DEEP DIVE INTO THE GROOVY COMPILER

by Cédric Champeau (@CedricChampeau)

WHO AM I

```
speaker {
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Misc OSS contribs (Gradle plugins, deck2pdf, jlangdetect, ...)'''
}
```
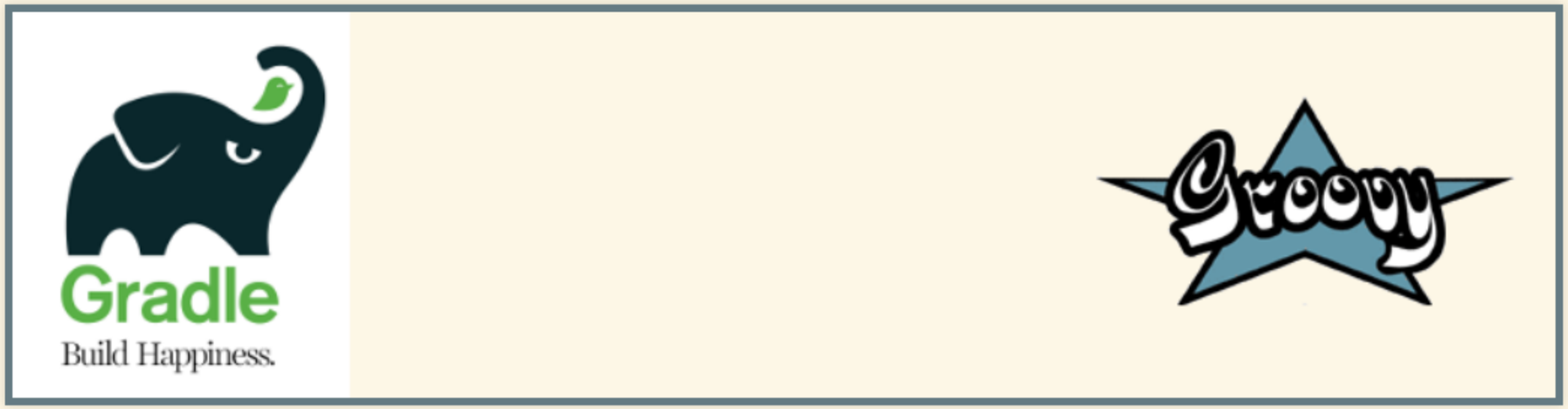
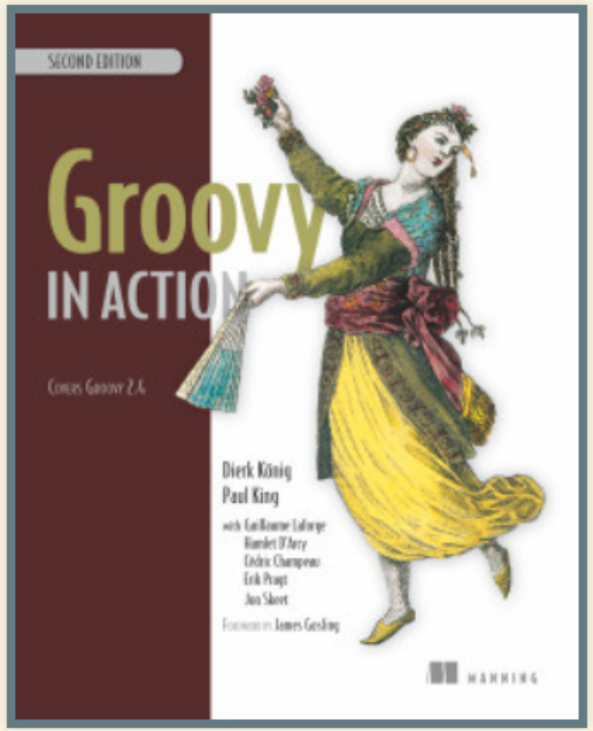



GROOVY IN ACTION 2



https://www.manning.com/books/groovy-in-action-second-edition

AGENDA

- Interpreted vs compiled
- Scripts vs classes
- Parsing
- Abstract Syntax Trees
- Resolving
- Run-time vs compile-time
- Static type checking
- Bytecode generation
- Class loading

INTERPRETED VS COMPILED

- Groovy is a dynamic language
- Dynamic != interpreted
- Interpreted == a runtime interprets an AST
- JVM is an interpreter + a JIT
- Groovy compiles down to JVM bytecode

SCRIPTS VS CLASSES

A JAVA CLASS

```java
public class Greeter {
    public static void main(String... args) {
        System.out.println("Hello, "+args[0]);
    }
}
```

A GROOVY SCRIPT

```
println "Hello, $args[0]"
```

WHAT IS THE DIFFERENCE?

- Classes are compiled to bytecode
- Scripts are **also** compiled to bytecode
- So it's more a run-time vs compile-time discussion!

COMPILE-TIME

- Given a set of source files
- Compile them
- Output is bytecode
  - cacheable (library, jar file, …)
  - loadable by the runtime (classloader)

RUN-TIME

- Same as compile-time but…
- done during execution of the program!
- Groovy does **both**
  - consequences on packaging
  - consequences on the size of the runtime

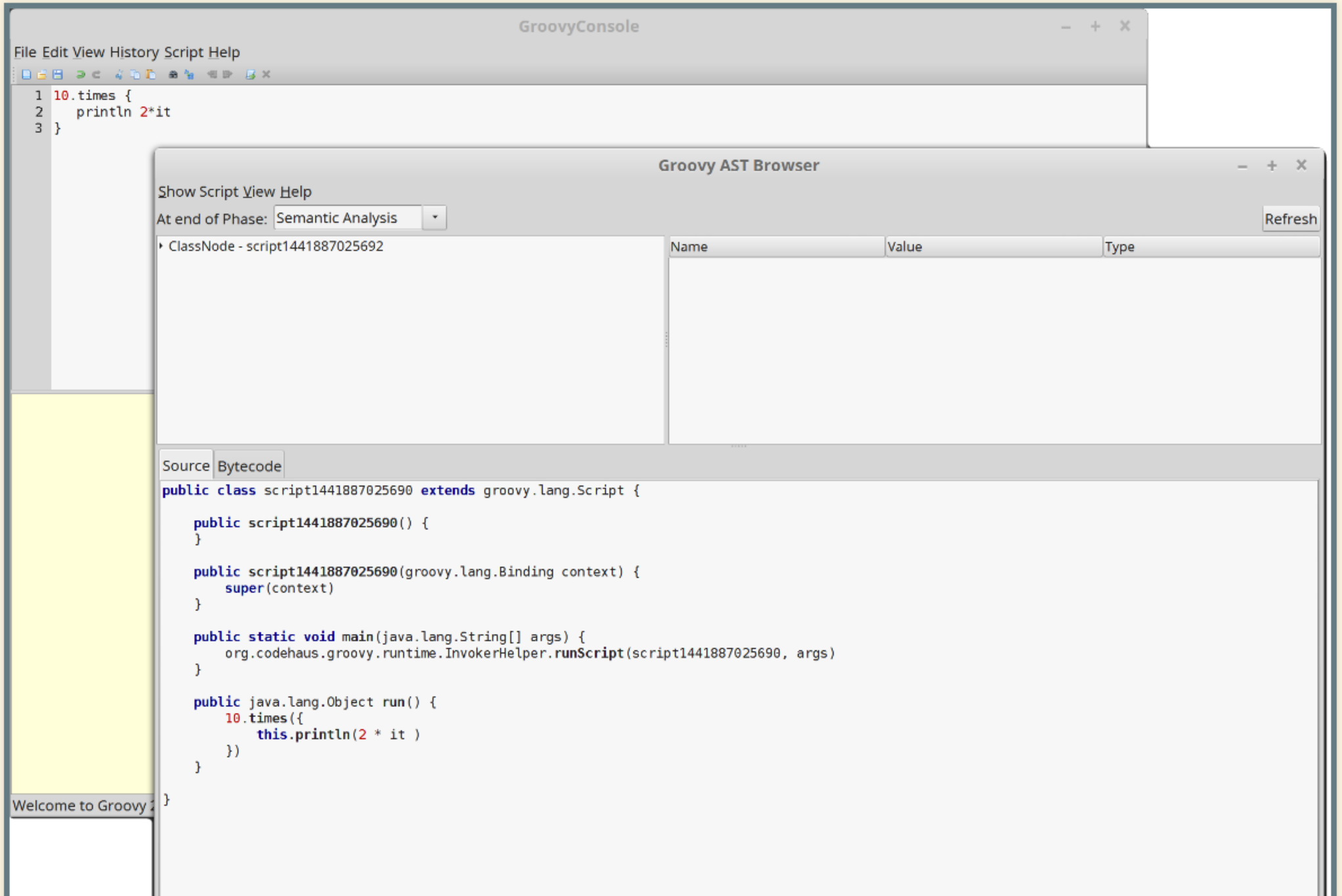
RUN-TIME VS RUNTIME

- A *runtime* provides support libraries to execute a compiled program
- Run-time is what happens at run time
- Groovy has a runtime
- Java also (the JRE, providing core classes)

COMPILATION PHASES

- Groovy has 9 compilation phases (see `org.codehaus.groovy.control.CompilePhase`)
  - initialization
  - **parsing**
  - **conversion**
  - **semantic analysis**
  - canonicalization
  - instruction selection
  - **class generation**
  - output
  - finalization

VISUALIZING COMPILATION PHASES



PARSING

- Converts source code (text) into a concrete syntax tree (CST)
- Where we send *syntax errors*
- Groovy tries to minimize the errors at that phase
- We make use of **Antlr 2**
  - Migration to **Antlr 4** in progress
- See `org.codehaus.groovy.antlr.AntlrParserPlugin`
- Limited transformations available (and not recommended)

CONVERSION

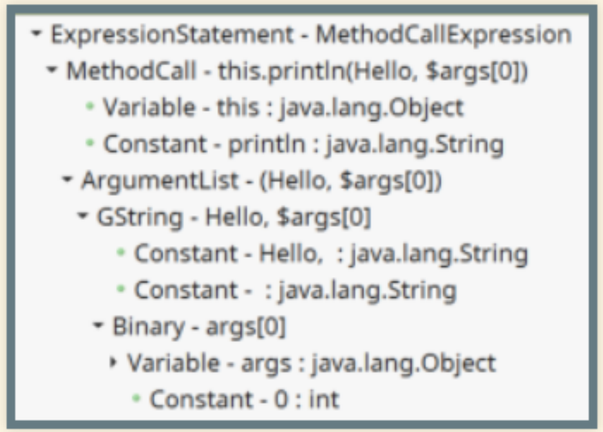
- Converts a CST into an Abstract Syntax Tree
- AST nodes are what the other compilation phases rely on
- There's already semantic information in an AST
- Earliest phase an AST transformation can hook into

CONVERSION: AST NODES

- 2 categories
  - statements (`IfStatement`, `BlockStatement`, ...)
  - expressions (`ConstantExpression`, `MethodCallExpression`, ...)
- Know your AST!
  - particularily useful if you plan on writing AST transformations

CONVERSION: AST NODES EXAMPLE

```
println "Hello, $args[0]"
```



CONVERSION: ABSTRACT SYNTAX TREE

- typically where an interpreter would step in
- at the core of the Groovy compiler
- AST classes live in `org.codehaus.groovy.ast`
- Still somehow *runtime agnostic*
  - In practice, `ClassNode` already bridges to `java.lang.Class`
- Start of visitor pattern

SEMANTIC ANALYSIS

- computation intensive phase
- resolves class literals (symbols in AST, imports, …)
- resolves static imports (constants, methods)
- computes the scope of parameters and local variables
- checks static scope vs instance scope
- updates the AST of inner classes
- collects AST transformations information

SEMANTIC ANALYSIS: RESOLVING

- High price in compilation time
- When we see Foo, need to:
  - check if Foo is something on classpath
  - check if Foo is another class being compiled (or script)
- Must avoid class initialization

CANONICALIZATION

- Finalizes the AST with information deduced from the semantic analysis
- Completes generation of AST of inner classes
- Completes enumerations with calls to `super`
- Weaves trait aspects into classes implementing traits
- Usually last chance to hook an AST transformation

INSTRUCTION SELECTION

- Formely used to select the instruction set (java version, …)
- (Optional) Type checking
- Post-type checking trait corrections
- (optional) static compiler specific AST transformations
- in short: all AST operations that need to be done just before generating bytecode

CLASS GENERATION

- Converts an AST into bytecode
- Makes use of the ASM library
- we'll get back to it…

OUTPUT

- (optional) write the generated bytecode into a file

FINALIZATION

- supposed to perform cleanup tasks
- Unused today!

PUTTING IT ALTOGETHER

- `CompilationUnit` is responsible for the compile phases lifecycle
- processes a set of `SourceUnit`
- a `SourceUnit` represents a single source file (or script)
- a `CompileUnit` gathers all ASTs of a compilation unit in a single place
  - typically used for *resolution*
- all source units are processed *phase by phase*

AST TRANSFORMATIONS

WHAT ARE AST XFORMS?

- User code that hooks into the compiler
- Allows transforming the AST during compilation
- A transform runs at a specific phases
  - a best, *conversion*
  - usually, *semantic analysis*
  - no later than **canonicalization**
- If you do it later… all bets are off!

USER CODE?

- Groovy comes with several AST xforms
- some features of the compiler are implemented as AST xforms
  - traits
  - static type checking

STATIC TYPE CHECKING

- Implemented (mostly) as an AST transformation
- Annotates AST nodes with **metadata**
- Flow typing
- **Must** be done very last in compiler phases
  - `INSTRUCTION_SELECTION`

BYTECODE GENERATION

- Groovy targets the JVM
- Android is supported by post-processing bytecode (dex)
- Bytecode generation library: ASM
- 3 different backends
  - legacy
  - invokedynamic
  - static compilation

BUT...

- ASM is a low level API
- Groovy uses a higher level API
  - `AsmCodeGenerator` : entry point, visitor pattern for the Groovy AST
  - writers: `WriterController`, `BinaryExpressionWriter`, `InvocationWriter`, … map ASTs to ASM patterns
  - helpers: `BytecodeHelper`, `CompileStack`, `OperandStack` simplify the generation of bytecode

DEALING WITH SPECIFIC RUNTIMES

- Dedicated writer versions
  - `CallSiteWriter` → `StaticTypesCallSiteWriter`
- Optimized paths
  - Primitive optimizations
  - Static compilation
  - Static compiler can delegate to a dynamic writer

DYNAMIC RUNTIME

```groovy
int sum(int... values) {
   values.sum()
}
```

```
groovyc example.groovy
javap -v example.class
```

DYNAMIC RUNTIME (2)

```
 0: invokestatic  #17       // Method $getCallSiteArray:()[Lorg/codehaus/groovy/runti
3: astore_2
4: aload_2
5: ldc           #42       // int 1
 7: aaload
 8: aload_1
 9: invokeinterface #45,  2 // InterfaceMethod org/codehaus/groovy/runtime/callsite/C
14: invokestatic  #51         // Method org/codehaus/groovy/runtime/typehandling/Defaul
17: ireturn
```

INVOKEDYNAMIC RUNTIME

```
groovyc --indy example.groovy
```

```
0: aload_1
1: invokedynamic #50,  0 // InvokeDynamic #1:invoke:([I)Ljava/lang/Object;
6: invokestatic  #56     // Method org/codehaus/groovy/runtime/typehandling/DefaultTy
9: ireturn
```

STATIC COMPILER RUNTIME

```
groovyc --configscript config.groovy
example.groovy
```

```
0: aload_1
1: invokestatic  #38    // Method org/codehaus/groovy/runtime/DefaultGroovyMethods.su
4: ireturn
```

PLAYING WITH BYTECODE GENERATION

```
int run(int i) {
   _new 'java/lang/Integer'
   dup
   iload 1
   invokespecial 'java/lang/Integer.<init>','(I)V'
   invokevirtual 'java/lang/Integer.intValue','()I'
   ireturn
}
```

WHAT HAPPENS?

- An **AST transformation** is applied (`@Bytecode`)
- Transforms "bytecode-like" method calls into actual **ASM** method calls
- So allows writing "bytecode" directly as method body
- Very useful for learning purposes
- Limited to method bodies

CLASSLOADING

- Bytecode → `byte[]`
- Still have to load that code
- For precompiled classes, can be done by any classloader
- `GroovyClassLoader`
  - supports generation of classes at **runtime**
  - will cache the generated classes

ROOTLOADER

- Special classloader that reverses the logic of parent vs child
- Used to implement different classpath
- Mutable

CALLSITECLASSLOADER

- Used **only** on the legacy dynamic runtime
- Loads *call site classes*
- Call site class: dynamically generated classes which avoid use of reflection

QUESTIONS

WE'RE HIRING!

http://gradle.org/gradle-jobs/

THANK YOU!

- Slides and code : https://github.com/melix/ggx2015-deepdive-groovy-compiler
- Groovy documentation : http://groovy-lang.org/documentation.html
- Follow me: @CedricChampeau