Easy Metaprogramming For Everyone!

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Metaprogramming is...

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

—Wikipedia

Metaprogramming is useful

- Code generation
- Program verification
- Style checking
- Refactoring
- Incremental compilation
- Documentation generation
- ...

Before Scala 2.10

Baby steps of Scala metaprogramming

- Text-based introspection with scalap
- Unstable and undocumented compiler plugins
- Ad-hoc textual code generation

After Scala 2.10

Current state of things

Metaprogramming with `scala.reflect`:

+ Full-fledged model of Scala available in standard distribution
+ Structured code generation with macros and quasiquotes

Current state of things

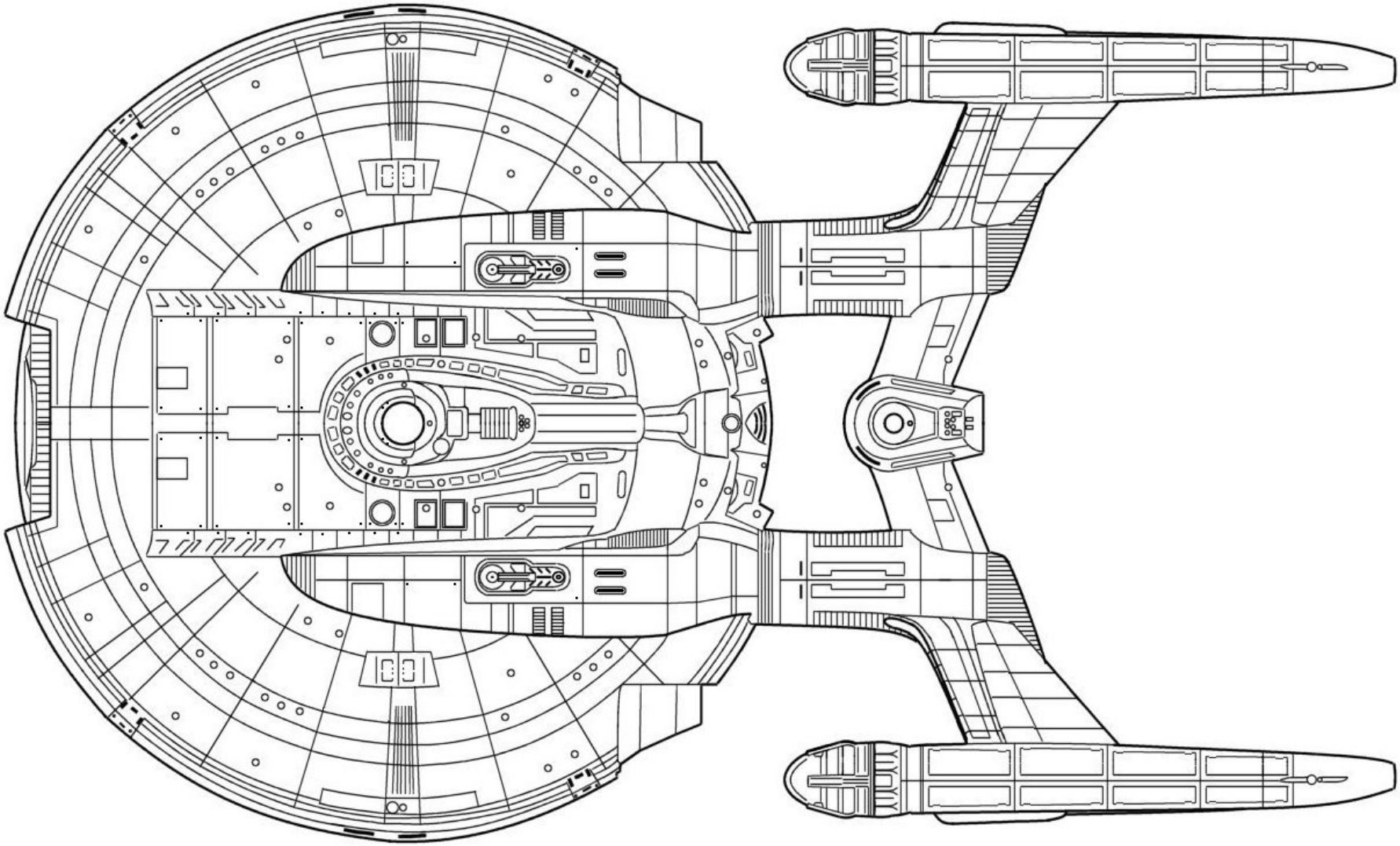
Metaprogramming with `scala.reflect`:

+ Full-fledged model of Scala available in standard distribution
+ Structured code generation with macros and quasiquotes
– Complicated: optimized towards compiler developers, not library users
– Brittle: a lot of unspecified and hard-to-satisfy invariants
– Locked-in: tightly bound to `scalac` internals

Nevertheless `scala.reflect` has proven to be useful

- Enables libraries like `async`, `pickling`, `scala-blitz`, etc
- Empowers existing solutions in `scalatest`, `Play!`, `parboiled`, etc
- Foundation for high-level abstractions: `shapeless`, `yin-yang`, etc

We are building an even better tech



Meet our new metaprogramming platform

- Name: `scala.meta` (formerly known as Project Palladium)
- Goal: Build a tool to conveniently work with programs as data
- Status: Alpha version, public preview coming this fall

Language model

Scala language model a là `scala.reflect`

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- Trees
  - TermTrees
  - TypTrees
  - DefTrees
  - ...

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- Symbols

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  - ...
- Types
- Symbols
- Scopes
- Names
- Annotations
- Constants
- Modifiers
- ...

A lot of concepts that interact in inconsistent ways

```
scala> val list = q"List(1, 2, 3)"
list: universe.Tree = List(1, 2, 3)

scala> toolbox.typecheck(list).tpe
res1: toolbox.u.Type = List[Int]
```

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res2: universe.Tree = List[Int]
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scala> res1 == res2
res3: Boolean = false
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res1: toolbox.u.Type = List[Int]

scala> tq"List[Int]"
res2: universe.Tree = List[Int]

scala> res1 == res2
res3: Boolean = false

scala> toolbox.typecheck(list, toolbox.TYPEmode).tpe
res4: toolbox.u.Type = List[Int]

scala> res1 == res4
res5: Boolean = true
```

Scala language model à la `scala.meta`

Trees

Scala language model à la `scala.meta`

Trees.

Scala language model à la `scala.meta`

Trees.

- In `scala.meta`, we model everything just with its abstract syntax
- Types, members, names, modifiers: all represented with trees
- There's only one data structure, so there's only one way to do it

Terms are trees

```
scala> q"List(1, 2, 3)"
res0: meta.Term = List(1, 2, 3)

scala> q"List(1, 2, 3)".tpe
res1: meta.Type = List[Int]
```

Types are trees

```
scala> t"List[Int]"
res2: meta.Type = List[Int]

scala> t"List[Int]" == q"List(1, 2, 3)".tpe
res3: Boolean = true

scala> t"List[Int]" <:< t"List[_]"
res4: Boolean = true

scala> t"List[Int]".subtypes
res5: Seq[meta.Type] = List(::[Int], Nil.type)
```

Symbols are trees

```
scala> val head1 = t"List[Int]".defs("head")
head1: meta.Def = def head: Int

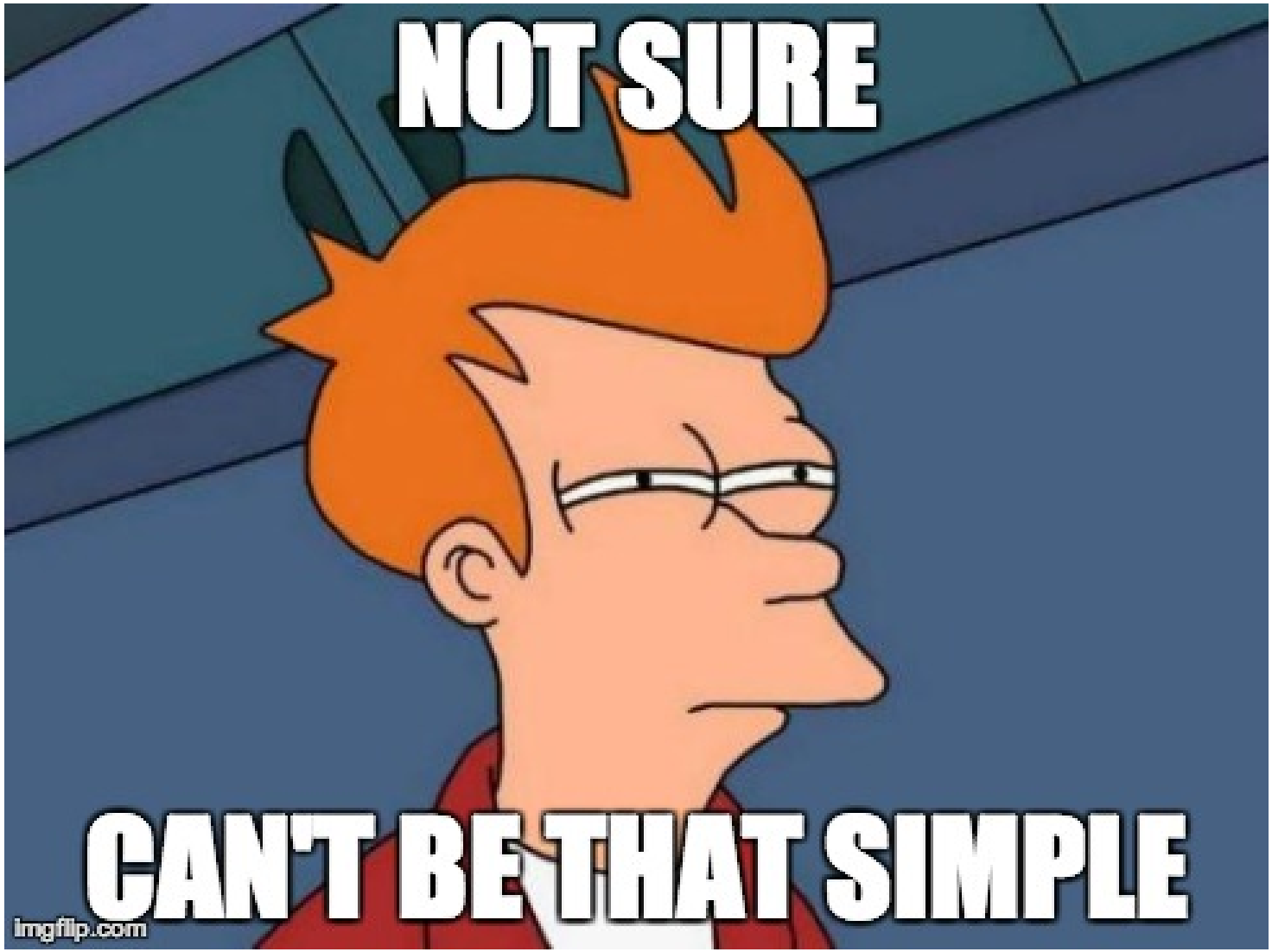
scala> val head2 = q"List(1, 2, 3).head".defn
head2: meta.Def = def head: Int

scala> head1 == head2
res8: Boolean = true

scala> head1.owner
res9: meta.Scope = class List { ... }

scala> head1.show[Raw]
res10: String = Decl.Def(Nil, Term.Name(head), Nil, Nil, Int)
```

Something seems fishy



You might be thinking

- If there's just trees and nothing more
- How do we know that `List` in `List(1, 2, 3)` is `scala.List`?

In scala.reflect

Trees only

```
scala> val list = q"List(1, 2, 3)"
list: universe.Tree = List(1, 2, 3)

scala> tb.eval(q"val List = 42; $list")
compilation has failed: Int does not take parameters
```

In scala.reflect

Trees only

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scala> val list = q"List(1, 2, 3)"
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compilation has failed: Int does not take parameters
```

Trees and symbols

```
scala> val List = mirror.staticModule("s.c.i.List")
res0: universe.ModuleSymbol = object List

scala> val list = q"$List(1, 2, 3)"
list: universe.Tree = List(1, 2, 3)

scala> tb.eval(q"val List = 42; $list")
res2: Any = List(1, 2, 3)
```

The missing technology

TECHNICAL REPORT NO. 194

Hygienic Macro Expansion

by

E. E. Kohlbecker, D. P. Friedman, M. Felleisen, and B. Duba
Indiana University

May, 1986

Hygiene in action

In scala.reflect

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compilation has failed: Int does not take parameters
```

In scala.meta

```
scala> val list = q"List(1, 2, 3)"
list: meta.Tree = List(1, 2, 3)

scala> q"val List = 42; $list".eval
res1: Any = List(1, 2, 3)
```

Tree design

Trees are now comprehensive

In `scala.reflect`

```
scala> q"for (i <- List(1, 2, 3)) println(i)"
res0: universe.Tree = List(1, 2, 3).foreach(i => println(i))
```

Trees are now comprehensive

In `scala.reflect`

```
scala> q"for (i <- List(1, 2, 3)) println(i)"
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In `scala.meta`

```
scala> q"for (i <- List(1, 2, 3)) println(i)"
res1: meta.Term = for (i <- List(1, 2, 3)) println(i)
```

Trees are now comprehensive

- In `scala.meta`, we keep all the information about the program
- Nothing is desugared (e.g. `for` loops or string interpolations)
- Nothing is thrown away (e.g. comments or formatting details)

Trees are now strongly-typed

In `scala.reflect`

```
case class Apply(fun: Tree, args: List[Tree])
```

In `scala.meta`

```
@ast class Apply(fun: Term, args: Seq[Arg])
```

In scala.reflect

```
scala> val List = tq"_root_.scala.List"
List: universe.Select = _root_.scala.List

scala> val list = q"$List(1, 2, 3)"
list: universe.Tree = _root_.scala.List(1, 2, 3)

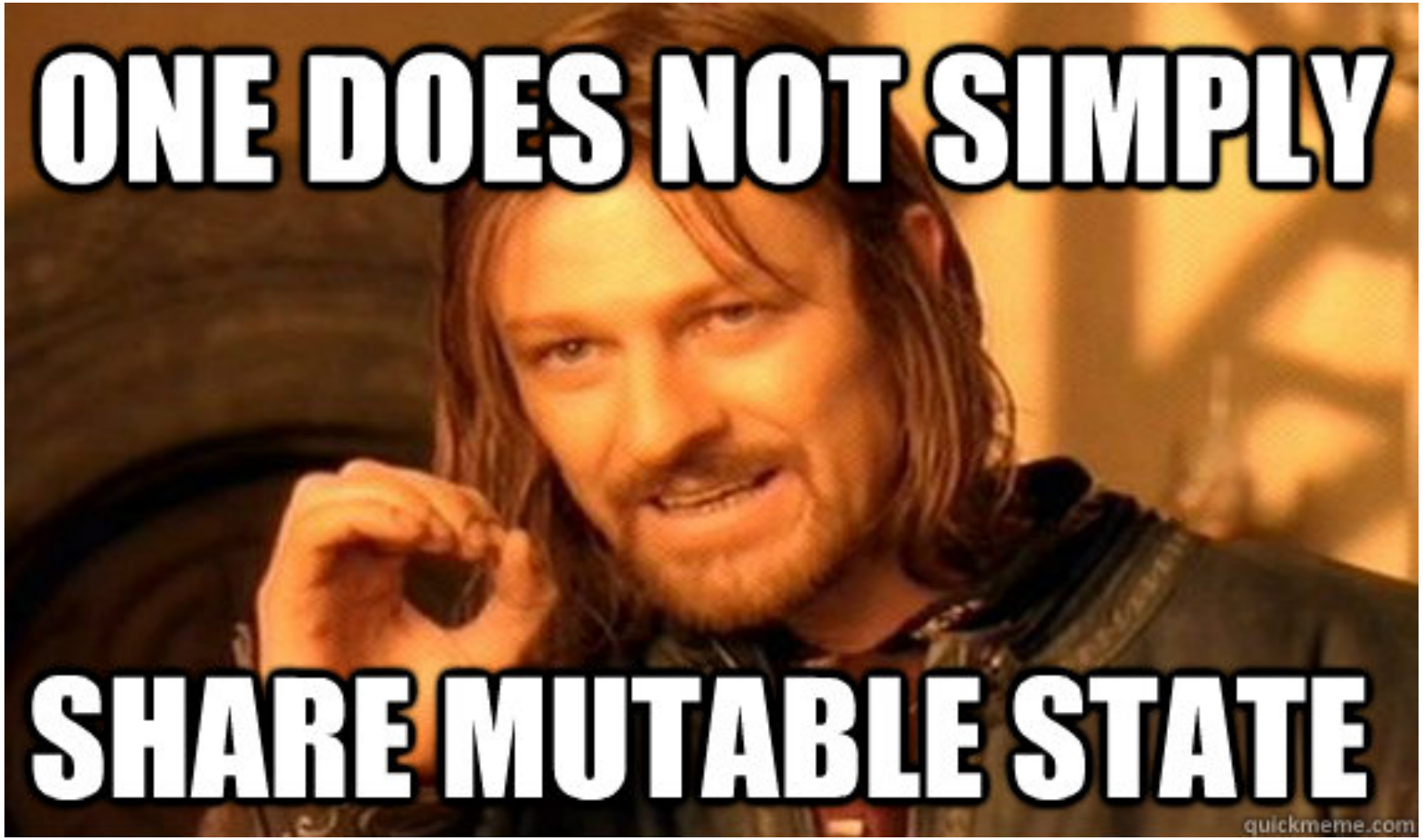
scala> toolbox.typecheck(list)
s.t.r.ToolBoxError: type scala.List is not a value
  at s.t.r.ToolBoxFactory$...apply(ToolBoxFactory.scala:178)
  at s.t.r.ToolBoxFactory$...apply(ToolBoxFactory.scala:170)
  at s.t.r.ToolBoxFactory$...apply(ToolBoxFactory.scala:148)
  ...
```

In scala.meta

```
scala> val List = t"_root_.scala.List"
List: meta.Type = _root_.scala.List

scala> val list = q"$List(1, 2, 3)"
<console>:27: error: type mismatch;
 found   : Type
 required: Term
             val list = q"$List(1, 2, 3)"
                            ^
```

Boromir has certain doubts about `scala.reflect`



Trees are now immutable

In `scala.reflect`

```
abstract class Tree {
  private[this] var rawtpe: Type = _
  def tpe: Type = rawtpe
  def setType(tp: Type): this.type = { rawtpe = tp; this }
  ...
}
```

Trees are now immutable

In `scala.reflect`

```
abstract class Tree {
  private[this] var rawtpe: Type = _
  def tpe: Type = rawtpe
  def setType(tp: Type): this.type = { rawtpe = tp; this }
  ...
}
```

In `scala.meta`

```
implicit class SemanticTermOps(val term: Term) extends AnyVal
  @hosted def tpe: Type = ...
}
```

Anytime metaprogramming

Flavors of metaprogramming

- Compile-time metaprogramming (macros)
- Runtime metaprogramming (runtime reflection, toolboxes)
- Some-time metaprogramming (IDEs, incremental compilation, linters)

Flavors of environments

- Scala compiler (`scala-reflect.jar` and `scala-compiler.jar`)
- IntelliJ IDEA (a very own implementation of Scala's typechecker)
- Scala IDE (Scala compiler running in a funny mode)
- SBT (A tiny compiler plugin + a very own analysis infrastructure)
- DIY (Just have some Scala sources and need to find something out)

Too complicated again!

- Typechecking and evaluation kind of work at runtime, but not quite
- Macros work at compile time, but only in a separate project
- Macros seem to work in IntelliJ, but they actually don't

With `scala.meta` it's no longer a problem

Demo!

But how is this supposed to work?!

But how is this supposed to work?!

- Macros are known to be just bytecode invoked by reflection
- But when macros aren't compiled yet, there's no bytecode
- Therefore having macros work in the same file would be most unusual
- This merits an explanation

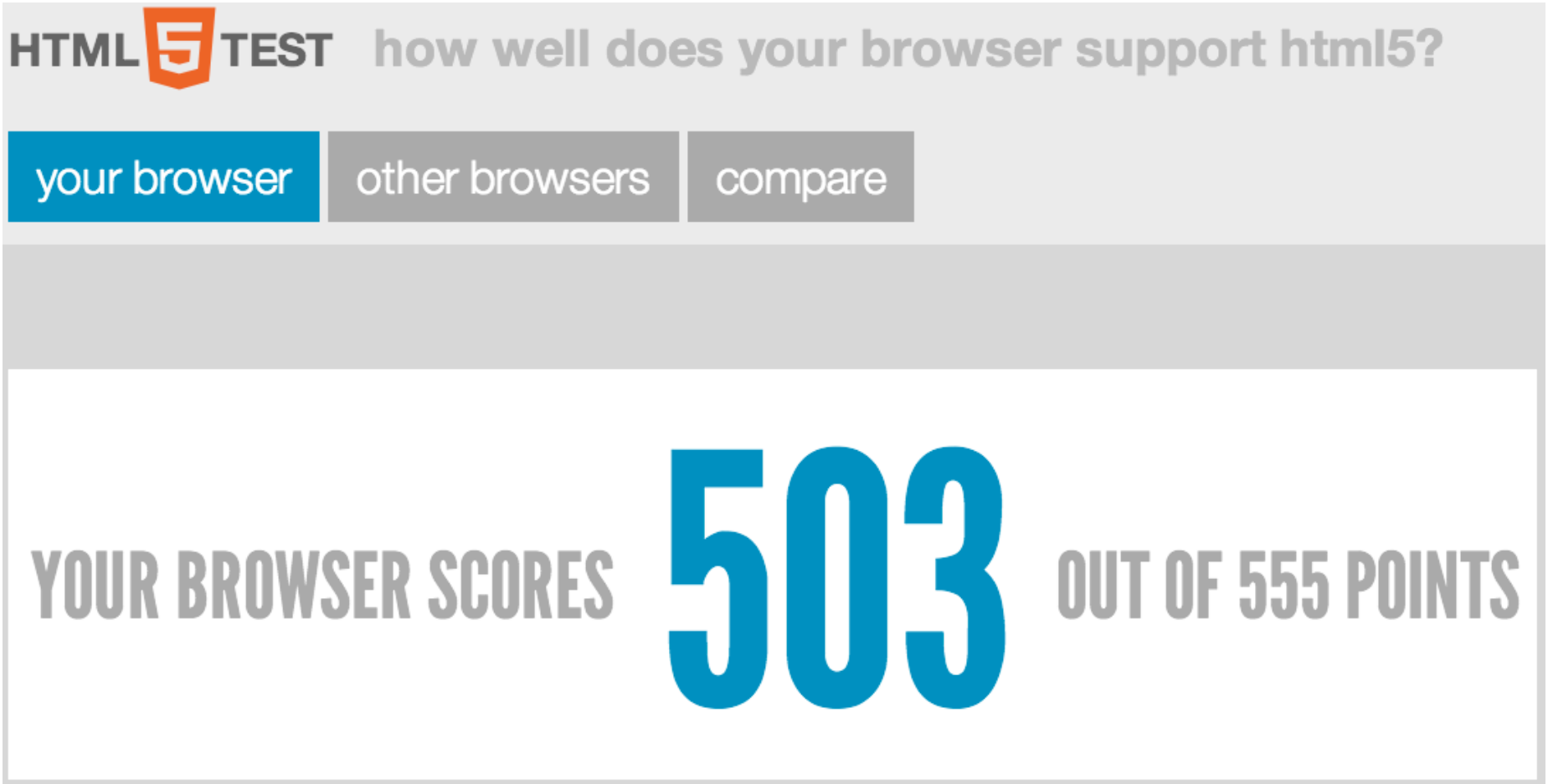
Explanation, in a nutshell

- With `scala.meta`, we have principled tools for metaprogramming
- This makes it possible to make macros principled
- When macros become a proper abstraction, all becomes much better

Explanation, part 1: Clear requirements for all hosts

- A standalone, independent metaprogramming interface
- Built on simple, strongly-typed and immutable foundation
- With clear and concise host API
- Prototype implementations for `scalac` and IntelliJ

Explanation, part 1: Clear requirements for all hosts



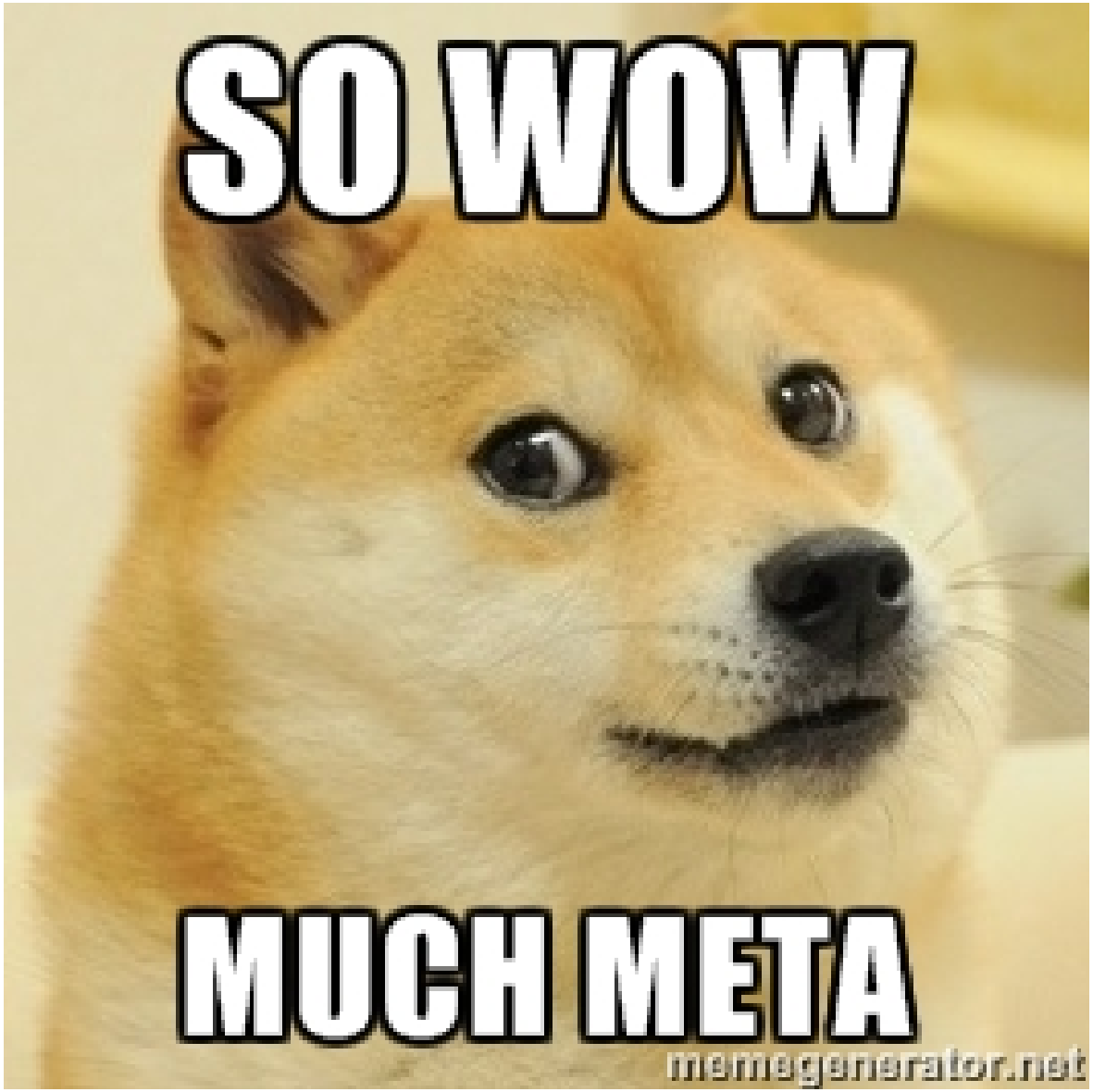
Explanation, part 2: Equal opportunities for all hosts

- With our plugin enabled, `scalac` saves all ASTs after typer
- This means that full info about any program is available at any time
- No information is lost anymore (e.g. signatures of local definitions)
- The overhead is actually quite reasonable (e.g. compressed *untyped* ASTs of scala-library.jar are less than 15% of the bytecodes)

Explanation, part 3: Brave new world!

- Easy access to all ASTs enables a lot of interesting things
- One of them is host-independent AST interpretation
- That's exactly what we're using to lift the precompilation restriction

Anytime metaprogramming



Automatic code rewriting tool

- As of late, there have been talks about deprecating procedure syntax
- But it's so common that warnings are only emitted under `-Xfuture`
- It would be nice to have an automatic migration tool for this!

Automatic code rewriting tool

- Unfortunately existing `scalac` functionality isn't quite fit for that
- Wheels are reinvented in order to do robust parsing and prettyprinting
- With `scala.meta`, this become very simple!

Automatic code rewriting tool

```
some/project$ sbt meta
[info] Loading project definition...
[info] Starting scala interpreter...
```

Automatic code rewriting tool

```
some/project$ sbt meta
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> project
res0: Project = Project(List("scalameta/package.scala",
"scalameta/Trees.scala", "scalameta/semantic/Hosts.scala"..))
```

Automatic code rewriting tool

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res0: Project = Project(List("scalameta/package.scala",
"scalameta/Trees.scala", "scalameta/semantic/Hosts.scala"..))

> project.rewrite {
|   case q"..$mods def $nme[..$tps](...$pss) { ..$body }" =>
|   q"..$mods def $nme[..$tps](...$pss): Unit = { ..$body }"
| }.persist
res1: Project = Project(List("scalameta/package.scala",
"scalameta/Trees.scala", "scalameta/semantic/Hosts.scala"..))
```

Wrapping up

Brought to you by the Palladium team

This project is brought to you by the Palladium team.
Thank you very much, folks, for making this presentation possible!

- Uladzimir Abramchuk
- Igor Bogomolov
- Eugene Burmako
- Mathieu Demarne
- Martin Duhem
- Adrien Ghosn
- Mikhail Mutcianko
- Dmitry Naydanov
- Artem Nikiforov
- Vladimir Nikolaev
- Alexander Podkhalyuzin
- Jatin Puri
- Denys Shabalin

What we've seen today

- Built on a simple principle that everything is a tree
- And designed in strongly-typed and fully immutable style
- `scala.meta` is a clean and portable metaprogramming toolkit

Public preview coming this fall at scalameta.org!