What Are Macros Good For?

Eugene Burmako

École Polytechnique Fédérale de Lausanne
http://scalamacros.org/

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What are macros?

- An experimental feature of 2.10 and 2.11
- You write functions against the reflection API
- Compiler invokes them during compilation

Macro flavors

- Many ways to hook into the compiler $\rightarrow$ many macro flavors
- Type macros, annotation macros, untyped macros, etc
- However in 2.10 and 2.11 there are only def macros

Def macros

```
log("does not compute")
```

⇩

```
if (Logger.enabled)
  Logger.log("does not compute")
```

- Def macros replace well-typed terms with other well-typed terms
- Generated code can contain arbitrary Scala constructs
- Code generation can involve arbitrary computations

Def macros

```
def log(msg: String): Unit = ...
```

- Macro signatures look like signatures of normal methods

Def macros

```
def log(msg: String): Unit = macro impl

def impl(c: Context)(msg: c.Expr[String]): c.Expr[Unit] = ...
```

- Macro signatures look like signatures of normal methods
- Macro bodies are just stubs, referring macro impls defined outside

Def macros

```
def log(msg: String): Unit = macro impl

def impl(c: Context)(msg: c.Expr[String]): c.Expr[Unit] = {
  import c.universe._




}
```

- Macro signatures look like signatures of normal methods
- Macro bodies are just stubs, referring macro impls defined outside
- Implementations use reflection API to analyze and generate code

Def macros

```
def log(msg: String): Unit = macro impl

def impl(c: Context)(msg: c.Expr[String]): c.Expr[Unit] = {
  import c.universe._
  q"""
    if (Logger.enabled)
      Logger.log($msg)
  """
}
```

- Macro signatures look like signatures of normal methods
- Macro bodies are just stubs, referring macro impls defined outside
- Implementations use reflection API to analyze and generate code

Quasiquotes

```
q"""
  if (Logger.enabled)
    Logger.log($msg)
"""
```

- `q"..."` string interpolators that build code are called quasiquotes
- They are very convenient to create and pattern match code snippets
- In 2.10 quasiquotes are available via the macro paradise plugin
- In 2.11 quasiquotes are available in the standard Scala distribution

Summary

```
log("does not compute")
```

⬇

```
if (Logger.enabled)
  Logger.log("does not compute")
```

- Local expansion of method calls
- Well-formed and well-typed arguments
- Now what is this good for?

Code generation

Code generation

- Create terms and types on-the-fly
- More convenient and robust than textual codegen

Example #1 - Term generation

```
def createArray[T: ClassTag](size: Int, el: T) = {
  val a = new Array[T](size)
  for (i <- 0 until size) a(i) = el
  a
}
```

- We want to write beautiful generic code, and Scala makes that easy
- Unfortunately, abstractions oftentimes bring overhead
- E.g. in this case erasure will cause boxing leading to a slowdown

Example #1 - Term generation

```
def createArray[@specialized T: ClassTag](...) = {
  val a = new Array[T](size)
  for (i <- 0 until size) a(i) = el
  a
}
```

- Methods can be `@specialized`, but it's viral and heavyweight
- Viral = the entire call chain needs to be specialized
- Heavyweight = specialization leads to duplication of bytecode

Example #1 - Term generation

```
def createArray[T: ClassTag](size: Int, el: T) = {
  val a = new Array[T](size)
  def specBody[@specialized T](el: T) {
    for (i <- 0 until size) a(i) = el
  }
  classTag[T] match {
    case ClassTag.Int => specBody(el.asInstanceOf[Int])
    ...
  }
  a
}
```

- We want to specialize just as much as we need
- As described in the recent Bridging Islands of Specialized Code paper
- But that's tiresome to do by hand, and this is where macros shine

Example #1 - Term generation

```
def specialized[T: ClassTag](code: => Any) = macro ...

def createArray[T: ClassTag](size: Int, el: T) = {
  val a = new Array[T](size)
  specialized[T] {
    for (i <- 0 until size) a(i) = el
  }
  a
}
```

- specialized macro gets pretty code and transforms it into fast code
- This is a typical scenario of using macros for performance
- Also see the talk on Macro-Based Scala Parallel Collections

Example #2 - Type generation

```
println(Db.Coffees.all)
Db.Coffees.insert("Brazilian", 99, 0)
```

- In F# one can generate wrappers over datasources
- These wrappers can then be used in a strongly-typed manner
- Can this be implemented with def macros?

Example #2 - Type generation

```
def h2db(connString: String): Any = macro ...
val db = h2db("jdbc:h2:coffees.h2.db")
```

```
val db = {
  trait Db {
    case class Coffee(...)
    val Coffees: Table[Coffee] = ...
  }
  new Db {}
}
```

- Def macros expand locally, therefore we get a bunch of local classes
- Locals are invisible from the outside, so it's a game over? Nope!

Example #2 - Type generation

```
scala> val db = h2db("jdbc:h2:coffees.h2.db")
db: AnyRef {
  type Coffee { val name: String; val price: Int; ... }
  val Coffees: Table[this.Coffee]
} = $anon$1...

scala> db.Coffees.all
res1: List[Db$1.this.Coffee] = List(Coffee(Brazilian,99,0))
```

- Scala can figure out and expose local signatures to the outer world
- Used by Specs2 to automatically create matchers for custom classes

Example #2 - Type generation

```
scala> val db = h2db("jdbc:h2:coffees.h2.db")
db: { type Coffee { ... }; val Coffees: List[this.Coffee]; }
```

- This is a fun technique stretching the boundaries of macrology
- There are some caveats, so it should be used with caution
- Alternatively you could use macro annotations available in 2.10 and 2.11 via the macro paradise plugin

Example #3 - Materialization

```
trait Reads[T] {
  def reads(json: JsValue): JsResult[T]
}

object Json {
  def fromJson[T](json: JsValue)
    (implicit fjs: Reads[T]): JsResult[T]
}
```

- Type classes are an idiomatic way of writing extensible code in Scala
- This is an example of typeclass-based design in Play

Example #3 - Materialization

```
def fromJson[T](json: JsValue)
  (implicit fjs: Reads[T]): JsResult[T]

implicit val IntReads = new Reads[Int] {
  def reads(json: JsValue): JsResult[T] = ...
}

fromJson[Int](json) // you write
fromJson[Int](json)(IntReads) // you get
```

- With type classes we externalize the moving parts
- Instances of type classes are provided once
- And then `scalac` fills them in automatically

Example #3 - Before macros

```
case class Person(name: String, age: Int)

implicit val personReads = (
  (__ \ 'name).reads[String] and
  (__ \ 'age).reads[Int]
)(Person)
```

- Everything is done manually, hence boilerplate
- There are alternatives, e.g. one presented at the Scala'13 workshop
- But each of them has its downsides

Example #3 - Vanilla macros (2.10.0)

```
implicit val personReads = Json.reads[Person]
```

- Boilerplate can be generated by a macro
- The code ends up being the same as if it were written manually
- Therefore performance remains excellent

Example #3 - Implicit macros (2.10.2+)

```
// no code necessary
```

- Implicit values can be transparently generated by implicit macros
- Used with success in pickling and shapeless

Example #3 - Implicit macros (2.10.2+)

```
trait Reads[T] { def reads(json: JsValue): JsResult[T] }

object Reads {
  implicit def materializeReads[T]: Reads[T] = macro ...
}
```

- When `scalac` looks for implicits, it traverses the implicit scope
- Implicit scope transcends lexical scope
- Among others it includes members of the targets companion

Example #3 - Implicit macros (2.10.2+)

```
fromJson[Person](json)
```

⇩

```
fromJson[Person](json)(materializeReads[Person])
```

⇩

```
fromJson[Person](json)(new Reads[Person]{ ... })
```

- Every time a `Reads[T]` isn't found, the compiler will call our macro
- Details on how this works can be found in our documentation

Static checks

Static checks

- Check your program during compilation
- Report errors and warnings as you go

Example #4 - Advanced type signatures

```
trait Request
case class Command(msg: String) extends Request

trait Reply
case object CommandSuccess extends Reply
case class CommandFailure(msg: String) extends Reply

val actor = someActor
actor ! Command
```

- Akka actors are dynamically typed, i.e. the `!` method takes `Any`
- This loosens type guarantees provided by Scala
- E.g. here we have a sneaky type error that leads to a runtime crash

Example #4 - Advanced type signatures

```
trait Request
case class Command(msg: String) extends Request

trait Reply
case object CommandSuccess extends Reply
case class CommandFailure(msg: String) extends Reply

type Spec = (Request, Reply) :+: TNil
val actor = new ChannelRef[Spec](someActor)
actor <-!- Command // doesn't compile
```

- We can implement type specification for actors even in standard Scala
- But this became practical only when we got macros
- Akka typed channels are specifically designed to make use of macros

Example #4 - Advanced type signatures

```
type Spec = (Request, Reply) :+: TNil
val actor = new ChannelRef[Spec](someActor)
actor <-!- Command // doesn't compile
```

- The `<-!-` macro takes the type of its target and extracts the spec
- Then it takes the argument type and validates it against the spec
- If necessary, the macro produces precise and clear compilation errors

Example #4 - Advanced type signatures

```
type Spec = (Request, Reply) :+: TNil
val actor = new ChannelRef[Spec](someActor)
actor <-!- Command // doesn't compile
```

- This all can be done with implicits and type-level computations
- But that's non-trivial both for the library authors and for the users
- Macros aren't ideal either, and we plan to further research this

Example #5 - Advanced static checks

```
def future[T](body: => T) = ...

def receive = {
  case Request(data) =>
    future {
      val result = transform(data)
      sender ! Response(result)
    }
}
```

- Capturing `sender` in the above closure is dangerous
- That's because `sender` is not a value, but a stateful method
- To validate captures we can use macros: SIP-21 – Spores

Example #5 - Advanced static checks

```
def future[T](body: Spore[T]) = ...

def spore[T](body: => T): Spore[T] = macro ...

def receive = {
  case Request(data) =>
    future(spore {
      val result = transform(data)
      sender ! Response(result) // doesn't compile
    })
}
```

- The spore macro takes its body and figures out all free variables
- If any of the free variables are deemed dangerous, an error is reported

Example #5 - Advanced static checks

```
def future[T](body: Spore[T]) = ...

implicit def anyToSpore[T](body: => T): Spore[T] = macro ...

def receive = {
  case Request(data) =>
    future {
      val result = transform(data)
      sender ! Response(result) // doesn't compile
    }
}
```

- The conversion to Spore can be made implicit
- That will verify closures without bothering the user

Domain-specific languages

Domain-specific languages

- Take a program written in an internal or external DSL
- Work with it as with a domain-specific data structure

Example #6 - Language virtualization

```
val usersMatching = query[String, (Int, String)](
  "select id, name from users where name = ?")
usersMatching("John")
```

- Database queries can be written in SQL

Example #6 - Language virtualization

```
val usersMatching = query[String, (Int, String)](
  "select id, name from users where name = ?")
usersMatching("John")

case class User(id: Column[Int], name: Column[String])
users.filter(_.name === "John")
```

- Database queries can be written in SQL
- They can also be written in a DSL, at times slightly awkward

Example #6 - Language virtualization

```
val usersMatching = query[String, (Int, String)](
  "select id, name from users where name = ?")
usersMatching("John")

case class User(id: Column[Int], name: Column[String])
users.filter(_.name === "John")

case class User(id: Int, name: String)
users.filter(_.name == "John")
```

- Database queries can be written in SQL
- They can also be written in a DSL, at times slightly awkward
- Or they can be written in Scala and virtualized by a macro

Example #6 - Language virtualization

```
trait Query[T] {
  def filter(p: T => Boolean): Query[T] = macro ...
}

val users: Query[User] = ...
users.filter(_.name == "John")
```

↓

```
Query(Filter(users, Equals(Ref("name"), Literal("John"))))
```

- The `filter` macro takes an AST corresponding to the predicate
- This AST is then analyzed and transformed into a query fragment
- Now we have a deeply embedded DSL, just like in LINQ and Slick

Example #7 - Internal DSLs

```
val futureDOY: Future[Response] =
  WS.url("http://api.day-of-year/today").get

val futureDaysLeft: Future[Response] =
  WS.url("http://api.days-left/today").get

futureDOY.flatMap { doyResponse =>
  val dayOfYear = doyResponse.body
  futureDaysLeft.map { daysLeftResponse =>
    val daysLeft = daysLeftResponse.body
    Ok(s"$dayOfYear: $daysLeft days left!")
  }
}
```

- Turning a synchronous program into an async one isn't easy
- One has to manually manage callbacks, introduce temps, etc

Example #7 - Internal DSLs

```
def async[T](body: => T): Future[T] = macro ...
def await[T](future: Future[T]): T = macro ...

async {
  val dayOfYear = await(futureDOY).body
  val daysLeft = await(futureDaysLeft).body
  Ok(s"$dayOfYear: $daysLeft days left!")
}
```

- Turning a synchronous program into an async one isn't easy
- Macros can do the transformation automatically: SIP-22 – Async
- Similar to C#'s `async/await` and parts of Clojure's `core/async`

Example #7 - Internal DSLs

```
def async[T](body: => T): Future[T] = macro ...
def await[T](future: Future[T]): T = macro ...
```

- At the heart of macro-based DSLs is the ability to analyze code
- The `async` macro sees detailed inner structure of code representing its argument and can transform that structure to its liking
- Also see today's talk JScala - Write Your JavaScript In Scala

Example #8 - External DSLs

```
scala> val x = "42"
x: String = 42

scala> "%d".format(x)
j.u.IllegalFormatConversionException: d != java.lang.String
  at java.util.Formatter$FormatSpecifier.failConversion...
```

- Strings are typically perceived to be unsafe

Example #8 - External DSLs

```
scala> val x = "42"
x: String = 42

scala> "%d".format(x)
j.u.IllegalFormatConversionException: d != java.lang.String
  at java.util.Formatter$FormatSpecifier.failConversion...

scala> f"$x%d"
<console>:31: error: type mismatch;
 found   : String
 required: Int
```

- Strings are typically perceived to be unsafe
- Though with macros they don't have to be

Example #8 - External DSLs

```
implicit class Formatter(c: StringContext) {
  def f(args: Any*): String = macro ???
}

val x = "42"
f"$x%d" // rewritten into: StringContext("", "%d").f(x)
```

- String interpolation desugars custom string literals into method calls
- These methods can be macros that validate strings at compile-time

Example #8 - External DSLs

```
val x = "42"
f"$x%d" // rewritten into: StringContext("", "%d").f(x)
```

```
{
  val arg$1: Int = x // doesn't compile
  "%d".format(arg$1)
}
```

- Here the `f` macro just inserts type ascriptions in strategic places
- But this approach can be used to embed much more complex DSLs
- This means static validation, typechecking and maybe even interop

Summary

What are macros good for?

- Code generation
- Static checks
- Domain-specific languages