

Metaprogramming in Scala 2.10

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Metaprogramming

Metaprogramming is the writing of computer programs that write or manipulate other programs or themselves as their data.

—Wikipedia

Compiler

Q: How to enable metaprogramming?

A: Who has more data about a program than a compiler?

Let's expose the compiler to the programmer.

Reflection

In 2.10 we expose data about programs via reflection API.

The API is spread between `scala-library.jar` (interfaces), `scala-reflect.jar` (implementations) and `scala-compiler.jar` (runtime compilation).

Martin knows better

Design of the reflection API is explained in great detail in a recent talk by Martin Odersky:

channel9.msdn.com/Lang-NEXT-2012/Reflection-and-Compilers

Hands on

Today we will learn the fundamentals of reflection API and learn to learn more about it via a series of hands-on examples.

Macros

Q: Hey! What about macros?

A: Reflection is at the core of macros, reflection provides macros with an API, reflection enables macros. Our focus today is understanding reflection, macros are just a tiny bolt-on.

For more information about macros, their philosophy and applications, take a look at my Scala Days talk: <http://scalamacros.org/talks/2012-04-18-ScalaDays2012.pdf>.

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Core data structures

- ▶ Trees
- ▶ Symbols
- ▶ Types

```
C:\Projects\Kepler>scalac -Xshow-phases
```

```
phase name id description
```

```
----- --
```

```
  parser    1  parse source into ASTs, simple desugaring
```

```
  namer     2  resolve names, attach symbols to named trees
```

```
  typer     4  the meat and potatoes: type the trees
```

```
  pickler   7  serialize symbol tables
```

I'll do my best to explain these concepts, but it's barely possible to do it better than Paul Phillips. Be absolutely sure to watch the [Inside the Sausage Factory](#) talk (when the video is up).

Trees

Short-lived, mostly immutable, mostly plain case classes.

```
Apply(Ident("println"), List(Literal(Constant("hi!"))))
```

Comprehensive list of public trees can be found here:
[scala/reflect/api/Trees.scala](#) (be sure to take a look at the
"standard pattern match" section in the end of the file).

Learn to learn

- ▶ `-Xprint:parser` (for naked trees)
- ▶ `-Xprint:typer` (for typechecked trees)
- ▶ `-Yshow-trees` and its cousins
- ▶ `scala.reflect.mirror.showRaw(scala.reflect.mirror.reify(...))`

Q: Where do I pull these compiler flags from?

A: [scala/tools/nsc/settings/ScalaSettings.scala](#)

-Yshow-trees

```
// also try -Yshow-trees-stringified
// and -Yshow-trees-compact (or both simultaneously)
>scalac -Xprint:parser -Yshow-trees HelloWorld.scala
[[syntax trees at end of parser]]// Scala source:
    HelloWorld.scala
PackageDef(
  "<empty>"
  ModuleDef(
    0
    "Test"
    Template(
      "App" // parents
      ValDef(
        private
        "_"
        <tpt>
        <empty>
      )
    )
  ...
```

showRaw

```
scala> scala.reflect.mirror.reify{object Test {  
  println("Hello World!")  
}}  
res0: reflect.mirror.Expr[Unit] = ...  
  
scala> scala.reflect.mirror.showRaw(res0.tree)  
res1: String = Block(List(ModuleDef(  
  Modifiers(),  
  newTermName("Test"),  
  Template(List(Ident(newTypeName("Object"))), List(  
    DefDef(Modifiers(), newTermName("<init>"), List(),  
      List(List()), TypeTree(),  
      Block(List(Apply(Select(Super(This(newTypeName("")),  
        newTypeName("")), newTermName("<init>")),  
        List()), Literal(Constant(())))),  
      Apply(Select(Select(This(newTypeName("scala")),  
        newTermName("Predef")), newTermName("println")),  
        List(Literal(Constant("Hello World!")))))),  
    Literal(Constant(())))
```

Symbols

Link definitions and references to definitions. Long-lived, mutable. Declared in [scala/reflect/api/Symbols.scala](#) (very much in flux right now!)

```
def foo[T: TypeTag](x: Any) = x.asInstanceOf[T]  
foo[Long](42)
```

foo, T, x introduce symbols (T actually produces two different symbols). DefDef, TypeDef, ValDef - all of those subtype DefTree.

TypeTag, x, T, foo, Long refer to symbols. They are all represented by Idents, which subtype RefTree.

Symbols are long-lived. This means that any reference to Int (from a tree or from a type) will point to the same symbol instance.

Learn to learn

- ▶ `-Xprint:namer` or `-Xprint:typer`
- ▶ `-uniqid`
- ▶ `symbol.kind` and `-Yshow-symkinds`
- ▶ `:type -v`
- ▶ Don't create them by yourself. Just don't, leave it to Namer.
In macros most of the time you create naked trees, and Typer will take care of the rest.

-uniqid and -Yshow-symkinds

```
>cat Foo.scala
def foo[T: TypeTag](x: Any) = x.asInstanceOf[T]
foo[Long](42)

// there is a mysterious factoid hidden in this printout!
>scalac -Xprint:typer -uniqid -Yshow-symkinds Foo.scala
[[syntax trees at end of typer]]// Scala source: Foo.scala
def foo#8339#METH
  [T#8340#TPE >: Nothing#4658#CLS <: Any#4657#CLS]
  (x#9529#VAL: Any#4657#CLS)
  (implicit evidence$1#9530#VAL:
    TypeTag#7861#TPE[T#8341#TPE#SKO])
  : T#8340#TPE =
  x#9529#VAL.asInstanceOf#6023#METH[T#8341#TPE#SKO];

Test#14#MODC.this.foo#8339#METH[Long#1641#CLS](42)
(scala#29#PK.reflect#2514#PK.‘package‘#3414#PKO
.mirror#3463#GET.TypeTag#10351#MOD.Long#10361#GET)
```

:type -v

We have just seen how to discover symbols used in trees.

However, symbols are also used in types.

Thanks to Paul (who hacked this during one of Scala Nights) there's an easy way to inspect types as well. Corresponding REPL incantation is shown on one of the next slides.

Types

Immutable, long-lived, sometimes cached case classes declared in [scala/reflect/api/Types.scala](#).

Store the information about the full wealth of the Scala type system: members, type arguments, higher kinds, path dependencies, erasures, etc.

Learn to learn

- ▶ `-Xprint:typer`
- ▶ `-Xprint-types`
- ▶ `:type -v`
- ▶ `-explaintypes`

-Xprint-types

-Xprint-types is yet another option that modifies tree printing. Nothing very fancy, let's move on to something really cool.

:type -v

```
scala> :type -v def impl[T: c.TypeTag](c: Context) = ???  
// Type signature  
[T](c: scala.reflect.makro.Context)(implicit evidence$1:  
    c.TypeTag[T])Nothing  
  
// Internal Type structure  
PolyType(  
  typeParams = List(TypeParam(T))  
  resultType = MethodType(  
    params = List(TermSymbol(c: ...))  
    resultType = MethodType(  
      params = List(TermSymbol(implicit evidence$1: ...))  
      resultType = TypeRef(  
        TypeSymbol(final abstract class Nothing)  
      )  
    )  
  )  
)
```

-explaintypes

```
>cat Test.scala
class Foo { class Bar; def bar(x: Bar) = ??? }

object Test extends App {
  val foo1 = new Foo
  val foo2 = new Foo
  foo2.bar(new foo1.Bar)
}

// prints explanations of type mismatches
>scalac -explaintypes Test.scala
Test.foo1.Bar <: Test.foo2.Bar?
  Test.foo1.type <: Test.foo2.type?
    Test.foo1.type = Test.foo2.type?
      false
    false
  false
false
Test.scala:6: error: type mismatch;
...

```

Big picture

- ▶ Trees are created naked by Parser.
- ▶ Both definitions and references (expressed as ASTs) get their symbols filled in by Namer (`tree.symbol`).
- ▶ When creating symbols, Namer also creates their completers, lazy thunks that know how to populate symbol types (`symbol.info`).
- ▶ Typer inspects trees, uses their symbols to transform trees and assign types to them (`tree.tpe`).
- ▶ Shortly afterwards Pickler kicks in and serializes reachable symbols along with their types into `ScalaSignature` annotations.

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Universes

Universes are environments that pack together trees, symbols and their types.

- ▶ Compiler (`scala.tools.nsc.Global`) is a universe.
- ▶ Reflective mirror (`scala.reflect.mirror`) is a universe too.
- ▶ Macro context (`scala.reflect.makro.Context`) holds a reference to a universe.

Symbol tables

Universes abstract population of symbol tables.

- ▶ Compiler loads symbols from pickles using its own *.class parser.
- ▶ Reflective mirror uses Java reflection to load and parse ScalaSignatures.
- ▶ Macro context refers to the compiler's symbol table.

Entry points

Using a universe depends on your scenario.

- ▶ You can play with compiler's universe (aka global) in REPL's `:power` mode.
- ▶ With mirrors you go through the [Mirror](#) interface, e.g. `symbolOfInstance` or `classToType`.
- ▶ In a macro context, you import `c.mirror._` and can use imported factories to create trees and types (don't create symbols manually, remember?).

Path dependency

An important quirk is that all universe artifacts are path-dependent on their universe. Note the "reflect.mirror" prefix in the type of the result printed below.

```
scala> scala.reflect.mirror.reify(2.toString)
res0: reflect.mirror.Expr[String] =
    Expr[String](2.toString())
```

When you deal with runtime reflection, you simply import `scala.reflect.mirror._`, and enjoy, because typically there is only one runtime mirror.

However with macros it's more complicated. To pass artifacts around (e.g. into helper functions), you need to also carry the universe with you. Or you can employ the technique outlined in [a discussion at scala-internals](#).

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Inspect members

```
scala> import scala.reflect.mirror
import scala.reflect.mirror
```

```
scala> trait X { def foo: String }
defined trait X
```

```
scala> typeTag[X]
res1: TypeTag[X] = ConcreteTypeTag[X]
```

```
scala> res1.tpe.members
res2: Iterable[reflect.mirror.Symbol] = List(method
  $asInstanceOf, method $isInstanceOf, method sync
hronized, method ##, method !=, method ==, method ne,
  method eq, constructor Object, method notifyAl
l, method notify, method clone, method getClass, method
  hashCode, method toString, method equals, me
thod wait, method wait, method wait, method finalize,
  method asInstanceOf, method isInstanceOf, meth
od !=, method ==, method foo)
```

Analyze, typecheck and invoke members

```
val d = new DynamicProxy{ val dynamicProxyTarget = x }  
d.noargs  
d.noargs()  
d.nullary  
d.value  
d.-  
d.$("x")  
d.overloaded("overloaded with object")  
d.overloaded(1)  
val car = new Car  
d.typeArgs(car) // inferred  
d.default(1, 3)  
d.default(1)  
d.named(1, c=3, b=2) // works, wow
```

The proxy uses reflection that is capable of resolving all these calls.
More examples at [test/files/run/dynamic-proxy.scala](#).
Implementation is at [scala/reflect/DynamicProxy.scala](#).

Defeat erasure

```
scala> def foo[T](x: T) = x.getClass
foo: [T](x: T)Class[_ <: T]

scala> foo(List(1, 2, 3))
res0: Class[_ <: List[Int]] = class
    scala.collection.immutable.$colon$colon

scala> def foo[T: TypeTag](x: T) = typeTag[T]
foo: [T](x: T)(implicit evidence$1: TypeTag[T])TypeTag[T]

scala> foo(List(1, 2, 3))
res1: TypeTag[List[Int]] = ConcreteTypeTag[List[Int]]

scala> res1.tpe
res2: reflect.mirror.Type = List[Int]
```

Compile at runtime

```
import scala.reflect.mirror._  
val tree = Apply(Select(Ident("Macros"),  
    newTermName("foo")), List(Literal(Constant(42))))  
println(Expr(tree).eval)
```

Eval creates a toolbox under the covers (`universe.mkToolBox`), which is a full-fledged compiler.

Toolbox wraps the input AST, sets its phase to Namer (skipping Parser) and performs the compilation into an in-memory directory.

After the compilation is finished, toolbox fires up a classloader that loads and launches the code.

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In our hackings above, we used the runtime mirror (`scala.reflect.mirror`) to reflect against program structure.

We can do absolutely the same during the compile time. The universe is already there (the compiler itself), the API is there as well (`scala.reflect.api.Universe` inside the macro context).

We only need to ask the compiler to call ourselves during the compilation (currently, our trigger is macro application and the hook is the macro keyword).

The end.

No, really

That's it.

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- ▶ In 2.10 you can have all the information about your program that the compiler has (well, almost).
- ▶ This information includes trees, symbols and types. And annotations. And positions. [And more](#).
- ▶ You can reflect at runtime (`scala.reflect.mirror`) or at compile-time (macros).

Status

We're already there.

Recently released 2.10.0-M3 includes reflection and macros.

Thanks!

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