof List
assert object.myList == [4, 8, 15, 16, 23, 42]
```

The JSON standard supports the following primitive data types: string, number, object, true, false and null. JsonSlurper converts these JSON types into corresponding Groovy types.

```
def jsonSlurper = new JsonSlurper()
def object = jsonSlurper.parseText '''
    { "simple": 123,
      "fraction": 123.66,
      "exponential": 123e12
    }'''

assert object instanceof Map
assert object.simple.class == Integer
assert object.fraction.class == BigDecimal
assert object.exponential.class == BigDecimal
```

As JsonSlurper is returning pure Groovy object instances without any special JSON classes in the back, its usage is transparent. In fact, JsonSlurper results conform to GPath expressions. GPath is a powerful expression language that is supported by multiple slurpers for different data formats

(`XmlSlurper` for XML being one example).

NOTE For more details please have a look at the section on GPath expressions.

The following table gives an overview of the JSON types and the corresponding Groovy data types:

JSON	Groovy
string	`java.lang.String`
number	`java.lang.BigDecimal` or `java.lang.Integer`
object	`java.util.LinkedHashMap`
array	`java.util.ArrayList`
true	`true`
false	`false`
null	`null`
date	`java.util.Date` based on the `yyyy-MM-dd'T'HH:mm:ssZ` date format

NOTE Whenever a value in JSON is `null`, `JsonSlurper` supplements it with the Groovy `null` value. This is in contrast to other JSON parsers that represent a `null` value with a library-provided singleton object.

Parser Variants

`JsonSlurper` comes with a couple of parser implementations. Each parser fits different requirements, it could well be that for certain scenarios the `JsonSlurper` default parser is not the best bet for all situations. Here is an overview of the shipped parser implementations:

- The `JsonParserCharArray` parser basically takes a JSON string and operates on the underlying character array. During value conversion it copies character sub-arrays (a mechanism known as "chopping") and operates on them.
- The `JsonFastParser` is a special variant of the `JsonParserCharArray` and is the fastest parser. However, it is not the default parser for a reason. `JsonFastParser` is a so-called index-overlay parser. During parsing of the given JSON `String` it tries as hard as possible to avoid creating new char arrays or `String` instances. It keeps pointers to the underlying original character array only. In addition, it defers object creation as late as possible. If parsed maps are put into long-term caches care must be taken as the map objects might not be created and still consist of pointer to the original char buffer only. However, `JsonFastParser` comes with a special chop mode which dices up the char buffer early to keep a small copy of the original buffer. Recommendation is to use the `JsonFastParser` for JSON buffers under 2MB and keeping the long-term cache restriction in mind.
- The `JsonParserLax` is a special variant of the `JsonParserCharArray` parser. It has similar performance characteristics as `JsonFastParser` but differs in that it isn't exclusively relying on the ECMA-404 JSON grammar. For example it allows for comments, no quote strings etc.
- The `JsonParserUsingCharacterSource` is a special parser for very large files. It uses a technique called "character windowing" to parse large JSON files (large means files over 2MB size in this

case) with constant performance characteristics.

The default parser implementation for `JsonSlurper` is `JsonParserCharArray`. The `JsonParserType` enumeration contains constants for the parser implementations described above:

Implementation	Constant
`JsonParserCharArray`	`JsonParserType#CHAR_BUFFER`
`JsonFastParser`	`JsonParserType#INDEX_OVERLAY`
`JsonParserLax`	`JsonParserType#LAX`
`JsonParserUsingCharacterSource`	`JsonParserType#CHARACTER_SOURCE`

Changing the parser implementation is as easy as setting the `JsonParserType` with a call to `JsonSlurper#setType()`.

```
def jsonSlurper = new JsonSlurper(type: JsonParserType.INDEX_OVERLAY)
def object = jsonSlurper.parseText('{ "myList": [4, 8, 15, 16, 23, 42] }')

assert object instanceof Map
assert object.myList instanceof List
assert object.myList == [4, 8, 15, 16, 23, 42]
```

JsonOutput

`JsonOutput` is responsible for serialising Groovy objects into JSON strings. It can be seen as companion object to JsonSlurper, being a JSON parser.

`JsonOutput` comes with overloaded, static `toJson` methods. Each `toJson` implementation takes a different parameter type. The static methods can either be used directly or by importing the methods with a static import statement.

The result of a `toJson` call is a `String` containing the JSON code.

```
def json = JsonOutput.toJson([name: 'John Doe', age: 42])

assert json == '{"name":"John Doe","age":42}'
```

`JsonOutput` does not only support primitive, maps or list data types to be serialized to JSON, it goes further and even has support for serialising POGOs, that is, plain-old Groovy objects.

```
class Person { String name }

def json = JsonOutput.toJson([ new Person(name: 'John'), new Person(name: 'Max') ])

assert json == '[{"name":"John"},{"name":"Max"}]'
```

Customizing Output

If you need control over the serialized output you can use a `JsonGenerator`. The `JsonGenerator.Options` builder can be used to create a customized generator. One or more options can be set on this builder in order to alter the resulting output. When you are done setting the options simply call the `build()` method in order to get a fully configured instance that will generate output based on the options selected.

```
class Person {
    String name
    String title
    int age
    String password
    Date dob
    URL favoriteUrl
}

Person person = new Person(name: 'John', title: null, age: 21, password: 'secret',
                            dob: Date.parse('yyyy-MM-dd', '1984-12-15'),
                            favoriteUrl: new URL('http://groovy-lang.org/'))

def generator = new JsonGenerator.Options()
    .excludeNulls()
    .dateFormat('yyyy@MM')
    .excludeFieldsByName('age', 'password')
    .excludeFieldsByType(URL)
    .build()

assert generator.toJson(person) == '{"name":"John","dob":"1984@12"}'
```

A closure can be used to transform a type. These closure converters are registered for a given type and will be called any time that type or a subtype is encountered. The first parameter to the closure is an object matching the type for which the converter is registered and this parameter is required. The closure may take an optional second `String` parameter and this will be set to the key name if one is available.

```
class Person {
    String name
    URL favoriteUrl
}

Person person = new Person(name: 'John', favoriteUrl: new URL('http://groovy-
lang.org/json.html#_jsonoutput'))

def generator = new JsonGenerator.Options()
    .addConverter(URL) { URL u, String key ->
        if (key == 'favoriteUrl') {
            u.getHost()
        } else {
```

```
            u
        }
    }
    .build()

assert generator.toJson(person) == '{"name":"John","favoriteUrl":"groovy-lang.org"}'

// No key available when generating a JSON Array
def list = [new URL('http://groovy-lang.org/json.html#_jsonoutput')]
assert generator.toJson(list) == '["http://groovy-lang.org/json.html#_jsonoutput"]'

// First parameter to the converter must match the type for which it is registered
shouldFail(IllegalArgumentException) {
    new JsonGenerator.Options()
        .addConverter(Date) { Calendar cal -> }
}
```

Formatted Output

As we saw in previous examples, the JSON output is not pretty printed per default. However, the `prettyPrint` method in `JsonOutput` comes to rescue for this task.

```
def json = JsonOutput.toJson([name: 'John Doe', age: 42])

assert json == '{"name":"John Doe","age":42}'

assert JsonOutput.prettyPrint(json) == '''\
{
    "name": "John Doe",
    "age": 42
}'''.stripIndent()
```

`prettyPrint` takes a `String` as single parameter; therefore, it can be applied on arbitrary JSON `String` instances, not only the result of `JsonOutput.toJson`.

Builders

Another way to create JSON from Groovy is to use `JsonBuilder` or `StreamingJsonBuilder`. Both builders provide a DSL which allows to formulate an object graph which is then converted to JSON.

NOTE For more details on builders, have a look at the builders chapter which covers both JsonBuilder and StreamingJsonBuilder.

Interacting with a SQL database

Groovy's `groovy-sql` module provides a higher-level abstraction over Java's JDBC technology. JDBC itself provides a lower-level but fairly comprehensive API which provides uniform access to a whole variety of supported relational database systems. We'll use HSQLDB in our examples here but you can alternatively use Oracle, SQL Server, MySQL and a host of others. The most frequently used class within the `groovy-sql` module is the `groovy.sql.Sql` class which raises the JDBC abstractions up one level. We'll cover that first.

Connecting to the database

Connecting to a database with Groovy's `Sql` class requires four pieces of information:

- The database uniform resource locator (URL)
- Username
- Password
- The driver class name (which can be derived automatically in some situations)

For our HSQLDB database, the values will be something like that shown in the following table:

Property	Value
url	`jdbc:hsqldb:mem:yourdb`
user	sa (or your *username*)
password	*yourPassword*
driver	`org.hsqldb.jdbcDriver`

Consult the documentation for the JDBC driver that you plan to use to determine the correct values for your situation.

The `Sql` class has a `newInstance` factory method which takes these parameters. You would typically use it as follows:

Connecting to HSQLDB

```
import groovy.sql.Sql

def url = 'jdbc:hsqldb:mem:yourDB'
def user = 'sa'
def password = ''
def driver = 'org.hsqldb.jdbcDriver'
def sql = Sql.newInstance(url, user, password, driver)

// use 'sql' instance ...

sql.close()
```

If you don't want to have to handle resource handling yourself (i.e. call `close()` manually) then you can use the `withInstance` variation as shown here:

Connecting to HSQLDB (`withInstance` variation)

```
Sql.withInstance(url, user, password, driver) { sql ->
```

```
  // use 'sql' instance ...
}
```

Connecting with a DataSource

It is often preferred to use a DataSource. You may have one available to you from a connection pool. Here we'll use the one provided as part of the HSQLDB driver jar as shown here:

Connecting to HSQLDB with a DataSource

```
import groovy.sql.Sql
import org.hsqldb.jdbc.JDBCDataSource

def dataSource = new JDBCDataSource(
    database: 'jdbc:hsqldb:mem:yourDB', user: 'sa', password: '')
def sql = new Sql(dataSource)

// use then close 'sql' instance ...
```

If you have your own connection pooling, the details will be different, e.g. for Apache Commons DBCP:

Connecting to HSQLDB with a DataSource using Apache Commons DBCP

```
@Grab('org.apache.commons:commons-dbcp2:2.7.0')
import groovy.sql.Sql
import org.apache.commons.dbcp2.BasicDataSource

def ds = new BasicDataSource(driverClassName: "org.hsqldb.jdbcDriver",
    url: 'jdbc:hsqldb:mem:yourDB', username: 'sa', password: '')
def sql = new Sql(ds)
// use then close 'sql' instance ...
```

Connecting using @Grab

The previous examples assume that the necessary database driver jar is already on your classpath. For a self-contained script you can add `@Grab` statements to the top of the script to automatically download the necessary jar as shown here:

Connecting to HSQLDB using @Grab

```
@Grab('org.hsqldb:hsqldb:2.7.4')
@GrabConfig(systemClassLoader=true)
// create, use, and then close sql instance ...
```

The `@GrabConfig` statement is necessary to make sure the system classloader is used. This ensures that the driver classes and system classes like `java.sql.DriverManager` are in the same classloader.

Executing SQL

You can execute arbitrary SQL commands using the `execute()` method. Let's have a look at using it to create a table.

Creating tables

The simplest way to execute SQL is to call the `execute()` method passing the SQL you wish to execute as a String as shown here:

Creating a table

```
// ... create 'sql' instance
sql.execute '''
  CREATE TABLE Author (
    id          INTEGER GENERATED BY DEFAULT AS IDENTITY,
    firstname   VARCHAR(64),
    lastname    VARCHAR(64)
  );
'''
// close 'sql' instance ...
```

There is a variant of this method which takes a GString and another with a list of parameters. There are also other variants with similar names: `executeInsert` and `executeUpdate`. We'll see examples of these variants in other examples in this section.

Basic CRUD operations

The basic operations on a database are Create, Read, Update and Delete (the so-called CRUD operations). We'll examine each of these in turn.

Creating/Inserting data

You can use the same `execute()` statement we saw earlier but to insert a row by using a SQL insert statement as follows:

Inserting a row

```
sql.execute "INSERT INTO Author (firstname, lastname) VALUES ('Dierk', 'Koenig')"
```

You can use a special `executeInsert` method instead of `execute`. This will return a list of all keys generated. Both the `execute` and `executeInsert` methods allow you to place '?' placeholders into your SQL string and supply a list of parameters. In this case a PreparedStatement is used which avoids any risk of SQL injection. The following example illustrates `executeInsert` using placeholders and parameters:

Inserting a row using executeInsert with placeholders and parameters

```
def insertSql = 'INSERT INTO Author (firstname, lastname) VALUES (?,?)'
def params = ['Jon', 'Skeet']
```

```
def keys = sql.executeInsert insertSql, params
assert keys[0] == [1]
```

In addition, both the `execute` and `executeInsert` methods allow you to use GStrings. Any '$' placeholders within the SQL are assumed to be placeholders. An escaping mechanism exists if you want to supply part of the GString with a variable in a position which isn't where normal placeholders go within SQL. See the GroovyDoc for more details. Also, `executeInsert` allows you to supply a list of key column names, when multiple keys are returned and you are only interested in some of them. Here is a fragment illustrating key name specification and GStrings:

Inserting a row using executeInsert with a GString and specifying key names

```
def first = 'Guillaume'
def last = 'Laforge'
def myKeyNames = ['ID']
def myKeys = sql.executeInsert """
  INSERT INTO Author (firstname, lastname)
  VALUES (${first}, ${last})
""", myKeyNames
assert myKeys[0] == [ID: 2]
```

Reading rows

Reading rows of data from the database is accomplished using one of several available methods: `query`, `eachRow`, `firstRow` and `rows`.

Use the `query` method if you want to iterate through the `ResultSet` returned by the underlying JDBC API as shown here:

Reading data using `query`

```
def expected = ['Dierk Koenig', 'Jon Skeet', 'Guillaume Laforge']

def rowNum = 0
sql.query('SELECT firstname, lastname FROM Author') { resultSet ->
  while (resultSet.next()) {
    def first = resultSet.getString(1)
    def last = resultSet.getString('lastname')
    assert expected[rowNum++] == "$first $last"
  }
}
```

Use the `eachRow` method if you want a slightly higher-level abstraction which provides a Groovy friendly map-like abstraction for the `ResultSet` as shown here:

Reading data using `eachRow`

```
rowNum = 0
sql.eachRow('SELECT firstname, lastname FROM Author') { row ->
```

```
  def first = row[0]
  def last = row.lastname
  assert expected[rowNum++] == "$first $last"
}
```

Note that you can use Groovy list-style and map-style notations when accessing the row of data.

Use the `firstRow` method if you for similar functionality as `eachRow` but returning only one row of data as shown here:

Reading data using `firstRow`

```
def first = sql.firstRow('SELECT lastname, firstname FROM Author')
assert first.values().sort().join(',') == 'Dierk,Koenig'
```

Use the `rows` method if you want to process a list of map-like data structures as shown here:

Reading data using `rows`

```
List authors = sql.rows('SELECT firstname, lastname FROM Author')
assert authors.size() == 3
assert authors.collect { "$it.FIRSTNAME ${it[-1]}" } == expected
```

Note that the map-like abstraction has case-insensitive keys (hence we can use 'FIRSTNAME' or 'firstname' as the key) and also that -ve indices (a standard Groovy feature) works when using an index value (to count column numbers from the right).

You can also use any of the above methods to return scalar values, though typically `firstRow` is all that is required in such cases. An example returning the count of rows is shown here:

Reading scalar values

```
assert sql.firstRow('SELECT COUNT(*) AS num FROM Author').num == 3
```

Updating rows

Updating rows can again be done using the `execute()` method. Just use a SQL update statement as the argument to the method. You can insert an author with just a lastname and then update the row to also have a firstname as follows:

Updating a row

```
sql.execute "INSERT INTO Author (lastname) VALUES ('Thorvaldsson')"
sql.execute "UPDATE Author SET firstname='Erik' where lastname='Thorvaldsson'"
```

There is also a special `executeUpdate` variant which returns the number of rows updated as a result of executing the SQL. For example, you can change the lastname of an author as follows:

Using executeUpdate

```
def updateSql = "UPDATE Author SET lastname='Pragt' where lastname='Thorvaldsson'"
def updateCount = sql.executeUpdate updateSql
assert updateCount == 1

def row = sql.firstRow "SELECT * FROM Author where firstname = 'Erik'"
assert "${row.firstname} ${row.lastname}" == 'Erik Pragt'
```

Deleting rows

The `execute` method is also used for deleting rows as this example shows:

Deleting rows

```
assert sql.firstRow('SELECT COUNT(*) as num FROM Author').num == 3
sql.execute "DELETE FROM Author WHERE lastname = 'Skeet'"
assert sql.firstRow('SELECT COUNT(*) as num FROM Author').num == 2
```

Advanced SQL operations

Working with transactions

The easiest way to perform database operations within a transaction is to include the database operation within a `withTransaction` closure as shown in the following example:

A successful transaction

```
assert sql.firstRow('SELECT COUNT(*) as num FROM Author').num == 0
sql.withTransaction {
  sql.execute "INSERT INTO Author (firstname, lastname) VALUES ('Dierk', 'Koenig')"
  sql.execute "INSERT INTO Author (firstname, lastname) VALUES ('Jon', 'Skeet')"
}
assert sql.firstRow('SELECT COUNT(*) as num FROM Author').num == 2
```

Here the database starts empty and has two rows after successful completion of the operation. Outside the scope of the transaction, the database is never seen as having just one row.

If something goes wrong, any earlier operations within the `withTransaction` block are rolled back. We can see that in operation in the following example where we use database metadata (more details coming up shortly) to find the maximum allowable size of the `firstname` column and then attempt to enter a firstname one larger than that maximum value as shown here:

A failed transaction will cause a rollback

```
def maxFirstnameLength
def metaClosure = { meta -> maxFirstnameLength = meta.getPrecision(1) }
def rowClosure = {}
def rowCountBefore = sql.firstRow('SELECT COUNT(*) as num FROM Author').num
```

```
try {
  sql.withTransaction {
    sql.execute "INSERT INTO Author (firstname) VALUES ('Dierk')"
    sql.eachRow "SELECT firstname FROM Author WHERE firstname = 'Dierk'", metaClosure,
rowClosure
    sql.execute "INSERT INTO Author (firstname) VALUES (?)", 'X' * (maxFirstnameLength
+ 1)
  }
} catch(ignore) { println ignore.message }
def rowCountAfter = sql.firstRow('SELECT COUNT(*) as num FROM Author').num
assert rowCountBefore == rowCountAfter
```

Even though the first sql execute succeeds initially, it will be rolled back and the number of rows will remain the same.

Using batches

When dealing with large volumes of data, particularly when inserting such data, it can be more efficient to chunk the data into batches. This is done using the `withBatch` statement as shown in the following example:

Batching SQL statements

```
sql.withBatch(3) { stmt ->
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Dierk', 'Koenig')"
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Paul', 'King')"
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Guillaume',
'Laforge')"
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Hamlet',
'D''Arcy')"
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Cedric',
'Champeau')"
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Erik', 'Pragt')"
  stmt.addBatch "INSERT INTO Author (firstname, lastname) VALUES ('Jon', 'Skeet')"
}
```

After executing these statements, there will be 7 new rows in the database. In fact, they will have been added in batches even though you can't easily tell that after that fact. If you want to confirm what is going on under the covers, you can add a little bit of extra logging into your program. Add the following lines before the `withBatch` statement:

Logging additional SQL information

```
import java.util.logging.*

// next line will add fine logging
Logger.getLogger('groovy.sql').level = Level.FINE
// also adjust logging.properties file in JRE_HOME/lib to have:
// java.util.logging.ConsoleHandler.level = FINE
```

With this extra logging turned on, and the changes made as per the above comment for the logging.properties file, you should see output such as:

SQL logging output with batching enable

```
FINE: Successfully executed batch with 3 command(s)
Apr 19, 2015 8:38:42 PM groovy.sql.BatchingStatementWrapper processResult

FINE: Successfully executed batch with 3 command(s)
Apr 19, 2015 8:38:42 PM groovy.sql.BatchingStatementWrapper processResult

FINE: Successfully executed batch with 1 command(s)
Apr 19, 2015 8:38:42 PM groovy.sql.Sql getStatement
```

We should also note, that any combination of SQL statements can be added to the batch. They don't all have to be inserting a new row to the same table.

We noted earlier that to avoid SQL injection, we encourage you to use prepared statements, this is achieved using the variants of methods which take GStrings or a list of extra parameters. Prepared statements can be used in combination with batches as shown in the following example:

Batching prepared statements

```
def qry = 'INSERT INTO Author (firstname, lastname) VALUES (?,?)'
sql.withBatch(3, qry) { ps ->
  ps.addBatch('Dierk', 'Koenig')
  ps.addBatch('Paul', 'King')
  ps.addBatch('Guillaume', 'Laforge')
  ps.addBatch('Hamlet', "D'Arcy")
  ps.addBatch('Cedric', 'Champeau')
  ps.addBatch('Erik', 'Pragt')
  ps.addBatch('Jon', 'Skeet')
}
```

This provides a much safer option if the data could come from a user such as via a script or a web form. Of course, given that a prepared statement is being used, you are limited to a batch of the same SQL operation (insert in our example) to the one table.

Performing pagination

When presenting large tables of data to a user, it is often convenient to present information a page at a time. Many of Groovy's SQL retrieval methods have extra parameters which can be used to select a particular page of interest. The starting position and page size are specified as integers as shown in the following example using `rows`:

Retrieving pages of data

```
def qry = 'SELECT * FROM Author'
assert sql.rows(qry, 1, 3)*.firstname == ['Dierk', 'Paul', 'Guillaume']
assert sql.rows(qry, 4, 3)*.firstname == ['Hamlet', 'Cedric', 'Erik']
```

```
assert sql.rows(qry, 7, 3)*.firstname == ['Jon']
```

Fetching metadata

JDBC metadata can be retrieved in numerous ways. Perhaps the most basic approach is to extract the metadata from any row as shown in the following example which examines the tablename, column names and column type names:

Using row metadata

```
sql.eachRow("SELECT * FROM Author WHERE firstname = 'Dierk'") { row ->
  def md = row.getMetaData()
  assert md.getTableName(1) == 'AUTHOR'
  assert (1..md.columnCount).collect{ md.getColumnName(it) } == ['ID', 'FIRSTNAME',
'LASTNAME']
  assert (1..md.columnCount).collect{ md.getColumnTypeName(it) } == ['INTEGER',
'VARCHAR', 'VARCHAR']
}
```

And another slight variant to the previous example, this time also looking at the column label:

Also using row metadata

```
sql.eachRow("SELECT firstname AS first FROM Author WHERE firstname = 'Dierk'") { row
->
  def md = row.getMetaData()
  assert md.getColumnName(1) == 'FIRSTNAME'
  assert md.getColumnLabel(1) == 'FIRST'
}
```

Accessing metadata is quite common, so Groovy also provides variants to many of its methods that let you supply a closure that will be called once with the row metadata in addition to the normal row closure which is called for each row. The following example illustrates the two closure variant for `eachRow`:

Using row and metadata closures

```
def metaClosure = { meta -> assert meta.getColumnName(1) == 'FIRSTNAME' }
def rowClosure = { row -> assert row.FIRSTNAME == 'Dierk' }
sql.eachRow("SELECT firstname FROM Author WHERE firstname = 'Dierk'", metaClosure,
rowClosure)
```

Note that our SQL query will only return one row, so we could have equally used `firstRow` for the previous example.

Finally, JDBC also provides metadata per connection (not just for rows). You can also access such metadata from Groovy as shown in this example:

Using connection metadata

```
def md = sql.connection.metaData
assert md.driverName == 'HSQL Database Engine Driver'
assert md.databaseProductVersion == '2.7.4'
assert ['JDBCMajorVersion', 'JDBCMinorVersion'].collect{ md[it] } == [4, 2]
assert md.stringFunctions.tokenize(',').contains('CONCAT')
def rs = md.getTables(null, null, 'AUTH%', null)
assert rs.next()
assert rs.getString('TABLE_NAME').startsWith('AUTHOR')
```

Consult the JavaDoc for your driver to find out what metadata information is available for you to access.

Named and named-ordinal parameters

Groovy supports some additional alternative placeholder syntax variants. The GString variants are typically preferred over these alternatives but the alternatives are useful for Java integration purposes and sometimes in templating scenarios where GStrings might already be in heavy use as part of a template. The named parameter variants are much like the String plus list of parameter variants but instead of having a list of `?` placeholders followed by a list of parameters, you have one or more placeholders having the form `:propName` or `?.propName` and a single map, named arguments or a domain object as the parameter. The map or domain object should have a property named `propName` corresponding to each supplied placeholder.

Here is an example using the colon form:

Named parameters (colon form)

```
sql.execute "INSERT INTO Author (firstname, lastname) VALUES (:first, :last)", first:
'Dierk', last: 'Koenig'
```

And another example using the question mark form:

Named parameters (question mark form)

```
sql.execute "INSERT INTO Author (firstname, lastname) VALUES (?.first, ?.last)",
first: 'Jon', last: 'Skeet'
```

If the information you need to supply is spread across multiple maps or domain objects you can use the question mark form with an additional ordinal index as shown here:

Named-ordinal parameters

```
class Rockstar { String first, last }
def pogo = new Rockstar(first: 'Paul', last: 'McCartney')
def map = [lion: 'King']
sql.execute "INSERT INTO Author (firstname, lastname) VALUES (?1.first, ?2.lion)",
```

```
pogo, map
```

Stored procedures

The exact syntax for creating a stored procedure or function varies slightly between different databases. For the HSQLDB database we are using, we can create a stored function which returns the initials of all authors in a table as follows:

Creating a stored function

```
sql.execute """
  CREATE FUNCTION SELECT_AUTHOR_INITIALS()
  RETURNS TABLE (firstInitial VARCHAR(1), lastInitial VARCHAR(1))
  READS SQL DATA
  RETURN TABLE (
    SELECT LEFT(Author.firstname, 1) as firstInitial, LEFT(Author.lastname, 1) as
lastInitial
    FROM Author
  )
"""
```

We can use a SQL `CALL` statement to invoke the function using Groovy's normal SQL retrieval methods. Here is an example using `eachRow`.

Creating a stored procedure or function

```
def result = []
sql.eachRow('CALL SELECT_AUTHOR_INITIALS()') {
  result << "$it.firstInitial$it.lastInitial"
}
assert result == ['DK', 'JS', 'GL']
```

Here is the code for creating another stored function, this one taking the lastname as a parameter:

Creating a stored function with a parameter

```
sql.execute """
  CREATE FUNCTION FULL_NAME (p_lastname VARCHAR(64))
  RETURNS VARCHAR(100)
  READS SQL DATA
  BEGIN ATOMIC
    DECLARE ans VARCHAR(100);
    SELECT CONCAT(firstname, ' ', lastname) INTO ans
    FROM Author WHERE lastname = p_lastname;
    RETURN ans;
  END
"""
```

We can use the placeholder syntax to specify where the parameter belongs and note the special placeholder position to indicate the result:

Using a stored function with a parameter

```
def result = sql.firstRow("{? = call FULL_NAME(?)}", ['Koenig'])
assert result[0] == 'Dierk Koenig'
```

Finally, here is a stored procedure with input and output parameters:

Creating a stored procedure with input and output parameters

```
sql.execute """
  CREATE PROCEDURE CONCAT_NAME (OUT fullname VARCHAR(100),
    IN first VARCHAR(50), IN last VARCHAR(50))
  BEGIN ATOMIC
    SET fullname = CONCAT(first, ' ', last);
  END
"""
```

To use the `CONCAT_NAME` stored procedure parameter, we make use of a special `call` method. Any input parameters are simply provided as parameters to the method call. For output parameters, the resulting type must be specified as shown here:

Using a stored procedure with input and output parameters

```
sql.call("{call CONCAT_NAME(?, ?, ?)}", [Sql.VARCHAR, 'Dierk', 'Koenig']) {
  fullname -> assert fullname == 'Dierk Koenig'
}
```

Creating a stored procedure with an input/output parameter

```
sql.execute """
  CREATE PROCEDURE CHECK_ID_POSITIVE_IN_OUT ( INOUT p_err VARCHAR(64), IN pparam
INTEGER, OUT re VARCHAR(15))
  BEGIN ATOMIC
    IF pparam > 0 THEN
      set p_err = p_err || '_OK';
      set re = 'RET_OK';
    ELSE
      set p_err = p_err || '_ERROR';
      set re = 'RET_ERROR';
    END IF;
  END;
"""
```

Using a stored procedure with an input/output parameter

```
def scall = "{call CHECK_ID_POSITIVE_IN_OUT(?, ?, ?)}"
sql.call scall, [Sql.inout(Sql.VARCHAR("MESSAGE")), 1, Sql.VARCHAR], {
```

```
    res, p_err -> assert res == 'MESSAGE_OK' && p_err == 'RET_OK'
}
```

Using DataSets

Groovy provides a groovy.sql.DataSet class which enhances the groovy.sql.Sql class with what can be thought of as mini ORM functionality. Databases are accessed and queried using POGO fields and operators rather than JDBC-level API calls and RDBMS column names.

So, instead of a query like:

```
def qry = """SELECT * FROM Author
  WHERE (firstname > ?)
  AND (lastname < ?)
  ORDER BY lastname DESC"""
def params = ['Dierk', 'Pragt']
def result = sql.rows(qry, params)
assert result*.firstname == ['Eric', 'Guillaume', 'Paul']
```

You can write code like this:

```
def authorDS = sql.dataSet('Author')
def result = authorDS.findAll{ it.firstname > 'Dierk' }
        .findAll{ it.lastname < 'Pragt' }
        .sort{ it.lastname }
        .reverse()
assert result.rows()*.firstname == ['Eric', 'Guillaume', 'Paul']
```

Here we have a helper "domain" class:

```
class Author {
    String firstname
    String lastname
}
```

Database access and manipulation involves creating or working with instances of the domain class.

Querying collections in SQL-like style

Groovy's `groovy-ginq` module provides a higher-level abstraction over collections. It could perform queries against in-memory collections of objects in SQL-like style. Also, querying XML, JSON, YAML, etc. could also be supported because they can be parsed into collections. As GORM and jOOQ are powerful enough to support querying DB, we will cover collections first.

GINQ a.k.a. Groovy-Integrated Query

GINQ is a DSL for querying with SQL-like syntax, which consists of the following structure:

```
GQ, i.e. abbreviation for GINQ
|__ from
|   |__ <data_source_alias> in <data_source>
|__ [join/innerjoin/leftjoin/rightjoin/fulljoin/crossjoin]*
|   |__ <data_source_alias> in <data_source>
|   |__ on <condition> ((&& | ||) <condition>)* (NOTE: `crossjoin` does not need `on`
clause)
|__ [where]
|   |__ <condition> ((&& | ||) <condition>)*
|__ [groupby]
|   |__ <expression> [as <alias>] (, <expression> [as <alias>])*
|   |__ [having]
|       |__ <condition> ((&& | ||) <condition>)*
|__ [orderby]
|   |__ <expression> [in (asc|desc)] (, <expression> [in (asc|desc)])*
|__ [limit]
|   |__ [<offset>,] <size>
|__ select
    |__ <expression> [as <alias>] (, <expression> [as <alias>])*
```

NOTE `[]` means the related clause is optional, `*` means zero or more times, and `+` means one or more times. Also, the clauses of GINQ are order sensitive, so the order of clauses should be kept as the above structure

As we could see, the simplest GINQ consists of a `from` clause and a `select` clause, which looks like:

```
from n in [0, 1, 2]
select n
```

NOTE *ONLY ONE* `from` clause is required in GINQ. Also, GINQ supports multiple data sources through `from` and the related joins.

As a DSL, GINQ should be wrapped with the following block to be executed:

```
GQ { /* GINQ CODE */ }
```

For example,

```
def numbers = [0, 1, 2]
assert [0, 1, 2] == GQ {
    from n in numbers
    select n
```

```
}.toList()
```

```
import java.util.stream.Collectors

def numbers = [0, 1, 2]
assert '0#1#2' == GQ {
    from n in numbers
    select n
}.stream()
    .map(e -> String.valueOf(e))
    .collect(Collectors.joining('#'))
```

And it is strongly recommended to use `def` to define the variable for the result of GINQ execution, which is a `Queryable` instance that is lazy.

```
def result = GQ {
    /* GINQ CODE */
}
def stream = result.stream() // get the stream from GINQ result
def list = result.toList() // get the list from GINQ result
```

WARNING Currently GINQ can not work well when STC is enabled.

Also, GINQ could be written in a method marked with `@GQ`:

```
@GQ
def someGinqMethod() {
    /* GINQ CODE */
}
```

For example,

- Mark the `ginq` method as a GINQ method with `@GQ` annotation:

```
@groovy.ginq.transform.GQ
def ginq(list, b, e) {
    from n in list
    where b < n && n < e
    select n
}

assert [3, 4] == ginq([1, 2, 3, 4, 5, 6], 2, 5).toList()
```

- Specify the result type as `List`:

```
import groovy.ginq.transform.GQ

@GQ(List)
def ginq(b, e) {
    from n in [1, 2, 3, 4, 5, 6]
    where b < n && n < e
    select n
}

assert [3, 4] == ginq(2, 5)
```

NOTE GINQ supports many result types, e.g. `List`, `Set`, `Collection`, `Iterable`, `Iterator`, `java.util.stream.Stream` and array types.

- Enable parallel querying:

```
import groovy.ginq.transform.GQ

@GQ(parallel=true)
def ginq(x) {
    from n in [1, 2, 3]
    where n < x
    select n
}

assert [1] == ginq(2).toList()
```

GINQ Syntax

Data Source

The data source for GINQ could be specified by `from` clause, which is equivalent to SQL's `FROM`. Currently GINQ supports `Iterable`, `Stream`, array and GINQ result set as its data source:

`Iterable` Data Source

```
from n in [1, 2, 3] select n
```

`Stream` Data Source

```
from n in [1, 2, 3].stream() select n
```

Array Data Source

```
from n in new int[] {1, 2, 3} select n
```

GINQ Result Set Data Source

```
def vt = GQ {from m in [1, 2, 3] select m}
assert [1, 2, 3] == GQ {
    from n in vt select n
}.toList()
```

Projection

The column names could be renamed with `as` clause:

```
def result = GQ {
    from n in [1, 2, 3]
    select Math.pow(n, 2) as powerOfN
}
assert [[1, 1], [4, 4], [9, 9]] == result.stream().map(r -> [r[0], r.powerOfN]).
toList()
```

NOTE The renamed column could be referenced by its new name, e.g. `r.powerOfN`. Also, it could be referenced by its index, e.g. `r[0]`

```
assert [[1, 1], [2, 4], [3, 9]] == GQ {
    from v in (
        from n in [1, 2, 3]
        select n, Math.pow(n, 2) as powerOfN
    )
    select v.n, v.powerOfN
}.toList()
```

NOTE `select P1, P2, …, Pn` is a simplified syntax of `select new NamedRecord(P1, P2, …, Pn)` when and only when `n` >= 2. Also, `NamedRecord` instance will be created if `as` clause is used. The values stored in the `NamedRecord` could be referenced by their names.

Construct new objects as column values:

```
@groovy.transform.EqualsAndHashCode
class Person {
    String name
    Person(String name) {
        this.name = name
    }
```

```
}
def persons = [new Person('Daniel'), new Person('Paul'), new Person('Eric')]
assert persons == GQ {
    from n in ['Daniel', 'Paul', 'Eric']
    select new Person(n)
}.toList()
```

Distinct

`distinct` is equivalent to SQL's `DISTINCT`

```
def result = GQ {
    from n in [1, 2, 2, 3, 3, 3]
    select distinct(n)
}
assert [1, 2, 3] == result.toList()
```

```
def result = GQ {
    from n in [1, 2, 2, 3, 3, 3]
    select distinct(n, n + 1)
}
assert [[1, 2], [2, 3], [3, 4]] == result.toList()
```

Filtering

`where` is equivalent to SQL's `WHERE`

```
from n in [0, 1, 2, 3, 4, 5]
where n > 0 && n <= 3
select n * 2
```

In

```
from n in [0, 1, 2]
where n in [1, 2]
select n
```

```
from n in [0, 1, 2]
where n in (
    from m in [1, 2]
    select m
)
select n
```

```
import static groovy.lang.Tuple.tuple
assert [0, 1] == GQ {
    from n in [0, 1, 2]
    where tuple(n, n + 1) in (
        from m in [1, 2]
        select m - 1, m
    )
    select n
}.toList()
```

Not In

```
from n in [0, 1, 2]
where n !in [1, 2]
select n
```

```
from n in [0, 1, 2]
where n !in (
    from m in [1, 2]
    select m
)
select n
```

```
import static groovy.lang.Tuple.tuple
assert [2] == GQ {
    from n in [0, 1, 2]
    where tuple(n, n + 1) !in (
        from m in [1, 2]
        select m - 1, m
    )
    select n
}.toList()
```

Exists

```
from n in [1, 2, 3]
where (
    from m in [2, 3]
    where m == n
    select m
).exists()
select n
```

Not Exists

```
from n in [1, 2, 3]
where !(
    from m in [2, 3]
    where m == n
    select m
).exists()
select n
```

Joining

More data sources for GINQ could be specified by join clauses.

```
from n1 in [1, 2, 3]
join n2 in [1, 3] on n1 == n2
select n1, n2
```

NOTE	`join` is preferred over `innerjoin` and `innerhashjoin` as it has better readability, and it is smart enough to choose the correct concrete join(i.e. `innerjoin` or `innerhashjoin`) by its `on` clause.

```
from n1 in [1, 2, 3]
innerjoin n2 in [1, 3] on n1 == n2
select n1, n2
```

```
from n1 in [1, 2, 3]
leftjoin n2 in [2, 3, 4] on n1 == n2
select n1, n2
```

```
from n1 in [2, 3, 4]
rightjoin n2 in [1, 2, 3] on n1 == n2
select n1, n2
```

```
from n1 in [1, 2, 3]
fulljoin n2 in [2, 3, 4] on n1 == n2
select n1, n2
```

```
from n1 in [1, 2, 3]
crossjoin n2 in [3, 4, 5]
select n1, n2
```

hash join is especially efficient when data sources contain lots of objects

```
from n1 in [1, 2, 3]
innerhashjoin n2 in [1, 3] on n1 == n2
select n1, n2
```

```
from n1 in [1, 2, 3]
lefthashjoin n2 in [2, 3, 4] on n1 == n2
select n1, n2
```

```
from n1 in [2, 3, 4]
righthashjoin n2 in [1, 2, 3] on n1 == n2
select n1, n2
```

```
from n1 in [1, 2, 3]
fullhashjoin n2 in [2, 3, 4] on n1 == n2
select n1, n2
```

NOTE Only binary expressions(`==`, `&&`) are allowed in the `on` clause of hash join

Grouping

`groupby` is equivalent to SQL's `GROUP BY`, and `having` is equivalent to SQL's `HAVING`. Each field in any nonaggregate expression in the `select` clause **must** be included in the `groupby` clause.

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
select n, count(n)
```

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
having n >= 3
select n, count(n)
```

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
having count() < 3
select n, count()
```

The group columns could be renamed with `as` clause:

```
from s in ['ab', 'ac', 'bd', 'acd', 'bcd', 'bef']
groupby s.size() as length, s[0] as firstChar
select length, firstChar, max(s)
```

```
from s in ['ab', 'ac', 'bd', 'acd', 'bcd', 'bef']
groupby s.size() as length, s[0] as firstChar
having length == 3 && firstChar == 'b'
select length, firstChar, max(s)
```

Aggregate Functions

GINQ provides some built-in aggregate functions:

Function	Argument Type(s)	Return Type	Description
count()		java.lang.Long	number of rows, similar to `count(*)` in SQL
count(*expression*)	any	java.lang.Long	number of rows for which the value of *expression* is not `null`
min(*expression*)	java.lang.Comparable	same as argument type	minimum value of expression across all non-null values
max(*expression*)	java.lang.Comparable	same as argument type	maximum value of expression across all non-null values
sum(*expression*)	java.lang.Number	java.math.BigDecimal	sum of expression across all non-null values
avg(*expression*)	java.lang.Number	java.math.BigDecimal	the average (arithmetic mean) of all non-null values
list(*expression*)	any	java.util.List	the aggregated list of all non-null values
median(*expression*)	java.lang.Number	java.math.BigDecimal	value such that the number of non-null values above and below it is the same ("middle" value, not necessarily same as average or mean)

Function	Argument Type(s)	Return Type	Description
stdev(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical standard deviation of all non-null values
stdevp(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical standard deviation for the population for all non-null values
var(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical variance of all non-null values
varp(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical variance for the population for all non-null values
agg(*expression*)	any	any	customizes the aggregation logic in *expression* and returns single value

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
select n, count()
```

```
from s in ['a', 'b', 'cd', 'ef']
groupby s.size() as length
select length, min(s)
```

```
from s in ['a', 'b', 'cd', 'ef']
groupby s.size() as length
select length, max(s)
```

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
select n, sum(n)
```

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
select n, avg(n)
```

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
```

```
select n, median(n)
```

```
assert [['A', ['APPLE', 'APRICOT']],
        ['B', ['BANANA']],
        ['C', ['CANTALOUPE']]] == GQL {
    from fruit in ['Apple', 'Apricot', 'Banana', 'Cantaloupe']
    groupby fruit[0] as firstChar
    select firstChar, list(fruit.toUpperCase()) as fruit_list
}
```

```
def persons = [new Person('Linda', 100, 'Female'),
               new Person('Daniel', 135, 'Male'),
               new Person('David', 122, 'Male')]
assert [['Male', ['Daniel', 'David']], ['Female', ['Linda']]] == GQL {
    from p in persons
    groupby p.gender
    select p.gender, list(p.name)
}
```

```
from n in [1, 1, 3, 3, 6, 6, 6]
groupby n
select n, agg(_g.stream().map(r -> r.n).reduce(BigDecimal.ZERO, BigDecimal::add))
```

NOTE `_g` is an implicit variable for `agg` aggregate function, it represents the grouped `Queryable` object and its record(e.g. `r`) could reference the data source by alias(e.g. `n`)

```
from fruit in ['Apple', 'Apricot', 'Banana', 'Cantaloupe']
groupby fruit.substring(0, 1) as firstChar
select firstChar, agg(_g.stream().map(r -> r.fruit).toList()) as fruit_list
```

Also, we could apply the aggregate functions for the whole GINQ result, i.e. no `groupby` clause is needed:

```
assert [3] == GQ {
    from n in [1, 2, 3]
    select max(n)
}.toList()
```

```
assert [[1, 3, 2, 2, 6, 3, 3, 6]] == GQ {
    from n in [1, 2, 3]
    select min(n), max(n), avg(n), median(n), sum(n), count(n), count(),
            agg(_g.stream().map(r -> r.n).reduce(BigDecimal.ZERO, BigDecimal::add))
```

```
}.toList()
```

```
assert [0.816496580927726] == GQ {
    from n in [1, 2, 3]
    select stdev(n)
}.toList()
```

```
assert [1] == GQ {
    from n in [1, 2, 3]
    select stdevp(n)
}.toList()
```

```
assert [0.6666666666666667] == GQ {
    from n in [1, 2, 3]
    select var(n)
}.toList()
```

```
assert [1] == GQ {
    from n in [1, 2, 3]
    select varp(n)
}.toList()
```

Sorting

`orderby` is equivalent to SQL's `ORDER BY`

```
from n in [1, 5, 2, 6]
orderby n
select n
```

NOTE `in asc` is optional when sorting `in` ascending order

```
from n in [1, 5, 2, 6]
orderby n in asc
select n
```

```
from n in [1, 5, 2, 6]
orderby n in desc
select n
```

```
from s in ['a', 'b', 'ef', 'cd']
orderby s.length() in desc, s in asc
select s
```

```
from s in ['a', 'b', 'ef', 'cd']
orderby s.length() in desc, s
select s
```

```
from n in [1, null, 5, null, 2, 6]
orderby n in asc(nullslast)
select n
```

NOTE nullslast is equivalent to SQL's NULLS LAST and applied by default. nullsfirst is equivalent to SQL's NULLS FIRST.

```
from n in [1, null, 5, null, 2, 6]
orderby n in asc(nullsfirst)
select n
```

```
from n in [1, null, 5, null, 2, 6]
orderby n in desc(nullslast)
select n
```

```
from n in [1, null, 5, null, 2, 6]
orderby n in desc(nullsfirst)
select n
```

Pagination

limit is similar to the limit clause of MySQL, which could specify the offset(first argument) and size(second argument) for paginating, or just specify the only one argument as size

```
from n in [1, 2, 3, 4, 5]
limit 3
select n
```

```
from n in [1, 2, 3, 4, 5]
limit 1, 3
select n
```

Nested GINQ

Nested GINQ in `from` clause

```
from v in (
    from n in [1, 2, 3]
    select n
)
select v
```

Nested GINQ in `where` clause

```
from n in [0, 1, 2]
where n in (
    from m in [1, 2]
    select m
)
select n
```

```
from n in [0, 1, 2]
where (
    from m in [1, 2]
    where m == n
    select m
).exists()
select n
```

Nested GINQ in `select` clause

```
assert [null, 2, 3] == GQ {
    from n in [1, 2, 3]
    select (
        from m in [2, 3, 4]
        where m == n
        limit 1
        select m
    )
}.toList()
```

NOTE	It's recommended to use `limit 1` to restrict the count of sub-query result because `TooManyValuesException` will be thrown if more than one values returned

We could use `as` clause to name the sub-query result

```
assert [[1, null], [2, 2], [3, 3]] == GQ {
```

```
    from n in [1, 2, 3]
    select n, (
        from m in [2, 3, 4]
        where m == n
        select m
    ) as sqr
}.toList()
```

Window Functions

Window can be defined by `partitionby`, `orderby`, `rows` and `range`:

```
over(
    [partitionby <expression> (, <expression>)*]
    [orderby <expression> (, <expression>)*
       [rows <lower>, <upper> | range <lower>, <upper>]]
)
```

- `0` used as bound of `rows` and `range` clause is equivalent to SQL's `CURRENT ROW`, and negative means `PRECEDING`, positive means `FOLLOWING`
- `null` used as the lower bound of `rows` and `range` clause is equivalent to SQL's `UNBOUNDED PRECEDING`
- `null` used as the upper bound of `rows` and `range` clause is equivalent to SQL's `UNBOUNDED FOLLOWING`

Also, GINQ provides some built-in window functions:

Function	Argument Type(s)	Return Type	Description
rowNumber()		java.lang.Long	number of the current row within its partition, counting from `0`
rank()		java.lang.Long	rank of the current row with gaps
denseRank()		java.lang.Long	rank of the current row without gaps
percentRank()		java.math.BigDecimal	relative rank of the current row: (rank - 1) / (total rows - 1)
cumeDist()		java.math.BigDecimal	relative rank of the current row: (number of rows preceding or peer with current row) / (total rows)

Function	Argument Type(s)	Return Type	Description
ntile(*expression*)	java.lang.Long	java.lang.Long	bucket index ranging from `0` to `expression - 1`, dividing the partition as equally as possible
lead(*expression* [, *offset* [, *default*]])	any [, java.lang.Long [, same as *expression* type]]	same as *expression* type	returns *expression* evaluated at the row that is *offset* rows after the current row within the partition; if there is no such row, instead return *default* (which must be of the same type as *expression*). Both *offset* and *default* are evaluated with respect to the current row. If omitted, *offset* defaults to `1` and *default* to `null`
lag(*expression* [, *offset* [, *default*]])	any [, java.lang.Long [, same as *expression* type]]	same as *expression* type	returns *expression* evaluated at the row that is *offset* rows before the current row within the partition; if there is no such row, instead return *default* (which must be of the same type as *expression*). Both *offset* and *default* are evaluated with respect to the current row. If omitted, *offset* defaults to `1` and *default* to `null`
firstValue(*expression*)	any	same type as *expression*	returns *expression* evaluated at the row that is the first row of the window frame
lastValue(*expression*)	any	same type as *expression*	returns *expression* evaluated at the row that is the last row of the window frame

Function	Argument Type(s)	Return Type	Description
nthValue(*expression*, *n*)	any, java.lang.Long	same type as *expression*	returns *expression* evaluated at the row that is the *nth* row of the window frame
count()		java.lang.Long	number of rows, similar to `count(*)` in SQL
count(*expression*)	any	java.lang.Long	number of rows for which the value of *expression* is not `null`
min(*expression*)	java.lang.Comparable	same as argument type	minimum value of expression across all non-null values
max(*expression*)	java.lang.Comparable	same as argument type	maximum value of expression across all non-null values
sum(*expression*)	java.lang.Number	java.math.BigDecimal	sum of expression across all non-null values
avg(*expression*)	java.lang.Number	java.math.BigDecimal	the average (arithmetic mean) of all non-null values
median(*expression*)	java.lang.Number	java.math.BigDecimal	value such that the number of non-null values above and below it is the same ("middle" value, not necessarily same as average or mean)
stdev(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical standard deviation of all non-null values
stdevp(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical standard deviation for the population for all non-null values
var(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical variance of all non-null values
varp(*expression*)	java.lang.Number	java.math.BigDecimal	the statistical variance for the population for all non-null values

Function	Argument Type(s)	Return Type	Description
agg(*expression*)	any	any	**INCUBATING**: customizes the aggregation logic in *expression* and returns single value

`rowNumber`

```
assert [[2, 1, 1, 1], [1, 0, 0, 2], [null, 3, 3, 3], [3, 2, 2, 0]] == GQ {
    from n in [2, 1, null, 3]
    select n, (rowNumber() over(orderby n)),
              (rowNumber() over(orderby n in asc)),
              (rowNumber() over(orderby n in desc))
}.toList()
```

```
assert [[1, 0, 1, 2, 3], [2, 1, 2, 1, 2], [null, 3, 0, 3, 0], [3, 2, 3, 0, 1]] == GQ {
    from n in [1, 2, null, 3]
    select n, (rowNumber() over(orderby n in asc(nullslast))),
              (rowNumber() over(orderby n in asc(nullsfirst))),
              (rowNumber() over(orderby n in desc(nullslast))),
              (rowNumber() over(orderby n in desc(nullsfirst)))
}.toList()
```

NOTE The parentheses around the window function is required.

`rank`, `denseRank`, `percentRank`, `cumeDist` **and** `ntile`

```
assert [['a', 1, 1], ['b', 2, 2], ['b', 2, 2],
        ['c', 4, 3], ['c', 4, 3], ['d', 6, 4],
        ['e', 7, 5]] == GQ {
    from s in ['a', 'b', 'b', 'c', 'c', 'd', 'e']
    select s,
        (rank() over(orderby s)),
        (denseRank() over(orderby s))
}.toList()
```

```
assert [[60, 0, 0.4], [60, 0, 0.4], [80, 0.5, 0.8], [80, 0.5, 0.8], [100, 1, 1]] == GQ
{
    from n in [60, 60, 80, 80, 100]
    select n,
        (percentRank() over(orderby n)),
        (cumeDist() over(orderby n))
}.toList()
```

```
assert [[1, 0], [2, 0], [3, 0],
        [4, 1], [5, 1],
        [6, 2], [7, 2],[8, 2],
        [9, 3], [10, 3]] == GQ {
    from n in 1..10
    select n, (ntile(4) over(orderby n))
}.toList()
```

`lead` and `lag`

```
assert [[2, 3], [1, 2], [3, null]] == GQ {
    from n in [2, 1, 3]
    select n, (lead(n) over(orderby n))
}.toList()
```

```
assert [[2, 3], [1, 2], [3, null]] == GQ {
    from n in [2, 1, 3]
    select n, (lead(n) over(orderby n in asc))
}.toList()
```

```
assert [['a', 'bc'], ['ab', null], ['b', 'a'], ['bc', 'ab']] == GQ {
    from s in ['a', 'ab', 'b', 'bc']
    select s, (lead(s) over(orderby s.length(), s in desc))
}.toList()
```

```
assert [['a', null], ['ab', null], ['b', 'a'], ['bc', 'ab']] == GQ {
    from s in ['a', 'ab', 'b', 'bc']
    select s, (lead(s) over(partitionby s.length() orderby s.length(), s in desc))
}.toList()
```

```
assert [[2, 1], [1, null], [3, 2]] == GQ {
    from n in [2, 1, 3]
    select n, (lag(n) over(orderby n))
}.toList()
```

```
assert [[2, 3], [1, 2], [3, null]] == GQ {
    from n in [2, 1, 3]
    select n, (lag(n) over(orderby n in desc))
}.toList()
```

```
assert [['a', null], ['b', 'a'], ['aa', null], ['bb', 'aa']] == GQ {
```

```
    from s in ['a', 'b', 'aa', 'bb']
    select s, (lag(s) over(partitionby s.length() orderby s))
}.toList()
```

```
assert [[2, 3, 1], [1, 2, null], [3, null, 2]] == GQ {
    from n in [2, 1, 3]
    select n, (lead(n) over(orderby n)), (lag(n) over(orderby n))
}.toList()
```

The offset can be specified other than the default offset `1`:

```
assert [[2, null, null], [1, 3, null], [3, null, 1]] == GQ {
    from n in [2, 1, 3]
    select n, (lead(n, 2) over(orderby n)), (lag(n, 2) over(orderby n))
}.toList()
```

The default value can be returned when the index specified by offset is out of window, e.g. `'NONE'`:

```
assert [[2, 'NONE', 'NONE'], [1, 3, 'NONE'], [3, 'NONE', 1]] == GQ {
    from n in [2, 1, 3]
    select n, (lead(n, 2, 'NONE') over(orderby n)), (lag(n, 2, 'NONE') over(orderby
n))
}.toList()
```

`firstValue`, `lastValue` and `nthValue`

```
assert [[2, 1], [1, 1], [3, 2]] == GQ {
    from n in [2, 1, 3]
    select n, (firstValue(n) over(orderby n rows -1, 1))
}.toList()
```

```
assert [[2, 3], [1, 2], [3, 3]] == GQ {
    from n in [2, 1, 3]
    select n, (lastValue(n) over(orderby n rows -1, 1))
}.toList()
```

```
assert [[2, 2], [1, 1], [3, 3]] == GQ {
    from n in [2, 1, 3]
    select n, (firstValue(n) over(orderby n rows 0, 1))
}.toList()
```

```
assert [[2, 1], [1, null], [3, 1]] == GQ {
```

```
    from n in [2, 1, 3]
    select n, (firstValue(n) over(orderby n rows -2, -1))
}.toList()
```

```
assert [[2, 1], [1, null], [3, 2]] == GQ {
    from n in [2, 1, 3]
    select n, (lastValue(n) over(orderby n rows -2, -1))
}.toList()
```

```
assert [[2, 3], [1, 3], [3, null]] == GQ {
    from n in [2, 1, 3]
    select n, (lastValue(n) over(orderby n rows 1, 2))
}.toList()
```

```
assert [[2, 3], [1, 2], [3, null]] == GQ {
    from n in [2, 1, 3]
    select n, (firstValue(n) over(orderby n rows 1, 2))
}.toList()
```

```
assert [[2, 2], [1, 1], [3, 3]] == GQ {
    from n in [2, 1, 3]
    select n, (lastValue(n) over(orderby n rows -1, 0))
}.toList()
```

```
assert [[2, 1], [1, 1], [3, 1]] == GQ {
    from n in [2, 1, 3]
    select n, (firstValue(n) over(orderby n rows null, 1))
}.toList()
```

```
assert [[2, 3], [1, 3], [3, 3]] == GQ {
    from n in [2, 1, 3]
    select n, (lastValue(n) over(orderby n rows -1, null))
}.toList()
```

```
assert [['a', 'a', 'b'], ['aa', 'aa', 'bb'], ['b', 'a', 'b'], ['bb', 'aa', 'bb']] ==
GQ {
    from s in ['a', 'aa', 'b', 'bb']
    select s, (firstValue(s) over(partitionby s.length() orderby s)),
            (lastValue(s) over(partitionby s.length() orderby s))
}.toList()
```

```
assert [[1, 1, 2, 3, null], [2, 1, 2, 3, null], [3, 1, 2, 3, null]] == GQ {
    from n in 1..3
    select n, (nthValue(n, 0) over(orderby n)),
              (nthValue(n, 1) over(orderby n)),
              (nthValue(n, 2) over(orderby n)),
              (nthValue(n, 3) over(orderby n))
}.toList()
```

`min`, `max`, `count`, `sum`, `avg`, `median`, `stdev`, `stdevp`, `var` ,`varp` **and** `agg`

```
assert [['a', 'a', 'b'], ['b', 'a', 'b'], ['aa', 'aa', 'bb'], ['bb', 'aa', 'bb']] ==
GQ {
    from s in ['a', 'b', 'aa', 'bb']
    select s, (min(s) over(partitionby s.length())), (max(s) over(partitionby s.
length()))
}.toList()
```

```
assert [[1, 2, 2, 2, 1, 1], [1, 2, 2, 2, 1, 1],
        [2, 2, 2, 4, 2, 2], [2, 2, 2, 4, 2, 2],
        [3, 2, 2, 6, 3, 3], [3, 2, 2, 6, 3, 3]] == GQ {
    from n in [1, 1, 2, 2, 3, 3]
    select n, (count() over(partitionby n)),
              (count(n) over(partitionby n)),
              (sum(n) over(partitionby n)),
              (avg(n) over(partitionby n)),
              (median(n) over(partitionby n))
}.toList()
```

```
assert [[2, 6, 3, 1, 3, 4], [1, 6, 3, 1, 3, 4],
        [3, 6, 3, 1, 3, 4], [null, 6, 3, 1, 3, 4]] == GQ {
    from n in [2, 1, 3, null]
    select n, (sum(n) over()),
              (max(n) over()),
              (min(n) over()),
              (count(n) over()),
              (count() over())
}.toList()
```

```
assert [[1, 1, 1], [2, 2, 3], [5, 2, 10], [5, 2, 10]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n range -2, 0)),
              (sum(n) over(orderby n range -2, 0))
}.toList()
```

```groovy
assert [[1, 2, 3], [2, 1, 2], [5, 2, 10], [5, 2, 10]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n range 0, 1)),
              (sum(n) over(orderby n range 0, 1))
}.toList()
```

```groovy
assert [[1, 2, 3], [2, 2, 3], [5, 2, 10], [5, 2, 10]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n range -1, 1)),
              (sum(n) over(orderby n range -1, 1))
}.toList()
```

```groovy
assert [[1, 1, 2], [2, 0, 0], [5, 0, 0], [5, 0, 0]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n in desc range 1, 2)),
              (sum(n) over(orderby n in desc range 1, 2))
}.toList()
```

```groovy
assert [[1, 0, 0], [2, 1, 1], [5, 0, 0], [5, 0, 0]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n in desc range -2, -1)),
              (sum(n) over(orderby n in desc range -2, -1))
}.toList()
```

```groovy
assert [[1, 3, 12], [2, 2, 10], [5, 0, 0], [5, 0, 0]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n range 1, null)),
              (sum(n) over(orderby n range 1, null))
}.toList()
```

```groovy
assert [[1, 2, 3], [2, 2, 3], [5, 4, 13], [5, 4, 13]] == GQ {
    from n in [1, 2, 5, 5]
    select n, (count() over(orderby n range null, 1)),
              (sum(n) over(orderby n range null, 1))
}.toList()
```

```groovy
assert [[1, 0.816496580927726],
        [2, 0.816496580927726],
        [3, 0.816496580927726]] == GQ {
    from n in [1, 2, 3]
    select n, (stdev(n) over())
}.toList()
```

```
assert [[1, 1], [2, 1], [3, 1]] == GQ {
    from n in [1, 2, 3]
    select n, (stdevp(n) over())
}.toList()
```

```
assert [[1, 0.6666666666666667],
        [2, 0.6666666666666667],
        [3, 0.6666666666666667]] == GQ {
    from n in [1, 2, 3]
    select n, (var(n) over())
}.toList()
```

```
assert [[1, 1], [2, 1], [3, 1]] == GQ {
    from n in [1, 2, 3]
    select n, (varp(n) over())
}.toList()
```

```
assert [[1, 4], [2, 2], [3, 4]] == GQ {
    from n in [1, 2, 3]
    select n,
           (agg(_g.stream().map(r -> r.n).reduce(BigDecimal.ZERO, BigDecimal::add))
over(partitionby n % 2))
}.toList()
```

GINQ Tips

Row Number

`_rn` is the implicit variable representing row number for each record in the result set. It starts with `0`

```
from n in [1, 2, 3]
select _rn, n
```

List Comprehension

List comprehension is an elegant way to define and create lists based on existing lists:

```
assert [4, 16, 36, 64, 100] == GQ {from n in 1..<11 where n % 2 == 0 select n ** 2
}.toList()
```

```
assert [4, 16, 36, 64, 100] == GQ {from n in 1..<11 where n % 2 == 0 select n ** 2} as
```

```
List
```

```
assert [4, 16, 36, 64, 100] == GQL {from n in 1..<11 where n % 2 == 0 select n ** 2}
```

NOTE `GQL {…}` is the abbreviation of `GQ {…}.toList()`

GINQ could be used as list comprehension in the loops directly:

```
def result = []
for (def x : GQ {from n in 1..<11 where n % 2 == 0 select n ** 2}) {
    result << x
}
assert [4, 16, 36, 64, 100] == result
```

Query & Update

This is like `update` statement in SQL

```
import groovy.transform.*
@TupleConstructor
@EqualsAndHashCode
@ToString
class Person {
    String name
    String nickname
}

def linda = new Person('Linda', null)
def david = new Person('David', null)
def persons = [new Person('Daniel', 'ShanFengXiaoZi'), linda, david]
def result = GQ {
    from p in persons
    where p.nickname == null
    select p
}.stream()
    .peek(p -> { p.nickname = 'Unknown' }) // update `nickname`
    .toList()

def expected = [new Person('Linda', 'Unknown'), new Person('David', 'Unknown')]
assert expected == result
assert ['Unknown', 'Unknown'] == [linda, david]*.nickname // ensure the original
objects are updated
```

Alternative for `with` clause

GINQ does not support `with` clause for now, but we could define a temporary variable to workaround:

```
def v = GQ { from n in [1, 2, 3] where n < 3 select n }
def result = GQ {
    from n in v
    where n > 1
    select n
}
assert [2] == result.toList()
```

Alternative for `case-when`

`case-when` of SQL could be replaced with switch expression:

```
assert ['a', 'b', 'c', 'c'] == GQ {
    from n in [1, 2, 3, 4]
    select switch (n) {
        case 1 -> 'a'
        case 2 -> 'b'
        default -> 'c'
    }
}.toList()
```

Query JSON

```
import groovy.json.JsonSlurper
def json = new JsonSlurper().parseText('''
    {
        "fruits": [
            {"name": "Orange", "price": 11},
            {"name": "Apple", "price": 6},
            {"name": "Banana", "price": 4},
            {"name": "Mongo", "price": 29},
            {"name": "Durian", "price": 32}
        ]
    }
''')

def expected = [['Mongo', 29], ['Orange', 11], ['Apple', 6], ['Banana', 4]]
assert expected == GQ {
    from f in json.fruits
    where f.price < 32
    orderby f.price in desc
    select f.name, f.price
}.toList()
```

Parallel Querying

Parallel querying is especially efficient when querying big data sources. It is disabled by default, but we could enable it by hand:

```
assert [[1, 1], [2, 2], [3, 3]] == GQ(parallel: true) {
    from n1 in 1..1000
    join n2 in 1..10000 on n2 == n1
    where n1 <= 3 && n2 <= 5
    select n1, n2
}.toList()
```

As parallel querying will use a shared thread pool, the following code can release resources after all GINQ statements execution are completed, and it will wait util all tasks of threads are completed.

```
GQ {
    shutdown
}
```

WARNING	Once `shutdown` is issued, parallel querying can not work anymore.

The following code is equivalent to the above code, in other words, `immediate` is optional:

```
GQ {
    shutdown immediate
}
```

Shutdown without waiting tasks to complete:

```
GQ {
    shutdown abort
}
```

Customize GINQ

For advanced users, you could customize GINQ behaviour by specifying your own target code generator. For example, we could specify the qualified class name `org.apache.groovy.ginq.provider.collection.GinqAstWalker` as the target code generator to generate GINQ method calls for querying collections, which is the default behaviour of GINQ:

```
assert [0, 1, 2] == GQ(astWalker:
'org.apache.groovy.ginq.provider.collection.GinqAstWalker') {
    from n in [0, 1, 2]
    select n
}.toList()
```

Optimize GINQ

GINQ optimizer is enabled by default for better performance. It will transform the GINQ AST to achieve better execution plan. We could disable it by hand:

```
assert [[2, 2]] == GQ(optimize: false) {
    from n1 in [1, 2, 3]
    join n2 in [1, 2, 3] on n1 == n2
    where n1 > 1 &&  n2 < 3
    select n1, n2
}.toList()
```

GINQ Examples

Generate Multiplication Table

```
from v in (
    from a in 1..9
    join b in 1..9 on a <= b
    select a as f, b as s, "$a * $b = ${a * b}".toString() as r
)
groupby v.s
select max(v.f == 1 ? v.r : '') as v1,
       max(v.f == 2 ? v.r : '') as v2,
       max(v.f == 3 ? v.r : '') as v3,
       max(v.f == 4 ? v.r : '') as v4,
       max(v.f == 5 ? v.r : '') as v5,
       max(v.f == 6 ? v.r : '') as v6,
       max(v.f == 7 ? v.r : '') as v7,
       max(v.f == 8 ? v.r : '') as v8,
       max(v.f == 9 ? v.r : '') as v9
```

More examples

link: the latest GINQ examples

NOTE	Some examples in the above link require the latest SNAPSHOT version of Groovy to run.

Processing XML

Parsing XML

XmlParser and XmlSlurper

The most commonly used approach for parsing XML with Groovy is to use one of:

- `groovy.xml.XmlParser`

* groovy.xml.XmlSlurper

Both have the same approach to parse an XML. Both come with a bunch of overloaded parse methods plus some special methods such as `parseText`, parseFile and others. For the next example we will use the `parseText` method. It parses an XML `String` and recursively converts it to a list or map of objects.

XmlSlurper

```
def text = '''
    <list>
        <technology>
            <name>Groovy</name>
        </technology>
    </list>
'''

def list = new XmlSlurper().parseText(text) ①

assert list instanceof groovy.xml.slurpersupport.GPathResult ②
assert list.technology.name == 'Groovy' ③
```

① Parsing the XML and returning the root node as a GPathResult

② Checking we're using a GPathResult

③ Traversing the tree in a GPath style

XmlParser

```
def text = '''
    <list>
        <technology>
            <name>Groovy</name>
        </technology>
    </list>
'''

def list = new XmlParser().parseText(text) ①

assert list instanceof groovy.util.Node ②
assert list.technology.name.text() == 'Groovy' ③
```

① Parsing the XML and returning the root node as a Node

② Checking we're using a Node

③ Traversing the tree in a GPath style

Let's see the **similarities** between `XMLParser` and `XMLSlurper` first:

* Both are based on `SAX` so they both are low memory footprint

- Both can update/transform the XML

But they have key **differences**:

- `XmlSlurper` evaluates the structure lazily. So if you update the xml you'll have to evaluate the whole tree again.
- `XmlSlurper` returns `GPathResult` instances when parsing XML
- `XmlParser` returns `Node` objects when parsing XML

When to use one or the another?

NOTE	There is a discussion at StackOverflow. The conclusions written here are based partially on this entry.

- **If you want to transform an existing document to another** then `XmlSlurper` will be the choice
- **If you want to update and read at the same time** then `XmlParser` is the choice.

The rationale behind this is that every time you create a node with `XmlSlurper` it won't be available until you parse the document again with another `XmlSlurper` instance. Need to read just a few nodes XmlSlurper is for you ".

- **If you just have to read a few nodes** `XmlSlurper` should be your choice, since it will not have to create a complete structure in memory"

In general both classes perform similar way. Even the way of using GPath expressions with them are the same (both use `breadthFirst()` and `depthFirst()` expressions). So I guess it depends on the write/read frequency.

DOMCategory

There is another way of parsing XML documents with Groovy with the use of `groovy.xml.dom.DOMCategory` which is a category class which adds GPath style operations to Java's DOM classes.

NOTE	Java has in-built support for DOM processing of XML using classes representing the various parts of XML documents, e.g. `Document`, `Element`, `NodeList`, `Attr` etc. For more information about these classes, refer to the respective JavaDocs.

Having an XML like the following:

```
static def CAR_RECORDS = '''
<records>
  <car name='HSV Maloo' make='Holden' year='2006'>
    <country>Australia</country>
    <record type='speed'>Production Pickup Truck with speed of 271kph</record>
  </car>
  <car name='P50' make='Peel' year='1962'>
    <country>Isle of Man</country>
```

```
    <record type='size'>Smallest Street-Legal Car at 99cm wide and 59 kg in
weight</record>
  </car>
  <car name='Royale' make='Bugatti' year='1931'>
    <country>France</country>
    <record type='price'>Most Valuable Car at $15 million</record>
  </car>
</records>
'''
```

You can parse it using `groovy.xml.DOMBuilder` and `groovy.xml.dom.DOMCategory`.

```
def reader = new StringReader(CAR_RECORDS)
def doc = DOMBuilder.parse(reader) ①
def records = doc.documentElement

use(DOMCategory) { ②
    assert records.car.size() == 3
}
```

① Parsing the XML

② Creating `DOMCategory` scope to be able to use helper method calls

GPath

The most common way of querying XML in Groovy is using `GPath`:

GPath is a path expression language integrated into Groovy which allows parts of nested structured data to be identified. In this sense, it has similar aims and scope as XPath does for XML. The two main places where you use GPath expressions is when dealing with nested POJOs or when dealing with XML

It is similar to XPath expressions and you can use it not only with XML but also with POJO classes. As an example, you can specify a path to an object or element of interest:

- `a.b.c` → for XML, yields all the `<c>` elements inside `<b>` inside `<a>`
- `a.b.c` → all POJOs, yields the `<c>` properties for all the `<b>` properties of `<a>` (sort of like a.getB().getC() in JavaBeans)

For XML, you can also specify attributes, e.g.:

- `a["@href"]` → the href attribute of all the a elements
- `a.'@href'` → an alternative way of expressing this
- `a.@href` → an alternative way of expressing this when using XmlSlurper

Let's illustrate this with an example:

```
static final String books = '''
```

```
    <response version-api="2.0">
        <value>
            <books>
                <book available="20" id="1">
                    <title>Don Quixote</title>
                    <author id="1">Miguel de Cervantes</author>
                </book>
                <book available="14" id="2">
                    <title>Catcher in the Rye</title>
                   <author id="2">JD Salinger</author>
               </book>
               <book available="13" id="3">
                   <title>Alice in Wonderland</title>
                   <author id="3">Lewis Carroll</author>
               </book>
               <book available="5" id="4">
                   <title>Don Quixote</title>
                   <author id="4">Miguel de Cervantes</author>
               </book>
           </books>
       </value>
    </response>
'''
```

Simply traversing the tree

First thing we could do is to get a value using POJO's notation. Let's get the first book's author's name

Getting node value

```
def response = new XmlSlurper().parseText(books)
def authorResult = response.value.books.book[0].author

assert authorResult.text() == 'Miguel de Cervantes'
```

First we parse the document with `XmlSlurper` and then we have to consider the returning value as the root of the XML document, so in this case is "response".

That's why we start traversing the document from response and then `value.books.book[0].author`. Note that in `XPath` the node arrays starts in [1] instead of [0], but because `GPath` is Java-based it begins at index 0.

In the end we'll have the instance of the `author` node and because we wanted the text inside that node we should be calling the `text()` method. The `author` node is an instance of `GPathResult` type and `text()` a method giving us the content of that node as a String.

When using `GPath` with an XML parsed with `XmlSlurper` we'll have as a result a `GPathResult` object. `GPathResult` has many other convenient methods to convert the text inside a node to any other type such as:

- toInteger()
- toFloat()
- toBigInteger()
- …

All these methods try to convert a String to the appropriate type.

If we were using an XML parsed with XmlParser we could be dealing with instances of type Node. But still all the actions applied to GPathResult in these examples could be applied to a Node as well. Creators of both parsers took into account GPath compatibility.

Next step is to get some values from a given node's attribute. In the following sample we want to get the first book's author's id. We'll be using two different approaches. Let's see the code first:

Getting an attribute's value

```
def response = new XmlSlurper().parseText(books)

def book = response.value.books.book[0] ①
def bookAuthorId1 = book.@id ②
def bookAuthorId2 = book['@id'] ③

assert bookAuthorId1 == '1' ④
assert bookAuthorId1.toInteger() == 1 ⑤
assert bookAuthorId1 == bookAuthorId2
```

① Getting the first book node

② Getting the book's id attribute @id

③ Getting the book's id attribute with map notation ['@id']

④ Getting the value as a String

⑤ Getting the value of the attribute as an Integer

As you can see there are two types of notations to get attributes, the

- *direct notation* with @nameoftheattribute
- *map notation* using ['@nameoftheattribute']

Both of them are equally valid.

Flexible navigation with children (*), depthFirst (**) and breadthFirst

If you ever have used XPath, you may have used expressions like:

- /following-sibling::othernode : Look for a node "othernode" in the same level
- // : Look everywhere

More or less we have their counterparts in GPath with the shortcuts * (aka children()) and ** (aka depthFirst()).

The first example shows a simple use of *, which only iterates over the direct children of the node.

*Using **

```
def response = new XmlSlurper().parseText(books)

// .'*' could be replaced by .children()
def catcherInTheRye = response.value.books.'*'.find { node ->
    // node.@id == 2 could be expressed as node['@id'] == 2
    node.name() == 'book' && node.@id == '2'
}

assert catcherInTheRye.title.text() == 'Catcher in the Rye'
```

This test searches for any child nodes of the "books" node matching the given condition. In a bit more detail, the expression says: *Look for any node with a tag name equal to 'book' having an id with a value of '2' directly under the 'books' node.*

This operation roughly corresponds to the breadthFirst() method, except that it only stops at **one level** instead of continuing to the inner levels.

What if we would like to look for a given value without having to know exactly where it is. Let's say that the only thing we know is the id of the author "Lewis Carroll" . How are we going to be able to find that book? Using ** is the solution:

*Using ***

```
def response = new XmlSlurper().parseText(books)

// .'**' could be replaced by .depthFirst()
def bookId = response.'**'.find { book ->
    book.author.text() == 'Lewis Carroll'
}.@id

assert bookId == 3
```

** is the same as looking for something *everywhere in the tree from this point down*. In this case, we've used the method find(Closure cl) to find just the first occurrence.

What if we want to collect all book's titles? That's easy, just use findAll:

```
def response = new XmlSlurper().parseText(books)

def titles = response.'**'.findAll { node -> node.name() == 'title' }*.text()

assert titles.size() == 4
```

In the last two examples, `**` is used as a shortcut for the `depthFirst()` method. It goes as far down the tree as it can while navigating down the tree from a given node. The `breadthFirst()` method finishes off all nodes on a given level before traversing down to the next level.

The following example shows the difference between these two methods:

depthFirst() vs .breadthFirst

```
def response = new XmlSlurper().parseText(books)
def nodeName = { node -> node.name() }
def withId2or3 = { node -> node.@id in [2, 3] }

assert ['book', 'author', 'book', 'author'] ==
        response.value.books.depthFirst().findAll(withId2or3).collect(nodeName)
assert ['book', 'book', 'author', 'author'] ==
        response.value.books.breadthFirst().findAll(withId2or3).collect(nodeName)
```

In this example, we search for any nodes with an id attribute with value 2 or 3. There are both `book` and `author` nodes that match that criteria. The different traversal orders will find the same nodes in each case but in different orders corresponding to how the tree was traversed.

It is worth mentioning again that there are some useful methods converting a node's value to an integer, float, etc. Those methods could be convenient when doing comparisons like this:

helpers

```
def response = new XmlSlurper().parseText(books)

def titles = response.value.books.book.findAll { book ->
    /* You can use toInteger() over the GPathResult object */
    book.@id.toInteger() > 2
}*.title

assert titles.size() == 2
```

In this case the number 2 has been hardcoded but imagine that value could have come from any other source (database… etc.).

Creating XML

The most commonly used approach for creating XML with Groovy is to use a builder, i.e. one of:

- `groovy.xml.MarkupBuilder`
- `groovy.xml.StreamingMarkupBuilder`

MarkupBuilder

Here is an example of using Groovy's MarkupBuilder to create a new XML file:

Creating Xml with MarkupBuilder

```
def writer = new StringWriter()
def xml = new MarkupBuilder(writer) ①

xml.records() { ②
    car(name: 'HSV Maloo', make: 'Holden', year: 2006) {
        country('Australia')
        record(type: 'speed', 'Production Pickup Truck with speed of 271kph')
    }
    car(name: 'Royale', make: 'Bugatti', year: 1931) {
        country('France')
        record(type: 'price', 'Most Valuable Car at $15 million')
    }
}

def records = new XmlSlurper().parseText(writer.toString()) ③

assert records.car.first().name.text() == 'HSV Maloo'
assert records.car.last().name.text() == 'Royale'
```

① Create an instance of `MarkupBuilder`

② Start creating the XML tree

③ Create an instance of `XmlSlurper` to traverse and test the generated XML

Let's take a look a little bit closer:

Creating XML elements

```
def xmlString = "<movie>the godfather</movie>" ①

def xmlWriter = new StringWriter() ②
def xmlMarkup = new MarkupBuilder(xmlWriter)

xmlMarkup.movie("the godfather") ③

assert xmlString == xmlWriter.toString() ④
```

① We're creating a reference string to compare against

② The `xmlWriter` instance is used by `MarkupBuilder` to convert the xml representation to a String instance eventually

③ The `xmlMarkup.movie(…)` call will create an XML node with a tag called `movie` and with content `the godfather`.

Creating XML elements with attributes

```
def xmlString = "<movie id='2'>the godfather</movie>"

def xmlWriter = new StringWriter()
```

```
def xmlMarkup = new MarkupBuilder(xmlWriter)

xmlMarkup.movie(id: "2", "the godfather") ①

assert xmlString == xmlWriter.toString()
```

① This time in order to create both attributes and node content you can create as many map entries as you like and finally add a value to set the node's content

NOTE The value could be any `Object`, the value will be serialized to its `String` representation.

Creating XML nested elements

```
def xmlWriter = new StringWriter()
def xmlMarkup = new MarkupBuilder(xmlWriter)

xmlMarkup.movie(id: 2) { ①
    name("the godfather")
}

def movie = new XmlSlurper().parseText(xmlWriter.toString())

assert movie.@id == 2
assert movie.name.text() == 'the godfather'
```

① A closure represents the children elements of a given node. Notice this time instead of using a String for the attribute we're using a number.

Sometimes you may want to use a specific namespace in your xml documents:

Namespace aware

```
def xmlWriter = new StringWriter()
def xmlMarkup = new MarkupBuilder(xmlWriter)

xmlMarkup
        .'x:movies'('xmlns:x': 'http://www.groovy-lang.org') { ①
    'x:movie'(id: 1, 'the godfather')
    'x:movie'(id: 2, 'ronin')
}

def movies =
        new XmlSlurper() ②
                .parseText(xmlWriter.toString())
                .declareNamespace(x: 'http://www.groovy-lang.org')

assert movies.'x:movie'.last().@id == 2
assert movies.'x:movie'.last().text() == 'ronin'
```

① Creating a node with a given namespace `xmlns:x`

② Creating a `XmlSlurper` registering the namespace to be able to test the XML we just created

What about having some more meaningful example. We may want to generate more elements, to have some logic when creating our XML:

Mix code

```
def xmlWriter = new StringWriter()
def xmlMarkup = new MarkupBuilder(xmlWriter)

xmlMarkup
        .'x:movies'('xmlns:x': 'http://www.groovy-lang.org') {
    (1..3).each { n -> ①
        'x:movie'(id: n, "the godfather $n")
        if (n % 2 == 0) { ②
            'x:movie'(id: n, "the godfather $n (Extended)")
        }
    }
}

def movies =
        new XmlSlurper()
                .parseText(xmlWriter.toString())
                .declareNamespace(x: 'http://www.groovy-lang.org')

assert movies.'x:movie'.size() == 4
assert movies.'x:movie'*.text().every { name -> name.startsWith('the') }
```

① Generating elements from a range

② Using a conditional for creating a given element

Of course the instance of a builder can be passed as a parameter to refactor/modularize your code:

Mix code

```
def xmlWriter = new StringWriter()
def xmlMarkup = new MarkupBuilder(xmlWriter)

①
Closure<MarkupBuilder> buildMovieList = { MarkupBuilder builder ->
    (1..3).each { n ->
        builder.'x:movie'(id: n, "the godfather $n")
        if (n % 2 == 0) {
            builder.'x:movie'(id: n, "the godfather $n (Extended)")
        }
    }

    return builder
}
```

```
xmlMarkup.'x:movies'('xmlns:x': 'http://www.groovy-lang.org') {
    buildMovieList(xmlMarkup) ②
}

def movies =
        new XmlSlurper()
                .parseText(xmlWriter.toString())
                .declareNamespace(x: 'http://www.groovy-lang.org')

assert movies.'x:movie'.size() == 4
assert movies.'x:movie'*.text().every { name -> name.startsWith('the') }
```

① In this case we've created a Closure to handle the creation of a list of movies

② Just using the `buildMovieList` function when necessary

StreamingMarkupBuilder

The class `groovy.xml.StreamingMarkupBuilder` is a builder class for creating XML markup. This implementation uses a `groovy.xml.streamingmarkupsupport.StreamingMarkupWriter` to handle output.

Using StreamingMarkupBuilder

```
def xml = new StreamingMarkupBuilder().bind { ①
    records {
        car(name: 'HSV Maloo', make: 'Holden', year: 2006) { ②
            country('Australia')
            record(type: 'speed', 'Production Pickup Truck with speed of 271kph')
        }
        car(name: 'P50', make: 'Peel', year: 1962) {
            country('Isle of Man')
            record(type: 'size', 'Smallest Street-Legal Car at 99cm wide and 59 kg in
weight')
        }
        car(name: 'Royale', make: 'Bugatti', year: 1931) {
            country('France')
            record(type: 'price', 'Most Valuable Car at $15 million')
        }
    }
}

def records = new XmlSlurper().parseText(xml.toString()) ③

assert records.car.size() == 3
assert records.car.find { it.@name == 'P50' }.country.text() == 'Isle of Man'
```

① Note that `StreamingMarkupBuilder.bind` returns a `Writable` instance that may be used to stream the markup to a Writer

② We're capturing the output in a String to parse it again and check the structure of the generated XML with `XmlSlurper`.

MarkupBuilderHelper

The `groovy.xml.MarkupBuilderHelper` is, as its name reflects, a helper for `groovy.xml.MarkupBuilder`.

This helper normally can be accessed from within an instance of class `groovy.xml.MarkupBuilder` or an instance of `groovy.xml.StreamingMarkupBuilder`.

This helper could be handy in situations when you may want to:

- Produce a comment in the output
- Produce an XML processing instruction in the output
- Produce an XML declaration in the output
- Print data in the body of the current tag, escaping XML entities
- Print data in the body of the current tag

In both `MarkupBuilder` and `StreamingMarkupBuilder` this helper is accessed by the property `mkp`:

Using MarkupBuilder's 'mkp'

```
def xmlWriter = new StringWriter()
def xmlMarkup = new MarkupBuilder(xmlWriter).rules {
    mkp.comment('THIS IS THE MAIN RULE') ①
    rule(sentence: mkp.yield('3 > n')) ②
}

③
assert xmlWriter.toString().contains('3 &gt; n')
assert xmlWriter.toString().contains('<!-- THIS IS THE MAIN RULE -->')
```

① Using `mkp` to create a comment in the XML

② Using `mkp` to generate an escaped value

③ Checking both assumptions were true

Here is another example to show the use of `mkp` property accessible from within the `bind` method scope when using `StreamingMarkupBuilder`:

Using StreamingMarkupBuilder's 'mkp'

```
def xml = new StreamingMarkupBuilder().bind {
    records {
        car(name: mkp.yield('3 < 5')) ①
        car(name: mkp.yieldUnescaped('1 < 3')) ②
    }
}

assert xml.toString().contains('3 &lt; 5')
assert xml.toString().contains('1 < 3')
```

① If we want to generate an escaped value for the name attribute with `mkp.yield`

② Checking the values later on with `XmlSlurper`

DOMToGroovy

Suppose we have an existing XML document and we want to automate generation of the markup without having to type it all in? We just need to use `org.codehaus.groovy.tools.xml.DOMToGroovy` as shown in the following example:

Building MarkupBuilder from DOMToGroovy

```
def songs = """
    <songs>
      <song>
        <title>Here I go</title>
        <band>Whitesnake</band>
      </song>
    </songs>
"""

def builder =
        javax.xml.parsers.DocumentBuilderFactory.newInstance().newDocumentBuilder()

def inputStream = new ByteArrayInputStream(songs.bytes)
def document = builder.parse(inputStream)
def output = new StringWriter()
def converter = new DomToGroovy(new PrintWriter(output)) ①

converter.print(document) ②

String xmlRecovered =
        new GroovyShell()
                .evaluate("""
           def writer = new StringWriter()
           def builder = new groovy.xml.MarkupBuilder(writer)
           builder.${output}

           return writer.toString()
        """) ③

assert new XmlSlurper().parseText(xmlRecovered).song.title.text() == 'Here I go' ④
```

① Creating `DOMToGroovy` instance

② Converts the XML to `MarkupBuilder` calls which are available in the output `StringWriter`

③ Using `output` variable to create the whole MarkupBuilder

④ Back to XML string

Manipulating XML

In this chapter you'll see the different ways of adding / modifying / removing nodes using `XmlSlurper` or `XmlParser`. The xml we are going to be handling is the following:

```
def xml = """
<response version-api="2.0">
    <value>
        <books>
            <book id="2">
                <title>Don Quixote</title>
                <author id="1">Miguel de Cervantes</author>
            </book>
        </books>
    </value>
</response>
"""
```

Adding nodes

The main difference between `XmlSlurper` and `XmlParser` is that when former creates the nodes they won't be available until the document's been evaluated again, so you should parse the transformed document again in order to be able to see the new nodes. So keep that in mind when choosing any of both approaches.

If you needed to see a node right after creating it then `XmlParser` should be your choice, but if you're planning to do many changes to the XML and send the result to another process maybe `XmlSlurper` would be more efficient.

You can't create a new node directly using the `XmlSlurper` instance, but you can with `XmlParser`. The way of creating a new node from XmlParser is through its method `createNode(..)`

```
def parser = new XmlParser()
def response = parser.parseText(xml)
def numberOfResults = parser.createNode(
        response,
        new QName("numberOfResults"),
        [:]
)

numberOfResults.value = "1"
assert response.numberOfResults.text() == "1"
```

The `createNode()` method receives the following parameters:

- parent node (could be null)
- The qualified name for the tag (In this case we only use the local part without any namespace). We're using an instance of `groovy.namespace.QName`

- A map with the tag's attributes (None in this particular case)

Anyway you won't normally be creating a node from the parser instance but from the parsed XML instance. That is from a `Node` or a `GPathResult` instance.

Take a look at the next example. We are parsing the xml with `XmlParser` and then creating a new node from the parsed document's instance (Notice the method here is slightly different in the way it receives the parameters):

```
def parser = new XmlParser()
def response = parser.parseText(xml)

response.appendNode(
        new QName("numberOfResults"),
        [:],
        "1"
)

response.numberOfResults.text() == "1"
```

When using `XmlSlurper`, `GPathResult` instances don't have `createNode()` method.

Modifying / Removing nodes

We know how to parse the document, add new nodes, now I want to change a given node's content. Let's start using `XmlParser` and `Node`. This example changes the first book information to actually another book.

```
def response = new XmlParser().parseText(xml)

/* Use the same syntax as groovy.xml.MarkupBuilder */
response.value.books.book[0].replaceNode { ①
    book(id: "3") {
        title("To Kill a Mockingbird")
        author(id: "3", "Harper Lee")
    }
}

def newNode = response.value.books.book[0]

assert newNode.name() == "book"
assert newNode.@id == "3"
assert newNode.title.text() == "To Kill a Mockingbird"
assert newNode.author.text() == "Harper Lee"
assert newNode.author.@id.first() == "3"
```

When using `replaceNode()` the closure we pass as parameter should follow the same rules as if we were using `groovy.xml.MarkupBuilder`:

Here's the same example using XmlSlurper:

```
def response = new XmlSlurper().parseText(books)

/* Use the same syntax as groovy.xml.MarkupBuilder */
response.value.books.book[0].replaceNode {
    book(id: "3") {
        title("To Kill a Mockingbird")
        author(id: "3", "Harper Lee")
    }
}

assert response.value.books.book[0].title.text() == "Don Quixote"

/* That mkp is a special namespace used to escape away from the normal building mode
   of the builder and get access to helper markup methods
   'yield', 'pi', 'comment', 'out', 'namespaces', 'xmlDeclaration' and
   'yieldUnescaped' */
def result = new StreamingMarkupBuilder().bind { mkp.yield response }.toString()
def changedResponse = new XmlSlurper().parseText(result)

assert changedResponse.value.books.book[0].title.text() == "To Kill a Mockingbird"
```

Notice how using XmlSlurper we have to parse the transformed document again in order to find the created nodes. In this particular example could be a little bit annoying isn't it?

Finally both parsers also use the same approach for adding a new attribute to a given attribute. This time again the difference is whether you want the new nodes to be available right away or not. First XmlParser:

```
def parser = new XmlParser()
def response = parser.parseText(xml)

response.@numberOfResults = "1"

assert response.@numberOfResults == "1"
```

And XmlSlurper:

```
def response = new XmlSlurper().parseText(books)
response.@numberOfResults = "2"

assert response.@numberOfResults == "2"
```

When using XmlSlurper, adding a new attribute does **not** require you to perform a new evaluation.

Printing XML

XmlUtil

Sometimes is useful to get not only the value of a given node but the node itself (for instance to add this node to another XML).

For that you can use `groovy.xml.XmlUtil` class. It has several static methods to serialize the xml fragment from several type of sources (Node, GPathResult, String…)

Getting a node as a string

```
def response = new XmlParser().parseText(xml)
def nodeToSerialize = response.'**'.find { it.name() == 'author' }
def nodeAsText = XmlUtil.serialize(nodeToSerialize)

assert nodeAsText ==
        XmlUtil.serialize('<?xml version="1.0" encoding="UTF-8"?><author id="1">Miguel
de Cervantes</author>')
```

Processing YAML

Groovy has an optional `groovy-yaml` module which provides support for converting between Groovy objects and YAML. The classes dedicated to YAML serialisation and parsing are found in the `groovy.yaml` package.

YamlSlurper

`YamlSlurper` is a class that parses YAML text or reader content into Groovy data structures (objects) such as maps, lists and primitive types like `Integer`, `Double`, `Boolean` and `String`.

The class comes with a bunch of overloaded `parse` methods plus some special methods such as `parseText` and others. For the next example we will use the `parseText` method. It parses a YAML `String` and recursively converts it to a list or map of objects. The other `parse*` methods are similar in that they return a YAML `String` but for different parameter types.

```
        def ys = new YamlSlurper()
        def yaml = ys.parseText '''
language: groovy
sudo: required
dist: trusty

matrix:
  include:
    - jdk: openjdk10
    - jdk: oraclejdk9
    - jdk: oraclejdk8

before_script:
```

```
  - |
    unset _JAVA_OPTIONS

        '''

        assert 'groovy' == yaml.language
        assert 'required' == yaml.sudo
        assert 'trusty' == yaml.dist
        assert ['openjdk10', 'oraclejdk9', 'oraclejdk8'] ==  yaml.matrix.include.jdk
        assert ['unset _JAVA_OPTIONS'] == yaml.before_script*.trim()
```

Notice the result is a plain map and can be handled like a normal Groovy object instance. `YamlSlurper` parses the given YAML as defined by the YAML Ain't Markup Language (YAML™).

As `YamlSlurper` is returning pure Groovy object instances without any special YAML classes in the back, its usage is transparent. In fact, `YamlSlurper` results conform to GPath expressions. GPath is a powerful expression language that is supported by multiple slurpers for different data formats (`XmlSlurper` for XML being one example).

NOTE For more details please have a look at the section on GPath expressions.

The following table gives an overview of the YAML types and the corresponding Groovy data types:

YAML	Groovy
string	`java.lang.String`
number	`java.lang.BigDecimal` or `java.lang.Integer`
object	`java.util.LinkedHashMap`
array	`java.util.ArrayList`
true	`true`
false	`false`
null	`null`
date	`java.util.Date` based on the `yyyy-MM-dd'T'HH:mm:ssZ` date format

NOTE Whenever a value in YAML is `null`, `YamlSlurper` supplements it with the Groovy `null` value. This is in contrast to other YAML parsers that represent a `null` value with a library-provided singleton object.

Builders

Another way to create YAML from Groovy is to use `YamlBuilder`. The builder provide a DSL which allows to formulate an object graph which is then converted to YAML.

```
        def builder = new YamlBuilder()
        builder.records {
            car {
```

```
                name 'HSV Maloo'
                make 'Holden'
                year 2006
                country 'Australia'
                homepage new URL('http://example.org')
                record {
                    type 'speed'
                    description 'production pickup truck with speed of 271kph'
                }
            }
        }

        assert builder.toString() == '''---
records:
  car:
    name: "HSV Maloo"
    make: "Holden"
    year: 2006
    country: "Australia"
    homepage: "http://example.org"
    record:
      type: "speed"
      description: "production pickup truck with speed of 271kph"
'''
```

Processing TOML

Groovy has an optional `groovy-toml` module which provides support for converting between Groovy objects and TOML. The classes dedicated to TOML serialisation and parsing are found in the `groovy.toml` package.

TomlSlurper

`TomlSlurper` is a class that parses TOML text or reader content into Groovy data structures (objects) such as maps, lists and primitive types like `Integer`, `Double`, `Boolean` and `String`.

The class comes with a bunch of overloaded `parse` methods plus some special methods such as `parseText` and others. For the next example we will use the `parseText` method. It parses a TOML `String` and recursively converts it to a list or map of objects. The other `parse*` methods are similar in that they return a TOML `String` but for different parameter types.

```
        def ts = new TomlSlurper()
        def toml = ts.parseText '''
language = "groovy"
sudo = "required"
dist = "trusty"
before_script = [ "unset _JAVA_OPTIONS\\n\\n    \\n" ]

[[matrix.include]]
```

```
jdk = "openjdk10"

[[matrix.include]]
jdk = "oraclejdk9"

[[matrix.include]]
jdk = "oraclejdk8"
'''

        assert 'groovy' == toml.language
        assert 'required' == toml.sudo
        assert 'trusty' == toml.dist
        assert ['openjdk10', 'oraclejdk9', 'oraclejdk8'] ==  toml.matrix.include.jdk
        assert ['unset _JAVA_OPTIONS'] == toml.before_script*.trim()
```

Notice the result is a plain map and can be handled like a normal Groovy object instance. `TomlSlurper` parses the given TOML as defined by the Tom's Obvious, Minimal Language.

As `TomlSlurper` is returning pure Groovy object instances without any special TOML classes in the back, its usage is transparent. In fact, `TomlSlurper` results conform to GPath expressions. GPath is a powerful expression language that is supported by multiple slurpers for different data formats (`XmlSlurper` for XML being one example).

NOTE For more details please have a look at the section on GPath expressions.

The following table gives an overview of the TOML types and the corresponding Groovy data types:

TOML	Groovy
string	`java.lang.String`
number	`java.lang.BigDecimal` or `java.lang.Integer`
object	`java.util.LinkedHashMap`
array	`java.util.ArrayList`
true	`true`
false	`false`
null	`null`
date	`java.util.Date` based on the `yyyy-MM-dd'T'HH:mm:ssZ` date format

NOTE Whenever a value in TOML is `null`, `TomlSlurper` supplements it with the Groovy `null` value. This is in contrast to other TOML parsers that represent a `null` value with a library-provided singleton object.

Builders

Another way to create TOML from Groovy is to use `TomlBuilder`. The builder provide a DSL which allows to formulate an object graph which is then converted to TOML.

```
        def builder = new TomlBuilder()
        builder.records {
            car {
                name 'HSV Maloo'
                make 'Holden'
                year 2006
                country 'Australia'
                homepage new URL('http://example.org')
                record {
                    type 'speed'
                    description 'production pickup truck with speed of 271kph'
                }
            }
        }

        assert builder.toString() == '''\
records.car.name = 'HSV Maloo'
records.car.make = 'Holden'
records.car.year = 2006
records.car.country = 'Australia'
records.car.homepage = 'http://example.org'
records.car.record.type = 'speed'
records.car.record.description = 'production pickup truck with speed of 271kph'
'''
```

Built-in auxiliary type checkers

Introduction

Groovy's static nature includes an extensible type-checking mechanism. This mechanism allows users to selectively strengthen or weaken type checking as needed to cater for scenarios where the standard type checking isn't sufficient.

In addition to allowing you to write your own customer checkers, Groovy offers a handful of useful built-in type checkers. These provide additional checks for specific scenarios.

In the examples which follow, we'll explicitly show declaring the type checker we want to use. As usual, Groovy's compiler customization mechanisms would allow you to simplify application of such checkers, e.g. make it apply globally using a compiler configuration script, as just one example.

Checking Regular Expressions

A regular expression (regex) defines a search pattern for text. The pattern can be as simple as a single character, a fixed string, or a complex expression containing special characters describing a pattern. The JDK has special regex classes and Groovy adds some special syntactic sugar and functionality on top of the JDK classes.

Here is an example the checks that the String 'Foo' matches a regular expression:

```
assert 'foo'.matches(/[Ff].{2}\b/)
```

The regex pattern is made up of three parts:

- `[Ff]` is a character class matching upper or lowercase 'f',
- `.{2}` means exactly two occurrences of the `.` character class which matches any character
- `\b` matches a word boundary

There are more options we could add here such as grouping, lookahead and look-behind, to name just a few. With so many options and special characters, it isn't hard to create an invalid regular expression pattern. Such invalid patterns are typically found at runtime with a runtime exception.

The goal of the `RegexChecker` is to find such errors at compile-time. If compilation of the expressions succeeds, they are guaranteed not to fail at runtime.

Typical usage

The previous example can be type checked as follows:

```
@TypeChecked(extensions='groovy.typecheckers.RegexChecker')
static main(args) {
    assert 'foo'.matches(/[Ff].{2}\b/)
}
```

If you have many examples where such checking is desirable, you could consider automatically adding this extension to your compilation process.

Covered methods

The methods which are checked include:

`java.util.regex.Pattern`

```
static Pattern compile(String regex)
static Pattern compile(String regex, int flags)
static boolean matches(String regex, CharSequence input)
```

`java.util.regex.Matcher`

```
String group(int group)
matcher[matchCount][groupCount]  // getAt shorthand
```

Operators

```
~/regex/                // pattern operator
'string' =~ /regex/     // find operator
'string' ==~ /regex/    // (exact) match operator
```

The RegexChecker will check any method calls listed above. It might find such methods when they involve explicit static method calls or when the receiver's type can be inferred.

The regular expression must be a *constant-like* String. Any group-count values must be a *constant-like* integer. By *constant-like*, we mean, either an explicit String literal, or a field with an initializer expression or a local variable with an initializer expression. These possibilities are shown in the following code, which contains 3 regular expressions:

```
static final String TWO_GROUPS_OF_THREE = /(...)(...)/  ①

@TypeChecked(extensions='groovy.typecheckers.RegexChecker')
static main(args) {
    var m = 'foobar' =~ TWO_GROUPS_OF_THREE  //  ②
    assert m.find()
    assert m.group(1) == 'foo'
    assert m.group(2) == 'bar'  ③

    var pets = ['cat', 'dog', 'goldfish']
    var shortNamed = ~/\w{3}/  ④
    assert pets.grep(shortNamed) == ['cat', 'dog']  ⑤

    assert Pattern.matches(/(\d{4})-(\d{1,2})-(\d{1,2})/, '2020-12-31')  ⑥
}
```

① A constant String regex

② Using the constant regex with the find operator

③ Checking the matcher's second group

④ A local variable containing a regex pattern

⑤ Using the pattern with grep

⑥ An API call passing a String literal regex

Errors detected

Luckily, in the above example, we made no errors in our regex definitions, and the code compiles and executes successfully.

If however, we did make certain errors in those definitions, then we would expect the potential of runtime errors. Using `RegexChecker`, we can find certain kinds of errors during compilation. Let's look at some examples.

Suppose at □ we looked for the third group instead of the second:

```
assert m.group(3) == 'bar'
```

We would see the following error at compile-time:

```
[Static type checking] - Invalid group count 3 for regex with 2 groups
```

Alternatively, suppose at □ we accidentally left off the closing curly brace:

```
var shortNamed = ~/\w{3/
```

We would see the following error at compile-time:

```
[Static type checking] - Bad regex: Unclosed counted closure near index 4
```

Alternatively, suppose at □ we accidentally left off the closing round bracket for the last (day of month) group:

```
assert Pattern.matches(/(\d{4})-(\d{1,2})-(\d{1,2}/, '2020-12-31')
```

We would see the following error at compile-time:

```
[Static type checking] - Bad regex: Unclosed group near index 26
```

Over-and-above these examples, detected errors include:

- Bad class syntax
- Bad named capturing group
- Dangling meta character
- Empty character family
- Illegal character range
- Illegal repetition
- Illegal/unsupported escape sequence
- Look-behind group does not have an obvious maximum length
- Unexpected character
- Unclosed character family
- Unclosed character class
- Unclosed counted closure

- Unclosed group
- Unknown character property name
- Unknown Unicode property
- Unknown group type
- Unknown inline modifier
- Unknown character name
- Unmatched closing ')'

Checking Format Strings

The `format` methods in `java.util.Formatter`, and other similar methods, support formatted printing in the style of C's `printf` method with a format string and zero or more arguments.

Let's consider an example which produces a string comprised of three terms:

- a floating-point representation (`%f`) of PI (with 2 decimal places of precision),
- the hex representation (`%X`) of 15 (as two uppercase digits with a leading 0),
- and the Boolean (`%B`) `True` (in uppercase).

The assertion checks our expectations:

```
assert String.format('%4.2f %02X %B', Math.PI, 15, true) == '3.14 0F TRUE'
```

This is a powerful method supporting numerous conversions and flags. If the developer supplies incorrect conversions or flags, they will receive one of numerous possible runtime errors. As examples, consider the following mistakes and resulting runtime exceptions:

- supplying a String as the parameter for either of the first two arguments results in an `IllegalFormatConversionException`,
- leaving out the last argument results in a `MissingFormatArgumentException`,
- supplying the *leading zero* flag for the Boolean parameter results in a `FlagsConversionMismatchException`.

The goal of the `FormatStringChecker` is to eliminate a large number of such runtime errors. If the API call passes type checking, it will be guaranteed to succeed at runtime.

Typical usage

Here is an example of correctly using some of these methods with type checking in place:

```
@TypeChecked(extensions='groovy.typecheckers.FormatStringChecker')
static main(args) {
    assert String.format('%x', 1023) == '3ff'
    assert String.format(Locale.US, '%x', 1024) == '400'
```

```
    assert sprintf('%s%s', 'foo', 'bar') == 'foobar'
    assert new Formatter().format('xy%s', 'zzy').toString() == 'xyzzy'
    def baos = new ByteArrayOutputStream()
    new PrintStream(baos).printf('%-4c|%6b', 'x' as char, true)
    assert baos.toString() == 'x   |  true'
}
```

Over and above these methods, if you have your own method of this style, you can annotate it with `@FormatMethod`, and it will also be checked.

```
@FormatMethod
static String log(String formatString, Object... args) {
    sprintf(formatString, args)
}

@TypeChecked(extensions='groovy.typecheckers.FormatStringChecker')
static main(args) {
    assert log('%x', 1023) == '3ff'
    assert log('%x', 1024) == '400'
}
```

You can use the `FormatMethod` annotation provided in the `groovy-typecheckers` module or the similarly named annotation from the Java-based checker framework.

Covered methods

The format string methods have the following characteristics:

- The first argument must be of type `java.util.Locale` or `java.lang.String`.
- If the first argument is of type `Locale`, the second argument must be of type `String`.
- The `String` argument is treated as a format string containing zero or more embedded format specifiers as well as plain text. The format specifiers determine how the remaining arguments will be used within the resulting output.

The `FormatStringChecker` ensures that the format string is valid and the remaining arguments are compatible with the embedded format specifiers.

The methods which are checked include:

`java.lang.String`

```
static String format(String format, Object... args)
static String format(Locale l, String format, Object... args)
String formatted(Object... args)  // JDK15+
```

`java.util.Formatter`

```
String format(String format, Object... args)
String format(Locale l, String format, Object... args)
```

`java.io.PrintStream`

```
PrintStream printf(String format, Object... args)
PrintStream printf(Locale l, String format, Object... args)
```

DGM methods

```
printf(String format, Object... args)
printf(Locale l, String format, Object... args)
sprintf(String format, Object... args)
sprintf(Locale l, String format, Object... args)
```

The format string checker looks for a constant literal format string. For arguments, it also looks for constant literals or otherwise makes checks based on inferred type. When looking for constants, the checker will find inline literals, local variables with a constant initializer, and fields with a constant initializer. Here are some examples:

```
static final String FIELD_PATTERN = '%x'
static final int FIELD_PARAM = 1023

@TypeChecked(extensions='groovy.typecheckers.FormatStringChecker')
static main(args) {
    assert sprintf('%x', 1024) == '400'  ①

    assert sprintf(FIELD_PATTERN, FIELD_PARAM) == '3ff'  ②

    var local_var_pattern = '%x'
    var local_var_param = 1022
    assert sprintf(local_var_pattern, local_var_param) == '3fe'  ③

    assert sprintf('%x%s', theParam(), 'a' + 'b') == '3fdab'  ④
}

static int theParam() { 1021 }
```

① Constant literals

② Fields with an initializer

③ Local variables with an initializer

④ Checking of the parameter will be based on inferred type

Errors detected

Here are some examples of the kinds of errors detected.

- The arguments much match the type of the format classifier, e.g. we can't use the character classifier with a boolean argument:

  ```
  sprintf '%c', true
  ```

  We would see the following error at compile-time:

  ```
  [Static type checking] - IllegalFormatConversion: c != java.lang.Boolean
  ```

- We shouldn't specify precision for non-scientific arguments, e.g. we shouldn't expect 7 decimal places of precision for an integral value:

  ```
  String.format('%1.7d', 3)
  ```

  We would see the following error at compile-time:

  ```
  [Static type checking] - IllegalFormatPrecision: 7
  ```

- We should specify only known format specifier conversions, e.g. `v` isn't known:

  ```
  System.out.printf('%v', 7)
  ```

  We would see the following error at compile-time:

  ```
  [Static type checking] - UnknownFormatConversion: Conversion = 'v'
  ```

The complete list of errors detected include:

- duplicate format flags
- illegal format flags
- illegal format precision values
- unknown format conversions
- illegal format conversions
- format flags conversion mismatches
- missing arguments

Groovy Contracts – design by contract support for Groovy

This module provides contract annotations that support the specification of class-invariants, as well as pre- and post-conditions on Groovy classes and interfaces. Special support is provided so that post-conditions may refer to the old value of variables or to the result value associated with calling a method.

Applying @Invariant, @Requires and @Ensures

With Groovy contracts in your classpath, contracts can be applied on a Groovy class or interface by using one of the annotations found in the `groovy.contracts` package.

```
package acme

import groovy.contracts.*

@Invariant({ speed() >= 0 })
class Rocket {
    int speed = 0
    boolean started = true

    @Requires({ isStarted() })
    @Ensures({ old.speed < speed })
    def accelerate(inc) { speed += inc }

    def speed() { speed }
}

def r = new Rocket()
r.accelerate(5)
```

More Features

Groovy contracts supports the following feature set:

- definition of class invariants, pre- and post-conditions via @Invariant, @Requires and @Ensures
- inheritance of class invariants, pre- and post-conditions of concrete predecessor classes
- inheritance of class invariants, pre- and post-conditions in implemented interfaces
- usage of old and result variable in post-condition assertions
- assertion injection in Plain Old Groovy Objects (POGOs)
- human-readable assertion messages, based on Groovy power asserts
- enabling contracts at package- or class-level with @AssertionsEnabled
- enable or disable contract checking with Java's -ea and -da VM parameters

- annotation contracts: a way to reuse reappearing contract elements in a project domain model
- detection of circular assertion method calls

The Stack Example

Currently, Groovy contracts supports 3 annotations: @Invariant, @Requires and @Ensures – all of them work as annotations with closures, where closures allow you to specify arbitrary code pieces as annotation parameters:

```
import groovy.contracts.*

@Invariant({ elements != null })
class Stack<T> {

    List<T> elements

    @Ensures({ is_empty() })
    def Stack()  {
        elements = []
    }

    @Requires({ preElements?.size() > 0 })
    @Ensures({ !is_empty() })
    def Stack(List<T> preElements)  {
        elements = preElements
    }

    boolean is_empty()  {
        elements.isEmpty()
    }

    @Requires({ !is_empty() })
    T last_item()  {
        elements.get(count() - 1)
    }

    def count() {
        elements.size()
    }

    @Ensures({ result == true ? count() > 0 : count() >= 0  })
    boolean has(T item)  {
        elements.contains(item)
    }

    @Ensures({ last_item() == item })
    def push(T item)  {
       elements.add(item)
    }
```

```
    @Requires({ !is_empty() })
    @Ensures({ last_item() == item })
    def replace(T item)  {
        remove()
        elements.add(item)
    }

    @Requires({ !is_empty() })
    @Ensures({ result != null })
    T remove()  {
        elements.remove(count() - 1)
    }

    String toString() { elements.toString() }
}

def stack = new Stack<Integer>()
```

The example above specifies a class-invariant and methods with pre- and post-conditions. Note, that preconditions may reference method arguments and post-conditions have access to the method's result with the result variable and old instance variables values with old.

Indeed, Groovy AST transformations change these assertion annotations into Java assertion statements (can be turned on and off with a JVM param) and inject them at appropriate places, e.g. class-invariants are used to check an object's state before and after each method call.

Annotation closure rules

- Invariants should reference class fields only.
- Preconditions may reference class fields and arguments.
- Postconditions may reference class fields, arguments, the `result` and the old value of class fields using the syntax `old.fieldname`.

Old values of class fields will only be stored where Groovy contracts knows how to make a copy. Currently, this means fields with a `Cloneable` class type, primitives, the primitive wrapper types, `BigInteger`, `BigDecimal`, and G/Strings.

Use within scripts

Currently, Groovy contracts intentionally doesn't support scripts, but you can use them with JEP-445 compatible scripts from Groovy 5 as shown in this example:

```
import groovy.contracts.*
import org.apache.groovy.contracts.*
import static groovy.test.GroovyAssert.shouldFail

@Requires({ arg > 0 })
@Ensures({ result < arg })
```

```
def sqrt(arg) { Math.sqrt(arg) }

def main() {
    assert sqrt(4) == 2
    shouldFail(PreconditionViolation) { sqrt(-1) }
}
```

You could even place an `@Invariant` annotation on the `main` method and it will be moved to the generated script class.

Scripting Ant tasks

Groovy integrates very well with Apache Ant thanks to AntBuilder.

The <groovy> Ant Task

`<groovy>`

NOTE Here we describe an Ant task for using Groovy from within an Ant build file. You may also be interested in Ant's built-in `script` task which supports Groovy and other languages, or `AntBuilder` which lets you write Ant build scripts in Groovy rather than XML.

Executes a series of Groovy statements from Apache Ant. Statements can either be read in from a resource or as direct text between the enclosing Groovy tags.

Required taskdef

Assuming all the groovy jars you need are in *my.classpath* (this will be `groovy-VERSION.jar`, `groovy-ant-VERSION.jar` plus any modules and transitive dependencies you might be using) you will need to declare this task at some point in the `build.xml` prior to the `groovy` task being invoked.

```
<taskdef name="groovy"
         classname="org.codehaus.groovy.ant.Groovy"
         classpathref="my.classpath"/>
```

You can simply place statements between the `groovy` tags like this:

```
<groovy>
...
</groovy>
```

Or you can supply the Groovy source script as a resource. You can specify the pathname using the `src` attribute like this:

```
<groovy src="/some/path/MyGroovyScript.groovy" otherAttributes="...">
```

Or as a nested `fileset` like this (though the fileset definition is expected to select just one file):

```
<groovy>
    <fileset file="MyGroovyScript.groovy"/>
</groovy>
```

Or as a nested single element resource collection which could look like any of these:

```
<groovy>
    <file file="MyGroovyScript.groovy"/>
</groovy>

<groovy>
    <url url="https://some.domain/some/path/to/MyGroovyScript.groovy"/>
</groovy>

<groovy>
    <javaconstant name="some.packagename.SomeClass.MY_CODE_FRAGMENT"/>
</groovy>
```

You may also supply a filter chain like this:

```
<groovy>
    <fileset file="MyGroovyScript.groovy"/>
    <!-- take 5 lines after skipping 18 lines, just as an example -->
    <filterchain>
        <headfilter lines="5" skip="18"/>
    </filterchain>
</groovy>
```

You might need to use the *contextClassLoader* attribute (see below) if any of your modules load services via the classpath, e.g. `groovy-json`.

<groovy> attributes

Attribute	Description	Required
src	File containing Groovy statements. The directory containing the file is added to the classpath.	Yes, unless statements enclosed within tags
classpath	The classpath to use.	No
classpathref	The classpath to use, given as reference to a PATH defined elsewhere.	No

Attribute	Description	Required
output	Set the output file; defaults to the Ant log.	No
append	If enabled and output is to a file, append to existing file rather than overwrite. Defaults to false.	No
fork	If enabled the script will be executed in a forked JVM process (disabled by default).	No
scriptBaseClass	The name of the base class for scripts.	No
parameters	Generates metadata for reflection on method parameter names on JDK 8 and above. Defaults to false.	No
useGroovyShell	If enabled a new GroovyShell is used to run the script. Special variables won't be available but you don't need Ant in the classpath. Defaults to false.	No
includeAntRuntime	If enabled the system classpath will be included on the classpath when forking. Defaults to true.	No
stacktrace	If enabled a stacktrace will be reported if an error occurs during compilation. Defaults to false.	No
configScript	Sets the configuration script for the groovy compiler configuration.	No
contextClassLoader	If enabled, the contextClassLoader to be set with the classLoader of the shell used to run the script. Not used if fork is true.	No

Parameters specified as nested elements

<classpath>

Groovy's classpath attribute is a PATH like structure and can also be set via a nested classpath element.

<arg>

Arguments can be set via one or more nested <arg> elements using the standard Ant command line conventions.

Available bindings

A number of bindings are in scope for use within your Groovy statements.

Name	Description
ant	an instance of `AntBuilder` that knows about the current ant project

Name	Description
project	the current ant project
properties	a Map of ant properties
target	the owning target that invoked this groovy script
task	the wrapping task, can access anything needed in org.apache.tools.ant.Task
args	command line arguments, if any

Examples

Hello world, version 1:

```
<groovy>
println "Hello World"
</groovy>
```

Hello world, version 2:

```
<groovy>
ant.echo "Hello World"
</groovy>
```

List all xml files in the current directory:

```
<groovy>
xmlfiles = new File(".").listFiles().findAll{ it =~ "\.xml$" }
xmlfiles.sort().each { println it.toString() }
</groovy>
```

List all xml files within a jar:

```
<zipfileset id="found" src="foobar.jar"
            includes="**/*.xml"/>
<groovy>
    project.references.found.each {
        println it.name
    }
</groovy>
```

Run a script:

```
<groovy src="/some/directory/some/file.groovy">
  <classpath>
    <pathelement location="/my/groovy/classes/directory"/>
```

```
    </classpath>
</groovy>
```

Find all `Builder` classes having an `org.*` package within a directory of jars:

```
<property name="local.target" value="C:/Projects/GroovyExamples"/>
<groovy>
import java.util.jar.JarFile
def classes = []
def resourceNamePattern = /org\/.*\/.*Builder.class/
def jarNamePattern = /.*(beta|commons).*jar$/

def libdir = new File("${properties['local.target']}/lib")
libdir.listFiles().grep(~jarNamePattern).each { candidate ->
    new JarFile(candidate).entries().each { entry ->
        if (entry.name ==~ resourceNamePattern) classes += entry.name
    }
}
properties["builder-classes"] = classes.join(' ')
</groovy>
<echo message='${builder-classes}'/>
```

Which might result in something like:

```
org/apache/commons/cli/PatternOptionBuilder.class
org/apache/commons/cli/OptionBuilder.class
org/codehaus/groovy/tools/groovydoc/GroovyRootDocBuilder.class
org/custommonkey/xmlunit/HTMLDocumentBuilder.class
org/custommonkey/xmlunit/TolerantSaxDocumentBuilder.class
```

FileScanner version of above (with a slight variation on collecting the names):

```
<groovy>
import java.util.jar.JarFile
def resourceNamePattern = /org\/.*\/.*Builder.class/
def candidates = ant.fileScanner {
    fileset(dir: '${local.target}/lib') {
        include(name: '*beta*.jar')
        include(name: '*commons*.jar')
    }
}
def classes = candidates.collect {
    new JarFile(it).entries().collect { it.name }.findAll {
        it ==~ resourceNamePattern
    }
}.flatten()
properties["builder-classes"] = classes.join(' ')
```

```
</groovy>
```

Calling out to a web service from your Ant script:

```
<?xml version="1.0" encoding="UTF-8"?>
<project name="SOAP example" default="main" basedir=".">
    <property environment="env"/>
    <property name="celsius" value="0"/>
    <target name="main">
        <taskdef name="groovy" classname="org.codehaus.groovy.ant.Groovy">
            <classpath>
                <fileset dir="${env.GROOVY_HOME}" includes="lib/groovy-
*.jar,lib/ivy*.jar"/>
            </classpath>
        </taskdef>
        <groovy>
            @Grab('org.codehaus.groovy.modules:groovyws:0.5.1')
            import groovyx.net.ws.WSClient
            def url = 'http://www.w3schools.com/webservices/tempconvert.asmx?WSDL'
            def proxy = new WSClient(url, this.class.classLoader)
            proxy.initialize()
            ant.echo "I'm freezing at ${properties.celsius} degrees Celsius"
            properties.result = proxy.CelsiusToFahrenheit(properties.celsius)
        </groovy>
        <antcall target="results"/>
    </target>
    <target name="results">
        <echo message="I'm freezing at ${result} degrees Fahrenheit"/>
    </target>
</project>
```

Which will output the following (along with some informational messages):

```
main:
     ...
     [echo] I'm freezing at 0 degrees Celsius
results:
     [echo] I'm freezing at 32 degrees Fahrenheit

BUILD SUCCESSFUL
```

Setting arguments:

```
<target name="run">
    <groovy>
        <arg line="1 2 3"/>
        <arg value="4 5"/>
```

```
        println args.size()
        println args[2]
        args.each{ ant.echo(message:it) }
    </groovy>
</target>
```

Output:

```
Buildfile: build.xml

run:
   [groovy] 4
   [groovy] 3
     [echo] 1
     [echo] 2
     [echo] 3
     [echo] 4 5

BUILD SUCCESSFUL
```

The <groovyc> Ant Task

`<groovyc>`

Description

Compiles Groovy source files and, if joint compilation option is used, Java source files from Apache Ant.

Required taskdef

Assuming the groovy jars are in *groovy.libs*, you will need to declare this task at some point in the `build.xml` prior to the `groovyc` task being invoked. Consider also adding any additional Groovy module jars, libraries and potentially transitive dependencies you might be using.

```
<taskdef name="groovyc" classname="org.codehaus.groovy.ant.Groovyc">
  <classpath>
    <fileset file="${groovy.libs}/groovy-ant-VERSION.jar"/>
    <fileset file="${groovy.libs}/groovy-VERSION.jar"/>
  </classpath>
</taskdef>
```

<groovyc> Attributes

Attribute	Description	Required
srcdir	Location of the Groovy (and possibly Java) source files.	Yes
destdir	Location to store the class files.	Yes
classpath	The classpath to use.	No
classpathref	The classpath to use given as a path references.	No
sourcepath	The sourcepath to use.	No
sourcepathref	The sourcepath to use given as a path reference.	No
encoding	Encoding of source files.	No
verbose	Asks the compiler for verbose output; defaults to no.	No
includeAntRuntime	Whether to include the Ant run-time libraries in the classpath; defaults to yes.	No
includeJavaRuntime	Whether to include the default run-time libraries from the executing VM in the classpath; defaults to no.	No
includeDestClasses	This property controls whether to include the destination classes directory in the classpath given to the compiler. The default value is "true".	No
fork	Whether to execute groovyc using a spawned instance of the JVM; defaults to no.	No
memoryInitialSize	The initial size of the memory for the underlying VM, if using fork mode; ignored otherwise. Defaults to the standard VM memory setting. (Examples: 83886080, 81920k, or 80m)	No
memoryMaximumSize	The maximum size of the memory for the underlying VM, if using fork mode; ignored otherwise. Defaults to the standard VM memory setting. (Examples: 83886080, 81920k, or 80m)	No

Attribute	Description	Required
failonerror	Indicates whether compilation errors will fail the build; defaults to true.	No
proceed	Inverse alias for *failonerror*.	No
listfiles	Indicates whether the source files to be compiled will be listed; defaults to no.	No
stacktrace	if true each compile error message will contain a stacktrace	No
indy	Enable compilation with the ``invoke dynamic'' support when using Groovy 2.0 and beyond and running on JDK 7	No
scriptBaseClass	Sets the base class for Groovy scripts	No
stubdir	Set the stub directory into which the Java source stub files should be generated. The directory need not exist and will not be deleted automatically - though its contents will be cleared unless 'keepStubs' is true. Ignored when forked.	No
keepStubs	Set the keepStubs flag. Defaults to false. Set to true for debugging. Ignored when forked.	No

Attribute	Description	Required
forceLookupUnnamedFiles	The Groovyc Ant task is frequently used in the context of a build system that knows the complete list of source files to be compiled. In such a context, it is wasteful for the Groovy compiler to go searching the classpath when looking for source files and hence by default the Groovyc Ant task calls the compiler in a special mode with such searching turned off. If you wish the compiler to search for source files then you need to set this flag to true. Defaults to false.	No
configscript	Set the configuration file used to customize the compilation configuration.	No
parameters	Generates metadata for reflection on method parameter names on JDK 8 and above. Defaults to false.	No
previewFeatures	Enables the JEP preview features on JDK 12 and above. Defaults to false.	No
targetBytecode	Sets the bytecode compatibility level.	No
javahome	Sets the `java.home` value to use, default is the current JDK's home.	No
executable	Sets the name of the java executable to use when invoking the compiler in forked mode, ignored otherwise.	No
scriptExtension	Set the extension to use when searching for Groovy source files. Accepts extensions in the form *.groovy, .groovy or groovy.	No

Attribute	Description	Required
updatedProperty	The property to set on compilation success. This property will not be set if the compilation fails, or if there are no files to compile.	No
errorProperty	The property to set on compilation failure. This property will be set if the compilation fails.	No

Example:

```
<path id="classpath.main">
  <fileset dir="${groovy.libs}" includes="*.jar" excludes="groovy-ant-*.jar"/>
  ...
</path>
<groovyc srcdir="${dir.sources}" destdir="${dir.classes}"
classpathref="classpath.main"
         fork="true" includeantruntime="false" configscript="config.groovy"
targetBytecode="1.8"/>
```

<groovyc> Nested Elements

element	kind	Required	Replaces Attribute
src	a path structure	Yes (unless srcdir is used)	srcdir
classpath	a path structure	No	classpath or classpathref
javac	javac task	No	N/A

Notes:

- For path structures see for example https://ant.apache.org/manual/using.html#path
- For usages of the `javac` task see https://ant.apache.org/manual/Tasks/javac.html
- The nested `javac` task behaves more or less as documented for the top-level `javac` task. `srcdir`, `destdir`, `fork`, `memoryInitialSize`, and `memoryMaximumSize` for the nested `javac` task are taken from the enclosing `groovyc` task. If these attributes or any else that are not explicitly supported are specified then a warning is logged, and they are ignored completely. `classpath` and `classpathref` specified on the nested `javac` task is merged with the values taken from the enclosing `groovyc` task and also used for the Groovy compilation. Nested inside the nested `javac` task the only element supported is `compilerarg`, and this only with the `value` attribute, which is treated like the `line` attribute of the top-level `javac` task, i.e. it is split by spaces into separate arguments. Only arguments starting with `-W`, `-X`, or `-proc:` are properly translated as needed. Anything else is supplied as-is to groovyc and has to be manually prefixed with `-F` or `-J`.

Joint Compilation

Joint compilation is enabled by using an embedded `javac` element, as shown in the following example:

```
<groovyc srcdir="${testSourceDirectory}" destdir="${testClassesDirectory}"
targetBytecode="1.8">
  <classpath>
    <pathelement path="${mainClassesDirectory}"/>
    <pathelement path="${testClassesDirectory}"/>
    <path refid="testPath"/>
  </classpath>
  <javac debug="true" source="1.8" target="1.8" />
</groovyc>
```

More details about joint compilation can be found in the joint compilation section.

Template engines

Introduction

Groovy supports multiple ways to generate text dynamically including `GStrings`, `printf` and MarkupBuilder just to name a few. In addition to these, there is a dedicated template framework which is well-suited to applications where the text to be generated follows the form of a static template.

Template framework

The template framework in Groovy consists of a `TemplateEngine` abstract base class that engines must implement and a `Template` interface that the resulting templates they generate must implement.

Included with Groovy are several template engines:

- `SimpleTemplateEngine` - for basic templates
- `StreamingTemplateEngine` - functionally equivalent to `SimpleTemplateEngine`, but can handle strings larger than 64k
- `GStringTemplateEngine` - stores the template as writeable closures (useful for streaming scenarios)
- `XmlTemplateEngine` - works well when the template and output are valid XML
- `MarkupTemplateEngine` - a very complete, optimized, template engine

SimpleTemplateEngine

Shown here is the `SimpleTemplateEngine` that allows you to use JSP-like scriptlets (see example below), script, and EL expressions in your template in order to generate parametrized text. Here is an example of using the system:

```
def text = 'Dear "$firstname $lastname",\nSo nice to meet you in <% print city
%>.\nSee you in ${month},\n${signed}'

def binding = ["firstname":"Sam", "lastname":"Pullara", "city":"San Francisco",
"month":"December", "signed":"Groovy-Dev"]

def engine = new groovy.text.SimpleTemplateEngine()
def template = engine.createTemplate(text).make(binding)

def result = 'Dear "Sam Pullara",\nSo nice to meet you in San Francisco.\nSee you in
December,\nGroovy-Dev'

assert result == template.toString()
```

While it is generally not deemed good practice to mix processing logic in your template (or view), sometimes very simple logic can be useful. E.g. in the example above, we could change this:

```
$firstname
```

to this (assuming we have set up a static import for capitalize **inside** the template):

```
${firstname.capitalize()}
```

or this:

```
<% print city %>
```

to this:

```
<% print city == "New York" ? "The Big Apple" : city %>
```

Advanced Usage Note

If you happen to be embedding your template directly in your script (as we did above) you have to be careful about backslash escaping. Because the template string itself will be parsed by Groovy before it is passed to the templating framework, you have to escape any backslashes inside GString expressions or scriptlet 'code' that are entered as part of a Groovy program. E.g. if we wanted quotes around *The Big Apple* above, we would use:

```
<% print city == "New York" ? "\\"The Big Apple\\"" : city %>
```

Similarly, if we wanted a newline, we would use:

```
\\n
```

in any GString expression or scriptlet 'code' that appears inside a Groovy script. A normal “\n” is fine within the static template text itself or if the entire template itself is in an external template file. Similarly, to represent an actual backslash in your text you would need

```
\\\\
```

in an external file or

```
\\\\
```

in any GString expression or scriptlet 'code'. (Note: the necessity to have this extra slash may go away in a future version of Groovy if we can find an easy way to support such a change.)

StreamingTemplateEngine

The `StreamingTemplateEngine` engine is functionally equivalent to the `SimpleTemplateEngine`, but creates the template using writable closures making it more scalable for large templates. Specifically this template engine can handle strings larger than 64k.

It uses JSP style <% %> script and <%= %> expression syntax or GString style expressions. The variable 'out' is bound to the writer that the template is being written to.

Frequently, the template source will be a file but here we show a simple example providing the template as a string:

```
def text = '''\
Dear <% out.print firstname %> ${lastname},

We <% if (accepted) out.print 'are pleased' else out.print 'regret' %> \
to inform you that your paper entitled
'$title' was ${ accepted ? 'accepted' : 'rejected' }.

The conference committee.'''

def template = new groovy.text.StreamingTemplateEngine().createTemplate(text)

def binding = [
    firstname : "Grace",
    lastname  : "Hopper",
    accepted  : true,
    title     : 'Groovy for COBOL programmers'
]
```

```
String response = template.make(binding)

assert response == '''Dear Grace Hopper,

We are pleased to inform you that your paper entitled
'Groovy for COBOL programmers' was accepted.

The conference committee.'''
```

GStringTemplateEngine

As an example of using the `GStringTemplateEngine`, here is the example above done again (with a few changes to show some other options). First we will store the template in a file this time:

test.template

```
Dear "$firstname $lastname",
So nice to meet you in <% out << (city == "New York" ? "\\"The Big Apple\\"" : city)
%>.
See you in ${month},
${signed}
```

Note that we used `out` instead of `print` to support the streaming nature of `GStringTemplateEngine`. Because we have the template in a separate file, there is no need to escape the backslashes. Here is how we call it:

```
def f = new File('test.template')
def engine = new groovy.text.GStringTemplateEngine()
def template = engine.createTemplate(f).make(binding)
println template.toString()
```

and here is the output:

```
Dear "Sam Pullara",
So nice to meet you in "The Big Apple".
See you in December,
Groovy-Dev
```

XmlTemplateEngine

`XmlTemplateEngine` for use in templating scenarios where both the template source and the expected output are intended to be XML. Templates may use the normal `${expression}` and `$variable` notations to insert an arbitrary expression into the template. In addition, support is also provided for special tags: `<gsp:scriptlet>` (for inserting code fragments) and `<gsp:expression>` (for code fragments which produce output).

Comments and processing instructions will be removed as part of processing and special XML characters such as <, >, " and ' will be escaped using the respective XML notation. The output will also be indented using standard XML pretty printing.

The xmlns namespace definition for gsp: tags will be removed but other namespace definitions will be preserved (but may change to an equivalent position within the XML tree).

Normally, the template source will be in a file but here is a simple example providing the XML template as a string:

```
def binding = [firstname: 'Jochen', lastname: 'Theodorou', nickname: 'blackdrag',
salutation: 'Dear']
def engine = new groovy.text.XmlTemplateEngine()
def text = '''\
    <document xmlns:gsp='http://groovy.codehaus.org/2005/gsp' xmlns:foo='baz'
type='letter'>
        <gsp:scriptlet>def greeting = "${salutation}est"</gsp:scriptlet>
        <gsp:expression>greeting</gsp:expression>
        <foo:to>$firstname "$nickname" $lastname</foo:to>
        How are you today?
    </document>
'''
def template = engine.createTemplate(text).make(binding)
println template.toString()
```

This example will produce this output:

```
<document type='letter'>
  Dearest
  <foo:to xmlns:foo='baz'>
    Jochen &quot;blackdrag&quot; Theodorou
  </foo:to>
  How are you today?
</document>
```

The MarkupTemplateEngine

This template engine is a template engine primarily aimed at generating XML-like markup (XML, XHTML, HTML5, ...), but that can be used to generate any text based content. Unlike traditional template engines, this one relies on a DSL that uses the builder syntax. Here is a sample template:

```
xmlDeclaration()
cars {
   cars.each {
       car(make: it.make, model: it.model)
   }
}
```

If you feed it with the following model:

```
model = [cars: [new Car(make: 'Peugeot', model: '508'), new Car(make: 'Toyota', model:
'Prius')]]
```

It would be rendered as:

```
<?xml version='1.0'?>
<cars><car make='Peugeot' model='508'/><car make='Toyota' model='Prius'/></cars>
```

The key features of this template engine are:

- a *markup builder like* syntax
- templates are compiled into bytecode
- fast rendering
- optional type checking of the model
- includes
- internationalization support
- fragments/layouts

The template format

Basics

Templates consist of Groovy code. Let's explore the first example more thoroughly:

```
xmlDeclaration()                                ①
cars {                                          ②
   cars.each {                                  ③
       car(make: it.make, model: it.model)      ④
   }                                            ⑤
}
```

① renders the XML declaration string.

② opens a `cars` tag

③ `cars` is a variable found in the *template model*, which is a list of `Car` instances

④ for each item, we create a `car` tag with the attributes from the `Car` instance

⑤ closes the `cars` tag

As you can see, regular Groovy code can be used in the template. Here, we are calling `each` on a list (retrieved from the model), allowing us to render one `car` tag per entry.

In a similar fashion, rendering HTML code is as simple as this:

```
yieldUnescaped '<!DOCTYPE html>'                                              ①
html(lang:'en') {                                                             ②
    head {                                                                    ③
        meta('http-equiv':'"Content-Type" content="text/html; charset=utf-8"') ④
        title('My page')                                                      ⑤
    }                                                                         ⑥
    body {                                                                    ⑦
        p('This is an example of HTML contents')                              ⑧
    }                                                                         ⑨
}                                                                             ⑩
```

① renders the HTML doctype special tag

② opens the `html` tag with an attribute

③ opens the `head` tag

④ renders a `meta` tag with one `http-equiv` attribute

⑤ renders the `title` tag

⑥ closes the `head` tag

⑦ opens the `body` tag

⑧ renders a `p` tag

⑨ closes the `body` tag

⑩ closes the `html` tag

The output is straightforward:

```
<!DOCTYPE html><html lang='en'><head><meta http-equiv='"Content-Type"
content="text/html; charset=utf-8"'/><title>My page</title></head><body><p>This is an
example of HTML contents</p></body></html>
```

NOTE With some configuration, you can have the output pretty printed, with newlines and indent automatically added.

Support methods

In the previous example, the doctype declaration was rendered using the `yieldUnescaped` method. We have also seen the `xmlDeclaration` method. The template engine provides several support methods that will help you render contents appropriately:

Method	Description	Example

yield	Renders contents, but escapes it before rendering	**Template**:
		`yield 'Some text with <angle brackets>'`
		Output:
		`Some text with <angle brackets>`

yieldUnescaped	Renders raw contents. The argument is rendered as is, without escaping.	**Template**:
		`yieldUnescaped 'Some text with <angle brackets>'`
		Output:
		`Some text with <angle brackets>`

xmlDeclaration	Renders an XML declaration String. If the encoding is specified in the configuration, it is written in the declaration.	**Template**:
		`xmlDeclaration()`
		Output:
		`<?xml version='1.0'?>`
		If `TemplateConfiguration#getDeclarationEncoding` is not null:
		Output:
		`<?xml version='1.0' encoding='UTF-8'?>`

Method	Description	Example

comment	Renders raw contents inside an XML comment	**Template**:
		`comment 'This is <a href="foo.html">commented out</a>'`
		Output:
		`<!--This is <a href="foo.html">commented out</a>-->`

newLine	Renders a new line. See also `TemplateConfiguration#setAutoNewLine` and `TemplateConfiguration#setNewLineString`.	**Template**:
		`p('text')`
		`newLine()`
		`p('text on new line')`
		Output:
		`<p>text</p>`
		`<p>text on new line</p>`

pi	Renders an XML processing instruction.	**Template**:
		`pi("xml-stylesheet":[href:"mystyle.css", type:"text/css"])`
		Output:
		`<?xml-stylesheet href='mystyle.css' type='text/css'?>`

tryEscape	Returns an escaped string for an object, if it is a `String` (or any type derived from `CharSequence`). Otherwise returns the object itself.	**Template**:
		`yieldUnescaped tryEscape('Some text with <angle brackets>')`
		Output:
		`Some text with <angle brackets>`

Includes

The `MarkupTemplateEngine` supports inclusion of contents from another file. Included contents may be:

- another template
- raw contents
- contents to be escaped

Including another template can be done using:

```
include template: 'other_template.tpl'
```

Including a file as raw contents, without escaping it, can be done like this:

```
include unescaped: 'raw.txt'
```

Eventually, inclusion of text that should be escaped before rendering can be done using:

```
include escaped: 'to_be_escaped.txt'
```

Alternatively, you can use the following helper methods instead:

- `includeGroovy(<name>)` to include another template
- `includeEscaped(<name>)` to include another file with escaping
- `includeUnescaped(<name>)` to include another file without escaping

Calling those methods instead of the `include xxx:` syntax can be useful if the name of the file to be included is dynamic (stored in a variable for example). Files to be included (independently of their type, template or text) are found on **classpath**. This is one of the reasons why the `MarkupTemplateEngine` takes an optional `ClassLoader` as constructor argument (the other reason being that you can include code referencing other classes in a template).

If you don't want your templates to be on classpath, the `MarkupTemplateEngine` accepts a convenient constructor that lets you define the directory where templates are to be found.

Fragments

Fragments are nested templates. They can be used to provide improved composition in a single template. A fragment consists of a string, the inner template, and a model, used to render this template. Consider the following template:

```
ul {
    pages.each {
        fragment "li(line)", line:it
    }
```

```
}
```

The `fragment` element creates a nested template, and renders it with a model which is specific to this template. Here, we have the `li(line)` fragment, where `line` is bound to `it`. Since `it` corresponds to the iteration of `pages`, we will generate a single `li` element for each page in our model:

```
<ul><li>Page 1</li><li>Page 2</li></ul>
```

Fragments are interesting to factorize template elements. They come at the price of the compilation of a fragment per template, and they cannot be externalized.

Layouts

Layouts, unlike fragments, refer to other templates. They can be used to compose templates and share common structures. This is often interesting if you have, for example, a common HTML page setup, and that you only want to replace the body. This can be done easily with a *layout*. First of all, you need to create a layout template:

layout-main.tpl

```
html {
    head {
        title(title)                ①
    }
    body {
        bodyContents()              ②
    }
}
```

① the `title` variable (inside the title tag) is a layout variable

② the `bodyContents` call will render the body

Then what you need is a template that includes the layout:

```
layout 'layout-main.tpl',                                   ①
    title: 'Layout example',                                ②
    bodyContents: contents { p('This is the body') }        ③
```

① use the `main-layout.tpl` layout file

② set the `title` variable

③ set the `bodyContents`

As you can see, `bodyContents` will be rendered inside the layout, thanks to the `bodyContents()` call in the layout file. As a result, the template will be rendered as this:

```
<html><head><title>Layout example</title></head><body><p>This is the
```

```
body</p></body></html>
```

The call to the `contents` method is used to tell the template engine that the block of code is in fact a specification of a template, instead of a helper function to be rendered directly. If you don't add `contents` before your specification, then the contents would be rendered, but you would also see a random string generated, corresponding to the result value of the block.

Layouts are a powerful way to share common elements across multiple templates, without having to rewrite everything or use includes.

Layouts use, by default, a model which is independent from the model of the page where they are used. It is however possible to make them inherit from the parent model. Imagine that the model is defined like this:

```
model = new HashMap<String,Object>();
model.put('title','Title from main model');
```

and the following template:

```
layout 'layout-main.tpl', true,                                  ①
    bodyContents: contents { p('This is the body') }
```

① note the use of `true` to enable model inheritance

then it is not necessary to pass the `title` value to the layout as in the previous example. The result will be:

```
<html><head><title>Title from main model</title></head><body><p>This is the
body</p></body></html>
```

But it is also possible to override a value from the parent model:

```
layout 'layout-main.tpl', true,                                  ①
    title: 'overridden title',                                    ②
    bodyContents: contents { p('This is the body') }
```

① `true` means inherit from the parent model

② but `title` is overridden

then the output will be:

```
<html><head><title>overridden title</title></head><body><p>This is the
body</p></body></html>
```

Rendering contents

Creation of a template engine

On the server side, rendering templates require an instance of `groovy.text.markup.MarkupTemplateEngine` and a `groovy.text.markup.TemplateConfiguration`:

```
TemplateConfiguration config = new TemplateConfiguration();         ①
MarkupTemplateEngine engine = new MarkupTemplateEngine(config);     ②
Template template = engine.createTemplate("p('test template')");    ③
Map<String, Object> model = new HashMap<>();                        ④
Writable output = template.make(model);                             ⑤
output.writeTo(writer);                                             ⑥
```

① creates a template configuration

② creates a template engine with this configuration

③ creates a template instance from a `String`

④ creates a model to be used in the template

⑤ bind the model to the template instance

⑥ render output

There are several possible options to parse templates:

- from a `String`, using `createTemplate(String)`
- from a `Reader`, using `createTemplate(Reader)`
- from a `URL`, using `createTemplate(URL)`
- given a template name, using `createTemplateByPath(String)`

The last version should in general be preferred:

```
Template template = engine.createTemplateByPath("main.tpl");
Writable output = template.make(model);
output.writeTo(writer);
```

Configuration options

The behavior of the engine can be tweaked with several configuration options accessible through the `TemplateConfiguration` class:

Option	Default value	Description	Example

declarationEncoding	null	Determines the value of the encoding to be written when `xmlDeclaration` is called. It does **not** influence the writer you are using as output.	**Template**:
			`xmlDeclaration()`
			Output:
			`<?xml version='1.0'?>`
			If `TemplateConfiguration#getDeclarationEncoding` is not null:
			Output:
			`<?xml version='1.0' encoding='UTF-8'?>`

expandEmptyElements	false	If true, empty tags are rendered in their expanded form.	**Template**:
			`p()`
			Output:
			`<p/>`
			If `expandEmptyElements` is true:
			Output:
			`<p></p>`

Option	Default value	Description	Example

useDoubleQuotes	false	If true, use double quotes for attributes instead of simple quotes	**Template**:
			`tag(attr:'value')`
			Output:
			`<tag attr='value'/>`
			If `useDoubleQuotes` is true:
			Output:
			`<tag attr="value"/>`

newLineString	System default (system property `line.separator`)	Allows to choose what string is used when a new line is rendered	**Template**:
			`p('foo')`
			`newLine()`
			`p('baz')`
			If `newLineString='BAR'`:
			Output:
			`<p>foo</p>BAR<p>baz</p>`

autoEscape	false	If true, variables from models are automatically escaped before rendering.	See the auto escape section
autoIndent	false	If true, performs automatic indentation after new lines	See the auto formatting section
autoIndentString	four (4) spaces	The string to be used as indent.	See the auto formatting section
autoNewLine	false	If true, performs automatic insertion of new lines	See the auto formatting section
baseTemplateClass	`groovy.text.markup.BaseTemplate`	Sets the super class of compiled templates. This can be used to provide application specific templates.	See the custom templates section

Option	Default value	Description	Example
locale	Default locale	Sets the default locale for templates.	See the internationalization section

WARNING Once the template engine has been created, it is **unsafe** to change the configuration.

Automatic formatting

By default, the template engine will render output without any specific formatting. Some configuration options can improve the situation:

- `autoIndent` is responsible for auto-indenting after a new line is inserted
- `autoNewLine` is responsible for automatically inserting new lines based on the original formatting of the template source

In general, it is recommended to set both `autoIndent` and `autoNewLine` to true if you want human-readable, pretty printed, output:

```
config.setAutoNewLine(true);
config.setAutoIndent(true);
```

Using the following template:

```
html {
    head {
        title('Title')
    }
}
```

The output will now be:

```
<html>
    <head>
        <title>Title</title>
    </head>
</html>
```

We can slightly change the template so that the `title` instruction is found on the same line as the `head` one:

```
html {
    head { title('Title')
    }
```

```
}
```

And the output will reflect that:

```
<html>
    <head><title>Title</title>
    </head>
</html>
```

New lines are **only** inserted where curly braces for tags are found, and the insertion corresponds to where the nested content is found. This means that tags in the body of another tag will **not** trigger new lines unless they use curly braces themselves:

```
html {
    head {
        meta(attr:'value')          ①
        title('Title')              ②
        newLine()                   ③
        meta(attr:'value2')         ④
    }
}
```

① a new line is inserted because `meta` is not on the same line as `head`

② no new line is inserted, because we're on the same depth as the previous tag

③ we can force rendering of a new line by explicitly calling `newLine`

④ and this tag will be rendered on a separate line

This time, the output will be:

```
<html>
    <head>
        <meta attr='value'/><title>Title</title>
        <meta attr='value2'/>
    </head>
</html>
```

By default, the renderer uses four(4) spaces as indent, but you can change it by setting the `TemplateConfiguration#autoIndentString` property.

Automatic escaping

By default, contents which is read from the model is rendered **as is**. If this contents comes from user input, it can be sensible, and you might want to escape it by default, for example to avoid XSS injection. For that, the template configuration provides an option which will automatically escape objects from the model, as long as they inherit from `CharSequence` (typically, `String`s).

Let's imagine the following setup:

```
config.setAutoEscape(false);
model = new HashMap<String,Object>();
model.put("unsafeContents", "I am an <html> hacker.");
```

and the following template:

```
html {
    body {
        div(unsafeContents)
    }
}
```

Then you wouldn't want the HTML from `unsafeContents` to be rendered as is, because of potential security issues:

```
<html><body><div>I am an <html> hacker.</div></body></html>
```

Automatic escaping will fix this:

```
config.setAutoEscape(true);
```

And now the output is properly escaped:

```
<html><body><div>I am an &lt;html&gt; hacker.</div></body></html>
```

Note that using automatic escaping doesn't prevent you from including unescaped contents from the model. To do this, your template should then explicitly mention that a model variable should not be escaped by prefixing it with `unescaped.`, like in this example:

Explicit bypass of automatic escaping

```
html {
    body {
        div(unescaped.unsafeContents)
    }
}
```

Common gotchas

Strings containing markup

Say that you want to generate a `<p>` tag which contains a string containing markup:

```
p {
    yield "This is a "
    a(href:'target.html', "link")
    yield " to another page"
}
```

and generates:

```
<p>This is a <a href='target.html'>link</a> to another page</p>
```

Can't this be written shorter? A naive alternative would be:

```
p {
    yield "This is a ${a(href:'target.html', "link")} to another page"
}
```

but the result will not look as expected:

```
<p><a href='target.html'>link</a>This is a  to another page</p>
```

The reason is that the markup template engine is a *streaming* engine. In the original version, the first `yield` call generates a string which is streamed to the output, then the `a` link is generated and streamed, and then the last `yield` call is streamed, leading in an execution **in order**. But with the string version above, the order of execution is different:

- the `yield` call requires an argument, a *string*
- that arguments need to be evaluated *before* the *yield* call is generated

so evaluating the string leads to an execution of the `a(href:…)` call **before** `yield` is itself called. This is not what you want to do. Instead, you want to generate a *string* which contains markup, which is then passed to the `yield` call. This can be done this way:

```
p("This is a ${stringOf {a(href:'target.html', "link")}} to another page")
```

Note the `stringOf` call, which basically tells the markup template engine that the underlying markup needs to be rendered separately and exported as a string. Note that for simple expressions, `stringOf` can be replaced by an alternate tag notation that starts with a *dollar* sign:

```
p("This is a ${$a(href:'target.html', "link")} to another page")
```

TIP It is worth noting that using `stringOf` or the special `$tag` notation triggers the creation of a distinct string writer which is then used to render the markup. It is slower than

> using the version with calls to `yield` which perform direct streaming of the markup instead.

Internationalization

The template engine has native support for internationalization. For that, when you create the `TemplateConfiguration`, you can provide a `Locale` which is the default locale to be used for templates. Each template may have different versions, one for each locale. The name of the template makes the difference:

- `file.tpl`: default template file
- `file_fr_FR.tpl`: french version of the template
- `file_en_US.tpl`: american english version of the template
- …

When a template is rendered or included, then:

- if the template name or include name **explicitly** sets a locale, the **specific** version is included, or the default version if not found
- if the template name doesn't include a locale, the version for the `TemplateConfiguration` locale is used, or the default version if not found

For example, imagine the default locale is set to `Locale.ENGLISH` and that the main template includes:

Use an explicit locale in include

```
include template: 'locale_include_fr_FR.tpl'
```

then the template is rendered using the specific template:

Bypass the template configuration

```
Texte en français
```

Using an include without specifying a locale will make the template engine look for a template with the configured locale, and if not, fallback to the default, like here:

Don't use a locale in include

```
include template: 'locale_include.tpl'
```

Fallback to the default template

```
Default text
```

However, changing the default locale of the template engine to `Locale.FRANCE` will change the output, because the template engine will now look for a file with the fr_FR locale:

Don't fall back to the default template because a locale specific template was found

```
Texte en français
```

This strategy lets you translate your templates one by one, by relying on default templates, for which no locale is set in the file name.

Custom template classes

By default, templates created inherit the groovy.text.markup.BaseTemplate class. It may be interesting for an application to provide a different template class, for example to provide additional helper methods which are aware of the application, or customized rendering primitives (for HTML, for example).

The template engine provides this ability by setting an alternative baseTemplateClass in the TemplateConfiguration:

```
config.setBaseTemplateClass(MyTemplate.class);
```

The custom base class has to extend BaseClass like in this example:

```
public abstract class MyTemplate extends BaseTemplate {
    private List<Module> modules
    public MyTemplate(
            final MarkupTemplateEngine templateEngine,
            final Map model,
            final Map<String, String> modelTypes,
            final TemplateConfiguration configuration) {
        super(templateEngine, model, modelTypes, configuration)
    }

    List<Module> getModules() {
        return modules
    }

    void setModules(final List<Module> modules) {
        this.modules = modules
    }

    boolean hasModule(String name) {
        modules?.any { it.name == name }
    }
}
```

This example shows a class which provides an additional method named hasModule, which can then be used directly in the template:

```
if (hasModule('foo')) {
    p 'Found module [foo]'
} else {
    p 'Module [foo] not found'
}
```

Type checked templates

Optional type checking

Even if templates are not type checked, they are statically compiled. This means that once the templates are compiled, performance should be very good. For some applications, it might be good to make sure that templates are valid before they are actually rendered. This means failing template compilation, for example, if a method on a model variable doesn't exist.

The `MarkupTemplateEngine` provides such a facility. Templates can be optionally type checked. For that, the developer must provide additional information at template creation time, which is the types of the variables found in the model. Imagine a model exposing a list of pages, where a page is defined as:

Page.groovy

```
public class Page {

    Long id
    String title
    String body
}
```

Then a list of pages can be exposed in the model, like this:

```
Page p = new Page();
p.setTitle("Sample page");
p.setBody("Page body");
List<Page> pages = new LinkedList<>();
pages.add(p);
model = new HashMap<String,Object>();
model.put("pages", pages);
```

A template can use it easily:

```
pages.each { page ->                    ①
    p("Page title: $page.title")        ②
    p(page.text)                        ③
}
```

① iterate on pages from the model

② `page.title` is valid

③ `page.text` is **not** (should be `page.body`)

Without type checking, the compilation of the template succeeds, because the template engine doesn't know about the model until a page is actually rendered. This means that the problem would only surface at runtime, once the page is rendered:

Runtime error

```
No such property: text
```

In some situations, this can be complicated to sort out or even notice. By declaring the type of the `pages` to the template engine, we're now capable of failing at compile time:

```
modelTypes = new HashMap<String,String>();                                          ①
modelTypes.put("pages", "List<Page>");                                              ②
Template template = engine.createTypeCheckedModelTemplate("main.tpl", modelTypes)  ③
```

① create a map which will hold the model types

② declare the type of the `pages` variables (note the use of a string for the type)

③ use `createTypeCheckedModelTemplate` instead of `createTemplate`

This time, when the template is compiled at the last line, an error occurs:

Template compilation time error

```
[Static type checking] - No such property: text for class: Page
```

This means that you don't need to wait for the page to be rendered to see an error. The use of `createTypeCheckedModelTemplate` is mandatory.

Alternative declaration of types

Alternatively, if the developer is also the one who writes the templates, it is possible to declare the types of the expected variables directly in the template. In this case, even if you call `createTemplate`, it will be type checked:

Inline declaration of types

```
modelTypes = {                          ①
    List<Page> pages                    ②
}

pages.each { page ->
    p("Page title: $page.title")
    p(page.text)
}
```

① types need to be declared in the `modelTypes` header

② declare one variable per object in the model

Performance of type checked templates

An additional interest of using type checked models is that performance should improve. By telling the type checker what are the expected types, you also let the compiler generate optimized code for that, so if you are looking for the best performance, consider using type checked templates.

Other solutions

Also, there are other templating solutions that can be used along with Groovy, such as FreeMarker, Velocity, StringTemplate and others.

Servlet support

The `groovy-servlet` module supports the following features:

- A `GroovyServlet` class let you use Groovy scripts as Servlets (called *Groovylets*).
- A `TemplateServlet` class which supports running Groovy's template engines to generate servlet content. A typical use case is to write Groovy Server Pages (GSPs) which are similar to Java Server Pages (JSPs) but embed Groovy code rather than Java code.
- An `AbstractHttpServlet` class for defining traditional Servlets.
- Helper classes like `ServletBinding` and `ServletCategory` which let you access some of the features offered by the `groovy-servlet` module in additional contexts.

From Groovy 5, `groovy-servlet` supports Jakarta EE Servlet specifications. Javax EE servlet specifications are supported in version before Groovy 5 or with Groovy 5 by using the `javax` classifier when specifying your dependency.

Groovlets

You can write (Java) Servlets in Groovy (called Groovlets).

This is supported by the `GroovyServlet` class. It will automatically compile your `.groovy` source files, turn them into bytecode, load the Class and cache it until you change the source file.

Here's a simple example to show you the kind of things you can do from a Groovlet.

Notice the use of implicit variables to access the `session`, `output` and `request`. Also notice that this is more like a script as the code isn't wrapped with a class definition.

```
if (!session) {
  session = request.getSession(true)
}

if (!session.counter) {
  session.counter = 1
```

```
}

println """
<html>
    <head>
        <title>Groovy Servlet</title>
    </head>
    <body>
        <p>
Hello, ${request.remoteHost}: ${session.counter}! ${new Date()}
        </p>
    </body>
</html>
"""
session.counter = session.counter + 1
```

Or, do the same thing using MarkupBuilder:

```
if (!session) {
    session = request.getSession(true)
}

if (!session.counter) {
    session.counter = 1
}

html.html { // html is implicitly bound to new MarkupBuilder(out)
  head {
      title('Groovy Servlet')
  }
  body {
    p("Hello, ${request.remoteHost}: ${session.counter}! ${new Date()}")
  }
}
session.counter = session.counter + 1
```

Implicit variables

The following variables are ready for use in Groovlets:

variable name	bound to	note
request	ServletRequest	-
response	ServletResponse	-
context	ServletContext	-
application	ServletContext	-
session	getSession(false)	can be null! see <1>

variable name	bound to	note
params		a Map object
headers		a Map object
out	response.getWriter()	see <2>
sout	response.getOutputStream()	see <2>
html	new MarkupBuilder(out)	see <2>
json	new StreamingJsonBuilder(out)	see <2>

1. The session variable is only set, if there was already a session object. See the `if (session == null)` checks in the examples above.
2. These variables cannot be re-assigned inside a `Groovlet`. They are bound on first access, allowing to e.g. calling methods on the `response` object before using `out`.

Setting up Groovlets

The traditional configuration approach for declaring new servlets is to add them to your Servlet engine configuration, e.g. you might add the following to your `web.xml`:

```
<servlet>
    <servlet-name>Groovy</servlet-name>
    <servlet-class>groovy.servlet.GroovyServlet</servlet-class>
</servlet>

<servlet-mapping>
    <servlet-name>Groovy</servlet-name>
    <url-pattern>*.groovy</url-pattern>
</servlet-mapping>
```

Then put the required groovy jar files into `WEB-INF/lib`.

Now put the .groovy files in, say, the root directory (i.e. where you would put your html files). The `GroovyServlet` takes care of compiling the .groovy files.

So for example using Apache Tomcat you could edit `tomcat/conf/server.xml` like this:

```
<Context path="/groovy" docBase="/path_to_servlet_base"/>
```

Then access it with http://localhost:8080/groovy/hello.groovy

Some Servlet engines let you define Servlets programmatically, e.g. here is how you might use Jetty with Groovlets enabled:

```
import groovy.servlet.GroovyServlet
import org.eclipse.jetty.server.Server
```

```
import org.eclipse.jetty.ee9.servlet.ServletContextHandler

var server = new Server(8080)
var handler = new ServletContextHandler(server, '/', ServletContextHandler.SESSIONS)
handler.baseResourceAsString = 'path_to_servlet_base'
handler.addServlet(GroovyServlet, '*.groovy')
server.start()
server.join()
```

Integrating Groovy in a Java application

Groovy integration mechanisms

The Groovy language proposes several ways to integrate itself into applications (Java or even Groovy) at runtime, from the most basic, simple code execution to the most complete, integrating caching and compiler customization.

TIP	All the examples written in this section are using Groovy, but the same integration mechanisms can be used from Java.

Eval

The `groovy.util.Eval` class is the simplest way to execute Groovy dynamically at runtime. This can be done by calling the `me` method:

```
import groovy.util.Eval

assert Eval.me('33*3') == 99
assert Eval.me('"foo".toUpperCase()') == 'FOO'
```

`Eval` supports multiple variants that accept parameters for simple evaluation:

```
assert Eval.x(4, '2*x') == 8                ①
assert Eval.me('k', 4, '2*k') == 8          ②
assert Eval.xy(4, 5, 'x*y') == 20           ③
assert Eval.xyz(4, 5, 6, 'x*y+z') == 26     ④
```

① Simple evaluation with one bound parameter named `x`

② Same evaluation, with a custom bound parameter named `k`

③ Simple evaluation with two bound parameters named `x` and `y`

④ Simple evaluation with three bound parameters named `x`, `y` and `z`

The `Eval` class makes it very easy to evaluate simple scripts, but doesn't scale: there is no caching of the script, and it isn't meant to evaluate more than one-liners.

GroovyShell

Multiple sources

The groovy.lang.GroovyShell class is the preferred way to evaluate scripts with the ability to cache the resulting script instance. Although the Eval class returns the result of the execution of the compiled script, the GroovyShell class offers more options.

```
def shell = new GroovyShell()                           ①
def result = shell.evaluate '3*5'                       ②
def result2 = shell.evaluate(new StringReader('3*5'))   ③
assert result == result2
def script = shell.parse '3*5'                          ④
assert script instanceof groovy.lang.Script
assert script.run() == 15                               ⑤
```

① create a new GroovyShell instance

② can be used as Eval with direct execution of the code

③ can read from multiple sources (String, Reader, File, InputStream)

④ can defer execution of the script. parse returns a Script instance

⑤ Script defines a run method

Sharing data between a script and the application

It is possible to share data between the application and the script using a groovy.lang.Binding:

```
def sharedData = new Binding()                          ①
def shell = new GroovyShell(sharedData)                 ②
def now = new Date()
sharedData.setProperty('text', 'I am shared data!')     ③
sharedData.setProperty('date', now)                     ④

String result = shell.evaluate('"At $date, $text"')     ⑤

assert result == "At $now, I am shared data!"
```

① create a new Binding that will contain shared data

② create a GroovyShell using this shared data

③ add a string to the binding

④ add a date to the binding (you are not limited to simple types)

⑤ evaluate the script

Note that it is also possible to write from the script into the binding:

```
def sharedData = new Binding()                          ①
def shell = new GroovyShell(sharedData)                 ②
```

```
shell.evaluate('foo=123')                                   ③

assert sharedData.getProperty('foo') == 123                 ④
```

① create a new Binding instance

② create a new GroovyShell using that shared data

③ use an **undeclared** variable to store the result into the binding

④ read the result from the caller

It is important to understand that you need to use an undeclared variable if you want to write into the binding. Using def or an explicit type like in the example below would fail because you would then create a *local variable*:

```
def sharedData = new Binding()
def shell = new GroovyShell(sharedData)

shell.evaluate('int foo=123')

try {
    assert sharedData.getProperty('foo')
} catch (MissingPropertyException e) {
    println "foo is defined as a local variable"
}
```

WARNING	You must be very careful when using shared data in a multithreaded environment. The Binding instance that you pass to GroovyShell is **not** thread safe, and shared by all scripts.

It is possible to work around the shared instance of Binding by leveraging the Script instance which is returned by parse:

```
def shell = new GroovyShell()

def b1 = new Binding(x:3)                               ①
def b2 = new Binding(x:4)                               ②
def script = shell.parse('x = 2*x')
script.binding = b1
script.run()
script.binding = b2
script.run()
assert b1.getProperty('x') == 6
assert b2.getProperty('x') == 8
assert b1 != b2
```

① will store the x variable inside b1

② will store the x variable inside b2

However, you must be aware that you are still sharing the **same instance** of a script. So this technique cannot be used if you have two threads working on the same script. In that case, you must make sure of creating two distinct script instances:

```
def shell = new GroovyShell()

def b1 = new Binding(x:3)
def b2 = new Binding(x:4)
def script1 = shell.parse('x = 2*x')          ①
def script2 = shell.parse('x = 2*x')          ②
assert script1 != script2
script1.binding = b1                          ③
script2.binding = b2                          ④
def t1 = Thread.start { script1.run() }       ⑤
def t2 = Thread.start { script2.run() }       ⑥
[t1,t2]*.join()                               ⑦
assert b1.getProperty('x') == 6
assert b2.getProperty('x') == 8
assert b1 != b2
```

① create an instance of script for thread 1

② create an instance of script for thread 2

③ assign first binding to script 1

④ assign second binding to script 2

⑤ start first script in a separate thread

⑥ start second script in a separate thread

⑦ wait for completion

In case you need thread safety like here, it is more advisable to use the GroovyClassLoader directly instead.

Custom script class

We have seen that the parse method returns an instance of groovy.lang.Script, but it is possible to use a custom class, given that it extends Script itself. It can be used to provide additional behavior to the script like in the example below:

```
abstract class MyScript extends Script {
    String name

    String greet() {
        "Hello, $name!"
    }
}
```

The custom class defines a property called `name` and a new method called `greet`. This class can be used as the script base class by using a custom configuration:

```
import org.codehaus.groovy.control.CompilerConfiguration

def config = new CompilerConfiguration()                                    ①
config.scriptBaseClass = 'MyScript'                                         ②

def shell = new GroovyShell(this.class.classLoader, new Binding(), config) ③
def script = shell.parse('greet()')                                        ④
assert script instanceof MyScript
script.setName('Michel')
assert script.run() == 'Hello, Michel!'
```

① create a `CompilerConfiguration` instance

② instruct it to use `MyScript` as the base class for scripts

③ then use the compiler configuration when you create the shell

④ the script now has access to the new method `greet`

NOTE You are not limited to the sole *scriptBaseClass* configuration. You can use any of the compiler configuration tweaks, including the compilation customizers.

GroovyClassLoader

In the previous section, we have shown that `GroovyShell` was an easy tool to execute scripts, but it makes it complicated to compile anything but scripts. Internally, it makes use of the `groovy.lang.GroovyClassLoader`, which is at the heart of the compilation and loading of classes at runtime.

By leveraging the `GroovyClassLoader` instead of `GroovyShell`, you will be able to load classes, instead of instances of scripts:

```
import groovy.lang.GroovyClassLoader

def gcl = new GroovyClassLoader()                                          ①
def clazz = gcl.parseClass('class Foo { void doIt() { println "ok" } }')  ②
assert clazz.name == 'Foo'                                                 ③
def o = clazz.newInstance()                                                ④
o.doIt()                                                                   ⑤
```

① create a new `GroovyClassLoader`

② `parseClass` will return an instance of `Class`

③ you can check that the class which is returns is really the one defined in the script

④ and you can create a new instance of the class, which is not a script

⑤ then call any method on it

NOTE
A GroovyClassLoader keeps a reference of all the classes it created, so it is easy to create a memory leak. In particular, if you execute the same script twice, if it is a String, then you obtain two distinct classes!

```
import groovy.lang.GroovyClassLoader

def gcl = new GroovyClassLoader()
def clazz1 = gcl.parseClass('class Foo { }')                    ①
def clazz2 = gcl.parseClass('class Foo { }')                    ②
assert clazz1.name == 'Foo'                                      ③
assert clazz2.name == 'Foo'
assert clazz1 != clazz2                                          ④
```

① dynamically create a class named "Foo"

② create an identical looking class, using a separate `parseClass` call

③ make sure both classes have the same name

④ but they are actually different!

The reason is that a `GroovyClassLoader` doesn't keep track of the source text. If you want to have the same instance, then the source **must** be a file, like in this example:

```
def gcl = new GroovyClassLoader()
def clazz1 = gcl.parseClass(file)                                ①
def clazz2 = gcl.parseClass(new File(file.absolutePath))         ②
assert clazz1.name == 'Foo'                                      ③
assert clazz2.name == 'Foo'
assert clazz1 == clazz2                                          ④
```

① parse a class from a `File`

② parse a class from a distinct file instance, but pointing to the same physical file

③ make sure our classes have the same name

④ but now, they are the same instance

Using a `File` as input, the `GroovyClassLoader` is capable of **caching** the generated class file, which avoids creating multiple classes at runtime for the same source.

GroovyScriptEngine

The `groovy.util.GroovyScriptEngine` class provides a flexible foundation for applications which rely on script reloading and script dependencies. While `GroovyShell` focuses on standalone `Script`s and `GroovyClassLoader` handles dynamic compilation and loading of any Groovy class, the `GroovyScriptEngine` will add a layer on top of `GroovyClassLoader` to handle both script dependencies and reloading.

To illustrate this, we will create a script engine and execute code in an infinite loop. First of all, you need to create a directory with the following script inside:

ReloadingTest.groovy

```
class Greeter {
    String sayHello() {
        def greet = "Hello, world!"
        greet
    }
}

new Greeter()
```

then you can execute this code using a `GroovyScriptEngine`:

```
def binding = new Binding()
def engine = new GroovyScriptEngine([tmpDir.toURI().toURL()] as URL[])         ①

while (true) {
    def greeter = engine.run('ReloadingTest.groovy', binding)                   ②
    println greeter.sayHello()                                                  ③
    Thread.sleep(1000)
}
```

① create a script engine which will look for sources into our source directory

② execute the script, which will return an instance of `Greeter`

③ print the greeting message

At this point, you should see a message printed every second:

```
Hello, world!
Hello, world!
...
```

Without interrupting the script execution, now replace the contents of the `ReloadingTest` file with:

ReloadingTest.groovy

```
class Greeter {
    String sayHello() {
        def greet = "Hello, Groovy!"
        greet
    }
}

new Greeter()
```

And the message should change to:

```
Hello, world!
...
Hello, Groovy!
Hello, Groovy!
...
```

But it is also possible to have a dependency on another script. To illustrate this, create the following file into the same directory, without interrupting the executing script:

Dependency.groovy

```
class Dependency {
    String message = 'Hello, dependency 1'
}
```

and update the `ReloadingTest` script like this:

ReloadingTest.groovy

```
import Dependency

class Greeter {
    String sayHello() {
        def greet = new Dependency().message
        greet
    }
}

new Greeter()
```

And this time, the message should change to:

```
Hello, Groovy!
...
Hello, dependency 1!
Hello, dependency 1!
...
```

And as a last test, you can update the `Dependency.groovy` file without touching the `ReloadingTest` file:

Dependency.groovy

```
class Dependency {
    String message = 'Hello, dependency 2'
}
```

And you should observe that the dependent file was reloaded:

```
Hello, dependency 1!
...
Hello, dependency 2!
Hello, dependency 2!
```

CompilationUnit

Ultimately, it is possible to perform more operations during compilation by relying directly on the `org.codehaus.groovy.control.CompilationUnit` class. This class is responsible for determining the various steps of compilation and would let you introduce new steps or even stop compilation at various phases. This is for example how stub generation is done, for the joint compiler.

However, overriding `CompilationUnit` is not recommended and should only be done if no other standard solution works.

JSR 223 javax.script API

WARNING	JSR-223 is a standard API for calling scripting frameworks in Java. It is available since Java 6 and aims at providing a common framework for calling multiple languages from Java. Groovy provides its own richer integration mechanisms, and if you don't plan to use multiple languages in the same application, it is recommended that you use the Groovy integration mechanisms instead of the limited JSR-223 API.

Here is how you need to initialize the JSR-223 engine to talk to Groovy from Java:

```
import javax.script.ScriptEngine;
import javax.script.ScriptEngineManager;
import javax.script.ScriptException;
...
ScriptEngineManager factory = new ScriptEngineManager();
ScriptEngine engine = factory.getEngineByName("groovy");
```

Then you can execute Groovy scripts easily:

```
Integer sum = (Integer) engine.eval("(1..10).sum()");
assertEquals(Integer.valueOf(55), sum);
```

It is also possible to share variables:

```
engine.put("first", "HELLO");
engine.put("second", "world");
String result = (String) engine.eval("first.toLowerCase() + ' ' +
second.toUpperCase()");
assertEquals("hello WORLD", result);
```

This next example illustrates calling an invokable function:

```
import javax.script.Invocable;
...
ScriptEngineManager factory = new ScriptEngineManager();
ScriptEngine engine = factory.getEngineByName("groovy");
String fact = "def factorial(n) { n == 1 ? 1 : n * factorial(n - 1) }";
engine.eval(fact);
Invocable inv = (Invocable) engine;
Object[] params = {5};
Object result = inv.invokeFunction("factorial", params);
assertEquals(Integer.valueOf(120), result);
```

The engine keeps per default hard references to the script functions. To change this you should set an engine level scoped attribute to the script context of the name `#jsr223.groovy.engine.keep.globals` with a String being `phantom` to use phantom references, `weak` to use weak references or `soft` to use soft references - casing is ignored. Any other string will cause the use of hard references.

Domain-Specific Languages

Command chains

Groovy lets you omit parentheses around the arguments of a method call for top-level statements. "command chain" feature extends this by allowing us to chain such parentheses-free method calls, requiring neither parentheses around arguments, nor dots between the chained calls. The general idea is that a call like `a b c d` will actually be equivalent to `a(b).c(d)`. This also works with multiple arguments, closure arguments, and even named arguments. Furthermore, such command chains can also appear on the right-hand side of assignments. Let's have a look at some examples supported by this new syntax:

```
// equivalent to: turn(left).then(right)
turn left then right

// equivalent to: take(2.pills).of(chloroquinine).after(6.hours)
take 2.pills of chloroquinine after 6.hours

// equivalent to: paint(wall).with(red, green).and(yellow)
paint wall with red, green and yellow

// with named parameters too
// equivalent to: check(that: margarita).tastes(good)
check that: margarita tastes good

// with closures as parameters
// equivalent to: given({}).when({}).then({})
given { } when { } then { }
```

It is also possible to use methods in the chain which take no arguments, but in that case, the parentheses are needed:

```
// equivalent to: select(all).unique().from(names)
select all unique() from names
```

If your command chain contains an odd number of elements, the chain will be composed of method / arguments, and will finish by a final property access:

```
// equivalent to: take(3).cookies
// and also this: take(3).getCookies()
take 3 cookies
```

This command chain approach opens up interesting possibilities in terms of the much wider range of DSLs which can now be written in Groovy.

The above examples illustrate using a command chain based DSL but not how to create one. There are various strategies that you can use, but to illustrate creating such a DSL, we will show a couple of examples - first using maps and Closures:

```
show = { println it }
square_root = { Math.sqrt(it) }

def please(action) {
  [the: { what ->
    [of: { n -> action(what(n)) }]
  }]
}

// equivalent to: please(show).the(square_root).of(100)
please show the square_root of 100
// ==> 10.0
```

As a second example, consider how you might write a DSL for simplifying one of your existing APIs. Maybe you need to put this code in front of customers, business analysts or testers who might be not hard-core Java developers. We'll use the `Splitter` from the Google Guava libraries project as it already has a nice Fluent API. Here is how we might use it out of the box:

```
@Grab('com.google.guava:guava:r09')
import com.google.common.base.*
def result = Splitter.on(',').trimResults(CharMatcher.is('_' as char)).split("_a ,_b_
,c__").iterator().toList()
```

It reads fairly well for a Java developer but if that is not your target audience or you have many such statements to write, it could be considered a little verbose. Again, there are many options for writing a DSL. We'll keep it simple with Maps and Closures. We'll first write a helper method:

```
@Grab('com.google.guava:guava:r09')
import com.google.common.base.*
def split(string) {
  [on: { sep ->
    [trimming: { trimChar ->
      Splitter.on(sep).trimResults(CharMatcher.is(trimChar as char)).split(string
).iterator().toList()
    }]
  }]
}
```

now instead of this line from our original example:

```
def result = Splitter.on(',').trimResults(CharMatcher.is('_' as char)).split("_a ,_b_
,c__").iterator().toList()
```

we can write this:

```
def result = split "_a ,_b_ ,c__" on ',' trimming '_\'
```

Operator overloading

Various operators in Groovy are mapped onto regular method calls on objects.

This allows you to provide your own Java or Groovy objects which can take advantage of operator overloading. The following table describes the operators supported in Groovy and the methods they map to.

Operator	Method
`a + b`	a.plus(b)
`a - b`	a.minus(b)
`a * b`	a.multiply(b)
`a ** b`	a.power(b)
`a / b`	a.div(b)
`a % b`	a.mod(b)
`a | b`	a.or(b)
`a & b`	a.and(b)
`a ^ b`	a.xor(b)
`a++` or `++a`	a.next()
`a--` or `--a`	a.previous()
`a[b]`	a.getAt(b)

Operator	Method
`a[b] = c`	a.putAt(b, c)
`a << b`	a.leftShift(b)
`a >> b`	a.rightShift(b)
`a >>> b`	a.rightShiftUnsigned(b)
`switch(a) { case(b) : }`	b.isCase(a)
`if(a)`	a.asBoolean()
`~a`	a.bitwiseNegate()
`-a`	a.negative()
`+a`	a.positive()
`a as b`	a.asType(b)
`a == b`	a.equals(b)
`a != b`	! a.equals(b)
`a <=> b`	a.compareTo(b)
`a > b`	a.compareTo(b) > 0
`a >= b`	a.compareTo(b) >= 0
`a \< b`	a.compareTo(b) < 0
`a <= b`	a.compareTo(b) <= 0

Script base classes

The Script class

Groovy scripts are always compiled to classes. For example, a script as simple as:

```
println 'Hello from Groovy'
```

is compiled to a class extending the abstract groovy.lang.Script class. This class contains a single abstract method called *run*. When a script is compiled, then its body will become the *run* method, while the other methods found in the script are found in the implementing class. The `Script` class provides base support for integration with your application through the `Binding` object, as illustrated in this example:

```
def binding = new Binding()             ①
def shell = new GroovyShell(binding)    ②
binding.setVariable('x',1)              ③
binding.setVariable('y',3)
shell.evaluate 'z=2*x+y'                ④
assert binding.getVariable('z') == 5    ⑤
```

① a binding is used to share data between the script and the calling class

② a GroovyShell can be used with this binding

③ input variables are set from the calling class inside the binding

④ then the script is evaluated

⑤ and the z variable has been "exported" into the binding

This is a very practical way to share data between the caller and the script, however it may be insufficient or not practical in some cases. For that purpose, Groovy allows you to set your own base script class. A base script class has to extend groovy.lang.Script and be a single abstract method type:

```
abstract class MyBaseClass extends Script {
    String name
    public void greet() { println "Hello, $name!" }
}
```

Then the custom script base class can be declared in the compiler configuration, for example:

```
def config = new CompilerConfiguration()                              ①
config.scriptBaseClass = 'MyBaseClass'                                ②
def shell = new GroovyShell(this.class.classLoader, config)           ③
shell.evaluate """
    setName 'Judith'                                                  ④
    greet()
"""
```

① create a custom compiler configuration

② set the base script class to our custom base script class

③ then create a GroovyShell using that configuration

④ the script will then extend the base script class, giving direct access to the name property and greet method

The @BaseScript annotation

As an alternative, it is also possible to use the @BaseScript annotation directly into a script:

```
import groovy.transform.BaseScript

@BaseScript MyBaseClass baseScript
setName 'Judith'
greet()
```

where @BaseScript should annotate a variable which type is the class of the base script. Alternatively, you can set the base script class as a member of the @BaseScript annotation itself:

```
@BaseScript(MyBaseClass)
import groovy.transform.BaseScript

setName 'Judith'
greet()
```

When using the special no-args `run` method, you can even annotate that method as shown here:

```
abstract class CustomScript extends Script {
    int getTheMeaningOfLife() { 42 }
}

@BaseScript(CustomScript)
def run() {
    assert theMeaningOfLife == 42
}
```

Alternate abstract method

We have seen that the base script class is a single abstract method type that needs to implement the `run` method. The `run` method is executed by the script engine automatically. In some circumstances it may be interesting to have a base class which implements the `run` method, but provides an alternative abstract method to be used for the script body. For example, the base script `run` method might perform some initialization before the `run` method is executed. This is possible by doing this:

```
abstract class MyBaseClass extends Script {
    int count
    abstract void scriptBody()                              ①
    def run() {
        count++                                             ②
        scriptBody()                                        ③
        count                                               ④
    }
}
```

① the base script class should define one (and only one) abstract method

② the `run` method can be overridden and perform a task before executing the script body

③ `run` calls the abstract `scriptBody` method which will delegate to the user script

④ then it can return something else than the value from the script

If you execute this code:

```
def result = shell.evaluate """
    println 'Ok'
"""
```

```
assert result == 1
```

Then you will see that the script is executed, but the result of the evaluation is `1` as returned by the `run` method of the base class. It is even clearer if you use `parse` instead of `evaluate`, because it would allow you to execute the `run` method several times on the same script instance:

```
def script = shell.parse("println 'Ok'")
assert script.run() == 1
assert script.run() == 2
```

Adding properties to numbers

In Groovy number types are considered equal to any other types. As such, it is possible to enhance numbers by adding properties or methods to them. This can be very handy when dealing with measurable quantities for example. Details about how existing classes can be enhanced in Groovy are found in the extension modules section or the categories section.

An illustration of this can be found in Groovy using the `TimeCategory`:

```
use(TimeCategory)  {
    println 1.minute.from.now       ①
    println 10.hours.ago

    def someDate = new Date()       ②
    println someDate - 3.months
}
```

① using the `TimeCategory`, a property `minute` is added to the `Integer` class

② similarly, the `months` method returns a `groovy.time.DatumDependentDuration` which can be used in calculus

Categories are lexically bound, making them a great fit for internal DSLs.

@DelegatesTo

Explaining delegation strategy at compile time

`@groovy.lang.DelegatesTo` is a documentation and compile-time annotation aimed at:

- documenting APIs that use closures as arguments
- providing type information for the static type checker and compiler

The Groovy language is a platform of choice for building DSLs. Using closures, it's quite easy to create custom control structures, as well as it is simple to create builders. Imagine that you have the following code:

```
email {
    from 'dsl-guru@mycompany.com'
    to 'john.doe@waitaminute.com'
    subject 'The pope has resigned!'
    body {
        p 'Really, the pope has resigned!'
    }
}
```

One way of implementing this is using the builder strategy, which implies a method, named `email` which accepts a closure as an argument. The method may delegate subsequent calls to an object that implements the `from`, `to`, `subject` and `body` methods. Again, `body` is a method which accepts a closure as an argument and that uses the builder strategy.

Implementing such a builder is usually done the following way:

```
def email(Closure cl) {
    def email = new EmailSpec()
    def code = cl.rehydrate(email, this, this)
    code.resolveStrategy = Closure.DELEGATE_ONLY
    code()
}
```

the `EmailSpec` class implements the `from`, `to`, … methods. By calling `rehydrate`, we're creating a copy of the closure for which we set the `delegate`, `owner` and `thisObject` values. Setting the owner and the `this` object is not very important here since we will use the `DELEGATE_ONLY` strategy which says that the method calls will be resolved only against the delegate of the closure.

```
class EmailSpec {
    void from(String from) { println "From: $from"}
    void to(String... to) { println "To: $to"}
    void subject(String subject) { println "Subject: $subject"}
    void body(Closure body) {
        def bodySpec = new BodySpec()
        def code = body.rehydrate(bodySpec, this, this)
        code.resolveStrategy = Closure.DELEGATE_ONLY
        code()
    }
}
```

The `EmailSpec` class has itself a `body` method accepting a closure that is cloned and executed. This is what we call the builder pattern in Groovy.

One of the problems with the code that we've shown is that the user of the `email` method doesn't have any information about the methods that he's allowed to call inside the closure. The only possible information is from the method documentation. There are two issues with this: first of all, documentation is not always written, and if it is, it's not always available (javadoc not downloaded, for example). Second, it doesn't help IDEs. What would be really interesting, here, is for IDEs to help the developer by suggesting, once they are in the closure body, methods that exist on the `email` class.

Moreover, if the user calls a method in the closure which is not defined by the `EmailSpec` class, the IDE should at least issue a warning (because it's very likely that it will break at runtime).

One more problem with the code above is that it is not compatible with static type checking. Type checking would let the user know if a method call is authorized at compile time instead of runtime, but if you try to perform type checking on this code:

```
email {
    from 'dsl-guru@mycompany.com'
    to 'john.doe@waitaminute.com'
    subject 'The pope has resigned!'
    body {
        p 'Really, the pope has resigned!'
    }
}
```

Then the type checker will know that there's an `email` method accepting a `Closure`, but it will complain about every method call **inside** the closure, because `from`, for example, is not a method which is defined in the class. Indeed, it's defined in the `EmailSpec` class and it has absolutely no hint to help it knowing that the closure delegate will, at runtime, be of type `EmailSpec`:

```
@groovy.transform.TypeChecked
void sendEmail() {
    email {
        from 'dsl-guru@mycompany.com'
        to 'john.doe@waitaminute.com'
        subject 'The pope has resigned!'
        body {
            p 'Really, the pope has resigned!'
        }
    }
}
```

will fail compilation with errors like this one:

```
[Static type checking] - Cannot find matching method MyScript#from(java.lang.String).
Please check if the declared type is correct and if the method exists.
 @ line 31, column 21.
                       from 'dsl-guru@mycompany.com'
```

@DelegatesTo

For those reasons, Groovy 2.1 introduced a new annotation named `@DelegatesTo`. The goal of this annotation is to solve both the documentation issue, that will let your IDE know about the expected methods in the closure body, and it will also solve the type checking issue, by giving hints to the compiler about what are the potential receivers of method calls in the closure body.

The idea is to annotate the `Closure` parameter of the `email` method:

```
def email(@DelegatesTo(EmailSpec) Closure cl) {
    def email = new EmailSpec()
    def code = cl.rehydrate(email, this, this)
    code.resolveStrategy = Closure.DELEGATE_ONLY
    code()
}
```

What we've done here is telling the compiler (or the IDE) that when the method will be called with a closure, the delegate of this closure will be set to an object of type `email`. But there is still a problem: the default delegation strategy is not the one which is used in our method. So we will give more information and tell the compiler (or the IDE) that the delegation strategy is also changed:

```
def email(@DelegatesTo(strategy=Closure.DELEGATE_ONLY, value=EmailSpec) Closure cl) {
    def email = new EmailSpec()
    def code = cl.rehydrate(email, this, this)
    code.resolveStrategy = Closure.DELEGATE_ONLY
    code()
}
```

Now, both the IDE and the type checker (if you are using `@TypeChecked`) will be aware of the delegate and the delegation strategy. This is very nice because it will both allow the IDE to provide smart completion, but it will also remove errors at compile time that exist only because the behaviour of the program is normally only known at runtime!

The following code will now pass compilation:

```
@TypeChecked
void doEmail() {
    email {
        from 'dsl-guru@mycompany.com'
        to 'john.doe@waitaminute.com'
        subject 'The pope has resigned!'
        body {
            p 'Really, the pope has resigned!'
        }
    }
}
```

DelegatesTo modes

`@DelegatesTo` supports multiple modes that we will describe with examples in this section.

Simple delegation

In this mode, the only mandatory parameter is the *value* which says to which class we delegate calls. Nothing more. We're telling the compiler that the type of the delegate will **always** be of the type documented by `@DelegatesTo` (note that it can be a subclass, but if it is, the methods defined by the subclass will not be visible to the type checker).

```
void body(@DelegatesTo(BodySpec) Closure cl) {
    // ...
}
```

Delegation strategy

In this mode, you must specify both the delegate class **and** a delegation strategy. This must be used if the closure will not be called with the default delegation strategy, which is `Closure.OWNER_FIRST`.

```
void body(@DelegatesTo(strategy=Closure.DELEGATE_ONLY, value=BodySpec) Closure cl) {
    // ...
}
```

Delegate to parameter

In this variant, we will tell the compiler that we are delegating to another parameter of the method. Take the following code:

```
def exec(Object target, Closure code) {
   def clone = code.rehydrate(target, this, this)
   clone()
}
```

Here, the delegate which will be used is **not** created inside the `exec` method. In fact, we take an argument of the method and delegate to it. Usage may look like this:

```
def email = new Email()
exec(email) {
   from '...'
   to '...'
   send()
}
```

Each of the method calls are delegated to the `email` parameter. This is a widely used pattern which is also supported by `@DelegatesTo` using a companion annotation:

```
def exec(@DelegatesTo.Target Object target, @DelegatesTo Closure code) {
   def clone = code.rehydrate(target, this, this)
   clone()
```

```
}
```

A closure is annotated with `@DelegatesTo`, but this time, without specifying any class. Instead, we're annotating another parameter with `@DelegatesTo.Target`. The type of the delegate is then determined at compile time. One could think that we are using the parameter type, which in this case is `Object` but this is not true. Take this code:

```
class Greeter {
   void sayHello() { println 'Hello' }
}
def greeter = new Greeter()
exec(greeter) {
   sayHello()
}
```

Remember that this works out of the box **without** having to annotate with `@DelegatesTo`. However, to make the IDE aware of the delegate type, or the **type checker** aware of it, we need to add `@DelegatesTo`. And in this case, it will know that the `Greeter` variable is of type `Greeter`, so it will not report errors on the *sayHello* method **even if the exec method doesn't explicitly define the target as of type Greeter**. This is a very powerful feature, because it prevents you from writing multiple versions of the same `exec` method for different receiver types!

In this mode, the `@DelegatesTo` annotation also supports the `strategy` parameter that we've described upper.

Multiple closures

In the previous example, the `exec` method accepted only one closure, but you may have methods that take multiple closures:

```
void fooBarBaz(Closure foo, Closure bar, Closure baz) {
    ...
}
```

Then nothing prevents you from annotating each closure with `@DelegatesTo`:

```
class Foo { void foo(String msg) { println "Foo ${msg}!" } }
class Bar { void bar(int x) { println "Bar ${x}!" } }
class Baz { void baz(Date d) { println "Baz ${d}!" } }

void fooBarBaz(@DelegatesTo(Foo) Closure foo, @DelegatesTo(Bar) Closure bar,
@DelegatesTo(Baz) Closure baz) {
   ...
}
```

But more importantly, if you have multiple closures **and** multiple arguments, you can use several targets:

```
void fooBarBaz(
    @DelegatesTo.Target('foo') foo,
    @DelegatesTo.Target('bar') bar,
    @DelegatesTo.Target('baz') baz,

    @DelegatesTo(target='foo') Closure cl1,
    @DelegatesTo(target='bar') Closure cl2,
    @DelegatesTo(target='baz') Closure cl3) {
    cl1.rehydrate(foo, this, this).call()
    cl2.rehydrate(bar, this, this).call()
    cl3.rehydrate(baz, this, this).call()
}

def a = new Foo()
def b = new Bar()
def c = new Baz()
fooBarBaz(
    a, b, c,
    { foo('Hello') },
    { bar(123) },
    { baz(new Date()) }
)
```

NOTE At this point, you may wonder why we don't use the parameter names as references. The reason is that the information (the parameter name) is not always available (it's a debug-only information), so it's a limitation of the JVM.

Delegating to a generic type

In some situations, it is interesting to instruct the IDE or the compiler that the delegate type will not be a parameter but a generic type. Imagine a configurator that runs on a list of elements:

```
public <T> void configure(List<T> elements, Closure configuration) {
   elements.each { e->
      def clone = configuration.rehydrate(e, this, this)
      clone.resolveStrategy = Closure.DELEGATE_FIRST
      clone.call()
   }
}
```

Then this method can be called with any list like this:

```
@groovy.transform.ToString
class Realm {
   String name
```

```
}
List<Realm> list = []
3.times { list << new Realm() }
configure(list) {
   name = 'My Realm'
}
assert list.every { it.name == 'My Realm' }
```

To let the type checker and the IDE know that the `configure` method calls the closure on each element of the list, you need to use `@DelegatesTo` differently:

```
public <T> void configure(
    @DelegatesTo.Target List<T> elements,
    @DelegatesTo(strategy=Closure.DELEGATE_FIRST, genericTypeIndex=0) Closure
configuration) {
   def clone = configuration.rehydrate(e, this, this)
   clone.resolveStrategy = Closure.DELEGATE_FIRST
   clone.call()
}
```

`@DelegatesTo` takes an optional `genericTypeIndex` argument that tells what is the index of the generic type that will be used as the delegate type. This **must** be used in conjunction with `@DelegatesTo.Target` and the index starts at 0. In the example above, that means that the delegate type is resolved against `List<T>`, and since the generic type at index 0 is `T` and inferred as a `Realm`, the type checker infers that the delegate type will be of type `Realm`.

NOTE	We're using a `genericTypeIndex` instead of a placeholder (`T`) because of JVM limitations.

Delegating to an arbitrary type

It is possible that none of the options above can represent the type you want to delegate to. For example, let's define a mapper class which is parametrized with an object and defines a map method which returns an object of another type:

```
class Mapper<T,U> {                             ①
    final T value                               ②
    Mapper(T value) { this.value = value }
    U map(Closure<U> producer) {                ③
        producer.delegate = value
        producer()
    }
}
```

① The mapper class takes two generic type arguments: the source type and the target type

② The source object is stored in a final field

③ The map method asks to convert the source object to a target object

As you can see, the method signature from map does not give any information about what object will be manipulated by the closure. Reading the method body, we know that it will be the value which is of type T, but T is not found in the method signature, so we are facing a case where none of the available options for @DelegatesTo is suitable. For example, if we try to statically compile this code:

```
def mapper = new Mapper<String,Integer>('Hello')
assert mapper.map { length() } == 5
```

Then the compiler will fail with:

```
Static type checking] - Cannot find matching method TestScript0#length()
```

In that case, you can use the type member of the @DelegatesTo annotation to reference T as a type token:

```
class Mapper<T,U> {
    final T value
    Mapper(T value) { this.value = value }
    U map(@DelegatesTo(type="T") Closure<U> producer) {  ①
        producer.delegate = value
        producer()
    }
}
```

① The @DelegatesTo annotation references a generic type which is not found in the method signature

Note that you are not limited to generic type tokens. The type member can be used to represent complex types, such as List<T> or Map<T,List<U>>. The reason why you should use that in last resort is that the type is only checked when the type checker finds usage of @DelegatesTo, not when the annotated method itself is compiled. This means that type safety is only ensured at the call site. Additionally, compilation will be slower (though probably unnoticeable for most cases).

Compilation customizers

Introduction

Whether you are using groovyc to compile classes or a GroovyShell, for example, to execute scripts, under the hood, a *compiler configuration* is used. This configuration holds information like the source encoding or the classpath but it can also be used to perform more operations like adding imports by default, applying AST transformations transparently or disabling global AST transformations.

The goal of compilation customizers is to make those common tasks easy to implement. For that, the CompilerConfiguration class is the entry point. The general schema will always be based on the following code:

```
import org.codehaus.groovy.control.CompilerConfiguration
// create a configuration
def config = new CompilerConfiguration()
// tweak the configuration
config.addCompilationCustomizers(...)
// run your script
def shell = new GroovyShell(config)
shell.evaluate(script)
```

Compilation customizers must extend the *org.codehaus.groovy.control.customizers.CompilationCustomizer* class. A customizer works:

- on a specific compilation phase
- on *every* class node being compiled

You can implement your own compilation customizer but Groovy includes some of the most common operations.

Import customizer

Using this compilation customizer, your code will have imports added transparently. This is in particular useful for scripts implementing a DSL where you want to avoid users from having to write imports. The import customizer will let you add all the variants of imports the Groovy language allows, that is:

- class imports, optionally aliased
- star imports
- static imports, optionally aliased
- static star imports

```
import org.codehaus.groovy.control.customizers.ImportCustomizer

def icz = new ImportCustomizer()
// "normal" import
icz.addImports('java.util.concurrent.atomic.AtomicInteger',
'java.util.concurrent.ConcurrentHashMap')
// "aliases" import
icz.addImport('CHM', 'java.util.concurrent.ConcurrentHashMap')
// "static" import
icz.addStaticImport('java.lang.Math', 'PI') // import static java.lang.Math.PI
// "aliased static" import
icz.addStaticImport('pi', 'java.lang.Math', 'PI') // import static java.lang.Math.PI
as pi
// "star" import
icz.addStarImports 'java.util.concurrent' // import java.util.concurrent.*
```

```
// "static star" import
icz.addStaticStars 'java.lang.Math' // import static java.lang.Math.*
```

A detailed description of all shortcuts can be found in org.codehaus.groovy.control.customizers.ImportCustomizer

AST transformation customizer

The AST transformation customizer is meant to apply AST transformations transparently. Unlike global AST transformations that apply on every class being compiled as long as the transform is found on classpath (which has drawbacks like increasing the compilation time or side effects due to transformations applied where they should not), the customizer will allow you to selectively apply a transform only for specific scripts or classes.

As an example, let's say you want to be able to use `@Log` in a script. The problem is that `@Log` is normally applied on a class node and a script, by definition, doesn't require one. But implementation wise, scripts are classes, it's just that you cannot annotate this implicit class node with `@Log`. Using the AST customizer, you have a workaround to do it:

```
import org.codehaus.groovy.control.customizers.ASTTransformationCustomizer
import groovy.util.logging.Log

def acz = new ASTTransformationCustomizer(Log)
config.addCompilationCustomizers(acz)
```

That's all! Internally, the `@Log` AST transformation is applied to every class node in the compilation unit. This means that it will be applied to the script, but also to classes defined within the script.

If the AST transformation that you are using accepts parameters, you can use parameters in the constructor too:

```
def acz = new ASTTransformationCustomizer(Log, value: 'LOGGER')
// use name 'LOGGER' instead of the default 'log'
config.addCompilationCustomizers(acz)
```

As the AST transformation customizers works with objects instead of AST nodes, not all values can be converted to AST transformation parameters. For example, primitive types are converted to `ConstantExpression` (that is `LOGGER` is converted to `new ConstantExpression('LOGGER')`, but if your AST transformation takes a closure as an argument, then you have to give it a `ClosureExpression`, like in the following example:

```
def configuration = new CompilerConfiguration()
def expression = new AstBuilder().buildFromCode(CompilePhase.CONVERSION) { -> true
}.expression[0]
def customizer = new ASTTransformationCustomizer(ConditionalInterrupt, value:
expression, thrown: SecurityException)
configuration.addCompilationCustomizers(customizer)
```

```
def shell = new GroovyShell(configuration)
shouldFail(SecurityException) {
    shell.evaluate("""
        // equivalent to adding @ConditionalInterrupt(value={true}, thrown:
SecurityException)
        class MyClass {
            void doIt() { }
        }
        new MyClass().doIt()
    """)
}
```

For a complete list of options, please refer to org.codehaus.groovy.control.customizers.ASTTransformationCustomizer

Secure AST customizer

This customizer will allow the developer of a DSL to restrict the **grammar** of the language, for example, to prevent users from using particular constructs. It is only ``secure'' in that one aspect, i.e. limiting the allowable constructs within a DSL. It does **not** replace a security manager which might additionally be needed as an orthogonal aspect of overall security. The only reason for it to exist is to limit the expressiveness of the language. This customizer only works at the AST (abstract syntax tree) level, not at runtime! It can be strange at first glance, but it makes much more sense if you think of Groovy as a platform to build DSLs. You may not want a user to have a complete language at hand. In the example below, we will demonstrate it using an example of language that only allows arithmetic operations, but this customizer allows you to:

- allow/disallow creation of closures
- allow/disallow imports
- allow/disallow package definition
- allow/disallow definition of methods
- restrict the receivers of method calls
- restrict the kind of AST expressions a user can use
- restrict the tokens (grammar-wise) a user can use
- restrict the types of the constants that can be used in code

For all those features, the secure AST customizer works using either an allowed list (list of elements that are permitted) **or** a disallowed list (list of elements that are not permitted). For each type of feature (imports, tokens, …) you have the choice to use either an allowed or disallowed list, but you can mix dis/allowed lists for distinct features. Typically, you will choose allowed lists (which permits only the constructs listed and disallows all others).

```
import org.codehaus.groovy.control.customizers.SecureASTCustomizer
import static org.codehaus.groovy.syntax.Types.* ①

def scz = new SecureASTCustomizer()
```

```
scz.with {
    closuresAllowed = false // user will not be able to write closures
    methodDefinitionAllowed = false // user will not be able to define methods
    allowedImports = [] // empty allowed list means imports are disallowed
    allowedStaticImports = [] // same for static imports
    allowedStaticStarImports = ['java.lang.Math'] // only java.lang.Math is allowed
    // the list of tokens the user can find
    // constants are defined in org.codehaus.groovy.syntax.Types
    allowedTokens = [ ①
            PLUS,
            MINUS,
            MULTIPLY,
            DIVIDE,
            REMAINDER,
            POWER,
            PLUS_PLUS,
            MINUS_MINUS,
            COMPARE_EQUAL,
            COMPARE_NOT_EQUAL,
            COMPARE_LESS_THAN,
            COMPARE_LESS_THAN_EQUAL,
            COMPARE_GREATER_THAN,
            COMPARE_GREATER_THAN_EQUAL,
    ].asImmutable()
    // limit the types of constants that a user can define to number types only
    allowedConstantTypesClasses = [ ②
            Integer,
            Float,
            Long,
            Double,
            BigDecimal,
            Integer.TYPE,
            Long.TYPE,
            Float.TYPE,
            Double.TYPE
    ].asImmutable()
    // method calls are only allowed if the receiver is of one of those types
    // be careful, it's not a runtime type!
    allowedReceiversClasses = [ ②
            Math,
            Integer,
            Float,
            Double,
            Long,
            BigDecimal
    ].asImmutable()
}
```

① use for token types from org.codehaus.groovy.syntax.Types

② you can use class literals here

If what the secure AST customizer provides out of the box isn't enough for your needs, before creating your own compilation customizer, you might be interested in the expression and statement checkers that the AST customizer supports. Basically, it allows you to add custom checks on the AST tree, on expressions (expression checkers) or statements (statement checkers). For this, you must implement `org.codehaus.groovy.control.customizers.SecureASTCustomizer.StatementChecker` or `org.codehaus.groovy.control.customizers.SecureASTCustomizer.ExpressionChecker`.

Those interfaces define a single method called `isAuthorized`, returning a boolean, and taking a `Statement` (or `Expression`) as a parameter. It allows you to perform complex logic over expressions or statements to tell if a user is allowed to do it or not.

For example, there's no predefined configuration flag in the customizer which will let you prevent people from using an attribute expression. Using a custom checker, it is trivial:

```
def scz = new SecureASTCustomizer()
def checker = { expr ->
    !(expr instanceof AttributeExpression)
} as SecureASTCustomizer.ExpressionChecker
scz.addExpressionCheckers(checker)
```

Then we can make sure that this works by evaluating a simple script:

```
new GroovyShell(config).evaluate '''
    class A {
        int val
    }

    def a = new A(val: 123)
    a.@val ①
'''
```

① will fail compilation

Statements can be checked using org.codehaus.groovy.control.customizers.SecureASTCustomizer.StatementChecker Expressions can be checked using org.codehaus.groovy.control.customizers.SecureASTCustomizer.ExpressionChecker

Source aware customizer

This customizer may be used as a filter on other customizers. The filter, in that case, is the `org.codehaus.groovy.control.SourceUnit`. For this, the source aware customizer takes another customizer as a delegate, and it will apply customization of that delegate only and only if predicates on the source unit match.

`SourceUnit` gives you access to multiple things but in particular the file being compiled (if compiling from a file, of course). It gives you the potential to perform operation based on the file name, for example. Here is how you would create a source aware customizer:

```
import org.codehaus.groovy.control.customizers.SourceAwareCustomizer
import org.codehaus.groovy.control.customizers.ImportCustomizer

def delegate = new ImportCustomizer()
def sac = new SourceAwareCustomizer(delegate)
```

Then you can use predicates on the source aware customizer:

```
// the customizer will only be applied to classes contained in a file name ending with
'Bean'
sac.baseNameValidator = { baseName ->
    baseName.endsWith 'Bean'
}

// the customizer will only be applied to files which extension is '.spec'
sac.extensionValidator = { ext -> ext == 'spec' }

// source unit validation
// allow compilation only if the file contains at most 1 class
sac.sourceUnitValidator = { SourceUnit sourceUnit -> sourceUnit.AST.classes.size() ==
1 }

// class validation
// the customizer will only be applied to classes ending with 'Bean'
sac.classValidator = { ClassNode cn -> cn.endsWith('Bean') }
```

Customizer builder

If you are using compilation customizers in Groovy code (like the examples above) then you can use an alternative syntax to customize compilation. A builder (`org.codehaus.groovy.control.customizers.builder.CompilerCustomizationBuilder`) simplifies the creation of customizers using a hierarchical DSL.

```
import org.codehaus.groovy.control.CompilerConfiguration
import static org.codehaus.groovy.control.customizers.builder
.CompilerCustomizationBuilder.withConfig ①

def conf = new CompilerConfiguration()
withConfig(conf) {
    // ... ②
}
```

① static import of the builder method

② configuration goes here

The code sample above shows how to use the builder. A static method, *withConfig*, takes a closure corresponding to the builder code, and automatically registers compilation customizers to the configuration. Every compilation customizer available in the distribution can be configured this way:

Import customizer

```
withConfig(configuration) {
   imports { // imports customizer
      normal 'my.package.MyClass' // a normal import
      alias 'AI', 'java.util.concurrent.atomic.AtomicInteger' // an aliased import
      star 'java.util.concurrent' // star imports
      staticMember 'java.lang.Math', 'PI' // static import
      staticMember 'pi', 'java.lang.Math', 'PI' // aliased static import
   }
}
```

AST transformation customizer

```
withConfig(conf) {
   ast(Log) ①
}

withConfig(conf) {
   ast(Log, value: 'LOGGER') ②
}
```

① apply @Log transparently

② apply @Log with a different name for the logger

Secure AST customizer

```
withConfig(conf) {
   secureAst {
       closuresAllowed = false
       methodDefinitionAllowed = false
   }
}
```

Source aware customizer

```
withConfig(configuration){
    source(extension: 'sgroovy') {
        ast(CompileStatic) ①
    }
}
```

```
withConfig(configuration){
    source(extensions: ['sgroovy','sg']) {
        ast(CompileStatic) ②
    }
}

withConfig(configuration) {
    source(extensionValidator: { it.name in ['sgroovy','sg']}) {
        ast(CompileStatic) ②
    }
}

withConfig(configuration) {
    source(basename: 'foo') {
        ast(CompileStatic) ③
    }
}

withConfig(configuration) {
    source(basenames: ['foo', 'bar']) {
        ast(CompileStatic) ④
    }
}

withConfig(configuration) {
    source(basenameValidator: { it in ['foo', 'bar'] }) {
        ast(CompileStatic) ④
    }
}

withConfig(configuration) {
    source(unitValidator: { unit -> !unit.AST.classes.any { it.name == 'Baz' } }) {
        ast(CompileStatic) ⑤
    }
}
```

① apply CompileStatic AST annotation on .sgroovy files

② apply CompileStatic AST annotation on .sgroovy or .sg files

③ apply CompileStatic AST annotation on files whose name is 'foo'

④ apply CompileStatic AST annotation on files whose name is 'foo' or 'bar'

⑤ apply CompileStatic AST annotation on files that do not contain a class named 'Baz'

Inlining a customizer

Inlined customizer allows you to write a compilation customizer directly, without having to create a class for it.

```
withConfig(configuration) {
```

```
    inline(phase:'CONVERSION') { source, context, classNode ->  ①
        println "visiting $classNode"                           ②
    }
}
```

① define an inlined customizer which will execute at the CONVERSION phase

② prints the name of the class node being compiled

Multiple customizers

Of course, the builder allows you to define multiple customizers at once:

```
withConfig(configuration) {
   ast(ToString)
   ast(EqualsAndHashCode)
}
```

The `configscript` commandline parameter

So far, we have described how you can customize compilation using a `CompilationConfiguration` class, but this is only possible if you embed Groovy and that you create your own instances of `CompilerConfiguration` (then use it to create a `GroovyShell`, `GroovyScriptEngine`, …).

If you want it to be applied on the classes you compile with the normal Groovy compiler (that is to say with `groovyc`, `ant` or `gradle`, for example), it is possible to use a commandline parameter named `configscript` that takes a Groovy configuration script as argument.

This script gives you access to the `CompilerConfiguration` instance **before** the files are compiled (exposed into the configuration script as a variable named `configuration`), so that you can tweak it.

It also transparently integrates the compiler configuration builder above. As an example, let's see how you would activate static compilation by default on all classes.

Configscript example: Static compilation by default

Normally, classes in Groovy are compiled with a dynamic runtime. You can activate static compilation by placing an annotation named `@CompileStatic` on any class. Some people would like to have this mode activated by default, that is to say not having to annotate (potentially many) classes. Using `configscript`, makes this possible. First of all, you need to create a file named `config.groovy` into say `src/conf` with the following contents:

```
withConfig(configuration) { ①
   ast(groovy.transform.CompileStatic)
}
```

① *configuration* references a `CompilerConfiguration` instance

That is actually all you need. You don't have to import the builder, it's automatically exposed in the script. Then, compile your files using the following command line:

```
groovyc -configscript src/conf/config.groovy src/main/groovy/MyClass.groovy
```

We strongly recommend you to separate configuration files from classes, hence why we suggest using the `src/main` and `src/conf` directories above.

Configscript example: Setting system properties

In a configuration script you can also set system properties, e.g.:

```
System.setProperty('spock.iKnowWhatImDoing.disableGroovyVersionCheck', 'true')
```

If you have numerous system properties to set, then using a configuration file will reduce the need to set a bunch of system properties with a long command line or appropriately defined environment variable. You can also share all the settings by simply sharing the config file.

AST transformations

If:

- runtime metaprogramming doesn't allow you to do what you want
- you need to improve the performance of the execution of your DSLs
- you want to leverage the same syntax as Groovy but with different semantics
- you want to improve support for type checking in your DSLs

Then AST transformations are the way to go. Unlike the techniques used so far, AST transformations are meant to change or generate code before it is compiled to bytecode. AST transformations are capable of adding new methods at compile time for example, or totally changing the body of a method based on your needs. They are a very powerful tool but also come at the price of not being easy to write. For more information about AST transformations, please take a look at the compile-time metaprogramming section of this manual.

Custom type checking extensions

It may be interesting, in some circumstances, to provide feedback about wrong code to the user as soon as possible, that is to say when the DSL script is compiled, rather than having to wait for the execution of the script. However, this is not often possible with dynamic code. Groovy actually provides a practical answer to this known as type checking extensions.

Builders

Many tasks require building things and the builder pattern is one technique used by developers to make building things easier, especially building of structures which are hierarchical in nature. This pattern is so ubiquitous that Groovy has special built-in support. Firstly, there are many built-in builders. Secondly, there are classes which make it easier to write your own builders.

Existing builders

Groovy comes with many built-in builders. Let's look at some of them.

MarkupBuilder

See Creating Xml - MarkupBuilder.

StreamingMarkupBuilder

See Creating Xml - StreamingMarkupBuilder.

SaxBuilder

A builder for generating Simple API for XML (SAX) events.

If you have the following SAX handler:

```
class LogHandler extends org.xml.sax.helpers.DefaultHandler {

    String log = ''

    void startElement(String uri, String localName, String qName, org.xml.sax
.Attributes attributes) {
        log += "Start Element: $localName, "
    }

    void endElement(String uri, String localName, String qName) {
        log += "End Element: $localName, "
    }
}
```

You can use `SaxBuilder` to generate SAX events for the handler like this:

```
def handler = new LogHandler()
def builder = new groovy.xml.SAXBuilder(handler)

builder.root() {
    helloWorld()
}
```

And then check that everything worked as expected:

```
assert handler.log == 'Start Element: root, Start Element: helloWorld, End Element:
helloWorld, End Element: root, '
```

StaxBuilder

A Groovy builder that works with Streaming API for XML (StAX) processors.

Here is a simple example using the StAX implementation of Java to generate XML:

```
def factory = javax.xml.stream.XMLOutputFactory.newInstance()
def writer = new StringWriter()
def builder = new groovy.xml.StaxBuilder(factory.createXMLStreamWriter(writer))

builder.root(attribute:1) {
    elem1('hello')
    elem2('world')
}

assert writer.toString() == '<?xml version="1.0" ?><root
attribute="1"><elem1>hello</elem1><elem2>world</elem2></root>'
```

An external library such as Jettison can be used as follows:

```
@Grab('org.codehaus.jettison:jettison:1.3.3')
@GrabExclude('stax:stax-api') // part of Java 6 and later
import org.codehaus.jettison.mapped.*

def writer = new StringWriter()
def mappedWriter = new MappedXMLStreamWriter(new MappedNamespaceConvention(), writer)
def builder = new groovy.xml.StaxBuilder(mappedWriter)

builder.root(attribute:1) {
     elem1('hello')
     elem2('world')
}

assert writer.toString() ==
'{"root":{"@attribute":"1","elem1":"hello","elem2":"world"}}'
```

DOMBuilder

A builder for parsing HTML, XHTML and XML into a W3C DOM tree.

For example this XML `String`:

```
String recordsXML = '''
    <records>
      <car name='HSV Maloo' make='Holden' year='2006'>
        <country>Australia</country>
        <record type='speed'>Production Pickup Truck with speed of 271kph</record>
      </car>
      <car name='P50' make='Peel' year='1962'>
```

```
        <country>Isle of Man</country>
        <record type='size'>Smallest Street-Legal Car at 99cm wide and 59 kg in
weight</record>
      </car>
      <car name='Royale' make='Bugatti' year='1931'>
        <country>France</country>
        <record type='price'>Most Valuable Car at $15 million</record>
      </car>
    </records>'''
```

Can be parsed into a DOM tree with a `DOMBuilder` like this:

```
def reader = new StringReader(recordsXML)
def doc = groovy.xml.DOMBuilder.parse(reader)
```

And then processed further e.g. by using DOMCategory:

```
def records = doc.documentElement
use(groovy.xml.dom.DOMCategory) {
    assert records.car.size() == 3
}
```

NodeBuilder

`NodeBuilder` is used for creating nested trees of groovy.util.Node objects for handling arbitrary data. To create a simple user list you use a `NodeBuilder` like this:

```
def nodeBuilder = new NodeBuilder()
def userlist = nodeBuilder.userlist {
    user(id: '1', firstname: 'John', lastname: 'Smith') {
        address(type: 'home', street: '1 Main St.', city: 'Springfield', state: 'MA',
zip: '12345')
        address(type: 'work', street: '2 South St.', city: 'Boston', state: 'MA', zip:
'98765')
    }
    user(id: '2', firstname: 'Alice', lastname: 'Doe')
}
```

Now you can process the data further, e.g. by using GPath expressions:

```
assert userlist.user.@firstname.join(', ') == 'John, Alice'
assert userlist.user.find { it.@lastname == 'Smith' }.address.size() == 2
```

JsonBuilder

Groovy's `JsonBuilder` makes it easy to create Json. For example to create this Json string:

```
String carRecords = '''
    {
        "records": {
        "car": {
            "name": "HSV Maloo",
            "make": "Holden",
            "year": 2006,
            "country": "Australia",
            "record": {
              "type": "speed",
              "description": "production pickup truck with speed of 271kph"
            }
          }
      }
    }
'''
```

you can use a `JsonBuilder` like this:

```
JsonBuilder builder = new JsonBuilder()
builder.records {
  car {
        name 'HSV Maloo'
        make 'Holden'
        year 2006
        country 'Australia'
        record {
            type 'speed'
            description 'production pickup truck with speed of 271kph'
        }
  }
}
String json = JsonOutput.prettyPrint(builder.toString())
```

We use JsonUnit to check that the builder produced the expected result:

```
JsonAssert.assertJsonEquals(json, carRecords)
```

If you need to customize the generated output you can pass a `JsonGenerator` instance when creating a `JsonBuilder`:

```
import groovy.json.*

def generator = new JsonGenerator.Options()
        .excludeNulls()
        .excludeFieldsByName('make', 'country', 'record')
        .excludeFieldsByType(Number)
```

```
        .addConverter(URL) { url -> "http://groovy-lang.org" }
        .build()

JsonBuilder builder = new JsonBuilder(generator)
builder.records {
  car {
        name 'HSV Maloo'
        make 'Holden'
        year 2006
        country 'Australia'
        homepage new URL('http://example.org')
        record {
            type 'speed'
            description 'production pickup truck with speed of 271kph'
        }
  }
}

assert builder.toString() == '{"records":{"car":{"name":"HSV
Maloo","homepage":"http://groovy-lang.org"}}}'
```

StreamingJsonBuilder

Unlike `JsonBuilder` which creates a data structure in memory, which is handy in those situations where you want to alter the structure programmatically before output, `StreamingJsonBuilder` directly streams to a writer without any intermediate memory data structure. If you do not need to modify the structure and want a more memory-efficient approach, use `StreamingJsonBuilder`.

The usage of `StreamingJsonBuilder` is similar to `JsonBuilder`. In order to create this Json string:

```
String carRecords = """
    {
      "records": {
        "car": {
          "name": "HSV Maloo",
          "make": "Holden",
          "year": 2006,
          "country": "Australia",
          "record": {
            "type": "speed",
            "description": "production pickup truck with speed of 271kph"
          }
        }
      }
    }
"""
```

you use a `StreamingJsonBuilder` like this:

```
StringWriter writer = new StringWriter()
StreamingJsonBuilder builder = new StreamingJsonBuilder(writer)
builder.records {
    car {
        name 'HSV Maloo'
        make 'Holden'
        year 2006
        country 'Australia'
        record {
            type 'speed'
            description 'production pickup truck with speed of 271kph'
        }
    }
}
String json = JsonOutput.prettyPrint(writer.toString())
```

We use JsonUnit to check the expected result:

```
JsonAssert.assertJsonEquals(json, carRecords)
```

If you need to customize the generated output you can pass a `JsonGenerator` instance when creating a `StreamingJsonBuilder`:

```
def generator = new JsonGenerator.Options()
        .excludeNulls()
        .excludeFieldsByName('make', 'country', 'record')
        .excludeFieldsByType(Number)
        .addConverter(URL) { url -> "http://groovy-lang.org" }
        .build()

StringWriter writer = new StringWriter()
StreamingJsonBuilder builder = new StreamingJsonBuilder(writer, generator)

builder.records {
    car {
        name 'HSV Maloo'
        make 'Holden'
        year 2006
        country 'Australia'
        homepage new URL('http://example.org')
        record {
            type 'speed'
            description 'production pickup truck with speed of 271kph'
        }
    }
}

assert writer.toString() == '{"records":{"car":{"name":"HSV
```

```
Maloo","homepage":"http://groovy-lang.org"}}}'
```

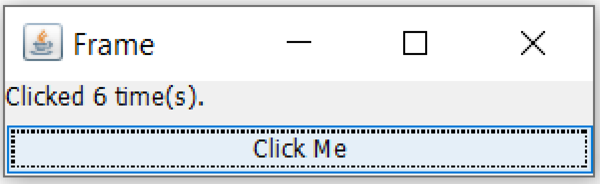
SwingBuilder

SwingBuilder allows you to create full-fledged Swing GUIs in a declarative and concise fashion. It accomplishes this by employing a common idiom in Groovy, builders. Builders handle the busywork of creating complex objects for you, such as instantiating children, calling Swing methods, and attaching these children to their parents. As a consequence, your code is much more readable and maintainable, while still allowing you to access to the full range of Swing components.

Here's a simple example of using SwingBuilder:

```
import groovy.swing.SwingBuilder
import java.awt.BorderLayout as BL

count = 0
new SwingBuilder().edt {
  frame(title: 'Frame', size: [250, 75], show: true) {
    borderLayout()
    textlabel = label(text: 'Click the button!', constraints: BL.NORTH)
    button(text:'Click Me',
         actionPerformed: {count++; textlabel.text = "Clicked ${count} time(s).";
println "clicked"}, constraints:BL.SOUTH)
  }
}
```

Here is what it will look like:



This hierarchy of components would normally be created through a series of repetitive instantiations, setters, and finally attaching this child to its respective parent. Using SwingBuilder, however, allows you to define this hierarchy in its native form, which makes the interface design understandable simply by reading the code.

The flexibility shown here is made possible by leveraging the many programming features built-in to Groovy, such as closures, implicit constructor calling, import aliasing, and string interpolation. Of course, these do not have to be fully understood in order to use SwingBuilder; as you can see from the code above, their uses are intuitive.

Here is a slightly more involved example, with an example of SwingBuilder code re-use via a closure.

```
import groovy.swing.SwingBuilder
import javax.swing.*
import java.awt.*

def swing = new SwingBuilder()

def sharedPanel = {
     swing.panel() {
        label("Shared Panel")
    }
}

count = 0
swing.edt {
    frame(title: 'Frame', defaultCloseOperation: JFrame.EXIT_ON_CLOSE, pack: true,
show: true) {
        vbox {
            textlabel = label('Click the button!')
            button(
                text: 'Click Me',
                actionPerformed: {
                    count++
                    textlabel.text = "Clicked ${count} time(s)."
                    println "Clicked!"
                }
            )
            widget(sharedPanel())
            widget(sharedPanel())
        }
    }
}
```

Here’s another variation that relies on observable beans and binding:

```
import groovy.swing.SwingBuilder
import groovy.beans.Bindable

class MyModel {
   @Bindable int count = 0
}

def model = new MyModel()
new SwingBuilder().edt {
  frame(title: 'Java Frame', size: [100, 100], locationRelativeTo: null, show: true) {
    gridLayout(cols: 1, rows: 2)
    label(text: bind(source: model, sourceProperty: 'count', converter: { v ->  v?
"Clicked $v times": ''}))
    button('Click me!', actionPerformed: { model.count++ })
  }
```

```
}
```

@Bindable is one of the core AST Transformations. It generates all the required boilerplate code to turn a simple bean into an observable one. The `bind()` node creates appropriate `PropertyChangeListeners` that will update the interested parties whenever a `PropertyChangeEvent` is fired.

AntBuilder

> **NOTE** Here we describe `AntBuilder` which lets you write Ant build scripts in Groovy rather than XML. You may also be interested in using Groovy from Ant using the Groovy Ant task.

Despite being primarily a build tool, Apache Ant is a very practical tool for manipulating files including zip files, copy, resource processing, and more. But if ever you've been working with a `build.xml` file or some *Jelly script* and found yourself a little restricted by all those pointy brackets, or found it a bit weird using XML as a scripting language and wanted something a little cleaner and more straight forward, then maybe Ant scripting with Groovy might be what you're after.

Groovy has a helper class called `AntBuilder` which makes the scripting of Ant tasks really easy; allowing a real scripting language to be used for programming constructs (variables, methods, loops, logical branching, classes etc). It still looks like a neat concise version of Ant's XML without all those pointy brackets; though you can mix and match this markup inside your script. Ant itself is a collection of jar files. By adding them to your classpath, you can easily use them within Groovy as is. We believe using `AntBuilder` leads to more concise and readily understood syntax.

`AntBuilder` exposes Ant tasks directly using the convenient builder notation that we are used to in Groovy. Here is the most basic example, which is printing a message on the standard output:

```
def ant = new groovy.ant.AntBuilder()          ①
ant.echo('hello from Ant!')          ②
```

① creates an instance of `AntBuilder`

② executes the `echo` task with the message in parameter

Imagine that you need to create a ZIP file. It can be as simple as:

```
def ant = new AntBuilder()
ant.zip(destfile: 'sources.zip', basedir: 'src')
```

In the next example, we demonstrate the use of `AntBuilder` to copy a list of files using a classical Ant pattern directly in Groovy:

```
// let's just call one task
ant.echo("hello")
```

```
// here is an example of a block of Ant inside GroovyMarkup
ant.sequential {
    echo("inside sequential")
    def myDir = "build/AntTest/"
    mkdir(dir: myDir)
    copy(todir: myDir) {
        fileset(dir: "src/test") {
            include(name: "**/*.groovy")
        }
    }
    echo("done")
}

// now let's do some normal Groovy again
def file = new File(ant.project.baseDir,"build/AntTest/some/pkg/MyTest.groovy")
assert file.exists()
```

Another example would be iterating over a list of files matching a specific pattern:

```
// let's create a scanner of filesets
def scanner = ant.fileScanner {
    fileset(dir:"src/test") {
        include(name:"**/My*.groovy")
    }
}

// now let's iterate over
def found = false
for (f in scanner) {
    println("Found file $f")
    found = true
    assert f instanceof File
    assert f.name.endsWith(".groovy")
}
assert found
```

Or executing a JUnit test:

```
ant.junit {
    classpath { pathelement(path: '.') }
    test(name:'some.pkg.MyTest')
}
```

We can even go further by compiling and executing a Java file directly from Groovy:

```
ant.echo(file:'Temp.java', '''
    class Temp {
```

```
        public static void main(String[] args) {
            System.out.println("Hello");
        }
    }
''')
ant.javac(srcdir:'.', includes:'Temp.java', fork:'true')
ant.java(classpath:'.', classname:'Temp', fork:'true')
ant.echo('Done')
```

It is worth mentioning that `AntBuilder` is included in Gradle, so you can use it in Gradle just like you would in Groovy. Additional documentation can be found in the Gradle manual.

CliBuilder

`CliBuilder` provides a compact way to specify the available options for a commandline application and then automatically parse the application's commandline parameters according to that specification. By convention, a distinction is made between *option* commandline parameters and any remaining parameters which are passed to an application as its arguments. Typically, several types of options might be supported such as `-V` or `--tabsize=4`. `CliBuilder` removes the burden of developing lots of code for commandline processing. Instead, it supports a somewhat declarative approach to declaring your options and then provides a single call to parse the commandline parameters with a simple mechanism to interrogate the options (you can think of this as a simple model for your options).

Even though the details of each commandline you create could be quite different, the same main steps are followed each time. First, a `CliBuilder` instance is created. Then, allowed commandline options are defined. This can be done using a *dynamic api* style or an *annotation* style. The commandline parameters are then parsed according to the options specification resulting in a collection of options which are then interrogated.

Here is a simple example `Greeter.groovy` script illustrating usage:

```
// import of CliBuilder not shown                         ①
// specify parameters
def cli = new CliBuilder(usage: 'groovy Greeter [option]') ②
cli.a(longOpt: 'audience', args: 1, 'greeting audience')   ③
cli.h(longOpt: 'help', 'display usage')                    ④

// parse and process parameters
def options = cli.parse(args)                              ⑤
if (options.h) cli.usage()                                 ⑥
else println "Hello ${options.a ? options.a : 'World'}"    ⑦
```

① Earlier versions of Groovy had a CliBuilder in the `groovy.util` package and no import was necessary. In Groovy 2.5, this approach became deprecated: applications should instead choose the `groovy.cli.picocli` or `groovy.cli.commons` version. The groovy.util version in Groovy 2.5 points to the commons-cli version for backwards compatibility but has been removed in Groovy 3.0.

② define a new `CliBuilder` instance specifying an optional usage string

③ specify a `-a` option taking a single argument with an optional long variant `--audience`

④ specify a `-h` option taking no arguments with an optional long variant `--help`

⑤ parse the commandline parameters supplied to the script

⑥ if the `h` option is found display a usage message

⑦ display a standard greeting or, if the `a` option is found, a customized greeting

Running this script with no commandline parameters, i.e.:

```
> groovy Greeter
```

results in the following output:

```
Hello World
```

Running this script with `-h` as the single commandline parameter, i.e.:

```
> groovy Greeter -h
```

results in the following output:

```
usage: groovy Greeter [option]
 -a,--audience <arg>   greeting audience
 -h,--help             display usage
```

Running this script with `--audience Groovologist` as the commandline parameters, i.e.:

```
> groovy Greeter --audience Groovologist
```

results in the following output:

```
Hello Groovologist
```

When creating the `CliBuilder` instance in the above example, we set the optional `usage` property within the constructor call. This follows Groovy's normal ability to set additional properties of the instance during construction. There are numerous other properties which can be set such as `header` and `footer`. For the complete set of available properties, see the available properties for the groovy.util.CliBuilder class.

When defining an allowed commandline option, both a short name (e.g. "h" for the `help` option shown previously) and a short description (e.g. "display usage" for the `help` option) must be supplied. In our example above, we also set some additional properties such as `longOpt` and `args`. The following additional properties are supported when specifying an allowed commandline option:

Name	Description	Type
argName	the name of the argument for this option used in output	`String`
longOpt	the long representation or long name of the option	`String`
args	the number of argument values	`int` or `String` (1)
optionalArg	whether the argument value is optional	`boolean`
required	whether the option is mandatory	`boolean`
type	the type of this option	`Class`
valueSeparator	the character that is the value separator	`char` (2)
defaultValue	a default value	`String`
convert	converts the incoming String to the required type	`Closure` (1)

(1) More details later
(2) Single character Strings are coerced to chars in special cases in Groovy

If you have an option with only a `longOpt` variant, you can use the special shortname of '_' to specify the option, e.g. : `cli._(longOpt: 'verbose', 'enable verbose logging')`. Some of the remaining named parameters should be fairly self-explanatory while others deserve a bit more explanation. But before further explanations, let's look at ways of using `CliBuilder` with annotations.

Using Annotations and an interface

Rather than making a series of method calls (albeit in a very declarative mini-DSL form) to specify the allowable options, you can provide an interface specification of the allowable options where annotations are used to indicate and provide details for those options and for how unprocessed parameters are handled. Two annotations are used: groovy.cli.Option and groovy.cli.Unparsed.

Here is how such a specification can be defined:

```
interface GreeterI {
    @Option(shortName='h', description='display usage') Boolean help()        ①
    @Option(shortName='a', description='greeting audience') String audience() ②
    @Unparsed(description = "positional parameters") List remaining()         ③
}
```

① Specify a Boolean option set using `-h` or `--help`

② Specify a String option set using `-a` or `--audience`

③ Specify where any remaining parameters will be stored

Note how the long name is automatically determined from the interface method name. You can use the `longName` annotation attribute to override that behavior and specify a custom long name if you wish or use a longName of '_' to indicate that no long name is to be provided. You will need to specify a shortName in such a case.

Here is how you could use the interface specification:

```
// import CliBuilder not shown
def cli = new CliBuilder(usage: 'groovy Greeter')  ①
def argz = '--audience Groovologist'.split()
def options = cli.parseFromSpec(GreeterI, argz)         ②
assert options.audience() == 'Groovologist'            ③

argz = '-h Some Other Args'.split()
options = cli.parseFromSpec(GreeterI, argz)             ④
assert options.help()
assert options.remaining() == ['Some', 'Other', 'Args']     ⑤
```

① Create a `CliBuilder` instance as before with optional properties

② Parse parameters using the interface specification

③ Interrogate options using the methods from the interface

④ Parse a different set of parameters

⑤ Interrogate the remaining parameters

When `parseFromSpec` is called, `CliBuilder` automatically creates an instance implementing the interface and populates it. You simply call the interface methods to interrogate the option values.

Using Annotations and an instance

Alternatively, perhaps you already have a domain class containing the option information. You can simply annotate properties or setters from that class to enable `CliBuilder` to appropriately populate your domain object. Each annotation both describes that option's properties through the annotation attributes and indicates the setter the `CliBuilder` will use to populate that option in your domain object.

Here is how such a specification can be defined:

```
class GreeterC {
    @Option(shortName='h', description='display usage')
    Boolean help                             ①

    private String audience
    @Option(shortName='a', description='greeting audience')
    void setAudience(String audience) { ②
```

```
        this.audience = audience
    }
    String getAudience() { audience }

    @Unparsed(description = "positional parameters")
    List remaining                      ③
}
```

① Indicate that a Boolean property is an option

② Indicate that a String property (with explicit setter) is an option

③ Specify where any remaining args will be stored

And here is how you could use the specification:

```
// import CliBuilder not shown
def cli = new CliBuilder(usage: 'groovy Greeter [option]') ①
def options = new GreeterC()                               ②
def argz = '--audience Groovologist foo'.split()
cli.parseFromInstance(options, argz)                       ③
assert options.audience == 'Groovologist'                  ④
assert options.remaining == ['foo']                        ⑤
```

① Create a `CliBuilder` instance as before with optional parameters

② Create an instance for `CliBuilder` to populate

③ Parse arguments populating the supplied instance

④ Interrogate the String option property

⑤ Interrogate the remaining arguments property

When `parseFromInstance` is called, `CliBuilder` automatically populates your instance. You simply interrogate the instance properties (or whatever accessor methods you have provided in your domain object) to access the option values.

Using Annotations and a script

Finally, there are two additional convenience annotation aliases specifically for scripts. They simply combine the previously mentioned annotations and groovy.transform.Field. The groovydoc for those annotations reveals the details: groovy.cli.OptionField and groovy.cli.UnparsedField.

Here is an example using those annotations in a self-contained script that would be called with the same arguments as shown for the instance example earlier:

```
// import CliBuilder not shown
import groovy.cli.OptionField
import groovy.cli.UnparsedField

@OptionField String audience
@OptionField Boolean help
```

```
@UnparsedField List remaining
new CliBuilder().parseFromInstance(this, args)
assert audience == 'Groovologist'
assert remaining == ['foo']
```

Options with arguments

We saw in our initial example that some options act like flags, e.g. `Greeter -h` but others take an argument, e.g. `Greeter --audience Groovologist`. The simplest cases involve options which act like flags or have a single (potentially optional) argument. Here is an example involving those cases:

```
// import CliBuilder not shown
def cli = new CliBuilder()
cli.a(args: 0, 'a arg') ①
cli.b(args: 1, 'b arg') ②
cli.c(args: 1, optionalArg: true, 'c arg') ③
def options = cli.parse('-a -b foo -c bar baz'.split()) ④

assert options.a == true
assert options.b == 'foo'
assert options.c == 'bar'
assert options.arguments() == ['baz']

options = cli.parse('-a -c -b foo bar baz'.split()) ⑤

assert options.a == true
assert options.c == true
assert options.b == 'foo'
assert options.arguments() == ['bar', 'baz']
```

① An option that is simply a flag - the default; setting args to 0 is allowed but not needed.

② An option with exactly one argument

③ An option with an optional argument; it acts like a flag if the option is left out

④ An example using this spec where an argument is supplied to the 'c' option

⑤ An example using this spec where no argument is supplied to the 'c' option; it's just a flag

Note: when an option with an optional argument is encountered, it will (somewhat) greedily consume the next parameter from the supplied commandline parameters. If however, the next parameter matches a known long or short option (with leading single or double hyphens), that will take precedence, e.g. `-b` in the above example.

Option arguments may also be specified using the annotation style. Here is an interface option specification illustrating such a definition:

```
interface WithArgsI {
    @Option boolean a()
    @Option String b()
```

```
    @Option(optionalArg=true) String[] c()
    @Unparsed List remaining()
}
```

And here is how it is used:

```
def cli = new CliBuilder()
def options = cli.parseFromSpec(WithArgsI, '-a -b foo -c bar baz'.split())
assert options.a()
assert options.b() == 'foo'
assert options.c() == ['bar']
assert options.remaining() == ['baz']

options = cli.parseFromSpec(WithArgsI, '-a -c -b foo bar baz'.split())
assert options.a()
assert options.c() == []
assert options.b() == 'foo'
assert options.remaining() == ['bar', 'baz']
```

This example makes use of an array-typed option specification. We cover this in more detail shortly when we discuss multiple arguments.

Specifying a type

Arguments on the commandline are by nature Strings (or arguably can be considered Booleans for flags) but can be converted to richer types automatically by supplying additional typing information. For the annotation-based argument definition style, these types are supplied using the field types for annotation properties or return types of annotated methods (or the setter argument type for setter methods). For the dynamic method style of argument definition a special 'type' property is supported which allows you to specify a Class name.

When an explicit type is defined, the `args` named-parameter is assumed to be 1 (except for Boolean-typed options where it is 0 by default). An explicit `args` parameter can still be provided if needed. Here is an example using types with the dynamic api argument definition style:

```
def argz = '''-a John -b -d 21 -e 1980 -f 3.5 -g 3.14159
    -h cv.txt -i DOWN and some more'''.split()
def cli = new CliBuilder()
cli.a(type: String, 'a-arg')
cli.b(type: boolean, 'b-arg')
cli.c(type: Boolean, 'c-arg')
cli.d(type: int, 'd-arg')
cli.e(type: Long, 'e-arg')
cli.f(type: Float, 'f-arg')
cli.g(type: BigDecimal, 'g-arg')
cli.h(type: File, 'h-arg')
cli.i(type: RoundingMode, 'i-arg')
def options = cli.parse(argz)
```

```
assert options.a == 'John'
assert options.b
assert !options.c
assert options.d == 21
assert options.e == 1980L
assert options.f == 3.5f
assert options.g == 3.14159
assert options.h == new File('cv.txt')
assert options.i == RoundingMode.DOWN
assert options.arguments() == ['and', 'some', 'more']
```

Primitives, numeric types, files, enums and arrays thereof, are supported (they are converted using org.codehaus.groovy.runtime.StringGroovyMethods#asType).

Custom parsing of the argument String

If the supported types aren't sufficient, you can supply a closure to handle the String to rich type conversion for you. Here is a sample using the dynamic api style:

```
def argz = '''-a John -b Mary -d 2016-01-01 and some more'''.split()
def cli = new CliBuilder()
def lower = { it.toLowerCase() }
cli.a(convert: lower, 'a-arg')
cli.b(convert: { it.toUpperCase() }, 'b-arg')
cli.d(convert: { Date.parse('yyyy-MM-dd', it) }, 'd-arg')
def options = cli.parse(argz)
assert options.a == 'john'
assert options.b == 'MARY'
assert options.d.format('dd-MM-yyyy') == '01-01-2016'
assert options.arguments() == ['and', 'some', 'more']
```

Alternatively, you can use the annotation style by supplying the conversion closure as an annotation parameter. Here is an example specification:

```
interface WithConvertI {
    @Option(convert={ it.toLowerCase() }) String a()
    @Option(convert={ it.toUpperCase() }) String b()
    @Option(convert={ Date.parse("yyyy-MM-dd", it) }) Date d()
    @Unparsed List remaining()
}
```

And an example using that specification:

```
Date newYears = Date.parse("yyyy-MM-dd", "2016-01-01")
def argz = '''-a John -b Mary -d 2016-01-01 and some more'''.split()
def cli = new CliBuilder()
def options = cli.parseFromSpec(WithConvertI, argz)
```

```
assert options.a() == 'john'
assert options.b() == 'MARY'
assert options.d() == newYears
assert options.remaining() == ['and', 'some', 'more']
```

Options with multiple arguments

Multiple arguments are also supported using an `args` value greater than 1. There is a special named parameter, `valueSeparator`, which can also be optionally used when processing multiple arguments. It allows some additional flexibility in the syntax supported when supplying such argument lists on the commandline. For example, supplying a value separator of ',' allows a comma-delimited list of values to be passed on the commandline.

The `args` value is normally an integer. It can be optionally supplied as a String. There are two special String symbols: ` and `*`. The `*` value means 0 or more. The ` value means 1 or more. The `*` value is the same as using `+` and also setting the `optionalArg` value to true.

Accessing the multiple arguments follows a special convention. Simply add an 's' to the normal property you would use to access the argument option and you will retrieve all the supplied arguments as a list. So, for a short option named 'a', you access the first 'a' argument using `options.a` and the list of all arguments using `options.as`. It's fine to have a shortname or longname ending in 's' so long as you don't also have the singular variant without the 's'. So, if `name` is one of your options with multiple arguments and `guess` is another with a single argument, there will be no confusion using `options.names` and `options.guess`.

Here is an excerpt highlighting the use of multiple arguments:

```
// import CliBuilder not shown
def cli = new CliBuilder()
cli.a(args: 2, 'a-arg')
cli.b(args: '2', valueSeparator: ',', 'b-arg') ①
cli.c(args: '+', valueSeparator: ',', 'c-arg') ②

def options = cli.parse('-a 1 2 3 4'.split()) ③
assert options.a == '1' ④
assert options.as == ['1', '2'] ⑤
assert options.arguments() == ['3', '4']

options = cli.parse('-a1 -a2 3'.split()) ⑥
assert options.as == ['1', '2']
assert options.arguments() == ['3']

options = cli.parse(['-b1,2']) ⑦
assert options.bs == ['1', '2']

options = cli.parse(['-c', '1'])
assert options.cs == ['1']

options = cli.parse(['-c1'])
```

```
assert options.cs == ['1']

options = cli.parse(['-c1,2,3'])
assert options.cs == ['1', '2', '3']
```

① Args value supplied as a String and comma value separator specified

② One or more arguments are allowed

③ Two commandline parameters will be supplied as the 'b' option's list of arguments

④ Access the 'a' option's first argument

⑤ Access the 'a' option's list of arguments

⑥ An alternative syntax for specifying two arguments for the 'a' option

⑦ The arguments to the 'b' option supplied as a comma-separated value

As an alternative to accessing multiple arguments using the *plural name* approach, you can use an array-based type for the option. In this case, all options will always be returned via the array which is accessed via the normal singular name. We'll see an example of this next when discussing types.

Multiple arguments are also supported using the annotation style of option definition by using an array type for the annotated class member (method or property) as this example shows:

```
interface ValSepI {
    @Option(numberOfArguments=2) String[] a()
    @Option(numberOfArgumentsString='2', valueSeparator=',') String[] b()
    @Option(numberOfArgumentsString='+', valueSeparator=',') String[] c()
    @Unparsed remaining()
}
```

And used as follows:

```
def cli = new CliBuilder()

def options = cli.parseFromSpec(ValSepI, '-a 1 2 3 4'.split())
assert options.a() == ['1', '2']
assert options.remaining() == ['3', '4']

options = cli.parseFromSpec(ValSepI, '-a1 -a2 3'.split())
assert options.a() == ['1', '2']
assert options.remaining() == ['3']

options = cli.parseFromSpec(ValSepI, ['-b1,2'] as String[])
assert options.b() == ['1', '2']

options = cli.parseFromSpec(ValSepI, ['-c', '1'] as String[])
assert options.c() == ['1']

options = cli.parseFromSpec(ValSepI, ['-c1'] as String[])
```

```
assert options.c() == ['1']

options = cli.parseFromSpec(ValSepI, ['-c1,2,3'] as String[])
assert options.c() == ['1', '2', '3']
```

Types and multiple arguments

Here is an example using types and multiple arguments with the dynamic api argument definition style:

```
def argz = '''-j 3 4 5 -k1.5,2.5,3.5 and some more'''.split()
def cli = new CliBuilder()
cli.j(args: 3, type: int[], 'j-arg')
cli.k(args: '+', valueSeparator: ',', type: BigDecimal[], 'k-arg')
def options = cli.parse(argz)
assert options.js == [3, 4, 5] ①
assert options.j == [3, 4, 5]  ①
assert options.k == [1.5, 2.5, 3.5]
assert options.arguments() == ['and', 'some', 'more']
```

① For an array type, the trailing 's' can be used but isn't needed

Setting a default value

Groovy makes it easy using the Elvis operator to provide a default value at the point of usage of some variable, e.g. `String x = someVariable ?: 'some default'`. But sometimes you wish to make such a default part of the options specification to minimise the interrogators work in later stages. `CliBuilder` supports the `defaultValue` property to cater for this scenario.

Here is how you could use it using the dynamic api style:

```
def cli = new CliBuilder()
cli.f longOpt: 'from', type: String, args: 1, defaultValue: 'one', 'f option'
cli.t longOpt: 'to', type: int, defaultValue: '35', 't option'

def options = cli.parse('-f two'.split())
assert options.hasOption('f')
assert options.f == 'two'
assert !options.hasOption('t')
assert options.t == 35

options = cli.parse('-t 45'.split())
assert !options.hasOption('from')
assert options.from == 'one'
assert options.hasOption('to')
assert options.to == 45
```

Similarly, you might want such a specification using the annotation style. Here is an example using an interface specification:

```
interface WithDefaultValueI {
    @Option(shortName='f', defaultValue='one') String from()
    @Option(shortName='t', defaultValue='35') int to()
}
```

Which would be used like this:

```
def cli = new CliBuilder()

def options = cli.parseFromSpec(WithDefaultValueI, '-f two'.split())
assert options.from() == 'two'
assert options.to() == 35

options = cli.parseFromSpec(WithDefaultValueI, '-t 45'.split())
assert options.from() == 'one'
assert options.to() == 45
```

You can also use the `defaultValue` annotation attribute when using annotations with an instance, though it's probably just as easy to provide an initial value for the property (or backing field).

Use with `TypeChecked`

The dynamic api style of using `CliBuilder` is inherently dynamic but you have a few options should you want to make use of Groovy's static type checking capabilities. Firstly, consider using the annotation style, for example, here is an interface option specification:

```
interface TypeCheckedI{
    @Option String name()
    @Option int age()
    @Unparsed List remaining()
}
```

And it can be used in combination with `@TypeChecked` as shown here:

```
@TypeChecked
void testTypeCheckedInterface() {
    def argz = "--name John --age 21 and some more".split()
    def cli = new CliBuilder()
    def options = cli.parseFromSpec(TypeCheckedI, argz)
    String n = options.name()
    int a = options.age()
    assert n == 'John' && a == 21
    assert options.remaining() == ['and', 'some', 'more']
}
```

Secondly, there is a feature of the dynamic api style which offers some support. The definition statements are inherently dynamic but actually return a value which we have ignored in earlier examples. The returned value is in fact a `TypedOption<Type>` and special `getAt` support allows the options to be interrogated using the typed option, e.g. `options[savedTypeOption]`. So, if you have statements similar to these in a non type checked part of your code:

```
def cli = new CliBuilder()
TypedOption<Integer> age = cli.a(longOpt: 'age', type: Integer, 'some age option')
```

Then, the following statements can be in a separate part of your code which is type checked:

```
def args = '--age 21'.split()
def options = cli.parse(args)
int a = options[age]
assert a == 21
```

Finally, there is one additional convenience method offered by `CliBuilder` to even allow the definition part to be type checked. It is a slightly more verbose method call. Instead of using the short name (the *opt* name) in the method call, you use a fixed name of `option` and supply the `opt` value as a property. You must also specify the type directly as shown in the following example:

```
import groovy.cli.TypedOption
import groovy.transform.TypeChecked

@TypeChecked
void testTypeChecked() {
    def cli = new CliBuilder()
    TypedOption<String> name = cli.option(String, opt: 'n', longOpt: 'name', 'name
option')
    TypedOption<Integer> age = cli.option(Integer, longOpt: 'age', 'age option')
    def argz = "--name John --age 21 and some more".split()
    def options = cli.parse(argz)
    String n = options[name]
    int a = options[age]
    assert n == 'John' && a == 21
    assert options.arguments() == ['and', 'some', 'more']
}
```

Advanced CLI Usage

NOTE	**NOTE** Advanced CLI features `CliBuilder` can be thought of as a Groovy friendly wrapper on top of either picocli or Apache Commons CLI. If there is a feature not provided by `CliBuilder` that you know is supported in the underlying library, the current `CliBuilder` implementation (and various Groovy language features) make it easy for you to call the underlying

> library methods directly. Doing so is a pragmatic way to leverage the Groovy-friendly syntax offered by `CliBuilder` and yet still access some of the underlying library's advanced features. A word of caution however; future versions of `CliBuilder` could potentially use another underlying library and in that event, some porting work may be required for your Groovy classes and/or scripts.

Apache Commons CLI

As an example, here is some code for making use of Apache Commons CLI's grouping mechanism:

```
import org.apache.commons.cli.*

def cli = new CliBuilder()
cli.f longOpt: 'from', 'f option'
cli.u longOpt: 'until', 'u option'
def optionGroup = new OptionGroup()
optionGroup.with {
  addOption cli.option('o', [longOpt: 'output'], 'o option')
  addOption cli.option('d', [longOpt: 'directory'], 'd option')
}
cli.options.addOptionGroup optionGroup
assert !cli.parse('-d -o'.split()) ①
```

① The parse will fail since only one option from a group can be used at a time.

Picocli

Below are some features available in the picocli version of `CliBuilder`.

New property: errorWriter

When users of your application give invalid command line arguments, CliBuilder writes an error message and the usage help message to the `stderr` output stream. It doesn't use the `stdout` stream to prevent the error message from being parsed when your program's output is used as input for another process. You can customize the destination by setting the `errorWriter` to a different value.

On the other hand, `CliBuilder.usage()` prints the usage help message to the `stdout` stream. This way, when users request help (e.g. with a `--help` parameter), they can pipe the output to a utility like `less` or `grep`.

You can specify different writers for testing. *Be aware that for backwards compatibility, setting the* `writer` *property to a different value will set* ***both*** *the* `writer` *and the* `errorWriter` *to the specified writer.*

ANSI colors

The picocli version of CliBuilder renders the usage help message in ANSI colors on supported platforms automatically. If desired you can customize this. (An example follows below.)

New property: name

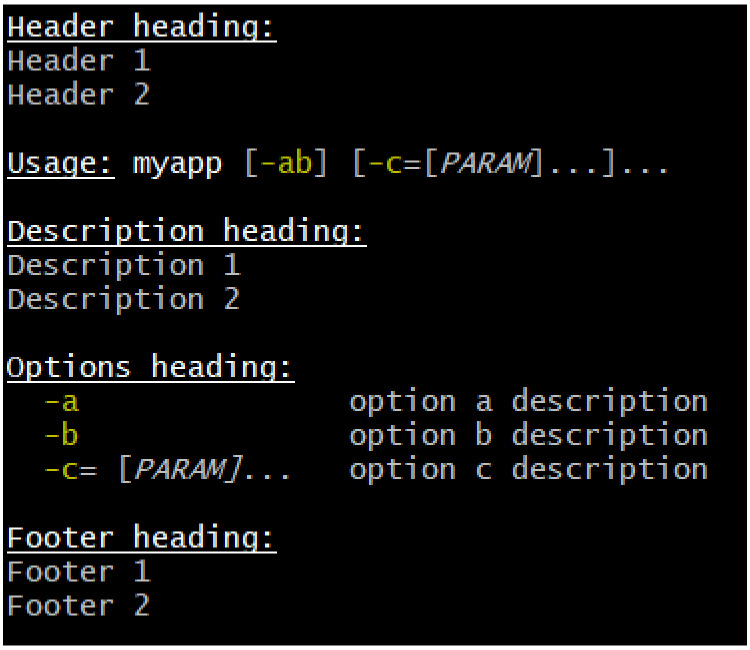
As before, you can set the synopsis of the usage help message with the `usage` property. You may be interested in a small improvement: if you only set the command `name`, a synopsis will be generated automatically, with repeating elements followed by `…` and optional elements surrounded with `[` and `]`. (An example follows below.)

New property: usageMessage

This property exposes a `UsageMessageSpec` object from the underlying picocli library, which gives fine-grained control over various sections of the usage help message. For example:

```
def cli = new CliBuilder()
cli.name = "myapp"
cli.usageMessage.with {
    headerHeading("@|bold,underline Header heading:|@%n")
    header("Header 1", "Header 2")                     // before the synopsis
    synopsisHeading("%n@|bold,underline Usage:|@ ")
    descriptionHeading("%n@|bold,underline Description heading:|@%n")
    description("Description 1", "Description 2")      // after the synopsis
    optionListHeading("%n@|bold,underline Options heading:|@%n")
    footerHeading("%n@|bold,underline Footer heading:|@%n")
    footer("Footer 1", "Footer 2")
}
cli.a('option a description')
cli.b('option b description')
cli.c(args: '*', 'option c description')
cli.usage()
```

Gives this output:



Property: parser

The `parser` property gives access to the picocli `ParserSpec` object that can be used to customize the parser behavior.

This can be useful when the `CliBuilder` options to control the parser are not fine-grained enough. For example, for backward compatibility with the Commons CLI implementation of `CliBuilder`, by default `CliBuilder` stops looking for options when an unknown option is encountered, and subsequent command line arguments are treated as positional parameters. `CliBuilder` provides a `stopAtNonOption` property, and by setting this to `false` you can make the parser more strict, so an unknown option results in `error: Unknown option: '-x'`.

But what if you want to treat unknown options as positional parameters, and still process subsequent command line arguments as options?

This can be accomplished with the `parser` property. For example:

```
def cli = new CliBuilder()
cli.parser.stopAtPositional(false)
cli.parser.unmatchedOptionsArePositionalParams(true)
// ...
def opts = cli.parse(args)
// ...
```

See the documentation for details.

Map options

Finally, if your application has options that are key-value pairs, you may be interested in picocli's support for maps. For example:

```
import java.util.concurrent.TimeUnit
import static java.util.concurrent.TimeUnit.DAYS
import static java.util.concurrent.TimeUnit.HOURS

def cli = new CliBuilder()
cli.D(args: 2,   valueSeparator: '=', 'the old way')                          ①
cli.X(type: Map, 'the new way')                                               ②
cli.Z(type: Map, auxiliaryTypes: [TimeUnit, Integer].toArray(), 'typed map')  ③

def options = cli.parse('-Da=b -Dc=d -Xx=y -Xi=j -ZDAYS=2 -ZHOURS=23'.split())④
assert options.Ds == ['a', 'b', 'c', 'd']                                     ⑤
assert options.Xs == [ 'x':'y', 'i':'j' ]                                     ⑥
assert options.Zs == [ (DAYS as TimeUnit):2, (HOURS as TimeUnit):23 ]         ⑦
```

① Previously, `key=value` pairs were split up into parts and added to a list

② Picocli map support: simply specify `Map` as the type of the option

③ You can even specify the type of the map elements

④ To compare, let's specify two key-value pairs for each option

⑤ Previously, all key-value pairs end up in a list and it is up to the application to work with this list

⑥ Picocli returns the key-value pairs as a `Map`

⑦ Both keys and values of the map can be strongly typed

Controlling the Picocli version

To use a specific version of picocli, add a dependency to that version in your build configuration. If running scripts using a pre-installed version of Groovy, use the `@Grab` annotation to control the version of picocli to use in `CliBuilder`.

```
@GrabConfig(systemClassLoader=true)
@Grab('info.picocli:picocli:4.2.0')
import groovy.cli.picocli.CliBuilder

def cli = new CliBuilder()
```

ObjectGraphBuilder

`ObjectGraphBuilder` is a builder for an arbitrary graph of beans that follow the JavaBean convention. It is in particular useful for creating test data.

Let's start with a list of classes that belong to your domain:

```
package com.acme

class Company {
    String name
    Address address
    List employees = []
}

class Address {
    String line1
    String line2
    int zip
    String state
}

class Employee {
    String name
    int employeeId
    Address address
    Company company
}
```

Then using `ObjectGraphBuilder` building a `Company` with three employees is as easy as:

```
def builder = new ObjectGraphBuilder()                          ①
builder.classLoader = this.class.classLoader                    ②
builder.classNameResolver = "com.acme"                          ③
```

```
def acme = builder.company(name: 'ACME') {                    ④
    3.times {
        employee(id: it.toString(), name: "Drone $it") {        ⑤
            address(line1:"Post street")                        ⑥
        }
    }
}

assert acme != null
assert acme instanceof Company
assert acme.name == 'ACME'
assert acme.employees.size() == 3
def employee = acme.employees[0]
assert employee instanceof Employee
assert employee.name == 'Drone 0'
assert employee.address instanceof Address
```

① creates a new object graph builder

② sets the classloader where the classes will be resolved

③ sets the base package name for classes to be resolved

④ creates a `Company` instance

⑤ with 3 `Employee` instances

⑥ each of them having a distinct `Address`

Behind the scenes, the object graph builder:

- will try to match a node name into a `Class`, using a default `ClassNameResolver` strategy that requires a package name
- then will create an instance of the appropriate class using a default `NewInstanceResolver` strategy that calls a no-arg constructor
- resolves the parent/child relationship for nested nodes, involving two other strategies:
  - `RelationNameResolver` will yield the name of the child property in the parent, and the name of the parent property in the child (if any, in this case, `Employee` has a parent property aptly named `company`)
  - `ChildPropertySetter` will insert the child into the parent taking into account if the child belongs to a `Collection` or not (in this case `employees` should be a list of `Employee` instances in `Company`).

All 4 strategies have a default implementation that work as expected if the code follows the usual conventions for writing JavaBeans. In case any of your beans or objects do not follow the convention you may plug your own implementation of each strategy. For example imagine that you need to build a class which is immutable:

```
@Immutable
class Person {
```

```
    String name
    int age
}
```

Then if you try to create a `Person` with the builder:

```
def person = builder.person(name:'Jon', age:17)
```

It will fail at runtime with:

```
Cannot set read-only property: name for class: com.acme.Person
```

Fixing this can be done by changing the new instance strategy:

```
builder.newInstanceResolver = { Class klazz, Map attributes ->
    if (klazz.getConstructor(Map)) {
        def o = klazz.newInstance(attributes)
        attributes.clear()
        return o
    }
    klazz.newInstance()
}
```

`ObjectGraphBuilder` supports ids per node, meaning that you can store a reference to a node in the builder. This is useful when multiple objects reference the same instance. Because a property named `id` may be of business meaning in some domain models `ObjectGraphBuilder` has a strategy named `IdentifierResolver` that you may configure to change the default name value. The same may happen with the property used for referencing a previously saved instance, a strategy named `ReferenceResolver` will yield the appropriate value (default is `refId'):

```
def company = builder.company(name: 'ACME') {
    address(id: 'a1', line1: '123 Groovy Rd', zip: 12345, state: 'JV')         ①
    employee(name: 'Duke', employeeId: 1, address: a1)                          ②
    employee(name: 'John', employeeId: 2 ){
      address( refId: 'a1' )                                                    ③
    }
}
```

① an address can be created with an `id`

② an employee can reference the address directly with its id

③ or use the `refId` attribute corresponding to the `id` of the corresponding address

Its worth mentioning that you cannot modify the properties of a referenced bean.

JmxBuilder

See Working with JMX - JmxBuilder for details.

FileTreeBuilder

groovy.util.FileTreeBuilder is a builder for generating a file directory structure from a specification. For example, to create the following tree:

```
src/
 |--- main
 |     |--- groovy
 |            |--- Foo.groovy
 |--- test
       |--- groovy
              |--- FooTest.groovy
```

You can use a `FileTreeBuilder` like this:

```
tmpDir = File.createTempDir()
def fileTreeBuilder = new FileTreeBuilder(tmpDir)
fileTreeBuilder.dir('src') {
    dir('main') {
       dir('groovy') {
          file('Foo.groovy', 'println "Hello"')
       }
    }
    dir('test') {
       dir('groovy') {
          file('FooTest.groovy', 'class FooTest extends groovy.test.GroovyTestCase
{}')
       }
    }
 }
```

To check that everything worked as expected we use the following `assert`s:

```
assert new File(tmpDir, '/src/main/groovy/Foo.groovy').text == 'println "Hello"'
assert new File(tmpDir, '/src/test/groovy/FooTest.groovy').text == 'class FooTest
extends groovy.test.GroovyTestCase {}'
```

`FileTreeBuilder` also supports a shorthand syntax:

```
tmpDir = File.createTempDir()
def fileTreeBuilder = new FileTreeBuilder(tmpDir)
fileTreeBuilder.src {
    main {
```

```
        groovy {
            'Foo.groovy'('println "Hello"')
        }
    }
    test {
        groovy {
            'FooTest.groovy'('class FooTest extends groovy.test.GroovyTestCase {}')
        }
    }
}
```

This produces the same directory structure as above, as shown by these `assert`s:

```
assert new File(tmpDir, '/src/main/groovy/Foo.groovy').text == 'println "Hello"'
assert new File(tmpDir, '/src/test/groovy/FooTest.groovy').text == 'class FooTest
extends groovy.test.GroovyTestCase {}'
```

Creating a builder

While Groovy has many built-in builders, the builder pattern is so common, you will no doubt eventually come across a building requirement that hasn't been catered for by those built-in builders. The good news is that you can build your own. You can do everything from scratch by relying on Groovy's metaprogramming capabilities. Alternatively, the `BuilderSupport` and `FactoryBuilderSupport` classes make designing your own builders much easier.

BuilderSupport

One approach to building a builder is to subclass `BuilderSupport`. With this approach, the general idea is to override one or more of a number of *lifecycle* methods including `setParent`, `nodeCompleted` and some or all of the `createNode` methods from the `BuilderSupport` abstract class.

As an example, suppose we want to create a builder of tracking athletic training programs. Each program is made up of a number of sets and each set has its own steps. A step might itself be a set of smaller steps. For each `set` or `step`, we might wish to record the `distance` required (or `time`), whether to `repeat` the steps a certain number of times, whether to take a `break` between each step and so forth.

For the simplicity of this example, we'll capture the training programming using maps and lists. A set has a list of steps. Information like `repeat` count or `distance` will be tracked in a map of attributes for each step and set.

The builder implementation is as follows:

- Override a couple of the `createNode` methods. We'll create a map capturing the set name, an empty list of steps, and potentially some attributes.
- Whenever we complete a node we'll add the node to the list of steps for the parent (if any).

The code looks like this:

```
class TrainingBuilder1 extends BuilderSupport {
    protected createNode(name) {
        [name: name, steps: []]
    }

    protected createNode(name, Map attributes) {
        createNode(name) + attributes
    }

    void nodeCompleted(maybeParent, node) {
        if (maybeParent) maybeParent.steps << node
    }

    // unused lifecycle methods
    protected void setParent(parent, child) { }
    protected createNode(name, Map attributes, value) { }
    protected createNode(name, value) { }
}
```

Next, we'll write a little helper method which recursively adds up the distances of all substeps, accounting for repeated steps as needed.

```
def total(map) {
    if (map.distance) return map.distance
    def repeat = map.repeat ?: 1
    repeat * map.steps.sum{ total(it) }
}
```

Finally, we can now use our builder and helper method to create a swimming training program and check its total distance:

```
def training = new TrainingBuilder1()

def monday = training.swimming {
    warmup(repeat: 3) {
        freestyle(distance: 50)
        breaststroke(distance: 50)
    }
    endurance(repeat: 20) {
        freestyle(distance: 50, break: 15)
    }
    warmdown {
        kick(distance: 100)
        choice(distance: 100)
    }
}
```

```
assert 1500 == total(monday)
```

FactoryBuilderSupport

A second approach to building a builder is to subclass `FactoryBuilderSupport`. This builder has similar goals to `BuilderSupport` but with extra features to simplify domain class construction.

With this approach, the general idea is to override one or more of a number of *lifecycle* methods including `resolveFactory`, `nodeCompleted` and `postInstantiate` methods from the `FactoryBuilderSupport` abstract class.

We'll use the same example as for the previous `BuilderSupport` example; a builder of tracking athletic training programs.

For this example, rather than capturing the training programming using maps and lists, we'll use some simple domain classes.

The builder implementation is as follows:

- Override the `resolveFactory` method to return a special factory which returns classes by capitalizing the names used in our mini DSL.
- Whenever we complete a node we'll add the node to the list of steps for the parent (if any).

The code, including the code for the special factory class, looks like this:

```
import static org.apache.groovy.util.BeanUtils.capitalize

class TrainingBuilder2 extends FactoryBuilderSupport {
    def factory = new TrainingFactory(loader: getClass().classLoader)

    protected Factory resolveFactory(name, Map attrs, value) {
        factory
    }

    void nodeCompleted(maybeParent, node) {
        if (maybeParent) maybeParent.steps << node
    }
}

class TrainingFactory extends AbstractFactory {
    ClassLoader loader
    def newInstance(FactoryBuilderSupport fbs, name, value, Map attrs) {
        def clazz = loader.loadClass(capitalize(name))
        value ? clazz.newInstance(value: value) : clazz.newInstance()
    }
}
```

Rather than using lists and maps, we'll have some simple domain classes and related traits:

```
trait HasDistance {
    int distance
}

trait Container extends HasDistance {
    List steps = []
    int repeat
}

class Cycling implements Container { }

class Interval implements Container { }

class Sprint implements HasDistance {}

class Tempo implements HasDistance {}
```

Just like for the BuilderSupport example, it is useful to have a helper method to calculate the total distance covered during the training session. The implementation is very similar to our earlier example, but is adjusted to work well with our newly defined traits.

```
def total(HasDistance c) {
    c.distance
}

def total(Container c) {
    if (c.distance) return c.distance
    def repeat = c.repeat ?: 1
    repeat * c.steps.sum{ total(it) }
}
```

Finally, we can now use our new builder and helper methods to create a cycling training program and check its total distance:

```
def training = new TrainingBuilder2()

def tuesday = training.cycling {
    interval(repeat: 5) {
        sprint(distance: 400)
        tempo(distance: 3600)
    }
}

assert 20000 == total(tuesday)
```

Working with JMX

Introduction

The Java Management Extensions (JMX) technology provides a standard way of managing resources such as applications, devices, and services on the JDK. Each resource to be managed is represented by a *Managed Bean* (or *MBean*). Given that Groovy sits directly on top of Java, Groovy can leverage the tremendous amount of work already done for JMX with Java. In addition, Groovy provides a `GroovyMBean` class, in the `groovy-jmx` module, which makes an MBean look like a normal Groovy object and simplifies Groovy code for interacting with MBeans. For example, the following code:

```
println server.getAttribute(beanName, 'Age')
server.setAttribute(beanName, new Attribute('Name', 'New name'))
Object[] params = [5, 20]
String[] signature = [Integer.TYPE, Integer.TYPE]
println server.invoke(beanName, 'add', params, signature)
```

can be simplified to:

```
def mbean = new GroovyMBean(server, beanName)
println mbean.Age
mbean.Name = 'New name'
println mbean.add(5, 20)
```

The remainder of this page shows you how to:

- Monitor the JVM using MXBeans
- Monitor Apache Tomcat and display statistics
- Monitor Oracle OC4J and display information
- Monitor BEA WebLogic and display information
- Leverage Spring's MBean annotation support to export your Groovy beans as MBeans

Monitoring the JVM

MBeans are not accessed directly by an application but are managed by a repository called an *MBean server*. Java includes a special MBean server called the *platform MBean server*, which is built into the JVM. Platform MBeans are registered in this server using unique names.

You can monitor the JVM through its platform MBeans with the following code:

```
import java.lang.management.*

def os = ManagementFactory.operatingSystemMXBean
println """OPERATING SYSTEM:
```

```
\tarchitecture = $os.arch
\tname = $os.name
\tversion = $os.version
\tprocessors = $os.availableProcessors
"""

def rt = ManagementFactory.runtimeMXBean
println """RUNTIME:
\tname = $rt.name
\tspec name = $rt.specName
\tvendor = $rt.specVendor
\tspec version = $rt.specVersion
\tmanagement spec version = $rt.managementSpecVersion
"""

def cl = ManagementFactory.classLoadingMXBean
println """CLASS LOADING SYSTEM:
\tisVerbose = ${cl.isVerbose()}
\tloadedClassCount = $cl.loadedClassCount
\ttotalLoadedClassCount = $cl.totalLoadedClassCount
\tunloadedClassCount = $cl.unloadedClassCount
"""

def comp = ManagementFactory.compilationMXBean
println """COMPILATION:
\ttotalCompilationTime = $comp.totalCompilationTime
"""

def mem = ManagementFactory.memoryMXBean
def heapUsage = mem.heapMemoryUsage
def nonHeapUsage = mem.nonHeapMemoryUsage
println """MEMORY:
HEAP STORAGE:
\tcommitted = $heapUsage.committed
\tinit = $heapUsage.init
\tmax = $heapUsage.max
\tused = $heapUsage.used
NON-HEAP STORAGE:
\tcommitted = $nonHeapUsage.committed
\tinit = $nonHeapUsage.init
\tmax = $nonHeapUsage.max
\tused = $nonHeapUsage.used
"""

ManagementFactory.memoryPoolMXBeans.each { mp ->
    println "\tname: " + mp.name
    String[] mmnames = mp.memoryManagerNames
    mmnames.each{ mmname ->
        println "\t\tManager Name: $mmname"
    }
    println "\t\tmtype = $mp.type"
```

```
    println "\t\tUsage threshold supported = " + mp.isUsageThresholdSupported()
}
println()

def td = ManagementFactory.threadMXBean
println "THREADS:"
td.allThreadIds.each { tid ->
    println "\tThread name = ${td.getThreadInfo(tid).threadName}"
}
println()

println "GARBAGE COLLECTION:"
ManagementFactory.garbageCollectorMXBeans.each { gc ->
    println "\tname = $gc.name"
    println "\t\tcollection count = $gc.collectionCount"
    println "\t\tcollection time = $gc.collectionTime"
    String[] mpoolNames = gc.memoryPoolNames
    mpoolNames.each { mpoolName ->
        println "\t\tmpool name = $mpoolName"
    }
}
```

When run, you will see something like this:

```
OPERATING SYSTEM:
                architecture = amd64
                name = Windows 10
                version = 10.0
                processors = 12

RUNTIME:
                name = 724176@QUOKKA
                spec name = Java Virtual Machine Specification
                vendor = Oracle Corporation
                spec version = 11
                management spec version = 2.0

CLASS LOADING SYSTEM:
                isVerbose = false
                loadedClassCount = 6962
                totalLoadedClassCount = 6969
                unloadedClassCount = 0

COMPILATION:
                totalCompilationTime = 7548

MEMORY:
            HEAP STORAGE:
                committed = 645922816
                init = 536870912
```

```
                max = 8560574464
                used = 47808352
            NON-HEAP STORAGE:
                committed = 73859072
                init = 7667712
                max = -1
                used = 70599520

    name: CodeHeap 'non-nmethods'
        Manager Name: CodeCacheManager
        mtype = Non-heap memory
        Usage threshold supported = true
    name: Metaspace
        Manager Name: Metaspace Manager
        mtype = Non-heap memory
        Usage threshold supported = true
    name: CodeHeap 'profiled nmethods'
        Manager Name: CodeCacheManager
        mtype = Non-heap memory
        Usage threshold supported = true
    name: Compressed Class Space
        Manager Name: Metaspace Manager
        mtype = Non-heap memory
        Usage threshold supported = true
    name: G1 Eden Space
        Manager Name: G1 Old Generation
        Manager Name: G1 Young Generation
        mtype = Heap memory
        Usage threshold supported = false
    name: G1 Old Gen
        Manager Name: G1 Old Generation
        Manager Name: G1 Young Generation
        mtype = Heap memory
        Usage threshold supported = true
    name: G1 Survivor Space
        Manager Name: G1 Old Generation
        Manager Name: G1 Young Generation
        mtype = Heap memory
        Usage threshold supported = false
    name: CodeHeap 'non-profiled nmethods'
        Manager Name: CodeCacheManager
        mtype = Non-heap memory
        Usage threshold supported = true

THREADS:
    Thread name = Reference Handler
    Thread name = Finalizer
    Thread name = Signal Dispatcher
    Thread name = Attach Listener
    Thread name = Common-Cleaner
    Thread name = Java2D Disposer
```

```
    Thread name = AWT-Shutdown
    Thread name = AWT-Windows
    Thread name = Image Fetcher 0
    Thread name = AWT-EventQueue-0
    Thread name = D3D Screen Updater
    Thread name = DestroyJavaVM
    Thread name = TimerQueue
    Thread name = Thread-0

GARBAGE COLLECTION:
    name = G1 Young Generation
        collection count = 6
        collection time = 69
        mpool name = G1 Eden Space
        mpool name = G1 Survivor Space
        mpool name = G1 Old Gen
    name = G1 Old Generation
        collection count = 0
        collection time = 0
        mpool name = G1 Eden Space
        mpool name = G1 Survivor Space
        mpool name = G1 Old Gen
```

Monitoring Tomcat

First start up Tomcat with JMX monitoring enabled by setting the following:

```
set JAVA_OPTS=-Dcom.sun.management.jmxremote -Dcom.sun.management.jmxremote.port=9004\
 -Dcom.sun.management.jmxremote.authenticate=false -Dcom.sun.management.jmxremote.ssl
=false
```

You can do this in your startup script and may choose any available port, we used 9004.

The following code uses JMX to discover the available MBeans in the running Tomcat, determine which are web modules, extract the processing time for each web module and displays the result in a graph using JFreeChart:

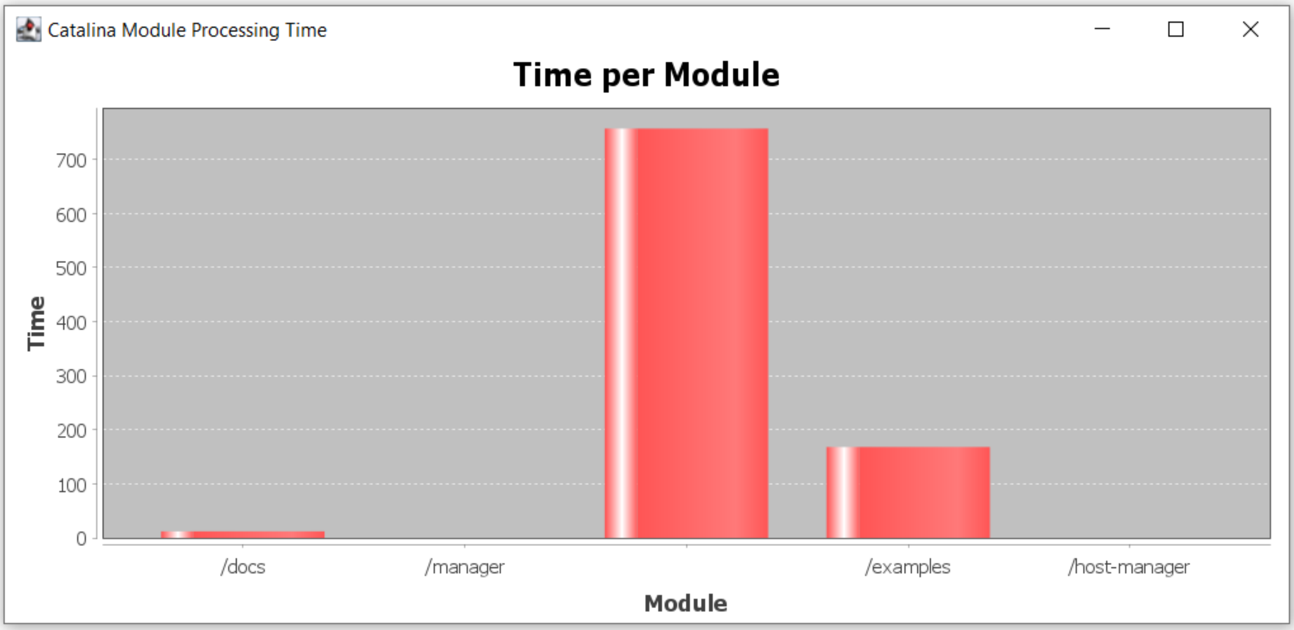
```
import groovy.swing.SwingBuilder
import groovy.jmx.GroovyMBean

import javax.management.ObjectName
import javax.management.remote.JMXConnectorFactory as JmxFactory
import javax.management.remote.JMXServiceURL as JmxUrl
import javax.swing.WindowConstants as WC

import org.jfree.chart.ChartFactory
import org.jfree.data.category.DefaultCategoryDataset as Dataset
import org.jfree.chart.plot.PlotOrientation as Orientation
```

```
def serverUrl = 'service:jmx:rmi:///jndi/rmi://localhost:9004/jmxrmi'
def server = JmxFactory.connect(new JmxUrl(serverUrl)).MBeanServerConnection
def serverInfo = new GroovyMBean(server, 'Catalina:type=Server').serverInfo
println "Connected to: $serverInfo"

def query = new ObjectName('Catalina:*')
String[] allNames = server.queryNames(query, null)
def modules = allNames.findAll { name ->
    name.contains('j2eeType=WebModule')
}.collect{ new GroovyMBean(server, it) }

println "Found ${modules.size()} web modules. Processing ..."
def dataset = new Dataset()

modules.each { m ->
    println m.name()
    dataset.addValue m.processingTime, 0, m.path
}

def labels = ['Time per Module', 'Module', 'Time']
def options = [false, true, true]
def chart = ChartFactory.createBarChart(*labels, dataset,
                Orientation.VERTICAL, *options)
def swing = new SwingBuilder()
def frame = swing.frame(title:'Catalina Module Processing Time',
defaultCloseOperation:WC.DISPOSE_ON_CLOSE) {
    panel(id:'canvas') { rigidArea(width:800, height:350) }
}
frame.pack()
frame.show()
chart.draw(swing.canvas.graphics, swing.canvas.bounds)
```

When run, we will see a trace of progress being made:

```
Connected to: Apache Tomcat/9.0.37
Found 5 web modules. Processing ...
Catalina:j2eeType=WebModule,name=//localhost/docs,J2EEApplication=none,J2EEServer=none
Catalina:j2eeType=WebModule,name=//localhost/manager,J2EEApplication=none,J2EEServer=n
one
Catalina:j2eeType=WebModule,name=//localhost/,J2EEApplication=none,J2EEServer=none
Catalina:j2eeType=WebModule,name=//localhost/examples,J2EEApplication=none,J2EEServer=
none
Catalina:j2eeType=WebModule,name=//localhost/host-
manager,J2EEApplication=none,J2EEServer=none
```

The output will look like this:



Note: if you get errors running this script, see the **Troubleshooting** section below.

OC4J Example

Here is a script to access OC4J and print out some information about the server, its runtime and (as an example) the configured JMS destinations:

```
import javax.management.remote.*
import oracle.oc4j.admin.jmx.remote.api.JMXConnectorConstant

def serverUrl = new JMXServiceURL('service:jmx:rmi://localhost:23791')
def serverPath = 'oc4j:j2eeType=J2EEServer,name=standalone'
def jvmPath = 'oc4j:j2eeType=JVM,name=single,J2EEServer=standalone'
def provider = 'oracle.oc4j.admin.jmx.remote'
def credentials = [
    (JMXConnectorConstant.CREDENTIALS_LOGIN_KEY): 'oc4jadmin',
    (JMXConnectorConstant.CREDENTIALS_PASSWORD_KEY): 'admin'
]
def env = [
    (JMXConnectorFactory.PROTOCOL_PROVIDER_PACKAGES): provider,
    (JMXConnector.CREDENTIALS): credentials
]
def server = JmxFactory.connect(serverUrl, env).MBeanServerConnection
def serverInfo = new GroovyMBean(server, serverPath)
def jvmInfo = new GroovyMBean(server, jvmPath)
println """Connected to $serverInfo.node. \
Server started ${new Date(serverInfo.startTime)}.
OC4J version:  $serverInfo.serverVersion from $serverInfo.serverVendor
JVM version:   $jvmInfo.javaVersion from $jvmInfo.javaVendor
Memory usage:  $jvmInfo.freeMemory bytes free, \
$jvmInfo.totalMemory bytes total
"""
```

```
def query = new javax.management.ObjectName('oc4j:*')
String[] allNames = server.queryNames(query, null)
def dests = allNames.findAll { name ->
    name.contains('j2eeType=JMSDestinationResource')
}.collect { new GroovyMBean(server, it) }

println "Found ${dests.size()} JMS destinations. Listing ..."
dests.each { d -> println "$d.name: $d.location" }
```

Here is the result of running this script:

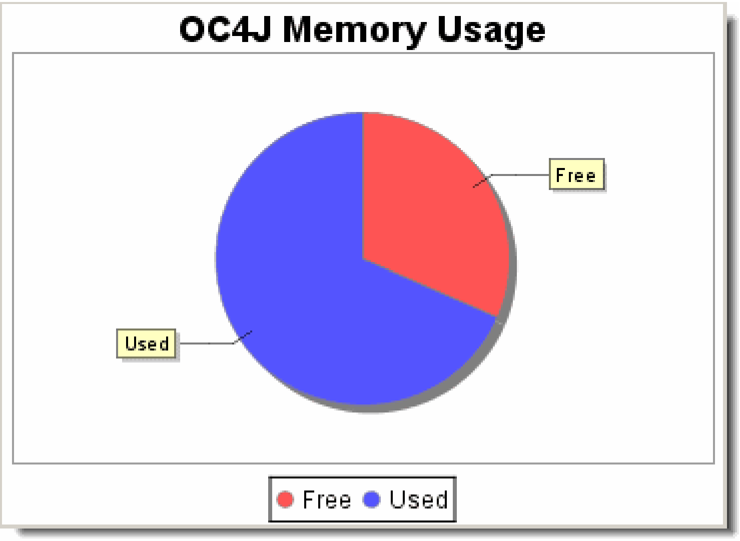
```
Connected to LYREBIRD. Server started Thu May 31 21:04:54 EST 2007.
OC4J version:  11.1.1.0.0 from Oracle Corp.
JVM version:   1.6.0_01 from Sun Microsystems Inc.
Memory usage:  8709976 bytes free, 25153536 bytes total

Found 5 JMS destinations. Listing ...
Demo Queue: jms/demoQueue
Demo Topic: jms/demoTopic
jms/Oc4jJmsExceptionQueue: jms/Oc4jJmsExceptionQueue
jms/RAExceptionQueue: jms/RAExceptionQueue
OracleASRouter_store: OracleASRouter_store
```

As a slight variation, this script displays a pie chart of memory usage using JFreeChart:

```
import org.jfree.chart.ChartFactory
import javax.swing.WindowConstants as WC
import javax.management.remote.*
import oracle.oc4j.admin.jmx.remote.api.JMXConnectorConstant

def url = 'service:jmx:rmi://localhost:23791'
def credentials = [:]
credentials[JMXConnectorConstant.CREDENTIALS_LOGIN_KEY] = "oc4jadmin"
credentials[JMXConnectorConstant.CREDENTIALS_PASSWORD_KEY] = "password"
def env = [:]
env[JMXConnectorFactory.PROTOCOL_PROVIDER_PACKAGES] = "oracle.oc4j.admin.jmx.remote"
env[JMXConnector.CREDENTIALS] = credentials
def server = JMXConnectorFactory.connect(new JMXServiceURL(url), env
).MBeanServerConnection
def jvmInfo = new GroovyMBean(server,
'oc4j:j2eeType=JVM,name=single,J2EEServer=standalone')

def piedata = new org.jfree.data.general.DefaultPieDataset()
piedata.setValue "Free", jvmInfo.freeMemory
piedata.setValue "Used", jvmInfo.totalMemory - jvmInfo.freeMemory

def options = [true, true, true]
def chart = ChartFactory.createPieChart('OC4J Memory Usage', piedata, *options)
```

```
chart.backgroundPaint = java.awt.Color.white
def swing = new groovy.swing.SwingBuilder()
def frame = swing.frame(title:'OC4J Memory Usage', defaultCloseOperation:WC
.EXIT_ON_CLOSE) {
    panel(id:'canvas') { rigidArea(width:350, height:250) }
}
frame.pack()
frame.show()
chart.draw(swing.canvas.graphics, swing.canvas.bounds)
```

Which looks like:



WebLogic Example

This script prints out information about the server followed by information about JMS Destinations (as an example). Many other mbeans are available.

```
import javax.management.remote.*
import javax.management.*
import javax.naming.Context
import groovy.jmx.GroovyMBean

def urlRuntime = '/jndi/weblogic.management.mbeanservers.runtime'
def urlBase = 'service:jmx:t3://localhost:7001'

def serviceURL = new JMXServiceURL(urlBase + urlRuntime)
def h = new Hashtable()
h.put(Context.SECURITY_PRINCIPAL, 'weblogic')
h.put(Context.SECURITY_CREDENTIALS, 'weblogic')
h.put(JMXConnectorFactory.PROTOCOL_PROVIDER_PACKAGES, 'weblogic.management.remote')
def server = JMXConnectorFactory.connect(serviceURL, h).MBeanServerConnection
def domainName = new ObjectName
('com.bea:Name=RuntimeService,Type=weblogic.management.mbeanservers.runtime.RuntimeSer
viceMBean')
def rtName = server.getAttribute(domainName, 'ServerRuntime')
```

```
def rt = new GroovyMBean(server, rtName)
println "Server: name=$rt.Name, state=$rt.State, version=$rt.WeblogicVersion"
def destFilter = Query.match(Query.attr('Type'), Query.value('JMSDestinationRuntime'))
server.queryNames(new ObjectName('com.bea:*'), destFilter).each { name ->
    def jms = new GroovyMBean(server, name)
    println "JMS Destination: name=$jms.Name, type=$jms.DestinationType,
messages=$jms.MessagesReceivedCount"
}
```

Here is the output:

```
Server: name=examplesServer, state=RUNNING, version=WebLogic Server 10.0  Wed May 9
18:10:27 EDT 2007 933139
JMS Destination: name=examples-jms!exampleTopic, type=Topic, messages=0
JMS Destination: name=examples-jms!exampleQueue, type=Queue, messages=0
JMS Destination: name=examples-jms!jms/MULTIDATASOURCE_MDB_QUEUE, type=Queue,
messages=0
JMS Destination: name=examplesJMSServer!examplesJMSServer.TemporaryQueue0, type=Queue,
messages=68
JMS Destination: name=examples-jms!quotes, type=Topic, messages=0
JMS Destination: name=examples-jms!weblogic.wsee.wseeExamplesDestinationQueue,
type=Queue, messages=0
JMS Destination: name=examples-jms!weblogic.examples.ejb30.ExampleQueue, type=Queue,
messages=0
```

Spring Example

You can also use Spring to automatically register beans as JMX aware.

Here is an example class (Calculator.groovy):

```
import org.springframework.jmx.export.annotation.*

@ManagedResource(objectName="bean:name=calcMBean", description="Calculator MBean")
public class Calculator {

    private int invocations

    @ManagedAttribute(description="The Invocation Attribute")
    public int getInvocations() {
        return invocations
    }

    private int base = 10

    @ManagedAttribute(description="The Base to use when adding strings")
    public int getBase() {
        return base
```

```
    }

    @ManagedAttribute(description="The Base to use when adding strings")
    public void setBase(int base) {
        this.base = base
    }

    @ManagedOperation(description="Add two numbers")
    @ManagedOperationParameters([
        @ManagedOperationParameter(name="x", description="The first number"),
        @ManagedOperationParameter(name="y", description="The second number")])
    public int add(int x, int y) {
        invocations++
        return x + y
    }

    @ManagedOperation(description="Add two strings representing numbers of a
particular base")
    @ManagedOperationParameters([
        @ManagedOperationParameter(name="x", description="The first number"),
        @ManagedOperationParameter(name="y", description="The second number")])
    public String addStrings(String x, String y) {
        invocations++
        def result = Integer.valueOf(x, base) + Integer.valueOf(y, base)
        return Integer.toString(result, base)
    }
}
```

Here is the Spring configuration file (beans.xml):

```
<?xml version="1.0" encoding="UTF-8"?>
<beans xmlns="http://www.springframework.org/schema/beans"
       xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
       xsi:schemaLocation="
http://www.springframework.org/schema/beans
http://www.springframework.org/schema/beans/spring-beans.xsd">
    <bean id="mbeanServer"
          class="org.springframework.jmx.support.MBeanServerFactoryBean">
        <property name="locateExistingServerIfPossible" value="true"/>
    </bean>

    <bean id="exporter"
          class="org.springframework.jmx.export.MBeanExporter">
        <property name="assembler" ref="assembler"/>
        <property name="namingStrategy" ref="namingStrategy"/>
        <property name="beans">
            <map>
                <entry key="bean:name=defaultCalcName" value-ref="calcBean"/>
            </map>
        </property>
```

```
        <property name="server" ref="mbeanServer"/>
        <property name="autodetect" value="true"/>
    </bean>

    <bean id="jmxAttributeSource"

class="org.springframework.jmx.export.annotation.AnnotationJmxAttributeSource"/>

    <!-- will create management interface using annotation metadata -->
    <bean id="assembler"
          class="org.springframework.jmx.export.assembler.MetadataMBeanInfoAssembler">
        <property name="attributeSource" ref="jmxAttributeSource"/>
    </bean>

    <!-- will pick up the ObjectName from the annotation -->
    <bean id="namingStrategy"
          class="org.springframework.jmx.export.naming.MetadataNamingStrategy">
        <property name="attributeSource" ref="jmxAttributeSource"/>
    </bean>

    <bean id="calcBean"
          class="Calculator">
        <property name="base" value="10"/>
    </bean>
</beans>
```

Here is a script which uses this bean and configuration:

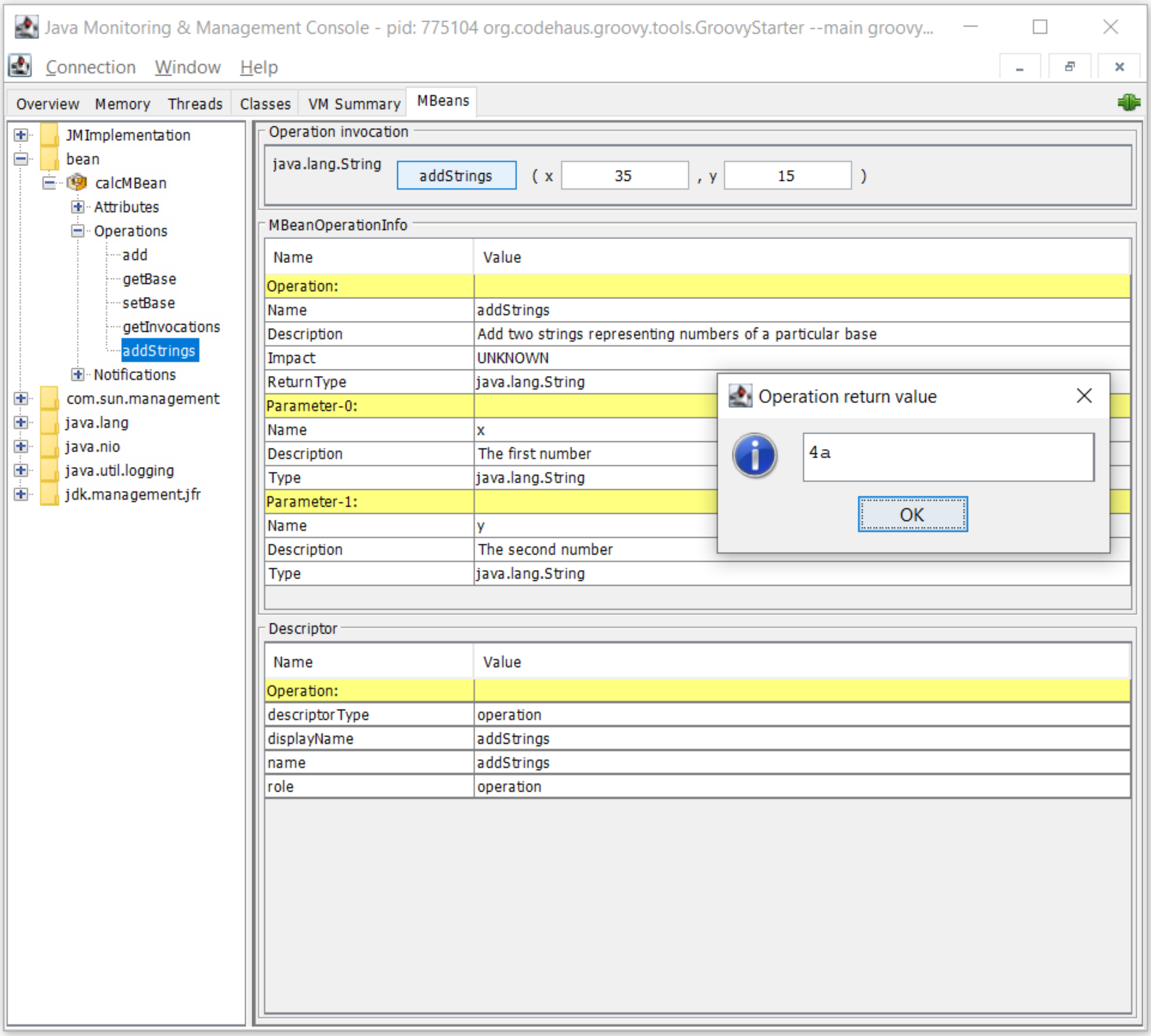
```
import org.springframework.context.support.ClassPathXmlApplicationContext
import java.lang.management.ManagementFactory
import javax.management.ObjectName
import javax.management.Attribute
import groovy.jmx.GroovyMBean

// get normal bean
def ctx = new ClassPathXmlApplicationContext("beans.xml")
def calc = ctx.getBean("calcBean")

Thread.start {
    // access bean via JMX, use a separate thread just to
    // show that we could access remotely if we wanted
    def server = ManagementFactory.platformMBeanServer
    def mbean = new GroovyMBean(server, 'bean:name=calcMBean')
    sleep 1000
    assert 8 == mbean.add(7, 1)
    mbean.Base = 8
    assert '10' == mbean.addStrings('7', '1')
    mbean.Base = 16
    sleep 2000
    println "Number of invocations: $mbean.Invocations"
```

```
    println mbean
}

assert 15 == calc.add(9, 6)
assert '11' == calc.addStrings('10', '1')
sleep 2000
assert '20' == calc.addStrings('1f', '1')
```

And here is the resulting output:

```
Number of invocations: 5
MBean Name:
  bean:name=calcMBean

Attributes:
  (rw) int Base
  (r) int Invocations
Operations:
  int add(int x, int y)
  java.lang.String addStrings(java.lang.String x, java.lang.String y)
  int getInvocations()
  int getBase()
  void setBase(int p1)
```

You can even attach to the process while it is running with jconsole. It will look something like:



We started the Groovy application with the `-Dcom.sun.management.jmxremote` JVM argument.

See also:

- Dynamic language beans in Spring
- Spring JMX Documentation

Troubleshooting

java.lang.SecurityException

If you get the following error, your container's JMX access is password protected:

```
java.lang.SecurityException: Authentication failed! Credentials required
```

To fix that, add an environment with the credentials when connecting, like this (password has to be set before that):

```
def jmxEnv = null
if (password != null) {
    jmxEnv = [(JMXConnector.CREDENTIALS): (String[])["monitor", password]]
}
def connector = JMXConnectorFactory.connect(new JMXServiceURL(serverUrl), jmxEnv)
```

Details for the software you are trying to monitor/manage may differ slightly. Check out the other examples using credentials above if appropriate (e.g. OC4J and WebLogic). If you still have troubles, you will have to consult the documentation for the software you are trying to monitor/manage for details on how to provide credentials.

JmxBuilder

JmxBuilder is a Groovy-based domain specific language for the Java Management Extension (JMX) API. It uses the builder pattern (FactoryBuilder) to create an internal DSL that facilitates the exposure of POJO's and Groovy beans as management components via the MBean server. JmxBuilder hides the complexity of creating and exporting management beans via the JMX API and provides a set of natural Groovy constructs to interact with the JMX infrastructure.

Instantiating JmxBuilder

To start using JmxBuilder, simply make sure the jar file is on your class path. Then you can do the following in your code:

```
def jmx = new JmxBuilder()
```

That's it! You are now ready to use the JmxBuilder.

NOTE

- You can pass in an instance of **your own MBeanServer** to the builder (**JmxBuilder(MBeanServer)**)
- If no MBeanServer is specified, the builder instance will default to the underlying platform MBeanServer.

Once you have an instance of JmxBuilder, you are now ready to invoke any of its builder nodes.

JMX Connectors

Remote connectivity is a crucial part of the JMX architecture. JmxBuilder facilitates the creation of connector servers and connector clients with a minimal amount of coding.

Connector Server

JmxBuilder.connectorServer() supports the full Connector api syntax and will let you specify properties, override the URL, specify your own host, etc.

Syntax

```
jmx.connectorServer(
    protocol:"rmi",
    host:"...",
    port:1099,
    url:"...",
    properties:[
        "authenticate":true|false,
        "passwordFile":"...",
        "accessFile":"...",
        "sslEnabled" : true | false
        // any valid connector property
    ]
)
```

Note that the serverConnector node will accept four ServerConnector property aliases (authenticate, passwordFile,accessFile, and sslEnabled). You can use these aliases or provided any of the RMI-supported properties.

Example - Connector Server (see correction below)

```
jmx.connectorServer(port: 9000).start()
```

The snippet above returns an RMI connector that will start listening on port 9000. By default, the builder will internally generate URL **"service:jmx:rmi:///jndi/rmi://localhost:9000/jmxrmi"**.

NOTE: Sadly you are as likely to get something like the following when attempting to run the previous snippet of code (example is incomplete, see below):

```
Caught: java.io.IOException: Cannot bind to URL [rmi://localhost:9000/jmxrmi]:
javax.naming.ServiceUnavailableException [Root exception is java.rmi.ConnectException:
Connection refused to host: localhost; nested exception is:
?????? java.net.ConnectException: Connection refused]
??
```

This occurs on Mac and Linux (CentOS 5) with Groovy 1.6 installed. Perhaps there were assumptions made about the configuration of the /etc/hosts file?

NOTE	*The correct example is shown below.*

Connector Example (Corrected) - Connector Server

The example above does not create the RMI registry. So, in order to export, you have to first export the RMI object registry (make sure to import `java.rmi.registry.LocateRegistry`).

```
import java.rmi.registry.LocateRegistry
//...
```

```
LocateRegistry.createRegistry(9000)
jmx.connectorServer(port: 9000).start()
```

Connector Client

JmxBuilder.connectorClient() node lets you create JMX connector client object to connect to a JMX MBean Server.

Syntax

```
jmx.connectorClient (
    protocol:"rmi",
    host:"...",
    port:1099,
    url:"...",
)
```

Example - Client Connector

Creating a connector client can be done just as easily. With one line of code, you can create an instance of a JMX Connector Client as shown below.

```
def client = jmx.connectorClient(port: 9000)
client.connect()
```

You can then access the MBeanServerConnection associated with the connector using:

```
client.getMBeanServerConnection()
```

JmxBuilder MBean Export

You can **export a Java object or a Groovy object** with minimal coding. JmxBuilder will even find and **export dynamic Groovy methods** injected at runtime.

Implicit vs Explicit Descriptors

When using the builder, you can **let JmxBuilder implicitly generate** all of your MBean descriptor info. This is useful when you want to write minimal code to quickly export your beans. You can also explicitly declare all descriptor info for the bean. This gives you total control on how you want to describe every piece of information that you want to export for the underlying bean.

The JmxBuilder.export() Node

The **JmxBuilder.export() node provides a container** where all management entities to be exported to the MBeanServer are placed. You can place one or more bean() or timer() nodes as children of the export() node. JmxBuilder will **automatically batch export the entities described** by the nodes to the MBean server for management (see example below).

```
def beans = jmx.export {
    bean(new Foo())
    bean(new Bar())
    bean(new SomeBar())
}
```

In the code snippet above, **JmxBuilder.export() will export three management beans** to the MBean server.

JmxBuilder.export() Syntax

JmxBuilder.export() node supports the **registrationPolicy** parameter to specify how JmxBuilder will behave to resolve bean name collision during MBean registration:

```
jmx.export(policy:"replace|ignore|error")
or
jmx.export(regPolicy:"replace|ignore|error")
```

- **replace** - JmxBuilder.export() will replace any bean already registered with the MBean during export.
- **ignore** - The bean being exported will be ignored if the same bean is already registered.
- **error** - JmxBuilder.export() throws an error upon bean name collision during registration.

Integration with GroovyMBean Class

When you export an MBean to the MBeanServer, **JmxBuilder will return an instance of GroovyMBean** representing the management bean that have been exported by the builder. Nodes such as **bean()** and **timer()** will return an instances of GroovyMBean when they are invoked. The **export()** node returns an **array of all of GroovyMBean[]** representing all managed objects exported to the MBean server.

MBean Registration with JmxBuilder.bean()

This portion of this reference uses class **RequestController** to illustrate how to use JmxBuilder to export runtime management beans. The class is for illustration purpose and can be a POJO or a Groovy bean.

RequestController

```
class RequestController {
    // constructors
    RequestController() { super() }
    RequestController(Map resource) { }

    // attributes
```

```
    boolean isStarted() { true }
    int getRequestCount() { 0 }
    int getResourceCount() { 0 }
    void setRequestLimit(int limit) { }
    int getRequestLimit() { 0 }

    // operations
    void start() { }
    void stop() { }
    void putResource(String name, Object resource) { }
    void makeRequest(String res) { }
    void makeRequest() { }
}
```

Implicit Export

As mentioned earlier, you can use JmxBuilder's flexible syntax to export any POJO/POGO with no descriptor. The builder can automatically describe all aspects of the management beans using implicit defaults. These default values can easily be overridden as we'll see in this in the next section.

The simplest way to export a POJO or POGO is listed below.

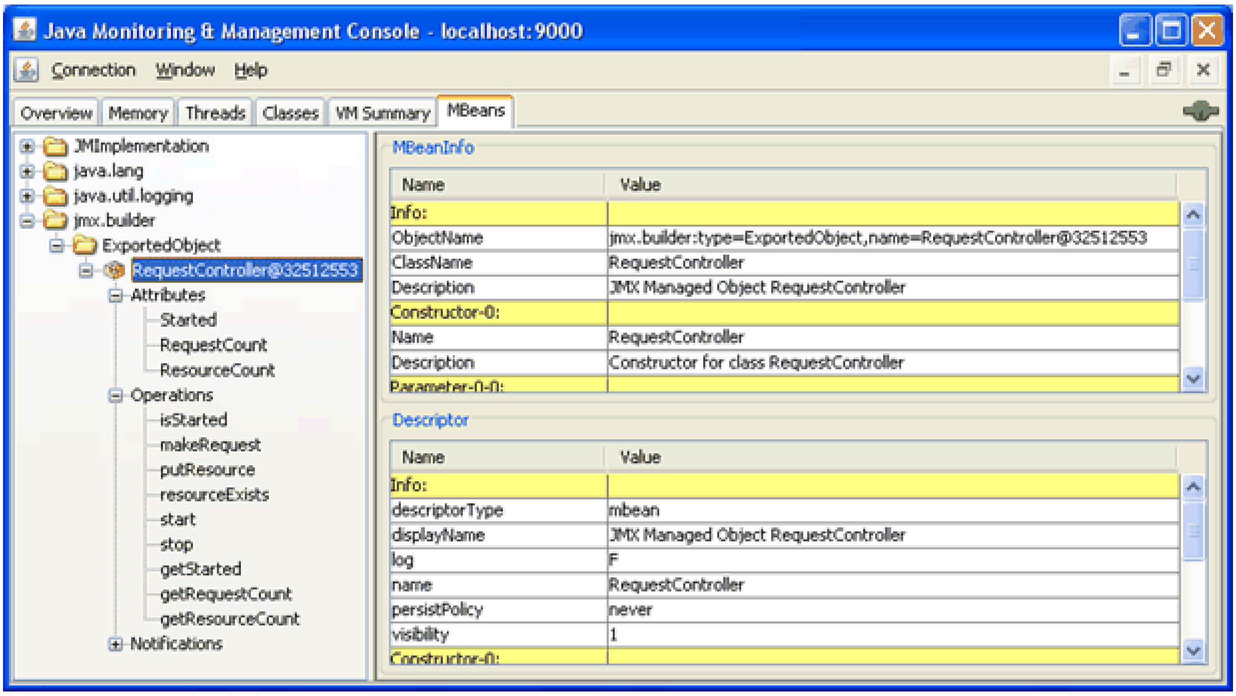
```
jmx.export {
    bean(new RequestController(resource: "Hello World"))
}
```

What this does:

- First, the **JmxBuilder.export() node will export** an MBean to the MBeanServer representing **the declared POJO** instance.
- The builder will **generate a default ObjectName** for the MBean and all other MBean descriptor information.
- **JmxBuilder will automatically export** all declared **attributes** (MBean getter/setters), **constructors**, and **operations** on the instance.
- The exported **attributes** will have **read-only** visibility.

Remember, **JmxBuilder.export() returns an array of GroovyMBean[] objects** for all exported instances. So, once you call JmxBuilder.export(), **you have immediate access to the underlying MBean proxy** (via GroovyMBean).

JConsole view of Exported Bean



JmxBuilder.bean() Syntax

The JmxBuilder.bean() node supports an extensive set of descriptors to describe your bean for management. The JMX MBeanServer uses these descriptors to expose metadata about the bean exposed for management.

```
jmx.export {
    bean(
        target:bean instance,
        name:ObjectName,
        desc:"...",
        attributes:"*",
        attributes:[]
        attributes:[ "AttrubuteName1","AttributeName2",...,"AttributeName_n" ]
        attributes:[
            "AttributeName":"*",
            "AttributeName":[
                desc:"...",
                defaultValue:value,
                writable:true|false,
                editable:true|false,
                onChange:{event-> // event handler}
            ]
        ],

        constructors:"*",
        constructors:[
            "Constructor Name":[],
            "Constructor Name":[ "ParamType1","ParamType2,...,ParamType_n" ],
            "Constructor Name":[
                desc:"...",
                params:[
```

```
                    "ParamType1":"*",
                    "ParamType2":[desc:"...", name:"..."],...,
                    "ParamType_n":[desc:"...", name:"..."]
                ]
            ]
        ],

        operations:"*",
        operations:[ "OperationName1", "OperationName2",...,"OperationNameN" ],
        operations:[
            "OperationName1":"*",
            "OperationName2":[ "type1","type2,"type3" ]
            "OperationName3":[
                desc:"...",
                params:[
                    "ParamType1":"*"
                    "ParamType2":[desc:"...", name:"..."],...,
                    "ParamType_n":[desc:"...", name:"..."]
                ],
                onInvoked:{event-> JmxBuilder.send(event:"", to:"")}
            ]
        ],

        listeners:[
            "ListenerName1":[event: "...", from:ObjectName, call:{event->}],
            "ListenerName2":[event: "...", from:ObjectName, call:&methodPointer]
        ]

    )
}
```

Instead of describing the entire node, the following section explore each attribute separately.

Bean() Node - Specifying MBean ObjectName

Using the bean() node descriptors, you can specify your own MBean ObjectName.

```
def ctrl = new RequestController(resource:"Hello World")
def beans = jmx.export {
    bean(target: ctrl, name: "jmx.tutorial:type=Object")
}
```

The ObjectName can be specified as a String or an instance of the ObjectName.

Bean() Node - Attribute Export

JMX attributes are the setters and getters on the underlying bean. The JmxBuilder.bean() node provides several ways to flexibly describe and export MBean attributes. You can combine them however you want to achieve any level of attribute visibility. Let's take a look.

Export All Attributes with Wildcard "*"

The following code snippet **will describe and export all attributes** on the bean as read-only. **JmxBuilder will use default values** to describe the attributes that exported for management.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(target: new RequestController(),
    name: objName,
    attributes: "*")
}
```

Export Attribute List

JmxBuilder will let you specify a list of attributes to export.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(
        target: new RequestController(),
        name: objName,
        attributes: ["Resource", "RequestCount"]
    )
}
```

In the snippet above, **only the "Resource" and "RequestCount" attributes will be exported**. Again, since no descriptors are provided, **JmxBuilder will use sensible defaults** to describe the exported attributes.

Export Attribute with Explicit Descriptors

One of the strengths of JmxBuilder is its flexibility in describing MBean. With the builder you can describe all aspects of the MBeans attribute that you want to export to the MBeanServer (see syntax above).

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(
        target: new RequestController(),
        name: objName,
        attributes: [
            "Resource": [desc: "The resource to request.", readable: true, writable:
true, defaultValue: "Hello"],
            "RequestCount": "*"
        ]
    )
}
```

In the snippet above, attribute **"Resource" is fully-described** using all supported descriptors (i.e. desc, readable, writable, defaultValue) for a JMX attribute. However, we use the wildcard to describe attribute **RequestCount** and it will be exported and described using defaults.

Bean() Node - Constructor Export

JmxBuilder **supports the explicit description and export of constructors** defined in the underlying bean. There are several options available when exporting constructors. You can combine them however you want to achieve the desired level of manageability.

Export all Constructors with "*"

You can use the builder's special "*" **notation to export all constructors** declared on the underlying bean. The builder will use default values to describe the MBean constructors.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(
        target: new RequestController(),
        name: objName,
        constructors: "*"
    )
}
```

Export Constructors using Parameter Descriptor

JmxBuilder lets you **target specific constructor** to export **by describing the parameter signature**. This is useful when you have several constructors with different parameter signature and you want to export specific constructors.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(
        target: new RequestController(),
        name: objName,
        constructors: [
            "RequestController": ["Object"]
        ]
    )
}
```

Here, JmxBuilder will **export a constructor that takes one parameter of type "Object"**. Again, JmxBuilder will use default values to fill in the description of the constructor and the parameters.

Export Constructor with Explicit Descriptors

JmxBuilder allows you to **fully-describe** the constructor that you want to target for export (see syntax above).

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(target: new RequestController(), name: objName,
        constructors: [
            "RequestController": [
                desc: "Constructor takes param",
                params: ["Object" : [name: "Resource", desc: "Resource for
controller"]]
            ]
        ]
    )
}
```

In the code above, JmxBuilder will target a constructor that takes one parameter for export to the MBeanServer. Notice how the constructor can be fully-described using all optional descriptor keys including parameter descriptors.

Bean() Node - Operation Export

Similar to constructors, JmxBuilder supports the description and export of MBean operations using a flexible notation (see above for syntax). You can combine these notations however you want to achieve the level of operation manageability desired.

Export All Operations with "*"

You can use the builder's special "*" **notation to export all operations** defined on the bean to be exposed for management. The builder will use default descriptor values for the operations being exported.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(
        target: new RequestController(),
        name: objName,
        operations: "*"
    )
}
```

In this snippet, JmxBuilder will **export all bean operations** and will use default values to describe them in the MBeanServer.

Export Operation List

JmxBuilder has a shorthand notation that lets you quickly target operations to be exported by providing a list of methods to export.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
```

```
    bean(
        target: new RequestController(),
        name: objName,
        operations: ["start", "stop"]
    )
}
```

In the snippet above, the **builder will only export methods start() and stop()**. All other methods will be ignored. JmxBuilder will use default descriptor values to describe the operations being exported.

Export Operations by Signature

Using JmxBuilder, you can target methods to export for management using the methods' parameter signature. This is useful when you want to distinguish methods with the same name that you want to export (i.e. stop() instead of stop(boolean)).

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(
        target: new RequestController(),
        name: objName,
        operations: [
            "makeRequest": ["String"]
        ]
    )
}
```

In the snippet above, JmxBuilder would **select method makeRequest(String)** to be exported instead of the other version makeRequest() which takes no parameter. In this shorthand context, the signature is specified as a list of type (i.e. "String").

Export Operations with Explicit Descriptors

JmxBuilder supports detailed descriptors for bean operations. You can supply deep descriptor info about any operation on your bean including a name, description, method parameters, parameter type, and parameter description.

```
def objName = new ObjectName("jmx.tutorial:type=Object")
def beans = jmx.export {
    bean(target: new RequestController(), name: objName,
        operations: [
            "start": [desc: "Starts request controller"],
            "stop": [desc: "Stops the request controller"],
            "setResource": [params: ["Object"]],
            "makeRequest": [
                desc: "Executes the request.",
                params: [
                    "String": [name: "Resource", desc: "The resource to request"]
```

```
                ]
            ]
        ]
    )
}
```

The snippet above shows all the ways JmxBuilder allows you to describe an operation targeted for management:

- Operations **start() and stop()** are described by the "desc" key (this is enough since there are no params).
- In operation **setResource()** uses of a shorthand version of **params**: to describe the parameters for the method.
- **makeRequest()** uses the extended descriptor syntax to describe all aspects of the operation.

Embedding Descriptor

JmxBuilder supports the ability to **embed descriptors directly in your Groovy class**. So, instead of wrapping your description around the declared object (as we've seen here), you can embed your JMX descriptors directly in your class.

RequestControllerGroovy

```
class RequestControllerGroovy {
    // attributes
    boolean started
    int requestCount
    int resourceCount
    int requestLimit
    Map resources

    // operations
    void start() { }
    void stop(){ }
    void putResource(String name, Object resource) { }
    void makeRequest(String res) { }
    void makeRequest() { }

    static descriptor = [
        name: "jmx.builder:type=EmbeddedObject",
        operations: ["start", "stop", "putResource"],
        attributes: "*"
    ]
}

// export
jmx.export(
    bean(new RequestControllerGroovy())
```

```
)
```

There are two things going on in the code above:

- Groovy class RequestControllerGroovy is defined and includes a **static descriptor** member. That member is used to declare a JmxBuilder descriptor to describe member of the class targeted for JMX export.
- The second part of the code shows how to use JmxBuilder to export that class for management.

Timer Export

JMX standards mandate that the implementation of the API makes available a timer service. Since JMX is a component-based architecture, timers provide an excellent signalling mechanism to communicate to registered listener components in the MBeanServer. JmxBuilder supports the creation and export of timers using the same easy syntax we've seen so far.

Timer Node Syntax

```
timer(
    name:ObjectName,
    event:"...",
    message:"...",
    data:dataValue
    startDate:"now"|dateValue
    period:"99d"|"99h"|"99m"|"99s"|99
    occurrences:long
)
```

The timer() node supports several attributes:

- **name**: - Required The qualified JMX ObjectName instance (or String) for the timer.
- **event**: - The JMX event type string that will be broadcast with every timing signal (default **"jmx.builder.event"**).
- **message**: - An optional string value that can be sent to listeners.
- **data**: - An optional object that can be sent to listeners of timing signal.
- **startDate**: - When to start timer. Set of valid values ["now", date object]. Default is "now"
- **period**: - A timer's period expressed as either a number of millisecond or time unit (day, hour, minute, second). See description below.
- **occurrences**: - A number indicating the number of time to repeat timer. Default is forever.

Exporting a Timer

```
def timer = jmx.timer(name: "jmx.builder:type=Timer", event: "heartbeat", period:
"1s")
timer.start()
```

This snippet above **describes, creates, and exports a standard JMX Timer** component. Here, the **timer()** node **returns a GroovyMBean** that represents the registered timer MBean in the MBeanServer.

An **alternative way of exporting timers** is within the JmxBuilder.export() node.

```
def beans = jmx.export {
    timer(name: "jmx.builder:type=Timer1", event: "event.signal", period: "1s")
    timer(name: "jmx.builder:type=Timer2", event: "event.log", period: "1s")
}
beans[0].start()
beans[1].start()
```

Timer Period

The **timer() node supports a flexible notation** for specifying the **timer period values**. You can specify the time in second, minutes, hour, and day. The default is millisecond.

- timer(**period: 100**) = 100 millisecond
- timer(**period: "1s"**) = 1 second
- timer(**period: "1m"**) = 1 minute
- timer(**period: "1h"**) = 1 hour
- timer(**period: "1d"**) = 1 day

The node will automatically translate.

JmxBuilder and Events

An integral part of **JMX** is its **event model**. Registered management beans can **communicate with each other by broadcasting events** on the MBeanServer's event bus. **JmxBuilder provides several ways to easily listen and react to events** broadcasted on the MBeanServer's event bus. Developers can **capture any event on the bus or throw their own** to be consumed by other components registered on the MBeanServer.

Event Handling Closures

JmxBuilder leverages Groovy's use of closures to provide simple, yet elegant, mean of reacting to JMX events. JmxBuilder supports two closure signatures:

Parameterless

```
callback = { ->
    // event handling code here.
}
```

JmxBuilder executes the closure and passes no information about the event that was captured on the bus.

With Event Parameter

```
callback = { event ->
    // event handling code
}
```

JmxBuilder will pass an **"event" object to the closure** using this format. The event object contains information about the event was intercepted so that it can be handled by the handler. The parameter will contain different set of info depending on the event that was captured.

Handling Attribute onChange Event

When describing attributes (see bean() node section above), you can **provide a closure (or method pointer) for callback to be executed when the value of the attribute is updated** on the exported MBean. This gives developers an opportunity to listen to and react to state changes on the MBean.

```
jmx.export {
    bean(
        target: new RequestController(), name: "jmx.tutorial:type=Object",
        attributes: [
            "Resource": [
                readable: true, writable: true,
                onChange: { e ->
                    println e.oldValue
                    println e.newValue
                }
            ]
        ]
    )
}
```

The sample snippet above shows how to **specify an "onChange" callback closure** when describing MBean attributes. In this sample code, whenever attribute "Resource" is updated via the exported MBean, the **onChange event will be executed**.

Attribute onChange Event Object

When handling the attribute onChange event, the handler closure will receive an event object with the following info:

- event.**oldValue** - the previous attribute value before the change event.
- event.**newValue** - the new value of the attribute after the change.
- event.**attribute** - the name of the attribute on which the event occurred.
- event.**attributeType** - the data type of the attribute that causes the event.
- event.**sequenceNumber** - a numeric value representing the sequence number of event.
- event.**timeStamp** - a time stamp for the event occurrence.

Handling Operation onCall Event

Similar to mbean attributes, JmxBuilder affords developers the **ability to listen for operation invocation** on an MBean registered in the MBeaServer. JmxBuilder accepts a **callback closure that will be executed after the MBean method has invoked**.

```
class EventHandler {
    void handleStart(e){
        println e
    }
}
```

```
def handler = new EventHandler()

def beans = jmx.export {
    bean(target: new RequestController(), name: "jmx.tutorial:type=Object",
        operations: [
            "start": [
                desc:"Starts request controller",
                onCall:handler.&handleStart
            ]
        ]
    )
}
```

The snippet above **shows how to declare an "onCall" closure to be used as listener** when operation "start()" is invoked on the MBean. This sample **uses the method pointer syntax** to illustrate the versatility of JmxBuilder.

Operation onCall Event Object

When handling the operation onCall event, the callback closure will receive an event object with the following info:

- event.**event** - the event type string that was broadcasted.
- event.**source** - The object on which the method was invoked.
- event.**data** - the data type of the attribute that causes the event.
- event.**sequenceNumber** - a numeric value representing the sequence number of event.
- event.**timeStamp** - a time stamp for the event occurrence.

Listener MBean

When you export an MBean with the bean() node, you can define events the MBean can listen and react to. The bean() node provides a "listeners:" attribute that lets you define event listeners that your bean can react to.

```
def beans = jmx.export {
    timer(name: "jmx.builder:type=Timer", event: "heartbeat", period: "1s").start()
    bean(target: new RequestController(), name: "jmx.tutorial:type=Object",
        operations: "*",
        listeners: [
            heartbeat: [
                from: "jmx.builder:type=Timer",
                call: { e ->
                    println e
                }
            ]
        ]
    )
}
```

In the sample above, we see the **syntax for adding listeners to an exported MBean**.

- First, a **timer is exported** and started.
- Then, an **MBean is declared that will listen to the timer** event and do something meaningful.
- The **"heartbeat:"** name is arbitrary and has no correlation to the timer declared above.
- The **source** of the event **is specified using the "from:" attribute**.

You can also specify an **event type** you are interested in receiving from a broadcaster (since a broadcaster can be emitting multiple events).

Listening to JMX Events

In some cases, you will want to create stand-alone event listeners (not attached to exported MBeans). JmxBuilder provides the Listener() node to let you create JMX listeners that can listen to MBeanServer events. This is useful when creating JMX client applications to monitor/manage JMX agents on remote JMX MBeanServers.

Listener Node Syntax

```
jmx.listener(
    event: "...",
    from: "object name" | ObjectName,
    call: { event-> }
)
```

Here is the description of the **listener()** node attributes:

- event: An optional string that identifies the JMX event type to listen for.
- from (required): The JMX ObjectName of the component to listen to. This can be specified as a string or an instance of ObjectName.
- call: The closure to execute when the event is captured. This can also be specified as a Groovy

method pointer.

Here is an example of JmxBuilder's listener node:

```
jmx.timer(name: "jmx.builder:type=Timer", period: "1s").start()

jmx.listener(
    from: "jmx.builder:type=Timer",
    call: { e ->
        println "beep..."
    }
)
```

This example shows how you can use a stand-alone listener (outside an MBean export). Here, we **export a timer with a 1 second** resolution. Then, we specify a listener to that timer that will print "beep" every second.

Emitting JMX Events

JmxBuilder provides the **tools needed to broadcast your own events** on the MBeanServer's event bus. There are no restrictions on the event type you can broadcast. You simply **declare your emitter** and the event type that you want to send, then **broadcast your event** at any time. Any registered component in the MBeanServer can register themselves to listen to your events.

Emitter Syntax

```
jmx.emitter(name:"Object:Name", event:"type")
```

The attributes for the node Emitter() can be summarized as follows:

- name: an optional JMX ObjectName used to register your emitter in the MBeanServer. Default is jmx.builder:type=Emitter,name=Emitter@OBJECT_HASH_VALUE
- event: an option string value that describes the JMX event type. Default is **"jmx.builder.event.emitter"**.

Declare the Emitter

```
def emitter = jmx.emitter()
```

The snippet **declares the emitter using implicit descriptor syntax**. JmxBuilder will do the followings:

- Create and register an emitter MBean with a default ObjectName.
- Setup a **default event type** with value **"jmx.builder.event.emitter"**.
- Return a GroovyMBean representing the emitter.

As with other nodes in the builder, **you can override all keys in the emitter() node**. You can specify the **ObjectName** and the **event type**.

Broadcast Event

Once you have declared your emitter, you can broadcast your event.

```
emitter.send()
```

The sample above shows the **emitter sending an event**, once it has been declared. Any JMX component registered in the MBeanServer can register to receive message from this emitter.

Sending Event Objects

You can optionally pass data to the receiver when you send the message.

```
emitter.send("Hello!")
```

If you use an **event listener closure (see above) that accepts a parameter**, you can access that value.

Further JMX Information

- Monitoring the Java Virtual Machine
- Using Groovy for System Management
- Groovier jconsole!
- JMX Scripts with Eclipse Monkey
- Using JMX to monitor Apache ActiveMQ

Creating Swing UIs

Creating Swing UIs is made easy thanks to the use of SwingBuilder.

Security

Security is a complex and multi-faceted issue and needs to be addressed in a holistic way. Groovy offers some features to improve security, but organisations concerned about security should already be addressing other necessary aspects such as network security, file-system security, operating system security, database security, passwords and potentially encryption.

Also, since Groovy runs on the JDK and optionally uses other library dependencies, users should ensure their JDK and all dependencies are up-to-date with respect to the latest security fixes.

With regard to security issues that may affect the Groovy project itself, the project follows the Apache general guidelines for handling security vulnerabilities. See also the project's security policy and list of past vulnerabilities.

By virtue of running on the JVM and following various Java conventions, Groovy programs offer some of the same security features as Java programs, including:

- programs cannot access arbitrary memory locations
- final variables cannot be changed
- array bounds are checked
- class loaders perform bytecode verification when loading classes
- casting cannot be done to an incompatible class
- access is available to APIs for encryption and authentication

Special security support is provided through:

- groovy.lang.GroovyShell, groovy.lang.GroovyClassLoader and other parts of the Groovy runtime fully support the Java security manager which allows you to sandbox script execution with a security policy. (Note: this functionality might be scaled back in future Groovy versions or when running on particular JDK versions in line with JEP 411)
- org.codehaus.groovy.control.customizers.SecureASTCustomizer secures source code by controlling what code constructs are permitted or prohibited in a code base (or part of a code base)
- Default XML processing has secure processing enabled and doctype definitions disabled
- Groovy's SQL processing features provide support to guard against SQL injection
- Temporary directory creation protects against known security vulnerabilities such as privilege escalation if scripts are stored in operating system temp directories

Design patterns in Groovy

Using design patterns with Java is a well-established topic. Design patterns also apply to Groovy:

- some patterns carry over directly (and can make use of normal Groovy syntax improvements for greater readability)
- some patterns are no longer required because they are built right into the language or because Groovy supports a better way of achieving the intent of the pattern
- some patterns that have to be expressed at the design level in other languages can be implemented directly in Groovy (due to the way Groovy can blur the distinction between design and implementation)

Patterns

Abstract Factory Pattern

The Abstract Factory Pattern provides a way to encapsulate a group of individual factories that have a common theme. It embodies the intent of a normal factory, i.e. remove the need for code using an interface to know the concrete implementation behind the interface, but applies to a set of interfaces and selects an entire family of concrete classes which implement those interfaces.

As an example, I might have interfaces Button, TextField and Scrollbar. I might have WindowsButton, MacButton, FlashButton as concrete classes for Button. I might have WindowsScrollBar, MacScrollBar and FlashScrollBar as concrete implementations for ScrollBar. Using the Abstract Factory Pattern should allow me to select which windowing system (i.e. Windows, Mac, Flash) I want to use once and from then on should be able to write code that references the interfaces but is always using the appropriate concrete classes (all from the one windowing system) under the covers.

Example

Suppose we want to write a game system. We might note that many games have very similar features and control.

We decide to try to split the common and game-specific code into separate classes.

First let's look at the game-specific code for a Two-up game:

```
class TwoupMessages {
    def welcome = 'Welcome to the twoup game, you start with $1000'
    def done = 'Sorry, you have no money left, goodbye'
}

class TwoupInputConverter {
    def convert(input) { input.toInteger() }
}

class TwoupControl {
    private money = 1000
    private random = new Random()
    private tossWasHead() {
        def next = random.nextInt()
        return next % 2 == 0
    }
    def moreTurns() {
        if (money > 0) {
            println "You have $money, how much would you like to bet?"
            return true
        }

        false
    }
    def play(amount) {
        def coin1 = tossWasHead()
        def coin2 = tossWasHead()
        if (coin1 && coin2) {
            money += amount
            println 'You win'
        } else if (!coin1 && !coin2) {
```

```
            money -= amount
            println 'You lose'
        } else {
            println 'Draw'
        }
    }
}
```

Now, let's look at the game-specific code for a number guessing game:

```
class GuessGameMessages {
    def welcome = 'Welcome to the guessing game, my secret number is between 1 and
100'
    def done = 'Correct'
}

class GuessGameInputConverter {
    def convert(input) { input.toInteger() }
}

class GuessGameControl {
    private lower = 1
    private upper = 100
    private guess = new Random().nextInt(upper - lower) + lower
    def moreTurns() {
        def done = (lower == guess || upper == guess)
        if (!done) {
            println "Enter a number between $lower and $upper"
        }

        !done
    }
    def play(nextGuess) {
        if (nextGuess <= guess) {
            lower = [lower, nextGuess].max()
        }
        if (nextGuess >= guess) {
            upper = [upper, nextGuess].min()
        }
    }
}
```

Now, let's write our factory code:

```
def guessFactory = [messages: GuessGameMessages, control: GuessGameControl, converter:
GuessGameInputConverter]
def twoupFactory = [messages: TwoupMessages, control: TwoupControl, converter:
TwoupInputConverter]
```

```
class GameFactory {
    def static factory
    def static getMessages() { return factory.messages.newInstance() }
    def static getControl() { return factory.control.newInstance() }
    def static getConverter() { return factory.converter.newInstance() }
}
```

The important aspect of this factory is that it allows selection of an entire family of concrete classes.

Here is how we would use the factory:

```
GameFactory.factory = twoupFactory
def messages = GameFactory.messages
def control = GameFactory.control
def converter = GameFactory.converter
println messages.welcome
def reader = new BufferedReader(new InputStreamReader(System.in))
while (control.moreTurns()) {
    def input = reader.readLine().trim()
    control.play(converter.convert(input))
}
println messages.done
```

Note that the first line configures which family of concrete game classes we will use. It's not important that we selected which family to use by using the factory property as shown in the first line. Other ways would be equally valid examples of this pattern. For example, we may have asked the user which game they wanted to play or determined which game from an environment setting.

With the code as shown, the game might look like this when run:

```
Welcome to the twoup game, you start with $1000
You have 1000, how much would you like to bet?
300
Draw
You have 1000, how much would you like to bet?
700
You win
You have 1700, how much would you like to bet?
1700
You lose
Sorry, you have no money left, goodbye
```

If we change the first line of the script to GameFactory.factory = guessFactory, then the sample run might look like this:

```
Welcome to the guessing game, my secret number is between 1 and 100
Enter a number between 1 and 100
```

```
75
Enter a number between 1 and 75
35
Enter a number between 1 and 35
15
Enter a number between 1 and 15
5
Enter a number between 5 and 15
10
Correct
```

Adapter Pattern

The Adapter Pattern (sometimes called the wrapper pattern) allows objects satisfying one interface to be used where another type of interface is expected. There are two typical flavours of the pattern: the *delegation* flavour and the *inheritance* flavour.

Delegation Example

Suppose we have the following classes:

```
class SquarePeg {
    def width
}

class RoundPeg {
    def radius
}

class RoundHole {
    def radius
    def pegFits(peg) {
        peg.radius <= radius
    }
    String toString() { "RoundHole with radius $radius" }
}
```

We can ask the `RoundHole` class if a `RoundPeg` fits in it, but if we ask the same question for a `SquarePeg`, then it will fail because the `SquarePeg` class doesn't have a `radius` property (i.e. doesn't satisfy the required interface).

To get around this problem, we can create an adapter to make it appear to have the correct interface. It would look like this:

```
class SquarePegAdapter {
    def peg
    def getRadius() {
        Math.sqrt(((peg.width / 2) ** 2) * 2)
    }
```

```
    String toString() {
        "SquarePegAdapter with peg width $peg.width (and notional radius $radius)"
    }
}
```

We can use the adapter like this:

```
def hole = new RoundHole(radius: 4.0)
(4..7).each { w ->
    def peg = new SquarePegAdapter(peg: new SquarePeg(width: w))
    if (hole.pegFits(peg)) {
        println "peg $peg fits in hole $hole"
    } else {
        println "peg $peg does not fit in hole $hole"
    }
}
```

Which results in the following output:

```
peg SquarePegAdapter with peg width 4 (and notional radius 2.8284271247461903) fits in
hole RoundHole with radius 4.0
peg SquarePegAdapter with peg width 5 (and notional radius 3.5355339059327378) fits in
hole RoundHole with radius 4.0
peg SquarePegAdapter with peg width 6 (and notional radius 4.242640687119285) does not
fit in hole RoundHole with radius 4.0
peg SquarePegAdapter with peg width 7 (and notional radius 4.949747468305833) does not
fit in hole RoundHole with radius 4.0
```

Inheritance Example

Let's consider the same example again using inheritance. First, here are the original classes (unchanged):

```
class SquarePeg {
    def width
}

class RoundPeg {
    def radius
}

class RoundHole {
    def radius
    def pegFits(peg) {
        peg.radius <= radius
    }
    String toString() { "RoundHole with radius $radius" }
```

```
}
```

An adapter using inheritance:

```
class SquarePegAdapter extends SquarePeg {
    def getRadius() {
        Math.sqrt(((width / 2) ** 2) * 2)
    }
    String toString() {
        "SquarePegAdapter with width $width (and notional radius $radius)"
    }
}
```

Using the adapter:

```
def hole = new RoundHole(radius: 4.0)
(4..7).each { w ->
    def peg = new SquarePegAdapter(width: w)
    if (hole.pegFits(peg)) {
        println "peg $peg fits in hole $hole"
    } else {
        println "peg $peg does not fit in hole $hole"
    }
}
```

The output:

```
peg SquarePegAdapter with width 4 (and notional radius 2.8284271247461903) fits in
hole RoundHole with radius 4.0
peg SquarePegAdapter with width 5 (and notional radius 3.5355339059327378) fits in
hole RoundHole with radius 4.0
peg SquarePegAdapter with width 6 (and notional radius 4.242640687119285) does not fit
in hole RoundHole with radius 4.0
peg SquarePegAdapter with width 7 (and notional radius 4.949747468305833) does not fit
in hole RoundHole with radius 4.0
```

Adapting using Closures

As a variation of the previous examples, we could instead define the following interface:

```
interface RoundThing {
    def getRadius()
}
```

We can then define an adapter as a closure as follows:

```
def adapter = {
    p -> [getRadius: { Math.sqrt(((p.width / 2) ** 2) * 2) }] as RoundThing
}
```

And use it like this:

```
def peg = new SquarePeg(width: 4)
if (hole.pegFits(adapter(peg))) {
    // ... as before
}
```

Adapting using the ExpandoMetaClass

As of Groovy 1.1, there is a built-in MetaClass which can automatically add properties and methods dynamically.

Here is how the example would work using that feature:

```
def peg = new SquarePeg(width: 4)
peg.metaClass.radius = Math.sqrt(((peg.width / 2) ** 2) * 2)
```

After you create a peg object, you can simply add a property to it on the fly. No need to change the original class and no need for an adapter class.

Bouncer Pattern

The Bouncer Pattern describes usage of a method whose sole purpose is to either throw an exception (when particular conditions hold) or do nothing. Such methods are often used to defensively guard pre-conditions of a method.

When writing utility methods, you should always guard against faulty input arguments. When writing internal methods, you may be able to ensure that certain pre-conditions always hold by having sufficient unit tests in place. Under such circumstances, you may reduce the desirability to have guards on your methods.

Groovy differs from other languages in that you frequently use the `assert` method within your methods rather than having a large number of utility checker methods or classes.

Null Checking Example

We might have a utility method such as:

```
class NullChecker {
    static check(name, arg) {
        if (arg == null) {
            throw new IllegalArgumentException(name + ' is null')
        }
```

```
    }
}
```

And we would use it like this:

```
void doStuff(String name, Object value) {
    NullChecker.check('name', name)
    NullChecker.check('value', value)
    // do stuff
}
```

But a more Groovy way to do this would simply be like this:

```
void doStuff(String name, Object value) {
    assert name != null, 'name should not be null'
    assert value != null, 'value should not be null'
    // do stuff
}
```

Validation Example

As an alternative example, we might have this utility method:

```
class NumberChecker {
    static final String NUMBER_PATTERN = "\\\\d+(\\\\.\\\\d+(E-?\\\\d+)?)?"
    static isNumber(str) {
        if (!str ==~ NUMBER_PATTERN) {
            throw new IllegalArgumentException("Argument '$str' must be a number")
        }
    }
    static isNotZero(number) {
        if (number == 0) {
            throw new IllegalArgumentException('Argument must not be 0')
        }
    }
}
```

And we would use it like this:

```
def stringDivide(String dividendStr, String divisorStr) {
    NumberChecker.isNumber(dividendStr)
    NumberChecker.isNumber(divisorStr)
    def dividend = dividendStr.toDouble()
    def divisor = divisorStr.toDouble()
    NumberChecker.isNotZero(divisor)
    dividend / divisor
```

```
}

println stringDivide('1.2E2', '3.0')
// => 40.0
```

But with Groovy we could just as easily use:

```
def stringDivide(String dividendStr, String divisorStr) {
    assert dividendStr =~ NumberChecker.NUMBER_PATTERN
    assert divisorStr =~ NumberChecker.NUMBER_PATTERN
    def dividend = dividendStr.toDouble()
    def divisor = divisorStr.toDouble()
    assert divisor != 0, 'Divisor must not be 0'
    dividend / divisor
}
```

Chain of Responsibility Pattern

In the Chain of Responsibility Pattern, objects using and implementing an interface (one or more methods) are intentionally loosely coupled. A set of objects that *implement* the interface are organised in a list (or in rare cases a tree). Objects using the interface make requests from the first *implementor* object. It will decide whether to perform any action itself and whether to pass the request further down the line in the list (or tree). Sometimes a default implementation for some request is also coded into the pattern if none of the implementors respond to the request.

Example using traditional classes

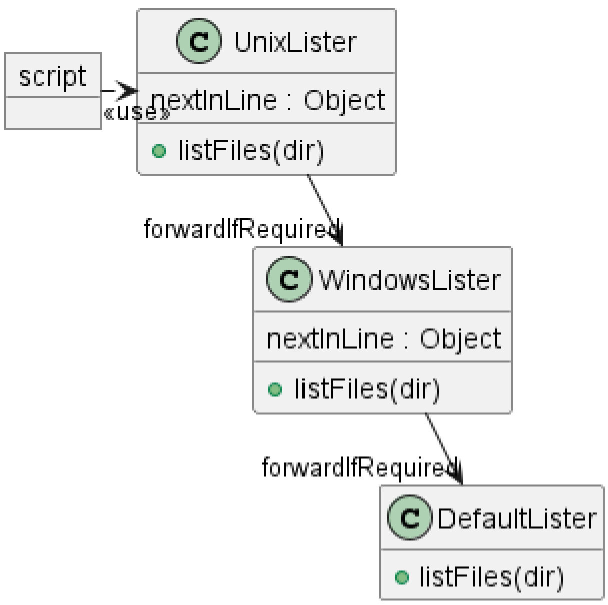
In this example, the script sends requests to the `lister` object. The `lister` points to a `UnixLister` object. If it can't handle the request, it sends the request to the `WindowsLister`. If it can't handle the request, it sends the request to the `DefaultLister`.

```
class UnixLister {
    private nextInLine
    UnixLister(next) { nextInLine = next }
    def listFiles(dir) {
        if (System.getProperty('os.name') == 'Linux') {
            println "ls $dir".execute().text
        } else {
            nextInLine.listFiles(dir)
        }
    }
}

class WindowsLister {
    private nextInLine
    WindowsLister(next) { nextInLine = next }
    def listFiles(dir) {
        if (System.getProperty('os.name').startsWith('Windows')) {
```

```
            println "cmd.exe /c dir $dir".execute().text
        } else {
            nextInLine.listFiles(dir)
        }
    }
}

class DefaultLister {
    def listFiles(dir) {
        new File(dir).eachFile { f -> println f }
    }
}

def lister = new UnixLister(new WindowsLister(new DefaultLister()))

lister.listFiles('Downloads')
```

The output will be a list of files (with slightly different format depending on the operating system).

Here is a UML representation:



Example using simplifying strategies

For simple cases, consider simplifying your code by not requiring the chain of classes. Instead, use Groovy truth and the elvis operator as shown here:

```
String unixListFiles(dir) {
    if (System.getProperty('os.name') == 'Linux') {
        "ls $dir".execute().text
    }
}

String windowsListFiles(dir) {
```

```
    if (System.getProperty('os.name').startsWith('Windows')) {
        "cmd.exe /c dir $dir".execute().text
    }
}

String defaultListFiles(dir) {
    new File(dir).listFiles().collect{ f -> f.name }.join('\\n')
}

def dir = 'Downloads'
println unixListFiles(dir) ?: windowsListFiles(dir) ?: defaultListFiles(dir)
```

Or Groovy's switch as shown here:

```
String listFiles(dir) {
    switch(dir) {
    case { System.getProperty('os.name') == 'Linux' }:
        return "ls $dir".execute().text
    case { System.getProperty('os.name').startsWith('Windows') }:
        return "cmd.exe /c dir $dir".execute().text
    default:
        new File(dir).listFiles().collect{ f -> f.name }.join('\\n')
    }
}

println listFiles('Downloads')
```

Alternatively, for Groovy 3+, consider using streams of lambdas as shown here:

```
Optional<String> unixListFiles(String dir) {
    Optional.ofNullable(dir)
        .filter(d -> System.getProperty('os.name') == 'Linux')
        .map(d -> "ls $d".execute().text)
}

Optional<String> windowsListFiles(String dir) {
    Optional.ofNullable(dir)
        .filter(d -> System.getProperty('os.name').startsWith('Windows'))
        .map(d -> "cmd.exe /c dir $d".execute().text)
}

Optional<String> defaultListFiles(String dir) {
    Optional.ofNullable(dir)
        .map(d -> new File(d).listFiles().collect{ f -> f.name }.join('\\n'))
}

def dir = 'Downloads'
def handlers = [this::unixListFiles, this::windowsListFiles, this::defaultListFiles]
println handlers.stream()
```

```
    .map(f -> f(dir))
    .filter(Optional::isPresent)
    .map(Optional::get)
    .findFirst()
    .get()
```

When not to use

If your use of chain of responsibility involves frequent use of the `instanceof` operator, like here:

```
import static Math.PI as π
abstract class Shape {
    String name
}
class Polygon extends Shape {
    String name
    double lengthSide
    int numSides
}
class Circle extends Shape {
    double radius
}

class CircleAreaCalculator {
    def next
    def area(shape) {
        if (shape instanceof Circle) {              ①
            return shape.radius ** 2 * π
        } else {
            next.area(shape)
        }
    }
}
class SquareAreaCalculator {
    def next
    def area(shape) {
        if (shape instanceof Polygon && shape.numSides == 4) {      ①
            return shape.lengthSide ** 2
        } else {
            next.area(shape)
        }
    }
}
class DefaultAreaCalculator {
    def area(shape) {
        throw new IllegalArgumentException("Don't know how to calculate area for
$shape")
    }
}
```

```
def chain = new CircleAreaCalculator(next: new SquareAreaCalculator(next: new
DefaultAreaCalculator()))
def shapes = [
    new Circle(name: 'Circle', radius: 5.0),
    new Polygon(name: 'Square', lengthSide: 10.0, numSides: 4)
]
shapes.each { println chain.area(it) }
```

① instanceof code smell

It could indicate that instead of using the chain of responsibility pattern, you might consider using richer types, perhaps in combination with Groovy's multimethods. For example, perhaps this:

```
// ...
class Square extends Polygon {
    // ...
}

double area(Circle c) {
    c.radius ** 2 * π
}

double area(Square s) {
    s.lengthSide ** 2
}

def shapes = [
    new Circle(radius: 5.0),
    new Square(lengthSide: 10.0, numSides: 4)
]
shapes.each { println area(it) }
```

or using more traditional object-oriented style like this:

```
import static Math.PI as π
interface Shape {
    double area()
}
abstract class Polygon implements Shape {
    double lengthSide
    int numSides
    abstract double area()
}
class Circle implements Shape {
    double radius
    double area() {
        radius ** 2 * π
    }
}
```

```
class Square extends Polygon {
    // ...
    double area() {
        lengthSide ** 2
    }
}

def shapes = [
    new Circle(radius: 5.0),
    new Square(lengthSide: 10.0, numSides: 4)
]
shapes.each { println it.area() }
```

Going further

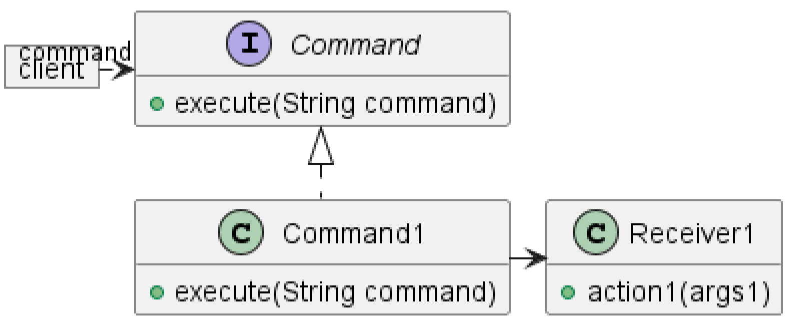
Other variations to this pattern:

- we could have an explicit interface in the traditional example, e.g. `Lister`, to statically type the implementations but because of *duck-typing* this is optional
- we could use a chain tree instead of a list, e.g. `if (animal.hasBackbone())` delegate to `VertebrateHandler` else delegate to `InvertebrateHandler`
- we could always pass down the chain even if we processed a request (no early return)
- we could decide at some point to not respond and not pass down the chain (pre-emptive abort)
- we could use Groovy's meta-programming capabilities to pass unknown methods down the chain, e.g. combine chain of responsibility with the use of `methodMissing`

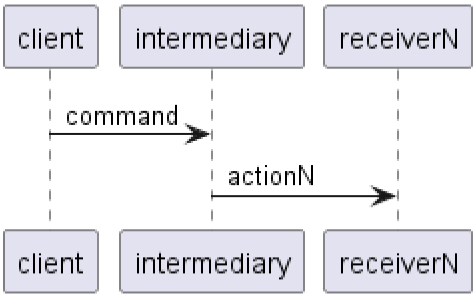
Command Pattern

The Command Pattern is a pattern for loosely coupling a client object which wants to execute a series of commands and receiver objects which enact those commands. Instead of talking to receivers directly, clients interact with an intermediary object which then relays the necessary commands to the receivers. The pattern is in common use within the JDK, for example the api:javax.swing.Action[] class in Swing decouples swing code from receivers like buttons, menu items and panels.

The class diagram showing the typical classes is:



The sequence of interactions is as shown below for an arbitrary receiver:



Example with traditional classes

The relevant classes required for turning a light on and off (see the example in the earlier wikipedia reference) would be as follows:

```
interface Command {
    void execute()
}

// invoker class
class Switch {
    private final Map<String, Command> commandMap = new HashMap<>()

    void register(String commandName, Command command) {
        commandMap[commandName] = command
    }

    void execute(String commandName) {
        Command command = commandMap[commandName]
        if (!command) {
            throw new IllegalStateException("no command registered for " +
commandName)
        }
        command.execute()
    }
}

// receiver class
class Light {
    void turnOn() {
        println "The light is on"
    }

    void turnOff() {
        println "The light is off"
    }
}

class SwitchOnCommand implements Command {
    Light light

    @Override // Command
```

```
    void execute() {
        light.turnOn()
    }
}

class SwitchOffCommand implements Command {
    Light light

    @Override // Command
    void execute() {
        light.turnOff()
    }
}

Light lamp = new Light()
Command switchOn = new SwitchOnCommand(light: lamp)
Command switchOff = new SwitchOffCommand(light: lamp)

Switch mySwitch = new Switch()
mySwitch.register("on", switchOn)
mySwitch.register("off", switchOff)

mySwitch.execute("on")
mySwitch.execute("off")
```

Our client scripts sends `execute` commands to an intermediary and knows nothing about any specific receivers, or any specific action method names and arguments.

Simplifying variations

Given that Groovy has first-class function support, we can do away with the actual command classes (like `SwitchOnCommand`) by instead using closures as shown here:

```
interface Command {
    void execute()
}

// invoker class
class Switch {
    private final Map<String, Command> commandMap = [:]

    void register(String commandName, Command command) {
        commandMap[commandName] = command
    }

    void execute(String commandName) {
        Command command = commandMap[commandName]
        if (!command) {
            throw new IllegalStateException("no command registered for $commandName")
        }
```

```
        command.execute()
    }
}

// receiver class
class Light {
    void turnOn() {
        println 'The light is on'
    }

    void turnOff() {
        println 'The light is off'
    }
}

Light lamp = new Light()

Switch mySwitch = new Switch()
mySwitch.register("on", lamp.&turnOn)       ①
mySwitch.register("off", lamp.&turnOff)     ①

mySwitch.execute("on")
mySwitch.execute("off")
```

① Command closures (here method closures) but could be lambdas/method references for Groovy 3+

We can simplify further using the JDK's existing `Runnable` interface and using a switch map rather than a separate `Switch` class as shown here:

```
class Light {
    void turnOn() {
        println 'The light is on'
    }

    void turnOff() {
        println 'The light is off'
    }
}

class Door {
    static void unlock() {
        println 'The door is unlocked'
    }
}

Light lamp = new Light()
Map<String, Runnable> mySwitch = [
    on: lamp::turnOn,
    off: lamp::turnOff,
```

```
    unlock: Door::unlock
]

mySwitch.on()
mySwitch.off()
mySwitch.unlock()
```

We have added an additional `Door` receiver to illustrate how to expand the original example. Running this script results in:

```
The light is on
The light is off
The door is unlocked
```

As a variation, if the command names aren't important to us, we can forgo using the switch map and just have a list of tasks to invoke as shown here:

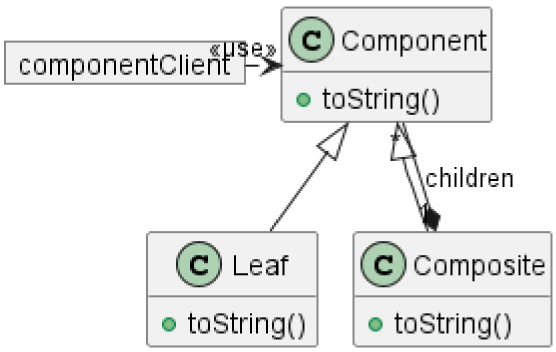
```
// ...
List<Runnable> tasks = [lamp::turnOn, lamp::turnOff, Door::unlock]
tasks.each{ it.run() }
```

Composite Pattern

The Composite Pattern allows you to treat single instances of an object the same way as a group of objects. The pattern is often used with hierarchies of objects. Typically, one or more methods should be callable in the same way for either *leaf* or *composite* nodes within the hierarchy. In such a case, composite nodes typically invoke the same named method for each of their children nodes.

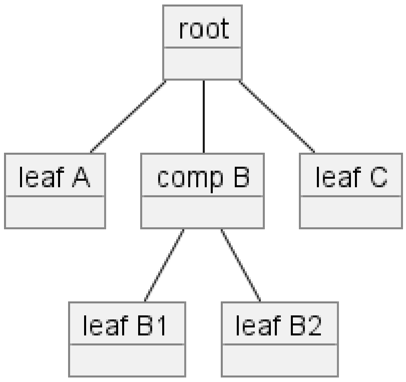
Example

Consider this usage of the composite pattern where we want to call `toString()` on either `Leaf` or `Composite` objects.



In Java, the `Component` class is essential as it provides the type used for both leaf and composite nodes. In Groovy, because of duck-typing, we don't need it for that purpose, however, it can still serve as a useful place to place common behaviour between the leaf and composite nodes.

For our purposes, we will assemble the following hierarchy of components.



Here is the code:

```
abstract class Component {
    def name
    def toString(indent) {
        ("-" * indent) + name
    }
}

class Composite extends Component {
    private children = []
    def toString(indent) {
        def s = super.toString(indent)
        children.each { child ->
            s += "\\n" + child.toString(indent + 1)
        }
        s
    }
    def leftShift(component) {
        children << component
    }
}

class Leaf extends Component { }

def root = new Composite(name: "root")
root << new Leaf(name: "leaf A")
def comp = new Composite(name: "comp B")
root << comp
root << new Leaf(name: "leaf C")
comp << new Leaf(name: "leaf B1")
comp << new Leaf(name: "leaf B2")
println root.toString(0)
```

Here is the resulting output:

```
root
-leaf A
-comp B
--leaf B1
--leaf B2
-leaf C
```

Decorator Pattern

The Decorator Pattern provides a mechanism to embellish the behaviour of an object without changing its essential interface. A decorated object should be able to be substituted wherever the original (non-decorated) object was expected. Decoration typically does not involve modifying the source code of the original object and decorators should be able to be combined in flexible ways to produce objects with several embellishments.

Traditional Example

Suppose we have the following `Logger` class.

```
class Logger {
    def log(String message) {
        println message
    }
}
```

There might be times when it is useful to timestamp a log message, or times when we might want to change the case of the message. We could try to build all of this functionality into our `Logger` class. If we did that, the `Logger` class would start to be very complex. Also, everyone would obtain all of the features even when they might want only a small subset of the features. Finally, feature interaction would become quite difficult to control.

To overcome these drawbacks, we instead define two decorator classes. Uses of the `Logger` class are free to embellish their base logger with zero or more decorator classes in whatever order they desire. The classes look like this:

```
class TimeStampingLogger extends Logger {
    private Logger logger
    TimeStampingLogger(logger) {
        this.logger = logger
    }
    def log(String message) {
        def now = Calendar.instance
        logger.log("$now.time: $message")
    }
}

class UpperLogger extends Logger {
```

```
    private Logger logger
    UpperLogger(logger) {
        this.logger = logger
    }
    def log(String message) {
        logger.log(message.toUpperCase())
    }
}
```

We can use the decorators like so:

```
def logger = new UpperLogger(new TimeStampingLogger(new Logger()))
logger.log("G'day Mate")
// => Tue May 22 07:13:50 EST 2007: G'DAY MATE
```

You can see that we embellish the logger behaviour with both decorators. Because of the order we chose to apply the decorators, our log message comes out capitalised and the timestamp is in normal case. If we swap the order around, let's see what happens:

```
logger = new TimeStampingLogger(new UpperLogger(new Logger()))
logger.log('Hi There')
// => TUE MAY 22 07:13:50 EST 2007: HI THERE
```

Now the timestamp itself has also been changed to be uppercase.

Simplifying with closures or lambdas

Closures make it easy to represent code. We can use that fact to make a general purpose logger class that accepts the decoration code as a closure. This saves us defining many decoration classes.

```
class DecoratingLogger {
    def decoration = Closure.IDENTITY

    def log(String message) {
        println decoration(message)
    }
}

def upper = { it.toUpperCase() }
def stamp = { "$Calendar.instance.time: $it" }
def logger = new DecoratingLogger(decoration: stamp << upper)
logger.log("G'day Mate")
// Sat Aug 29 15:28:29 AEST 2020: G'DAY MATE
```

We can use the same approach with lambdas:

```
import java.util.function.Function

class DecoratingLogger {
    Function<String, String> decoration = Function.identity()

    def log(String message) {
        println decoration.apply(message)
    }
}

Function<String, String> upper = s -> s.toUpperCase()
Function<String, String> stamp = s -> "$Calendar.instance.time: $s"
def logger = new DecoratingLogger(decoration: upper.andThen(stamp))
logger.log("G'day Mate")
// => Sat Aug 29 15:38:28 AEST 2020: G'DAY MATE
```

A touch of dynamic behaviour

Our previous decorators were specific to `Logger` objects. We can use Groovy's Meta-Object Programming capabilities to create a decorator which is far more general purpose in nature. Consider this class:

```
class GenericLowerDecorator {
    private delegate
    GenericLowerDecorator(delegate) {
        this.delegate = delegate
    }
    def invokeMethod(String name, args) {
        def newargs = args.collect { arg ->
            if (arg instanceof String) {
                return arg.toLowerCase()
            } else {
                return arg
            }
        }
        delegate.invokeMethod(name, newargs)
    }
}
```

It takes any class and decorates it so that any `String` method parameter will automatically be changed to lower case.

```
logger = new GenericLowerDecorator(new TimeStampingLogger(new Logger()))
logger.log('IMPORTANT Message')
// => Tue May 22 07:27:18 EST 2007: important message
```

Just be careful with ordering here. The original decorators were restricted to decorating `Logger` objects. This decorator works with any object type, so we can't swap the ordering around, i.e. this won't work:

```
// Can't mix and match Interface-Oriented and Generic decorators
// logger = new TimeStampingLogger(new GenericLowerDecorator(new Logger()))
```

We could overcome this limitation be generating an appropriate Proxy type at runtime but we won't complicate the example here.

Runtime behaviour embellishment

You can also consider using the `ExpandoMetaClass` from Groovy 1.1 to dynamically embellish a class with behaviour. This isn't the normal style of usage of the decorator pattern (it certainly isn't nearly as flexible) but may help you to achieve similar results in some cases without creating a new class.

Here's what the code looks like:

```
// current mechanism to enable ExpandoMetaClass
GroovySystem.metaClassRegistry.metaClassCreationHandle = new
ExpandoMetaClassCreationHandle()

def logger = new Logger()
logger.metaClass.log = { String m -> println 'message: ' + m.toUpperCase() }
logger.log('x')
// => message: X
```

This achieves a similar result to applying a single decorator but we have no way to easily apply and remove embellishments on the fly.

More dynamic decorating

Suppose we have a calculator class (Actually any class would do).

```
class Calc {
    def add(a, b) { a + b }
}
```

We might be interested in observing usage of the class over time. If it is buried deep within our codebase, it might be hard to determine when it is being called and with what parameters. Also, it might be hard to know if it is performing well. We can easily make a generic tracing decorator that prints out tracing information whenever any method on the `Calc` class is called and also provide timing information about how long it took to execute. Here is the code for the tracing decorator:

```
class TracingDecorator {
    private delegate
    TracingDecorator(delegate) {
        this.delegate = delegate
```

```
    }
    def invokeMethod(String name, args) {
        println "Calling $name$args"
        def before = System.currentTimeMillis()
        def result = delegate.invokeMethod(name, args)
        println "Got $result in ${System.currentTimeMillis()-before} ms"
        result
    }
}
```

Here is how to use the class in a script:

```
def tracedCalc = new TracingDecorator(new Calc())
assert 15 == tracedCalc.add(3, 12)
```

And here is what you would see after running this script:

```
Calling add{3, 12}
Got 15 in 31 ms
```

Decorating with an Interceptor

The above timing example hooks into the lifecycle of Groovy objects (via `invokeMethod`). This is such an important style performing meta-programming that Groovy has special support for this style of decorating using *interceptors*.

Groovy even comes with a built-in `TracingInterceptor`. We can extend the built-in class like this:

```
class TimingInterceptor extends TracingInterceptor {
    private beforeTime
    def beforeInvoke(object, String methodName, Object[] arguments) {
        super.beforeInvoke(object, methodName, arguments)
        beforeTime = System.currentTimeMillis()
    }
    Object afterInvoke(Object object, String methodName, Object[] arguments, Object
result) {
        super.afterInvoke(object, methodName, arguments, result)
        def duration = System.currentTimeMillis() - beforeTime
        writer.write("Duration: $duration ms\\n")
        writer.flush()
        result
    }
}
```

Here is an example of using this new class:

```
def proxy = ProxyMetaClass.getInstance(Calc)
proxy.interceptor = new TimingInterceptor()
proxy.use {
    assert 7 == new Calc().add(1, 6)
}
```

And here is the output:

```
before Calc.ctor()
after  Calc.ctor()
Duration: 0 ms
before Calc.add(java.lang.Integer, java.lang.Integer)
after  Calc.add(java.lang.Integer, java.lang.Integer)
Duration: 2 ms
```

Decorating with java.lang.reflect.Proxy

If you are trying to decorate an object (i.e. just a particular instance of the class, not the class generally), then you can use Java's `java.lang.reflect.Proxy`. Groovy makes working with this easier than just Java. Below is a code sample taken out of a grails project that wraps a `java.sql.Connection` so that it's close method is a no-op:

```
protected Sql getGroovySql() {
    final Connection con = session.connection()
    def invoker = { object, method, args ->
        if (method.name == "close") {
            log.debug("ignoring call to Connection.close() for use by groovy.sql.Sql")
        } else {
            log.trace("delegating $method")
            return con.invokeMethod(method.name, args)
        }
    } as InvocationHandler;
    def proxy = Proxy.newProxyInstance( getClass().getClassLoader(), [Connection] as
Class[], invoker )
    return new Sql(proxy)
}
```

If there were many methods to intercept, then this approach could be modified to look up closure in a map by method name and invoke it.

Decorating with Spring

The Spring Framework allows decorators to be applied with *interceptors* (you may have heard the terms *advice* or *aspect*). You can leverage this mechanism from Groovy as well.

First define a class that you want to decorate (we'll also use an interface as is normal Spring practice):

Here's the interface:

```
interface Calc {
    def add(a, b)
}
```

Here's the class:

```
class CalcImpl implements Calc {
    def add(a, b) { a + b }
}
```

Now, we define our wiring in a file called `beans.xml` as follows:

```
<?xml version="1.0" encoding="UTF-8"?>
<beans xmlns="http://www.springframework.org/schema/beans"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns:lang="http://www.springframework.org/schema/lang"
    xsi:schemaLocation="
        http://www.springframework.org/schema/beans
https://www.springframework.org/schema/beans/spring-beans.xsd
        http://www.springframework.org/schema/lang
https://www.springframework.org/schema/lang/spring-lang.xsd">

    <bean id="performanceInterceptor" autowire="no"
          class="org.springframework.aop.interceptor.PerformanceMonitorInterceptor">
        <property name="loggerName" value="performance"/>
    </bean>
    <bean id="calc" class="util.CalcImpl"/>
    <bean class=
"org.springframework.aop.framework.autoproxy.BeanNameAutoProxyCreator">
        <property name="beanNames" value="calc"/>
        <property name="interceptorNames" value="performanceInterceptor"/>
    </bean>
</beans>
```

Now, our script looks like this:

```
@Grab('org.springframework:spring-context:5.2.8.RELEASE')
import org.springframework.context.support.ClassPathXmlApplicationContext

def ctx = new ClassPathXmlApplicationContext('beans.xml')
def calc = ctx.getBean('calc')
println calc.add(3, 25)
```

And when we run it, we see the results:

```
21/05/2007 23:02:35 org.springframework.aop.interceptor.PerformanceMonitorInterceptor
invokeUnderTrace
FINEST: StopWatch 'util.Calc.add': running time (millis) = 16
```

You may have to adjust your `logging.properties` file for messages at log level `FINEST` to be displayed.

Asynchronous Decorators using GPars

The following example is inspired by some of the early example code for the Panini programming language. These days, you'll see this style used with async functions in JavaScript.

```
@Grab('org.codehaus.gpars:gpars:0.10')
import static groovyx.gpars.GParsPool.withPool

interface Document {
    void print()
    String getText()
}

class DocumentImpl implements Document {
    def document
    void print() { println document }
    String getText() { document }
}

def words(String text) {
    text.replaceAll('[^a-zA-Z]', ' ').trim().split("\\\\s+")*.toLowerCase()
}

def avgWordLength = {
    def words = words(it.text)
    sprintf "Avg Word Length: %4.2f", words*.size().sum() / words.size()
}
def modeWord = {
    def wordGroups = words(it.text).groupBy {it}.collectEntries { k, v -> [k, v.
size()] }
    def maxSize = wordGroups*.value.max()
    def maxWords = wordGroups.findAll { it.value == maxSize }
    "Mode Word(s): ${maxWords*.key.join(', ')} ($maxSize occurrences)"
}
def wordCount = { d -> "Word Count: " + words(d.text).size() }

def asyncDecorator(Document d, Closure c) {
    ProxyGenerator.INSTANCE.instantiateDelegate([print: {
        withPool {
            def result = c.callAsync(d)
            d.print()
            println result.get()
        }
```

```
    }], [Document], d)
}

Document d = asyncDecorator(asyncDecorator(asyncDecorator(
        new DocumentImpl(document:"This is the file with the words in it\\n\\t\\nDo
you see the words?\\n"),
//        new DocumentImpl(document: new File('AsyncDecorator.groovy').text),
        wordCount), modeWord), avgWordLength)
d.print()
```

Delegation Pattern

The Delegation Pattern is a technique where an object's behavior (public methods) is implemented by delegating responsibility to one or more associated objects.

Groovy allows the traditional style of applying the delegation pattern, e.g. see Replace Inheritance with Delegation.

Implement Delegation Pattern using ExpandoMetaClass

The groovy.lang.ExpandoMetaClass allows usage of this pattern to be encapsulated in a library. This allows Groovy to emulate similar libraries available for the Ruby language.

Consider the following library class:

```
class Delegator {
    private targetClass
    private delegate
    Delegator(targetClass, delegate) {
        this.targetClass = targetClass
        this.delegate = delegate
    }
    def delegate(String methodName) {
        delegate(methodName, methodName)
    }
    def delegate(String methodName, String asMethodName) {
        targetClass.metaClass."$asMethodName" = delegate.&"$methodName"
    }
    def delegateAll(String[] names) {
        names.each { delegate(it) }
    }
    def delegateAll(Map names) {
        names.each { k, v -> delegate(k, v) }
    }
    def delegateAll() {
        delegate.class.methods*.name.each { delegate(it) }
    }
}
```

With this in your classpath, you can now apply the delegation pattern dynamically as shown in the following examples. First, consider we have the following classes:

```
class Person {
    String name
}

class MortgageLender {
    def borrowAmount(amount) {
       "borrow \\$$amount"
    }
    def borrowFor(thing) {
       "buy \\$thing"
    }
}

def lender = new MortgageLender()

def delegator = new Delegator(Person, lender)
```

We can now use the *delegator* to automatically borrow methods from the *lender* object to extend the *Person* class. We can borrow the methods as is or with a rename:

```
delegator.delegate 'borrowFor'
delegator.delegate 'borrowAmount', 'getMoney'

def p = new Person()

println p.borrowFor('present')   // => buy present
println p.getMoney(50)
```

The first line above, adds the *borrowFor* method to the *Person* class by delegating to the *lender* object. The second line adds a *getMoney* method to the *Person* class by delegating to the *lender* object's *borrowAmount* method.

Alternatively, we could borrow multiple methods like this:

```
delegator.delegateAll 'borrowFor', 'borrowAmount'
```

Which adds these two methods to the *Person* class.

Or if we want all the methods, like this:

```
delegator.delegateAll()
```

Which will make all the methods in the delegate object available in the *Person* class.

Alternatively, we can use a map notation to rename multiple methods:

```
delegator.delegateAll borrowAmount:'getMoney', borrowFor:'getThing'
```

Implement Delegation Pattern using @Delegate annotation

Since version 1.6 you can use the built-in delegation mechanism which is based on AST transformation.

This make delegation even easier:

```
class Person {
    def name
    @Delegate MortgageLender mortgageLender = new MortgageLender()
}

class MortgageLender {
    def borrowAmount(amount) {
       "borrow \\$$amount"
    }
    def borrowFor(thing) {
       "buy $thing"
    }
}

def p = new Person()

assert "buy present" == p.borrowFor('present')
assert "borrow \\$50" == p.borrowAmount(50)
```

Flyweight Pattern

The Flyweight Pattern is a pattern for greatly reducing memory requirements by not requiring that heavy-weight objects be created in large numbers when dealing with systems that contain many things that are mostly the same. If for instance, a document was modelled using a complex character class that knew about unicode, fonts, positioning, etc., then the memory requirements could be quite large for large documents if each physical character in the document required its own character class instance. Instead, characters themselves might be kept within Strings and we might have one character class (or a small number such as one character class for each font type) that knew the specifics of how to deal with characters.

In such circumstances, we call the state that is shared with many other things (e.g. the character type) *intrinsic* state. It is captured within the heavy-weight class. The state which distinguishes the physical character (maybe just its ASCII code or Unicode) is called its *extrinsic* state.

Example

First we are going to model some complex aircraft (the first being a hoax competitor of the second -

though that is not relevant to the example).

```
class Boeing797 {
    def wingspan = '80.8 m'
    def capacity = 1000
    def speed = '1046 km/h'
    def range = '14400 km'
    // ...
}
```

```
class Airbus380 {
    def wingspan = '79.8 m'
    def capacity = 555
    def speed = '912 km/h'
    def range = '10370 km'
    // ...
}
```

If we want to model our fleet, our first attempt might involve using many instances of these heavy-weight objects. It turns out though that only a few small pieces of state (our extrinsic state) change for each aircraft, so we will have singletons for the heavy-weight objects and capture the extrinsic state (bought date and asset number in the code below) separately.

```
class FlyweightFactory {
    static instances = [797: new Boeing797(), 380: new Airbus380()]
}

class Aircraft {
    private type         // intrinsic state
    private assetNumber  // extrinsic state
    private bought       // extrinsic state
    Aircraft(typeCode, assetNumber, bought) {
        type = FlyweightFactory.instances[typeCode]
        this.assetNumber = assetNumber
        this.bought = bought
```

```
    }
    def describe() {
        println """
        Asset Number: $assetNumber
        Capacity: $type.capacity people
        Speed: $type.speed
        Range: $type.range
        Bought: $bought
        """
    }
}

def fleet = [
    new Aircraft(380, 1001, '10-May-2007'),
    new Aircraft(380, 1002, '10-Nov-2007'),
    new Aircraft(797, 1003, '10-May-2008'),
    new Aircraft(797, 1004, '10-Nov-2008')
]

fleet.each { p -> p.describe() }
```

So here, even if our fleet contained hundreds of planes, we would only have one heavy-weight object for each type of aircraft.

As a further efficiency measure, we might use lazy creation of the flyweight objects rather than create the initial map up front as in the above example.

Running this script results in:

```
Asset Number: 1001
Capacity: 555 people
Speed: 912 km/h
Range: 10370 km
Bought: 10-May-2007

Asset Number: 1002
Capacity: 555 people
Speed: 912 km/h
Range: 10370 km
Bought: 10-Nov-2007

Asset Number: 1003
Capacity: 1000 people
Speed: 1046 km/h
Range: 14400 km
Bought: 10-May-2008

Asset Number: 1004
Capacity: 1000 people
Speed: 1046 km/h
```

```
Range: 14400 km
Bought: 10-Nov-2008
```

Iterator Pattern

The Iterator Pattern allows sequential access to the elements of an aggregate object without exposing its underlying representation.

Groovy has the iterator pattern built right in to many of its closure operators, e.g. `each` and `eachWithIndex` as well as the `for .. in` loop.

For example:

```
def printAll(container) {
    for (item in container) { println item }
}

def numbers = [ 1,2,3,4 ]
def months = [ Mar:31, Apr:30, May:31 ]
def colors = [ java.awt.Color.BLACK, java.awt.Color.WHITE ]
printAll numbers
printAll months
printAll colors
```

Results in the output:

```
1
2
3
4
May=31
Mar=31
Apr=30
java.awt.Color[r=0,g=0,b=0]
java.awt.Color[r=255,g=255,b=255]
```

Another example:

```
colors.eachWithIndex { item, pos ->
    println "Position $pos contains '$item'"
}
```

Results in:

```
Position 0 contains 'java.awt.Color[r=0,g=0,b=0]'
Position 1 contains 'java.awt.Color[r=255,g=255,b=255]'
```

The iterator pattern is also built in to other special operators such as the `eachByte`, `eachFile`, `eachDir`, `eachLine`, `eachObject`, `eachMatch` operators for working with streams, URLs, files, directories and regular expressions matches.

Loan my Resource Pattern

The Loan my Resource pattern ensures that a resource is deterministically disposed of once it goes out of scope.

This pattern is built in to many Groovy helper methods. You should consider using it yourself if you need to work with resources in ways beyond what Groovy supports.

Example

Consider the following code which works with a file. First we might write some line to the file and then print its size:

```
def f = new File('junk.txt')
f.withPrintWriter { pw ->
    pw.println(new Date())
    pw.println(this.class.name)
}
println f.size()
// => 42
```

We could also read back the contents of the file a line at a time and print each line out:

```
f.eachLine { line ->
    println line
}
// =>
// Mon Jun 18 22:38:17 EST 2007
// RunPattern
```

Note that normal Java `Reader` and `PrintWriter` objects were used under the covers by Groovy but the code writer did not have to worry about explicitly creating or closing those resources. The built-in Groovy methods loan the respective reader or writer to the closure code and then tidy up after themselves. So, you are using this pattern without having to do any work.

Sometimes however, you wish to do things slightly differently to what you can get for free using Groovy's built-in mechanisms. You should consider utilising this pattern within your own resource-handling operations.

Consider how you might process the list of words on each line within the file. We could actually do this one too using Groovy's built-in functions, but bear with us and assume we have to do some resource handling ourselves. Here is how we might write the code without using this pattern:

```
def reader = f.newReader()
```

```
reader.splitEachLine(' ') { wordList ->
    println wordList
}
reader.close()
// =>
// [ "Mon", "Jun", "18", "22:38:17", "EST", "2007" ]
// [ "RunPattern" ]
```

Notice that we now have an explicit call to `close()` in our code. If we didn't code it just right (here we didn't surround the code in a `try … finally` block, we run the risk of leaving the file handle open.

Let's now apply the loan pattern. First, we'll write a helper method:

```
def withListOfWordsForEachLine(File f, Closure c) {
    def r = f.newReader()
    try {
        r.splitEachLine(' ', c)
    } finally {
        r?.close()
    }
}
```

Now, we can re-write our code as follows:

```
withListOfWordsForEachLine(f) { wordList ->
    println wordList
}
// =>
// [ "Mon", "Jun", "18", "22:38:17", "EST", "2007" ]
// [ "RunPattern" ]
```

This is much simpler and has removed the explicit `close()`. This is now catered for in one spot so we can apply the appropriate level of testing or reviewing in just one spot to be sure we have no problems.

Using Monoids

Monoids allow the mechanics of an aggregation algorithm to be separated from the algorithm-specific logic associated with that aggregation. It is often thought to be a functional design pattern.

Perhaps, it is easiest seen with an example. Consider the code for integer sum, integer product and string concatenation. We might note various similarities:

```
def nums = [1, 2, 3, 4]

def sum = 0    ①
```

```
for (num in nums) { sum += num }    ②
assert sum == 10

def product = 1    ①
for (num in nums) { product *= num }    ②
assert product == 24

def letters = ['a', 'b', 'c']

def concat = ''    ①
for (letter in letters) { concat += letter }    ②
assert concat == 'abc'
```

① Initialize an aggregate counter

② Loop throw elements with for/while/iteration adjusting counter

We can remove the duplicate aggregation coding and the tease out the important differences for each algorithm. We might instead use Groovy's `inject` method. This is a *fold* operation in functional programming jargon.

```
assert nums.inject(0){ total, next -> total + next } == 10
assert nums.inject(1){ total, next -> total * next } == 24
assert letters.inject(''){ total, next -> total + next } == 'abc'
```

Here the first parameter is the initial value, and the supplied closure contains the algorithm-specific logic.

Similarly, for Groovy 3+, we can use the JDK stream API and lambda syntax as follows:

```
assert nums.stream().reduce(0, (total, next) -> total + next) == 10
assert nums.stream().reduce(1, (total, next) -> total * next) == 24
assert letters.stream().reduce('', (total, next) -> total + next) == 'abc'
```

A touch of formalism

Looking at these examples, we might think all aggregation can be supported this way. In fact, we look for certain characteristics to ensure that this aggregation pattern will apply:

- Closure: performing the aggregation step should produce a result of the same type as the elements being aggregated.

> Examples: `1L + 3L` produces a `Long`, and `'foo' + 'bar'` produces a `String`.
> Non-monoid examples: `'foo'.size() + 'bar'.size()` (takes strings, returns an integer), the type *odd numbers* with respect to addition, algorithms which don't handle null arguments if such arguments are possible.

NOTE When using the term *closure* here, we simply mean closed under the operation, not the Groovy `Closure` class.

- Associativity: the order in which we apply the aggregation step should not matter.

> Examples: `(1 + 3) + 5` is the same as `1 + (3 + 5)`, and `('a' + 'b') + 'c'` is the same as `'a' + ('b' + 'c')`.
> Non-monoid example: `(10 - 5) - 3` is not equal to `10 - (5 - 3)` therefore integers are not a monoid with respect to subtraction.

- Identity element (sometimes also called a 'zero' element): there should be an element which aggregated with any element returns the original element.

> Examples: `0 + 42 == 42`, `42 + 0 == 42`, `1 * 42 == 42`, and `'' + 'foo' == 'foo'`.
> Non-monoid example: the type *non-empty strings* is not a monoid with respect to concatenation.

If your algorithm doesn't satisfy all the monoid properties, that doesn't mean aggregation isn't possible. It just means that you won't get all the benefits from monoids, which we'll cover shortly, or you might have a little more work to do. Also, you might be able to convert your data structures slightly to turn your problem into one involving monoids. We'll cover that topic a little later in this section.

Benefits of monoids

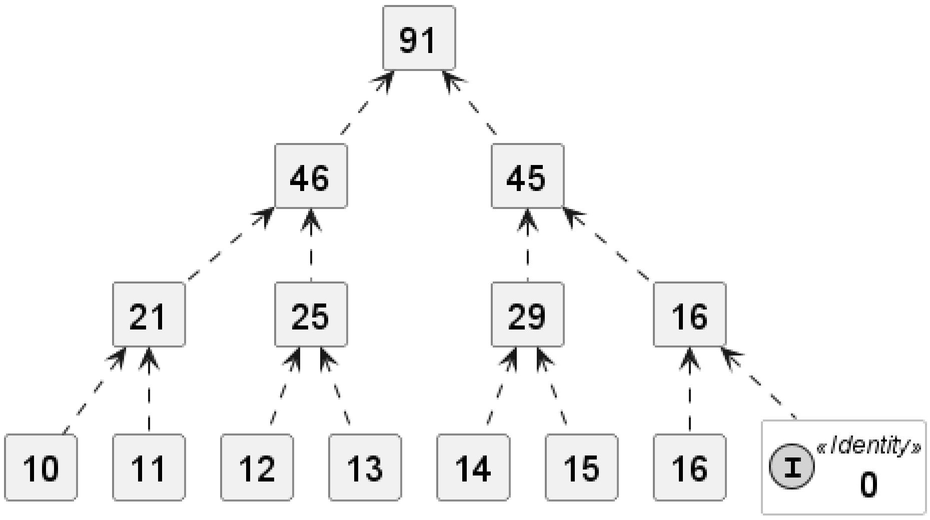
Consider adding the integers 10 through 16. Because the operation of addition for integers is a monoid, we already know that we can save writing code and instead use the approach we saw in the earlier `inject` examples. There are some other nice properties.

Because of the *closure* property, if we have a pairwise method like `sum(Integer a, Integer b)`, then for a monoid, we can always extend that method to work with a list, e.g. `sum(List<Integer> nums)` or `sum(Integer first, Integer… rest)`.

Because of *associativity*, we can employ some interesting ways to solve the aggregation including:

- Divide and conquer algorithms which break the problem into smaller pieces
- Various incremental algorithms for example memoization would allow summing from 1..5 to potentially start part way through be reusing a cached value of summing 1..4 if that had been calculated earlier
- Inherent parallelization can make use of multiple cores

Let's just look at the first of these in more detail. With a multicore processor, one core could add `10` plus `11`, another core `12` plus `13`, and so on. We'd use the *identity* element if needed (shown being added to `16` in our example). Then the intermediate results could also be added together concurrently and so on until the result was reached.



We have reduced the amount of code we need to write, and we also have potential performance gains.

Here is how we might code the previous example using the GPars concurrency and parallelism framework (two alternatives shown):

```
def nums = 10..16
GParsPool.withPool {
    assert 91 == nums.injectParallel(0){ total, next -> total + next }
    assert 91 == nums.parallel.reduce(0, (total, next) -> total + next)
}
```

Working with Non-monoids

Suppose we want to find the average of the numbers 1..10. Groovy has a built-in method for this:

```
assert (1..10).average() == 5.5
```

Now, suppose we want to build our own monoid solution instead of using the built-in version. It might seem difficult to find the *identity* element. After all:

```
assert (0..10).average() == 5
```

Similarly, if we are tempted to write the pairwise aggregation closure it might be something like:

```
def avg = { a, b -> (a + b) / 2 }
```

What `b` can we use for the *identity* element here so that our equation returns the original? We need to use `a`, but that isn't a fixed value, so there is no *identity*.

Also, associativity doesn't hold for this initial attempt at defining `avg` as these examples show:

```
assert 6 == avg(avg(10, 2), 6)
assert 7 == avg(10, avg(2, 6))
```

Also, what about our *closure* property? Our original numbers were integers, but our average (`5.5`) is not. We can solve this by making our average work for any `Number` instances, but it might not always be this easy.

It might appear that this problem is not amenable to a monoidal solution. However, there are numerous ways to bring monoids into the solution.

We can split it into two parts:

```
def nums = 1..10
def total = nums.sum()
def avg = total / nums.size()
assert avg == 5.5
```

The calculation of `sum()` can follow monoid rules and then our last step can calculate the average. We can even do a concurrent version with GPars:

```
withPool {
    assert 5.5 == nums.sumParallel() / nums.size()
}
```

Here, we were using the built-in `sum()` method (and `sumParallel()` for the GPars example), but if you were doing it by hand, the monoid nature of that part of your calculation would make it easier to write your own code for that step.

Alternatively, we can introduce a helper data structure that reworks the problem to be a monoid. Instead of just keeping the total, let's keep a list containing the total and count of numbers. The code could look something like this:

```
def holder = nums
    .collect{ [it, 1] }
    .inject{ a, b -> [a[0] + b[0], a[1] + b[1]] }
def avg = holder[0] / holder[1]
assert avg == 5.5
```

Or, to be a little fancier, we could introduce a class for our data structure and even calculate concurrently:

```
class AverageHolder {
    int total
    int count
    AverageHolder plus(AverageHolder other) {
```

```
        return new AverageHolder(total: total + other.total,
                                 count: count + other.count)
    }
    static final AverageHolder ZERO =
        new AverageHolder(total: 0, count: 0)
}

def asHolder = {
    it instanceof Integer ? new AverageHolder(total: it, count : 1) : it
}
def pairwiseAggregate = { aggregate, next ->
    asHolder(aggregate) + asHolder(next)
}
withPool {
    def holder = nums.injectParallel(AverageHolder.ZERO, pairwiseAggregate)
    def avg = holder.with{ total / count }
    assert avg == 5.5
}
```

Null Object Pattern

The Null Object Pattern involves using a special object place-marker object representing null. Typically, if you have a reference to null, you can't invoke `reference.field` or `reference.method()` You receive the dreaded `NullPointerException`. The null object pattern uses a special object representing null, instead of using an actual `null`. This allows you to invoke field and method references on the null object. The result of using the null object should semantically be equivalent to *doing nothing*.

Simple Example

Suppose we have the following system:

```
class Job {
    def salary
}

class Person {
    def name
    def Job job
}

def people = [
    new Person(name: 'Tom', job: new Job(salary: 1000)),
    new Person(name: 'Dick', job: new Job(salary: 1200)),
]

def biggestSalary = people.collect { p -> p.job.salary }.max()
println biggestSalary
```

When run, this prints out `1200`. Suppose now that we now invoke:

```
people << new Person(name: 'Harry')
```

If we now try to calculate `biggestSalary` again, we receive a null pointer exception.

To overcome this problem, we can introduce a `NullJob` class and change the above statement to become:

```
class NullJob extends Job { def salary = 0 }

people << new Person(name: 'Harry', job: new NullJob())
biggestSalary = people.collect { p -> p.job.salary }.max()
println biggestSalary
```

This works as we require but it's not always the best way to do this with Groovy. Groovy's safe-dereference operator (`?.`) operator and null aware closures often allow Groovy to avoid the need to create a special null object or null class. This is illustrated by examining a groovier way to write the above example:

```
people << new Person(name:'Harry')
biggestSalary = people.collect { p -> p.job?.salary }.max()
println biggestSalary
```

Two things are going on here to allow this to work. First of all, `max()` is *'null aware'* so that [300, null, 400].max() == 400. Secondly, with the `?.` operator, an expression like `p?.job?.salary` will be equal to null if `salary` is equal to null, or if `job` is equal ` null or if `p` is equal to null. You don't need to code a complex nested if ... then ... else to avoid a `NullPointerException`.

Tree Example

Consider the following example where we want to calculate size, cumulative sum and cumulative product of all the values in a tree structure.

Our first attempt has special logic within the calculation methods to handle null values.

```
class NullHandlingTree {
    def left, right, value

    def size() {
        1 + (left ? left.size() : 0) + (right ? right.size() : 0)
    }

    def sum() {
       value + (left ? left.sum() : 0) + (right ? right.sum() : 0)
    }
```

```
    def product() {
        value * (left ? left.product() : 1) * (right ? right.product() : 1)
    }
}

def root = new NullHandlingTree(
    value: 2,
    left: new NullHandlingTree(
        value: 3,
        right: new NullHandlingTree(value: 4),
        left: new NullHandlingTree(value: 5)
    )
)

println root.size()
println root.sum()
println root.product()
```

If we introduce the null object pattern (here by defining the `NullTree` class), we can now simplify the logic in the `size()`, `sum()` and`product()` methods. These methods now much more clearly represent the logic for the normal (and now universal) case. Each of the methods within `NullTree` returns a value which represents doing nothing.

```
class Tree {
    def left = new NullTree(), right = new NullTree(), value

    def size() {
        1 + left.size() + right.size()
    }

    def sum() {
        value + left.sum() + right.sum()
    }

    def product() {
        value * left.product() * right.product()
    }
}

class NullTree {
    def size() { 0 }
    def sum() { 0 }
    def product() { 1 }
}

def root = new Tree(
    value: 2,
    left: new Tree(
        value: 3,
        right: new Tree(value: 4),
```

```
        left: new Tree(value: 5)
    )
)

println root.size()
println root.sum()
println root.product()
```

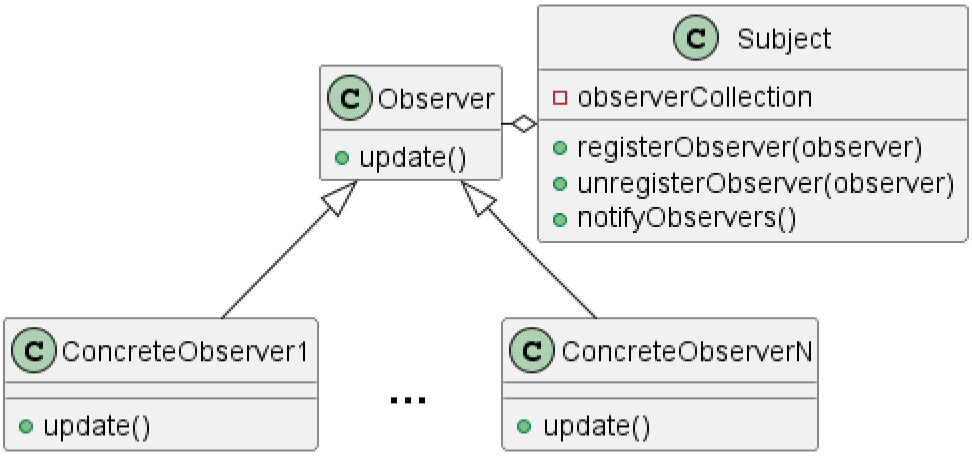
The result of running either of these examples is:

```
4
14
120
```

Note: a slight variation with the null object pattern is to combine it with the singleton pattern. So, we wouldn't write new NullTree() wherever we needed a null object as shown above. Instead we would have a single null object instance which we would place within our data structures as needed.

Observer Pattern

The Observer Pattern allows one or more *observers* to be notified about changes or events from a *subject* object.



Example

Here is a typical implementation of the classic pattern:

```
interface Observer {
    void update(message)
}

class Subject {
    private List observers = []
    void register(observer) {
```

```
        observers << observer
    }
    void unregister(observer) {
        observers -= observer
    }
    void notifyAll(message) {
        observers.each{ it.update(message) }
    }
}

class ConcreteObserver1 implements Observer {
    def messages = []
    void update(message) {
        messages << message
    }
}

class ConcreteObserver2 implements Observer {
    def messages = []
    void update(message) {
        messages << message.toUpperCase()
    }
}

def o1a = new ConcreteObserver1()
def o1b = new ConcreteObserver1()
def o2 = new ConcreteObserver2()
def observers = [o1a, o1b, o2]
new Subject().with {
    register(o1a)
    register(o2)
    notifyAll('one')
}
new Subject().with {
    register(o1b)
    register(o2)
    notifyAll('two')
}
def expected = [['one'], ['two'], ['ONE', 'TWO']]
assert observers*.messages == expected
```

Using Closures, we can avoid creating the concrete observer classes as shown below:

```
interface Observer {
    void update(message)
}

class Subject {
    private List observers = []
    void register(Observer observer) {
```

```
        observers << observer
    }
    void unregister(observer) {
        observers -= observer
    }
    void notifyAll(message) {
        observers.each{ it.update(message) }
    }
}

def messages1a = [], messages1b = [], messages2 = []
def o2 = { messages2 << it.toUpperCase() }
new Subject().with {
    register{ messages1a << it }
    register(o2)
    notifyAll('one')
}
new Subject().with {
    register{ messages1b << it }
    register(o2)
    notifyAll('two')
}
def expected = [['one'], ['two'], ['ONE', 'TWO']]
assert [messages1a, messages1b, messages2] == expected
```

As a variation for Groovy 3+, let's consider dropping the `Observer` interface and using lambdas as shown below:

```
import java.util.function.Consumer

class Subject {
    private List<Consumer> observers = []
    void register(Consumer observer) {
        observers << observer
    }
    void unregister(observer) {
        observers -= observer
    }
    void notifyAll(message) {
        observers.each{ it.accept(message) }
    }
}

def messages1a = [], messages1b = [], messages2 = []
def o2 = { messages2 << it.toUpperCase() }
new Subject().with {
    register(s -> messages1a << s)
    register(s -> messages2 << s.toUpperCase())
    notifyAll('one')
}
```

```
new Subject().with {
    register(s -> messages1b << s)
    register(s -> messages2 << s.toUpperCase())
    notifyAll('two')
}
def expected = [['one'], ['two'], ['ONE', 'TWO']]
assert [messages1a, messages1b, messages2] == expected
```

We are now calling the `accept` method from `Consumer` rather than the `update` method from `Observer`.

@Bindable and @Vetoable

The JDK has some built-in classes which follow the observer pattern. The `java.util.Observer` and `java.util.Observable` classes are deprecated from JDK 9 due to various limitations. Instead, you are recommended to use various more powerful classes in the `java.beans` package such as `java.beans.PropertyChangeListener`. Luckily, Groovy has some built-in transforms (groovy.beans.Bindable and groovy.beans.Vetoable) which support for some key classes from that package.

```
import groovy.beans.*
import java.beans.*

class PersonBean {
    @Bindable String first
    @Bindable String last
    @Vetoable Integer age
}

def messages = [:].withDefault{[]}
new PersonBean().with {
    addPropertyChangeListener{ PropertyChangeEvent ev ->
        messages[ev.propertyName] << "prop: $ev.newValue"
    }
    addVetoableChangeListener{ PropertyChangeEvent ev ->
        def name = ev.propertyName
        if (name == 'age' && ev.newValue > 40)
            throw new PropertyVetoException()
        messages[name] << "veto: $ev.newValue"
    }
    first = 'John'
    age = 35
    last = 'Smith'
    first = 'Jane'
    age = 42
}

def expected = [
    first:['prop: John', 'prop: Jane'],
    age:['veto: 35'],
    last:['prop: Smith']
```

```
]
assert messages == expected
```

Here, methods like addPropertyChangeListener perform the same role as registerObserver in previous examples. There is a firePropertyChange method corresponding to notifyAll /notifyObservers in previous examples but Groovy adds that automatically here, so it isn't visible in the source code. There is also a propertyChange method that corresponds to the update method in previous examples, though again, that isn't visible here.

Pimp my Library Pattern

The Pimp my Library Pattern suggests an approach for extending a library that nearly does everything that you need but just needs a little more. It assumes that you do not have source code for the library of interest.

Example

Suppose we want to make use of the built-in Integer facilities in Groovy (which build upon the features already in Java). Those libraries have nearly all of the features we want but not quite everything. We may not have all of the source code to the Groovy and Java libraries so we can't just change the library. Instead we augment the library. Groovy has a number of ways to do this. One way is to use a Category.

First, we'll define a suitable category.

```
class EnhancedInteger {
    static boolean greaterThanAll(Integer self, Object[] others) {
        greaterThanAll(self, others)
    }
    static boolean greaterThanAll(Integer self, others) {
        others.every { self > it }
    }
}
```

We have added two methods which augment the Integer methods by providing the greaterThanAll method. Categories follow conventions where they are defined as static methods with a special first parameter representing the class we wish to extend. The greaterThanAll(Integer self, others) static method becomes the greaterThanAll(other) instance method.

We defined two versions of greaterThanAll. One which works for collections, ranges etc. The other which works with a variable number of Integer arguments.

Here is how you would use the category.

```
use(EnhancedInteger) {
    assert 4.greaterThanAll(1, 2, 3)
    assert !5.greaterThanAll(2, 4, 6)
    assert 5.greaterThanAll(-4..4)
```

```
    assert 5.greaterThanAll([])
    assert !5.greaterThanAll([4, 5])
}
```

As you can see, using this technique you can effectively enrich an original class without having access to its source code. Moreover, you can apply different enrichments in different parts of the system as well as work with un-enriched objects if we need to.

Proxy Pattern

The Proxy Pattern allows one object to act as a pretend replacement for some other object. In general, whoever is using the proxy, doesn't realise that they are not using the real thing. The pattern is useful when the real object is hard to create or use: it may exist over a network connection, or be a large object in memory, or be a file, database or some other resource that is expensive or impossible to duplicate.

Example

One common use of the proxy pattern is when talking to remote objects in a different JVM. Here is the client code for creating a proxy that talks via sockets to a server object as well as an example usage:

```
class AccumulatorProxy {
    def accumulate(args) {
        def result
        def s = new Socket("localhost", 54321)
        s.withObjectStreams { ois, oos ->
            oos << args
            result = ois.readObject()
        }
        s.close()
        return result
    }
}

println new AccumulatorProxy().accumulate([1, 2, 3, 4, 5, 6, 7, 8, 9, 10])
// => 55
```

Here is what your server code might look like (start this first):

```
class Accumulator {
    def accumulate(args) {
        args.inject(0) { total, arg -> total += arg }
    }
}

def port = 54321
def accumulator = new Accumulator()
```

```
def server = new ServerSocket(port)
println "Starting server on port $port"
while(true) {
    server.accept() { socket ->
        socket.withObjectStreams { ois, oos ->
            def args = ois.readObject()
            oos << accumulator.accumulate(args)
        }
    }
}
```

Singleton Pattern

The Singleton Pattern is used to make sure only one object of a particular class is ever created. This can be useful when exactly one object is needed to coordinate actions across a system; perhaps for efficiency where creating lots of identical objects would be wasteful, perhaps because a particular algorithm needing a single point of control is required or perhaps when an object is used to interact with a non-shareable resource.

Weaknesses of the Singleton pattern include:

- It can reduce reuse. For instance, there are issues if you want to use inheritance with Singletons. If `SingletonB` extends `SingletonA`, should there be exactly (at most) one instance of each or should the creation of an object from one of the classes prohibit creation from the other. Also, if you decide both classes can have an instance, how do you override the `getInstance()` method which is static?
- It is also hard to test singletons in general because of the static methods but Groovy can support that if required.

Example: The Classic Java Singleton

Suppose we wish to create a class for collecting votes. Because getting the right number of votes may be very important, we decide to use the singleton pattern. There will only ever be one `VoteCollector` object, so it makes it easier for us to reason about that objects creation and use.

```
class VoteCollector {
    def votes = 0
    private static final INSTANCE = new VoteCollector()
    static getInstance() { return INSTANCE }
    private VoteCollector() { }
    def display() { println "Collector:${hashCode()}, Votes:$votes" }
}
```

Some points of interest in this code:

- it has a private constructor, so no `VoteCollector` objects can be created in our system (except for the `INSTANCE` we create)
- the `INSTANCE` is also private, so it can't be changed once set

- we haven't made the updating of votes thread-safe at this point (it doesn't add to this example)
- the vote collector instance is not lazily created (if we never reference the class, the instance won't be created; however, as soon as we reference the class, the instance will be created even if not needed initially)

We can use this singleton class in some script code as follows:

```
def collector = VoteCollector.instance
collector.display()
collector.votes++
collector = null

Thread.start{
    def collector2 = VoteCollector.instance
    collector2.display()
    collector2.votes++
    collector2 = null
}.join()

def collector3 = VoteCollector.instance
collector3.display()
```

Here we used the instance 3 times. The second usage was even in a different thread (but don't try this in a scenario with a new class loader).

Running this script yields (your hashcode value will vary):

```
Collector:15959960, Votes:0
Collector:15959960, Votes:1
Collector:15959960, Votes:2
```

Variations to this pattern:

- To support lazy-loading and multi-threading, we could just use the `synchronized` keyword with the `getInstance()` method. This has a performance hit but will work.
- We can consider variations involving double-checked locking and the `volatile` keyword, but see the limitations of this approach here.

Example: Singleton via MetaProgramming

Groovy's meta-programming capabilities allow concepts like the singleton pattern to be enacted in a far more fundamental way. This example illustrates a simple way to use Groovy's meta-programming capabilities to achieve the singleton pattern but not necessarily the most efficient way.

Suppose we want to keep track of the total number of calculations that a calculator performs. One way to do that is to use a singleton for the calculator class and keep a variable in the class with the count.

First we define some base classes. A `Calculator` class which performs calculations and records how many such calculations it performs and a `Client` class which acts as a facade to the calculator.

```
class Calculator {
    private total = 0
    def add(a, b) { total++; a + b }
    def getTotalCalculations() { 'Total Calculations: ' + total }
    String toString() { 'Calc: ' + hashCode() }
}

class Client {
    def calc = new Calculator()
    def executeCalc(a, b) { calc.add(a, b) }
    String toString() { 'Client: ' + hashCode() }
}
```

Now we can define and register a *MetaClass* which intercepts all attempts to create a `Calculator` object and always provides a pre-created instance instead. We also register this MetaClass with the Groovy system:

```
class CalculatorMetaClass extends MetaClassImpl {
    private static final INSTANCE = new Calculator()
    CalculatorMetaClass() { super(Calculator) }
    def invokeConstructor(Object[] arguments) { return INSTANCE }
}

def registry = GroovySystem.metaClassRegistry
registry.setMetaClass(Calculator, new CalculatorMetaClass())
```

Now we use instances of our `Client` class from within a script. The client class will attempt to create new instances of the calculator but will always get the singleton.

```
def client = new Client()
assert 3 == client.executeCalc(1, 2)
println "$client, $client.calc, $client.calc.totalCalculations"

client = new Client()
assert 4 == client.executeCalc(2, 2)
println "$client, $client.calc, $client.calc.totalCalculations"
```

Here is the result of running this script (your hashcode values may vary):

```
Client: 7306473, Calc: 24230857, Total Calculations: 1
Client: 31436753, Calc: 24230857, Total Calculations: 2
```

Guice Example

We can also implement the Singleton Pattern using Guice.

Consider the Calculator example again.

Guice is a Java-oriented framework that supports Interface-Oriented design. Hence we create a `Calculator` interface first. We can then create our `CalculatorImpl` implementation and a `Client` object which our script will interact with. The `Client` class isn't strictly needed for this example but allows us to show that non-singleton instances are the default. Here is the code:

```
@Grapes([@Grab('aopalliance:aopalliance:1.0'), @Grab(
'com.google.code.guice:guice:1.0')])
import com.google.inject.*

interface Calculator {
    def add(a, b)
}

class CalculatorImpl implements Calculator {
    private total = 0
    def add(a, b) { total++; a + b }
    def getTotalCalculations() { 'Total Calculations: ' + total }
    String toString() { 'Calc: ' + hashCode() }
}

class Client {
    @Inject Calculator calc
    def executeCalc(a, b) { calc.add(a, b) }
    String toString() { 'Client: ' + hashCode() }
}

def injector = Guice.createInjector (
    [configure: { binding ->
        binding.bind(Calculator)
               .to(CalculatorImpl)
               .asEagerSingleton() } ] as Module
)

def client = injector.getInstance(Client)
assert 3 == client.executeCalc(1, 2)
println "$client, $client.calc, $client.calc.totalCalculations"

client = injector.getInstance(Client)
assert 4 == client.executeCalc(2, 2)
println "$client, $client.calc, $client.calc.totalCalculations"
```

Note the `@Inject` annotation in the `Client` class. We can always tell right in the source code which fields will be injected.

In this example we chose to use an *explicit* binding. All of our dependencies (ok, only one in this example at the moment) are configured in the binding. The Guide injector knows about the binding and injects the dependencies as required when we create objects. For the singleton pattern to hold, you must always use Guice to create your instances. Nothing shown so far would stop you creating another instance of the calculator manually using new CalculatorImpl() which would of course violate the desired singleton behaviour.

In other scenarios (though probably not in large systems), we could choose to express dependencies using annotations, such as the following example shows:

```
@Grapes([@Grab('aopalliance:aopalliance:1.0'), @Grab(
'com.google.code.guice:guice:1.0')])
import com.google.inject.*

@ImplementedBy(CalculatorImpl)
interface Calculator {
    // as before ...
}

@Singleton
class CalculatorImpl implements Calculator {
    // as before ...
}

class Client {
    // as before ...
}

def injector = Guice.createInjector()

// ...
```

Note the `@Singleton` annotation on the `CalculatorImpl` class and the `@ImplementedBy` annotation in the `Calculator` interface.

When run, the above example (using either approach) yields (your hashcode values will vary):

```
Client: 8897128, Calc: 17431955, Total Calculations: 1
Client: 21145613, Calc: 17431955, Total Calculations: 2
```

You can see that we obtained a new client object whenever we asked for an instance but it was injected with the same calculator object.

Spring Example

We can do the Calculator example again using Spring as follows:

```
@Grapes([@Grab('org.springframework:spring-core:5.2.8.RELEASE'), @Grab
```

```
('org.springframework:spring-beans:5.2.8.RELEASE')])
import org.springframework.beans.factory.support.*

interface Calculator {
    def add(a, b)
}

class CalculatorImpl implements Calculator {
    private total = 0
    def add(a, b) { total++; a + b }
    def getTotalCalculations() { 'Total Calculations: ' + total }
    String toString() { 'Calc: ' + hashCode() }
}

class Client {
    Client(Calculator calc) { this.calc = calc }
    def calc
    def executeCalc(a, b) { calc.add(a, b) }
    String toString() { 'Client: ' + hashCode() }
}

// Here we 'wire' up our dependencies through the API. Alternatively,
// we could use XML-based configuration or the Grails Bean Builder DSL.
def factory = new DefaultListableBeanFactory()
factory.registerBeanDefinition('calc', new RootBeanDefinition(CalculatorImpl))
def beanDef = new RootBeanDefinition(Client, false)
beanDef.setAutowireMode(AbstractBeanDefinition.AUTOWIRE_AUTODETECT)
factory.registerBeanDefinition('client', beanDef)

def client = factory.getBean('client')
assert 3 == client.executeCalc(1, 2)
println "$client, $client.calc, $client.calc.totalCalculations"

client = factory.getBean('client')
assert 4 == client.executeCalc(2, 2)
println "$client, $client.calc, $client.calc.totalCalculations"
```

And here is the result (your hashcode values will vary):

```
Client: 29418586, Calc: 10580099, Total Calculations: 1
Client: 14800362, Calc: 10580099, Total Calculations: 2
```

Further information

- Simply Singleton
- Use your singletons wisely
- Double-checked locking and the Singleton pattern
- Lazy Loading Singletons

- Implementing the Singleton Pattern in C#

State Pattern

The State Pattern provides a structured approach to partitioning the behaviour within complex systems. The overall behaviour of a system is partitioned into well-defined states. Typically, each state is implemented by a class. The overall system behaviour can be determined firstly by knowing the *current state* of the system; secondly, by understanding the behaviour possible while in that state (as embodied in the methods of the class corresponding to that state).

Example

Here is an example:

```
class Client {
    def context = new Context()
    def connect() {
        context.state.connect()
    }
    def disconnect() {
        context.state.disconnect()
    }
    def send_message(message) {
        context.state.send_message(message)
    }
    def receive_message() {
        context.state.receive_message()
    }
}

class Context {
    def state = new Offline(this)
}

class ClientState {
    def context
    ClientState(context) {
        this.context = context
        inform()
    }
}

class Offline extends ClientState {
    Offline(context) {
        super(context)
    }
    def inform() {
        println "offline"
    }
    def connect() {
```

```
        context.state = new Online(context)
    }
    def disconnect() {
        println "error: not connected"
    }
    def send_message(message) {
        println "error: not connected"
    }
    def receive_message() {
        println "error: not connected"
    }
}

class Online extends ClientState {
    Online(context) {
        super(context)
    }
    def inform() {
        println "connected"
    }
    def connect() {
        println "error: already connected"
    }
    def disconnect() {
        context.state = new Offline(context)
    }
    def send_message(message) {
        println "\"$message\" sent"
    }
    def receive_message() {
        println "message received"
    }
}

client = new Client()
client.send_message("Hello")
client.connect()
client.send_message("Hello")
client.connect()
client.receive_message()
client.disconnect()
```

Here is the output:

```
offline
error: not connected
connected
"Hello" sent
error: already connected
message received
```

```
offline
```

One of the great things about a dynamic language like Groovy though is that we can take this example and express it in many different ways depending on our particular needs. Some potential variations for this example are shown below.

Variation 1: Leveraging Interface-Oriented Design

One approach we could take is to leverage Interface-Oriented Design. To do this, we could introduce the following interface:

```
interface State {
    def connect()
    def disconnect()
    def send_message(message)
    def receive_message()
}
```

Then our `Client`, `Online` and 'Offline` classes could be modified to implement that interface, e.g.:

```
class Client implements State {
  // ... as before ...
}

class Online implements State {
  // ... as before ...
}

class Offline implements State {
  // ... as before ...
}
```

You might ask: Haven't we just introduced additional boilerplate code? Can't we rely on duck-typing for this? The answer is 'yes' and 'no'. We can get away with duck-typing but one of the key intentions of the state pattern is to partition complexity. If we know that the *client* class and each *state* class all satisfy one interface, then we have placed some key boundaries around the complexity. We can look at any state class in isolation and know the bounds of behaviour possible for that state.

We don't have to use interfaces for this, but it helps express the intent of this particular style of partitioning and it helps reduce the size of our unit tests (we would have to have additional tests in place to express this intent in languages which have less support for interface-oriented design).

Variation 2: Extract State Pattern Logic

Alternatively, or in combination with other variations, we might decide to extract some of our State Pattern logic into helper classes. For example, we could define the following classes in a state pattern package/jar/script:

```
abstract class InstanceProvider {
    static def registry = GroovySystem.metaClassRegistry
    static def create(objectClass, param) {
        registry.getMetaClass(objectClass).invokeConstructor([param] as Object[])
    }
}

abstract class Context {
    private context
    protected setContext(context) {
        this.context = context
    }
    def invokeMethod(String name, Object arg) {
        context.invokeMethod(name, arg)
    }
    def startFrom(initialState) {
        setContext(InstanceProvider.create(initialState, this))
    }
}

abstract class State {
    private client

    State(client) { this.client = client }

    def transitionTo(nextState) {
        client.setContext(InstanceProvider.create(nextState, client))
    }
}
```

This is all quite generic and can be used wherever we want to introduce the state pattern. Here is what our code would look like now:

```
class Client extends Context {
    Client() {
        startFrom(Offline)
    }
}

class Offline extends State {
    Offline(client) {
        super(client)
        println "offline"
    }
    def connect() {
        transitionTo(Online)
    }
    def disconnect() {
        println "error: not connected"
```

```
    }
    def send_message(message) {
        println "error: not connected"
    }
    def receive_message() {
        println "error: not connected"
    }
}

class Online extends State {
    Online(client) {
        super(client)
        println "connected"
    }
    def connect() {
        println "error: already connected"
    }
    def disconnect() {
        transitionTo(Offline)
    }
    def send_message(message) {
        println "\"$message\" sent"
    }
    def receive_message() {
        println "message received"
    }
}

client = new Client()
client.send_message("Hello")
client.connect()
client.send_message("Hello")
client.connect()
client.receive_message()
client.disconnect()
```

You can see here the `startFrom` and `transitionTo` methods begin to give our example code a DSL feel.

Variation 3: Bring on the DSL

Alternatively, or in combination with other variations, we might decide to fully embrace a Domain Specific Language (DSL) approach to this example.

We can define the following generic helper functions (first discussed here):

```
class Grammar {
    def fsm

    def event
    def fromState
```

```
    def toState

    Grammar(a_fsm) {
        fsm = a_fsm
    }

    def on(a_event) {
        event = a_event
        this
    }

    def on(a_event, a_transitioner) {
        on(a_event)
        a_transitioner.delegate = this
        a_transitioner.call()
        this
    }

    def from(a_fromState) {
        fromState = a_fromState
        this
    }

    def to(a_toState) {
        assert a_toState, "Invalid toState: $a_toState"
        toState = a_toState
        fsm.registerTransition(this)
        this
    }

    def isValid() {
        event && fromState && toState
    }

    public String toString() {
        "$event: $fromState=>$toState"
    }
}
```

```
class FiniteStateMachine {
    def transitions = [:]

    def initialState
    def currentState

    FiniteStateMachine(a_initialState) {
        assert a_initialState, "You need to provide an initial state"
        initialState = a_initialState
        currentState = a_initialState
    }
```

```
    def record() {
        Grammar.newInstance(this)
    }

    def reset() {
        currentState = initialState
    }

    def isState(a_state) {
        currentState == a_state
    }

    def registerTransition(a_grammar) {
        assert a_grammar.isValid(), "Invalid transition ($a_grammar)"
        def transition
        def event = a_grammar.event
        def fromState = a_grammar.fromState
        def toState = a_grammar.toState

        if (!transitions[event]) {
            transitions[event] = [:]
        }

        transition = transitions[event]
        assert !transition[fromState], "Duplicate fromState $fromState for transition
$a_grammar"
        transition[fromState] = toState
    }

    def fire(a_event) {
        assert currentState, "Invalid current state '$currentState': passed into
constructor"
        assert transitions.containsKey(a_event), "Invalid event '$a_event', should be
one of ${transitions.keySet()}"
        def transition = transitions[a_event]
        def nextState = transition[currentState]
        assert nextState, "There is no transition from '$currentState' to any other
state"
        currentState = nextState
        currentState
    }
}
```

Now we can define and test our state machine like this:

```
class StatePatternDslTest extends GroovyTestCase {
    private fsm

    protected void setUp() {
```

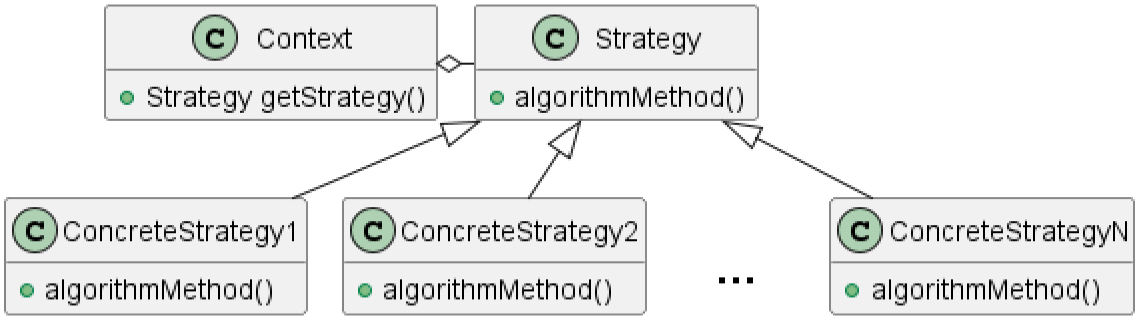
```
        fsm = FiniteStateMachine.newInstance('offline')
        def recorder = fsm.record()
        recorder.on('connect').from('offline').to('online')
        recorder.on('disconnect').from('online').to('offline')
        recorder.on('send_message').from('online').to('online')
        recorder.on('receive_message').from('online').to('online')
    }

    void testInitialState() {
        assert fsm.isState('offline')
    }

    void testOfflineState() {
        shouldFail{
            fsm.fire('send_message')
        }
        shouldFail{
            fsm.fire('receive_message')
        }
        shouldFail{
            fsm.fire('disconnect')
        }
        assert 'online' == fsm.fire('connect')
    }

    void testOnlineState() {
        fsm.fire('connect')
        fsm.fire('send_message')
        fsm.fire('receive_message')
        shouldFail{
            fsm.fire('connect')
        }
        assert 'offline' == fsm.fire('disconnect')
    }
}
```

This example isn't an exact equivalent of the others. It doesn't use predefined `Online` and `Offline` classes. Instead, it defines the entire state machine on the fly as needed. See the previous reference for more elaborate examples of this style.

See also: Model-based testing using ModelJUnit

Strategy Pattern

The Strategy Pattern allows you to abstract away particular algorithms from their usage. This allows you to easily swap the algorithm being used without having to change the calling code. The general form of the pattern is:



In Groovy, because of its ability to treat code as a first class object using anonymous methods (which we loosely call *Closures*), the need for the strategy pattern is greatly reduced. You can simply place algorithms inside Closures.

Example using traditional class hierarchy

First let's look at the traditional way of encapsulating the Strategy Pattern.

```
interface Calc {
    def execute(n, m)
}

class CalcByMult implements Calc {
    def execute(n, m) { n * m }
}

class CalcByManyAdds implements Calc {
    def execute(n, m) {
        def result = 0
        n.times{
            result += m
        }

        result
    }
}

def sampleData = [
    [3, 4, 12],
    [5, -5, -25]
]

Calc[] multiplicationStrategies = [
    new CalcByMult(),
    new CalcByManyAdds()
]

sampleData.each{ data ->
    multiplicationStrategies.each { calc ->
        assert data[2] == calc.execute(data[0], data[1])
    }
```

```
}
```

Here we have defined an interface `Calc` which our concrete strategy classes will implement (we could also have used an abstract class). We then defined two algorithms for doing simple multiplication: `CalcByMult` the normal way, and CalcByManyAdds using only addition (don't try this one using negative numbers - yes we could fix this but it would just make the example longer). We then use normal polymorphism to invoke the algorithms.

Example using closures

Here is the Groovier way to achieve the same thing using Closures:

```
def multiplicationStrategies = [
    { n, m -> n * m },
    { n, m -> def result = 0; n.times{ result += m }; result }
]

def sampleData = [
    [3, 4, 12],
    [5, -5, -25]
]

sampleData.each{ data ->
    multiplicationStrategies.each { calc ->
        assert data[2] == calc(data[0], data[1])
    }
}
```

Example using lambdas

For Groovy 3+, we can leverage lambda syntax:

```
interface Calc {
    def execute(n, m)
}

List<Calc> multiplicationStrategies = [
    (n, m) -> n * m,
    (n, m) -> { def result = 0; n.times{ result += m }; result }
]

def sampleData = [
    [3, 4, 12],
    [5, -5, -25]
]

sampleData.each{ data ->
    multiplicationStrategies.each { calc ->
        assert data[2] == calc(data[0], data[1])
```

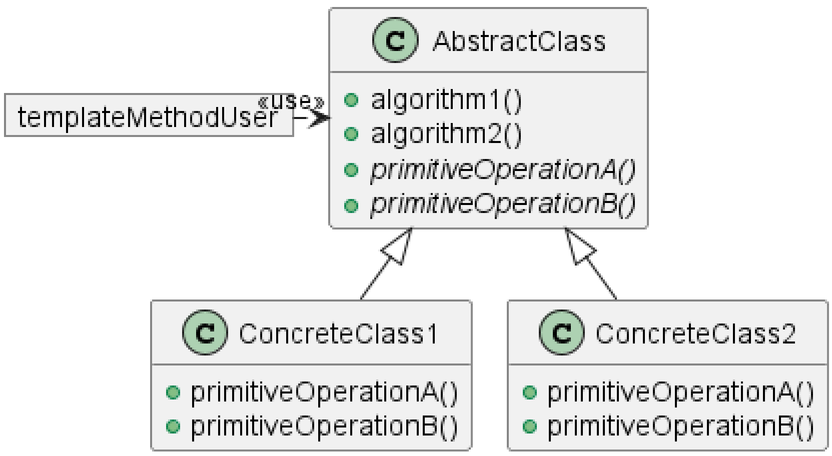
```
    }
}
```

Or we can use the built-in JDK `BiFunction` class:

```
import java.util.function.BiFunction

List<BiFunction<Integer, Integer, Integer>> multiplicationStrategies = [
    (n, m) -> n * m,
    (n, m) -> { def result = 0; n.times{ result += m }; result }
]

def sampleData = [
    [3, 4, 12],
    [5, -5, -25]
]

sampleData.each{ data ->
    multiplicationStrategies.each { calc ->
        assert data[2] == calc(data[0], data[1])
    }
}
```

Template Method Pattern

The Template Method Pattern abstracts away the details of several algorithms. The generic part of an algorithm is contained within a base class. Particular implementation details are captured within child classes. The generic pattern of classes involved looks like this:



Example with traditional classes

In this example, the base `Accumulator` class captures the essence of the accumulation algorithm. The child classes `Sum` and `Product` provide particular customised ways to use the generic accumulation algorithm.

```
abstract class Accumulator {
```

```
    protected initial
    abstract doAccumulate(total, v)
    def accumulate(values) {
        def total = initial
        values.each { v -> total = doAccumulate(total, v) }
        total
    }
}

class Sum extends Accumulator {
    def Sum() { initial = 0 }
    def doAccumulate(total, v) { total + v }
}

class Product extends Accumulator {
    def Product() { initial = 1 }
    def doAccumulate(total, v) { total * v }
}

assert 10 == new Sum().accumulate([1,2,3,4])
assert 24 == new Product().accumulate([1,2,3,4])
```

Example with simplifying strategies

In this particular case, you could use Groovy's inject method to achieve a similar result using Closures:

```
Closure addAll = { total, item -> total += item }
def accumulated = [1, 2, 3, 4].inject(0, addAll)
assert accumulated == 10
```

Thanks to duck-typing, this would also work with other objects which support an add (`plus()` in Groovy) method, e.g.:

```
accumulated = [ "1", "2", "3", "4" ].inject("", addAll)
assert accumulated == "1234"
```

We could also do the multiplication case as follows (re-writing as a one-liner):

```
assert 24 == [1, 2, 3, 4].inject(1) { total, item -> total *= item }
```

Using closures this way looks like the Strategy Pattern, but if we realise that Groovy's `inject` method is the generic part of the algorithm for our template method, then the Closures become the customised parts of the template method pattern.

For Groovy 3+, we can use lambda syntax as an alternative to the closure syntax:

```
assert 10 == [1, 2, 3, 4].stream().reduce(0, (l, r) -> l + r)
assert 24 == [1, 2, 3, 4].stream().reduce(1, (l, r) -> l * r)
assert '1234' == ['1', '2', '3', '4'].stream().reduce('', (l, r) -> l + r)
```

Here the stream api's `reduce` method is the generic part of the algorithm for our template method, and the lambdas are the customised parts of the template method pattern.

Visitor Pattern

The Visitor Pattern is one of those well-known but not often used patterns. Perhaps this is because it seems a little complex at first. But once you become familiar with it, it becomes a powerful way to evolve your code and as we'll see, Groovy provides ways to reduce some to the complexity, so there is no reason not to consider using this pattern.

The goal of the pattern is to separate an algorithm from an object structure. A practical result of this separation is the ability to add new operations to existing object structures without modifying those structures.

Simple Example

This example considers how to calculate the bounds of shapes (or collections of shapes). Our first attempt uses the traditional visitor pattern. We will see a more Groovy way to do this shortly.

```
abstract class Shape { }

@ToString(includeNames=true)
class Rectangle extends Shape {
    def x, y, w, h

    Rectangle(x, y, w, h) {
        this.x = x; this.y = y; this.w = w; this.h = h
    }

    def union(rect) {
        if (!rect) return this
        def minx = [rect.x, x].min()
        def maxx = [rect.x + rect.w, x + w].max()
        def miny = [rect.y, y].min()
        def maxy = [rect.y + rect.h, y + h].max()
        new Rectangle(minx, miny, maxx - minx, maxy - miny)
    }

    def accept(visitor) {
        visitor.visit_rectangle(this)
    }
}

class Line extends Shape {
    def x1, y1, x2, y2
```

```
    Line(x1, y1, x2, y2) {
        this.x1 = x1; this.y1 = y1; this.x2 = x2; this.y2 = y2
    }

    def accept(visitor){
        visitor.visit_line(this)
    }
}

class Group extends Shape {
    def shapes = []
    def add(shape) { shapes += shape }
    def remove(shape) { shapes -= shape }
    def accept(visitor) {
        visitor.visit_group(this)
    }
}

class BoundingRectangleVisitor {
    def bounds

    def visit_rectangle(rectangle) {
        if (bounds)
            bounds = bounds.union(rectangle)
        else
            bounds = rectangle
    }

    def visit_line(line) {
        def line_bounds = new Rectangle([line.x1, line.x2].min(),
                                        [line.y1, line.y2].min(),
                                        line.x2 - line.y1,
                                        line.x2 - line.y2)
        if (bounds)
            bounds = bounds.union(line_bounds)
        else
            bounds = line_bounds
    }

    def visit_group(group) {
        group.shapes.each { shape -> shape.accept(this) }
    }
}

def group = new Group()
group.add(new Rectangle(100, 40, 10, 5))
group.add(new Rectangle(100, 70, 10, 5))
group.add(new Line(90, 30, 60, 5))
def visitor = new BoundingRectangleVisitor()
group.accept(visitor)
```

```
bounding_box = visitor.bounds
assert bounding_box.toString() == 'Rectangle(x:60, y:5, w:50, h:70)'
```

That took quite a bit of code, but the idea now is that we could add further algorithms just by adding new visitors with our shape classes remaining unchanged, e.g. we could add a total area visitor or a collision detection visitor.

We can improve the clarity of our code (and shrink it to about half the size) by making use of Groovy Closures as follows:

```
abstract class Shape {
    def accept(Closure yield) { yield(this) }
}

@ToString(includeNames=true)
class Rectangle extends Shape {
    def x, y, w, h
    def bounds() { this }
    def union(rect) {
        if (!rect) return this
        def minx = [ rect.x, x ].min()
        def maxx = [ rect.x + rect.w, x + w ].max()
        def miny = [ rect.y, y ].min()
        def maxy = [ rect.y + rect.h, y + h ].max()
        new Rectangle(x:minx, y:miny, w:maxx - minx, h:maxy - miny)
    }
}

class Line extends Shape {
    def x1, y1, x2, y2
    def bounds() {
        new Rectangle(x:[x1, x2].min(), y:[y1, y2].min(),
                      w:(x2 - x1).abs(), h:(y2 - y1).abs())
    }
}

class Group {
    def shapes = []
    def leftShift(shape) { shapes += shape }
    def accept(Closure yield) { shapes.each{it.accept(yield)} }
}

def group = new Group()
group << new Rectangle(x:100, y:40, w:10, h:5)
group << new Rectangle(x:100, y:70, w:10, h:5)
group << new Line(x1:90, y1:30, x2:60, y2:5)
def bounds
group.accept{ bounds = it.bounds().union(bounds) }
assert bounds.toString() == 'Rectangle(x:60, y:5, w:50, h:70)'
```

Or, using lambdas as follows:

```
abstract class Shape {
    def accept(Function<Shape, Shape> yield) { yield.apply(this) }
}

@ToString(includeNames=true)
class Rectangle extends Shape {
    /* ... same as with Closures ... */
}

class Line extends Shape {
    /* ... same as with Closures ... */
}

class Group {
    def shapes = []
    def leftShift(shape) { shapes += shape }
    def accept(Function<Shape, Shape> yield) {
        shapes.stream().forEach(s -> s.accept(yield))
    }
}

def group = new Group()
group << new Rectangle(x:100, y:40, w:10, h:5)
group << new Rectangle(x:100, y:70, w:10, h:5)
group << new Line(x1:90, y1:30, x2:60, y2:5)
def bounds
group.accept(s -> { bounds = s.bounds().union(bounds) })
assert bounds.toString() == 'Rectangle(x:60, y:5, w:50, h:70)'
```

Advanced Example

Let’s consider another example to illustrate some more points about this pattern.

```
interface Visitor {
    void visit(NodeType1 n1)
    void visit(NodeType2 n2)
}

interface Visitable {
    void accept(Visitor visitor)
}

class NodeType1 implements Visitable {
    Visitable[] children = new Visitable[0]
    void accept(Visitor visitor) {
        visitor.visit(this)
        for(int i = 0; i < children.length; ++i) {
```

```
            children[i].accept(visitor)
        }
    }
}

class NodeType2 implements Visitable {
    Visitable[] children = new Visitable[0]
    void accept(Visitor visitor) {
        visitor.visit(this)
        for(int i = 0; i < children.length; ++i) {
            children[i].accept(visitor)
        }
    }
}

class NodeType1Counter implements Visitor {
    int count = 0
    void visit(NodeType1 n1) {
        count++
    }
    void visit(NodeType2 n2){}
}
```

If we now use `NodeType1Counter` on a tree like this:

```
NodeType1 root = new NodeType1()
root.children = new Visitable[]{new NodeType1(), new NodeType2()}

def counter = new NodeType1Counter()
root.accept(counter)
assert counter.count == 2
```

Then we have one `NodeType1` object as root and one of the children is also a `NodeType1` instance. The other child is a `NodeType2` instance. That means using `NodeType1Counter` here should count 2 `NodeType1` objects as the last statement verifies.

When to use this

This example illustrates some of the advantages of the visitor pattern. For example, while our visitor has state (the count of `NodeType1` objects), the tree of objects itself is not changed. Similarly, if we wanted to have a visitor counting all node types, or one that counts how many different types are used, or one that gathers information using methods special to the node types, again, the visitor alone is all that would need to be written.

What happens if we add a new type?

In this case we might have a fair bit of work to do. We probably have to change the `Visitor` interface to accept the new type, and change potentially most existing visitors based on that interface change, and we have to write the new type itself. A better approach is to write a default implementation of the visitor which all concrete visitors will extend. We'll see this approach in use shortly.

What if we want to have different iteration patterns?

Then you have a problem. Since the node describes how to iterate, you have no influence and stop iteration at a point or change the order. So maybe we should change this a little to this:

```
interface Visitor {
    void visit(NodeType1 n1)
    void visit(NodeType2 n2)
}

class DefaultVisitor implements Visitor{
    void visit(NodeType1 n1) {
        for(int i = 0; i < n1.children.length; ++i) {
            n1.children[i].accept(this)
        }
    }
    void visit(NodeType2 n2) {
        for(int i = 0; i < n2.children.length; ++i) {
            n2.children[i].accept(this)
        }
    }
}

interface Visitable {
    void accept(Visitor visitor)
}

class NodeType1 implements Visitable {
    Visitable[] children = new Visitable[0]
    void accept(Visitor visitor) {
        visitor.visit(this)
    }
}

class NodeType2 implements Visitable {
    Visitable[] children = new Visitable[0];
    void accept(Visitor visitor) {
        visitor.visit(this)
    }
}

class NodeType1Counter extends DefaultVisitor {
    int count = 0
    void visit(NodeType1 n1) {
        count++
        super.visit(n1)
    }
```

```
}
```

Some small changes but with big effect. The visitor is now recursive and tells me how to iterate. The implementation in the Nodes is minimized to `visitor.visit(this)`, `DefaultVisitor` is now able to catch the new types, we can stop iteration by not delegating to super. Of course the big disadvantage now is that it is no longer iterative, but you can't get all the benefits.

Make it Groovy

The question now is how to make that a bit more Groovy. Didn't you find this `visitor.visit(this)` strange? Why is it there? The answer is to simulate double dispatch. In Java, the compile time type is used, so for `visitor.visit(children[i])` the compiler won't be able to find the correct method, because `Visitor` does not contain a method `visit(Visitable)`. And even if it would, we would like to visit the more special methods with `NodeType1` or `NodeType2`.

Now Groovy is not using the static type, Groovy uses the runtime type. This means we can use `visitor.visit(children[i])` without any problem. Since we minimized the accept method to just do the double dispatch part and since the runtime type system of Groovy will already cover that, do we need the accept method? Not really, but we can do even more. We had the disadvantage of not knowing how to handle unknown tree elements. We had to *extend* the interface `Visitor` for that, resulting in changes to `DefaultVisitor` and then we have the task to provide a useful default like iterating the node or not doing anything at all. Now with Groovy we can catch that case by adding a `visit(Visitable)` method that does nothing. That would be the same in Java btw.

But don't let us stop here. Do we need the `Visitor` interface? If we don't have the accept method, then we don't need the `Visitor` interface at all. So the new code would be:

```
class DefaultVisitor {
    void visit(NodeType1 n1) {
        n1.children.each { visit(it) }
    }
    void visit(NodeType2 n2) {
        n2.children.each { visit(it) }
    }
    void visit(Visitable v) { }
}

interface Visitable { }

class NodeType1 implements Visitable {
    Visitable[] children = []
}

class NodeType2 implements Visitable {
    Visitable[] children = []
}

class NodeType1Counter extends DefaultVisitor {
    int count = 0
```

```
    void visit(NodeType1 n1) {
        count++
        super.visit(n1)
    }
}
```

Looks like we saved a few lines of code here, but we made more. The Visitable nodes now do not refer to any Visitor class or interface. This is about the best level of separation you might expect here, but we can go further. Let's change the Visitable interface a little and let it return the children we want to visit next. This allows us a general iteration method.

```
class DefaultVisitor {
    void visit(Visitable v) {
        doIteration(v)
    }
    void doIteration(Visitable v) {
        v.children.each {
            visit(it)
        }
    }
}

interface Visitable {
    Visitable[] getChildren()
}

class NodeType1 implements Visitable {
    Visitable[] children = []
}

class NodeType2 implements Visitable {
    Visitable[] children = []
}

class NodeType1Counter extends DefaultVisitor {
    int count = 0
    void visit(NodeType1 n1) {
        count++
        super.visit(n1)
    }
}
```

DefaultVisitor now looks a bit different. It has a doIteration method that will get the children it should iterate over and then call visit on each element. Per default this will call visit(Visitable) which then iterates over the children of this child. Visitable has also changed to ensure that any node will be able to return children (even if empty). We didn't have to change the NodeType1 and NodeType2 class, because the way the children field was defined already made them a property, which means Groovy is so nice to generate a get method for us. Now the really interesting part is

`NodeType1Counter`, it is interesting because we have not changed it. `super.visit(n1)` will now call `visit(Visitable)` which will call `doIteration` which will start the next level of iteration. So no change. But `visit(it)` will call `visit(NodeType1)` if it is of type `NodeType1`. In fact, we don't need the `doIteration` method, we could do that in `visit(Visitable)` too, but this variant has some benefits. It allows us to write a new `Visitor` that overwrites visit(`Visitable`) for error cases which of course means we must not do `super.visit(n1)` but `doIteration(n1)`.

Summary

In the end we got ~40% less code, a robust and stable architecture, and we completely removed the Visitor from the Visitable. To achieve the same in Java, you would probably need to resort to reflection.

The visitor pattern has sometimes been described as a poor fit for extreme programming techniques because you need to make changes to so many classes all the time. With our design, if we add new types we don't need to change anything. So, the pattern is a good fit for agile approaches when using Groovy.

There are variants of the Visitor pattern, like the acyclic visitor pattern, that try to solve the problem of adding new node types with special visitors. The implementations of these visitors have their own code smells, like using casts, overuse of `instanceof`, and other tricks. What's more the problems such approaches are trying to solve don't occur within the Groovy version. We recommend avoiding that variant of this pattern.

Finally, in case it isn't obvious, `NodeType1Counter` could be implemented in Java as well. Groovy will recognize the visit methods and call them as needed because `DefaultVisitor` is still Groovy and does all the magic.

Further Information

- Componentization: the Visitor example

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