Scala Macros for Mortals,

or: How I Learned To Stop Worrying and Mumbling “WTF?!?!”

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@rit

What Are Macros?

(There's some really good documentation)


Summarize it in one word

“metaprogramming”

But Seriously, What *Are* Macros?

- ‘metaprogramming’, from the Latin: ‘WTF?’.
- I mean, “code that writes code”.
- Write ‘extensions’ to Scala which are evaluated/expanded at compile time.
- Macros may generate new code or simply evaluate existing code.

Examples of Macros

Def Macros

- Def Macros are used to write, essentially, new methods.
- Facility for us to write powerful new syntax that feels ‘built-in’, such as Shapeless' “This Shouldn't Compile” **`illTyped`** macro...

```
scala> illTyped { """1+1 : Int""" }

<console>:19: error: Type-checking succeeded unexpectedly.

Expected some error.

   illTyped { """1+1 : Int""" }

              ^
```

Examples of Macros

Annotation Macros

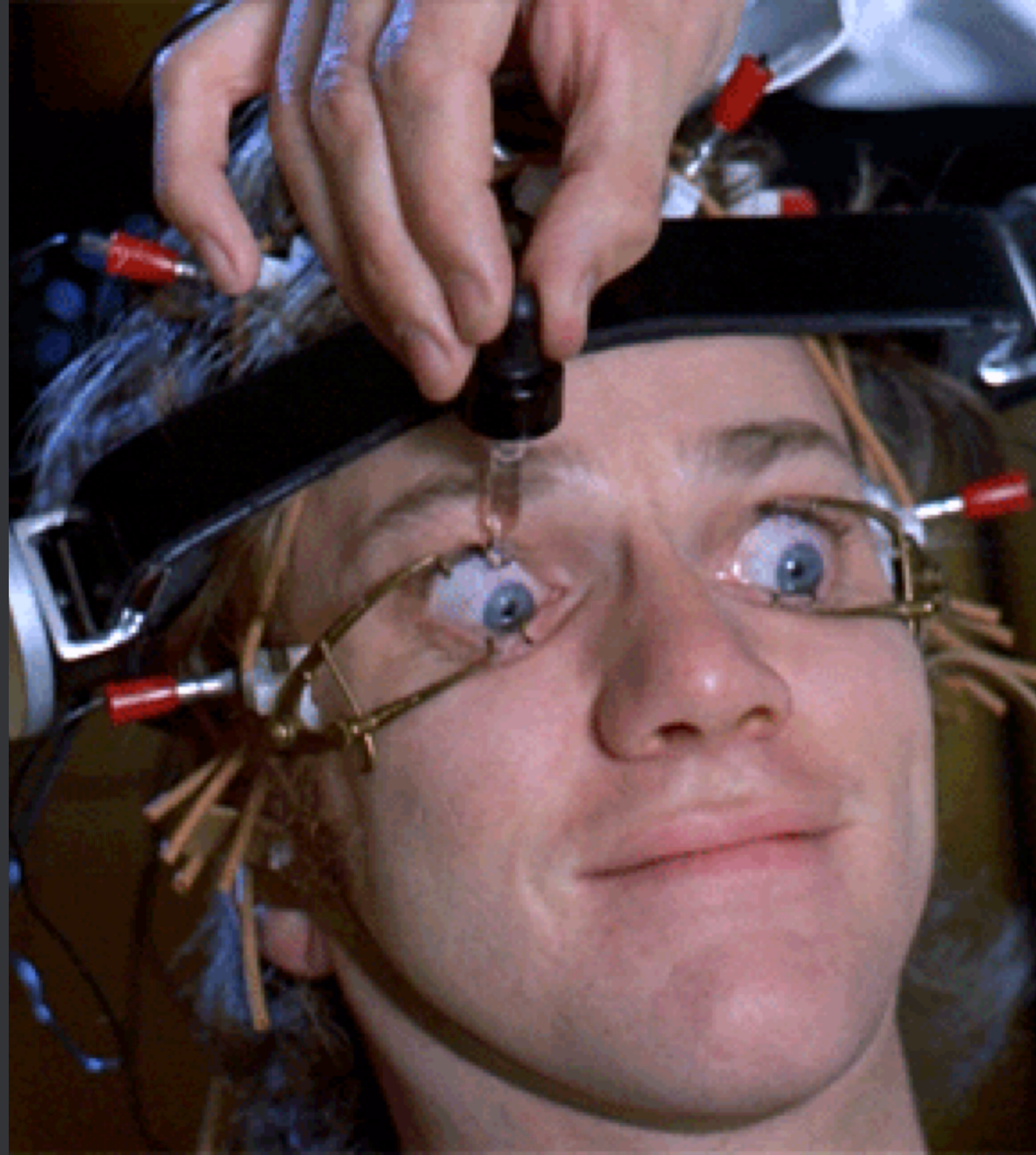
- Annotations Macros let us write annotations which can be then rewritten or expanded at compile time:

```
@hello

object Test extends App {

  println(this.hello)

}
```

- ... And a lot more.

I'm Hoping To Make This Easy For You

- I'm pretty new to this Macro thing, and hoping to share knowledge from a beginner's standpoint.
- Without naming names, *many* Macros talks are given by Deeply Scary Sorcerers and Demigods who sometimes forget how hard this stuff is for newbies.
- Let's take a look at this through *really fresh*, profusely bleeding eyeballs.



Once Upon A Time...

- The only way to add compile time functionality to Scala was by writing compiler plugins.
- Esoteric, harder to ship (i.e. user must include a compiler plugin), not a lot of docs or examples.
- Required *deep* knowledge of the AST: Essentially generating new Scala by hand-coding ASTs.[†]
- I've done a little bit of compiler plugin work: the AST can be tough to deal with.[§]

[†] Abstract Syntax Tree. A simple “tree” of case-class like objects to be converted to bytecode... or JavaScript.

[§] Some of the cool stuff in Macros like Quasiquotes can be used in Compiler Plugins now, too.

An AST Amuse Bouche

Given a small piece of Scala code, what might the AST look like?

```
class StringInterp {
  val int = 42
  val dbl = Math.PI
  val str = "My hovercraft is full of eels"

  println(s"String: $str Double: $dbl Int: $int Int Expr: ${int * 1.0}")
}
```

My God... It's Full of ... Uhm

```
Block(
  List(
    ClassDef(Modifiers(), TypeName("StringInterp"), List(), Template(
      List(Ident(TypeName("AnyRef"))), noSelfType, List(DefDef(Modifiers(), termNames.CONSTRUCTOR,
        List(),
        List(List()),
        TypeTree(), Block(List(Apply(Select(Super(This(typeNames.EMPTY), typeNames.EMPTY),
        termNames.CONSTRUCTOR), List())), Literal(Constant(())))), ValDef(Modifiers(), TermName("int"),
        TypeTree(), Literal(Constant(42))), ValDef(Modifiers(), TermName("dbl"), TypeTree(),
        Literal(Constant(3.141592653589793))), ValDef(Modifiers(), TermName("str"), TypeTree(),
        Literal(Constant("My hovercraft is full of eels"))), Apply(Select(Ident(scala.Predef),
        TermName("println")), List(Apply(Select(Apply(Select(Ident(scala.StringContext), TermName("apply")),
        List(Literal(Constant("String: ")), Literal(Constant(" Double: ")), Literal(Constant(" Int: ")),
          Literal(Constant(" Int Expr: ")), Literal(Constant("")))), TermName("s")),
        List(Select(This(TypeName("StringInterp")), TermName("str")), Select(This(TypeName("StringInterp")),
          TermName("dbl")), Select(This(TypeName("StringInterp")), TermName("int")),
          Apply(Select(Select(This(TypeName("StringInterp")), TermName("int")), TermName("$times")),
            List(Literal(Constant(1.0)))))))))
    ))), Literal(Constant(())))
```

Enter The Macro

- Since Scala 2.10, Macros have shipped as an experimental feature.
- Seem to have been adopted fairly quickly: I see them all over the place.
- AST Knowledge can be somewhat avoided, with some really cool tools to generate it for you.
- Macros make enhancing Scala *much* easier than writing compiler plugins.
- NOTE: You need to define your macros in a *separate* project / library from anywhere you call it.


HAIL SCIENCE!

Macro Paradise

- The Macro project for Scala is evolving *quickly*.
  - They release and add new features *far more frequently* than Scala does.
- "Macro Paradise" is a compiler plugin meant to bring Macro improvements into Scala[¶] as they become available.
  - One of the features currently existing purely in Macro Paradise is Macro Annotations.
- You can learn more about Macro Paradise at http://docs.scala-lang.org/overviews/macros/paradise.html

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[¶] Focused on reliability with the current production release of Scala.

Macro Annotations

ADT Validation

- Macro Annotations let us build annotations that expand via Macros.
- I've written a Macro that verifies the "Root" type of an ADT is valid. The rules:
  - The root type must be either a trait or an abstract class.
  - The root type must be sealed.
- I've done this with AST manipulation to demo what that looks like.

Macro Annotations

ADT Validation

- You can find this code at https://github.com/bwmcadams/supreme-macro-adventure
  - I was feeling whimsical, and used part of a suggested random repo name from Github...
- Let's look at some chunks of ScalaTest “should compile” / “should not compile” code I use to validate my ADT Macro

Macro Annotations

ADT Validation

```
"A test of annotating stuff with the ADT Compiler Annotation" should "Reject an unsealed trait" in {
  """
    | @ADT trait Foo
  """.stripMargin mustNot compile
}

 it should "Reject a Singleton Object" in {
  """
    | @ADT object Bar
  """.stripMargin mustNot compile
}
```

Macro Annotations

ADT Validation

```
it should "Approve a sealed trait" in {
  """
    | @ADT sealed trait Spam {
    |   def x: Int
    | }
  """.stripMargin must compile
}

it should "Approve a sealed, abstract class" in {
  """
    | @ADT sealed abstract class Eggs
  """.stripMargin must compile
}
```

Macro Annotations

ADT Validation

```
it should "Approve a sealed trait with type parameters" in {
  """
    | @ADT sealed trait Klang[T] {
    |   def x: Int
    | }
  """.stripMargin must compile
}

it should "Approve a sealed, abstract class with type parameters" in {
  """
    | @ADT sealed abstract class Odersky[T]
  """.stripMargin must compile
}
```

ADT Validation

- First, we need to define an annotation:

```
@compileTimeOnly("Enable Macro Paradise for Expansion of Annotations via
Macros.")
final class ADT extends StaticAnnotation {
  def macroTransform(annottees: Any*): Any = macro ADTMacros.annotation_impl
}
```

- **`@compileTimeOnly`** makes sure we've enabled Macro Paradise: otherwise, our annotation fails to expand at compile time.
- **`macroTransform`** delegates to an actual Macro implementation which validates our ‘annottees’.

ADT Validation

A quick note on the ‘annottees’ variable...

- This annotation macro is called *once per annotated class*. The fact that it has to take varargs can be confusing.
- If you annotate a class with a companion object, *both* are passed in.
  - If you annotate an object with a companion class, only the object is passed in.
- You must return *both* from your macro, or you get an error: **`top-level class with companion can only expand into a block consisting in eponymous companions`**

The Code...

We *could* do this with the AST...

```
def annotation_impl(c: whitebox.Context)(annottees: c.Expr[Any]*): c.Expr[Any] = {
  import c.universe._
  import Flag._

  val p = c.enclosingPosition

  val inputs = annottees.map(_.tree).toList

  val result: Tree = {
    // Tree manipulation code
  }

  // if no errors, return the original syntax tree
  c.Expr[Any](result)
}
```

Matching Our Tree

```
inputs match {
  // both classes & traits
  case (cD @ ClassDef(mods, name, tparams, impl)) :: Nil ⇒
    validateClassDef(cD, mods, name, tparams, impl, companion = None)
  // annotated class with companion object.
  case (cD @ ClassDef(mods, name, tparams, impl)) :: (mD: ModuleDef) :: Nil ⇒
    validateClassDef(cD, mods, name, tparams, impl, companion = Some(mD))
  case (o @ ModuleDef(_, name, _)) :: Nil ⇒
    c.error(p, s"ADT Roots (object $name) may not be Objects.")
    o
  // ... corner cases such as vals, vars, defs
```

Matching Our Tree

```
case x :: Nil ⇒
  c.error(p, s"Invalid ADT Root ($x) [${x.getClass}].")
  x
case Nil ⇒
  c.error(p, "Cannot validate ADT Root of empty Tree.")
  // the errors should cause us to stop before this but needed to match up our match type
  reify {}.tree
```

Validating "Valid" Possibilities

```
def validateClassDef(cD: c.universe.ClassDef, mods: c.universe.Modifiers,
  name: c.universe.TypeName, tparams: List[c.universe.TypeDef],
  impl: c.universe.Template, companion: Option[ModuleDef]): c.universe.Tree = {

  if (mods.hasFlag(TRAIT)) {
    if (!mods.hasFlag(SEALED)) {
      c.error(p, s"ADT Root traits (trait $name) must be sealed.")
    }
    else {
      c.info(p, s"ADT Root trait $name sanity checks OK.", force = true)
    }
    companion match {
      case Some(mD) ⇒ q"$cD; $mD"
      case None ⇒ cD
    }
```

Validating "Valid" Possibilities

```
    } else if (!mods.hasFlag(ABSTRACT)) {
      c.error(p, s"ADT Root classes (class $name) must be abstract.")
      cD
    } else if (!mods.hasFlag(SEALED)) {
      // class that's abstract
      c.error(p, s"ADT Root classes (abstract class $name) must be sealed.")
      cD
    } else {
      c.info(p, s"ADT Root class $name sanity checks OK.", force = true)
      companion match {
         // Using ClassDef match, Scala requires tree includes all annottees (companions) sent in.
        case Some(mD) ⇒ q"$cD; $mD"
        case None ⇒ cD
      }
    }
  }
```

Macros & The AST

- Macros are still really built with the AST, but lately Macros provide tools to generate ASTs from code (which is what I use, mostly).
- The first, and simplest, is **`reify`**, which we can use to generate an AST for us.

Peeking at AST Examples for “Inspiration”

Remember my first example of the AST? I actually printed it out using **`reify`**:

```
println(showRaw(reify {
  class StringInterp {
    val int = 42
    val dbl = Math.PI
    val str = "My hovercraft is full of eels"

    println(s"String: $str Double: $dbl Int: $int Int Expr: ${int * 1.0}")
  }
}.tree))
```

`.tree` will replace the **`reify`** ‘expansion’ code with the AST associated. **`showRaw`** converts it to a printable format for us.


COMEDY
CENTRAL

Quasiquotes for More Sanity

- There's really no way – yet – to avoid the AST Completely. But the Macro system continues to improve to give us ways to use it less and less.
- Quasiquotes, added in Scala 2.11, lets us write the equivalent of String Interpolation code that ‘evals’ to a Syntax Tree.
- We'll introduce Quasiquotes, and, time permitting, we're going to also look at a Quasiquotes version of the ADT Macro.

Quasiquotes in Action

Setting Up Our Imports

There are some implicits we need in scope for Quasiquotes Ah, the joy of imports...

```
import language.experimental.macros
import reflect.macros.Context
import scala.annotation.StaticAnnotation
import scala.reflect.runtime.{universe => ru}
import ru._
```

Now we're ready to generate some Syntax Trees!

Quasiquotes in Action

Writing Some Trees

Quasiquotes look like String Interpolation, but we place a **q** in front of our string instead of **s**... and generate code!

```
scala> q"def echo(str: String): String = str"

res4: reflect.runtime.universe.DefDef =
    def echo(str: String): String = str
```

Quasiquotes in Action

Writing Some Trees

```
scala> val wtfException = q"""
case class OMGWTFBBQ(message: String = null)
    extends Exception
    with scala.util.control.NoStackTrace
"""

wtfException: reflect.runtime.universe.ClassDef =
case class OMGWTFBBQ extends Exception with scala.util.control.NoStackTrace
    with scala.Product with scala.Serializable {
  <caseaccessor> <paramaccessor> val message: String = _;
  def <init>(message: String = null) = {
    super.<init>();
    ()
}
```

Extracting with Quasiquotes

It turns out Quasiquotes can do extraction too, which I find sort of fun.

```
scala> val q"""case class $cname[..$tparams](..$params)
                 extends $parent with ..$traits { ..$body }""" = wtfException

cname: reflect.runtime.universe.TypeName = OMGWTFBBQ
tparams: List[reflect.runtime.universe.TypeDef] = List()
params: List[reflect.runtime.universe.ValDef] =
    List(<caseaccessor> <paramaccessor> val message: String = null)
parent: reflect.runtime.universe.Tree = Exception
traits: List[reflect.runtime.universe.Tree] = List(scala.util.control.NoStackTrace)
body: List[reflect.runtime.universe.Tree] = List()
```


BRILLIANT!

ADT Macro with Quasiquotes

- With Quasiquotes, we can implement our ADT in a pure match with pattern guards.
- It is nearly half the # of lines.

Traits & Classes Validation

```
val result: Tree = inputs match {
  case (t @ q"$mods trait $name[..$tparams] extends ..$parents { ..$body }") :: Nil
    if mods.hasFlag(SEALED) ⇒
    c.info(p, s"ADT Root trait $name sanity checks OK.", force = true)
    t
  case (t @ q"$mods trait $name[..$tparams] extends ..$parents { ..$body }") :: Nil ⇒
    c.error(p, s"ADT Root traits (trait $name) must be sealed.")
    t
```

Classes Validation

```
// there's no bitwise AND (just OR) on Flags
case (cls @ q"$mods class $name[..$tparams] extends ..$parents { ..$body }") :: Nil
  if mods.hasFlag(ABSTRACT) && mods.hasFlag(SEALED) ⇒
  c.info(p, s"ADT Root class $name sanity checks OK.", force = true)
  cls
case (cls @ q"$mods class $name[..$tparams] extends ..$parents { ..$body }") :: Nil ⇒
  c.error(p, s"ADT Root classes (class $name) must be abstract and sealed.")
  cls
```

Singletons & Trait Companions Validation

```
case (o @ q"$mods object $name") :: Nil ⇒
  c.error(p, s"ADT Roots (object $name) may not be Objects.")
  o
// companions
case (t @ q"$mods trait $name[..$tparams] extends ..$parents { ..$body }") ::
  (mD: ModuleDef):: Nil
  if mods.hasFlag(SEALED) ⇒
  c.info(p, s"ADT Root trait $name sanity checks OK.", force = true)
  q"$t; $mD"
case (t @ q"$mods trait $name[..$tparams] extends ..$parents { ..$body }") ::
  (mD: ModuleDef) :: Nil ⇒
  c.error(p, s"ADT Root traits (trait $name) must be sealed.")
  q"$t; $mD"
```

Singletons & Trait Companions Validation

```
// there's no bitwise AND (just OR) on Flags
case (cls @ q"$mods class $name[..$tparams] extends ..$parents { ..$body }") ::
  (mD: ModuleDef) :: Nil ⇒
  c.info(p, s"ADT Root class $name sanity checks OK.", force = true)
  q"$cls; $mD"
case (cls @ q"$mods class $name[..$tparams] extends ..$parents { ..$body }")
  :: (mD: ModuleDef) :: Nil ⇒
  c.error(p, s"ADT Root classes (class $name) must be abstract and sealed.")
  q"$cls; $mD"
```


AWESOME.
AWESOME TO THE MAX.

Closing Thoughts

- Macros are undoubtedly cool, and rapidly evolving. But be cautious.
- “When all you have is a hammer, everything starts to look like a thumb…”

— me

- Macros can enable great development, but also hinder it if overused. Think carefully about their introduction, and their impact on your codebase.

Questions?