Scala 2.12 ❤️ Java 8

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Changes on the Surface

- Lambdas for SAM types: Java 8 interop
- Scaladoc: a new look
- REPL: tab-completion
- Minor changes in the standard library

Changes Under the Hood

- Java-style encoding for lambdas
- Default methods for traits
- A new bytecode optimizer

Agenda

- I: Changes on the surface
- II: Some internals of HotSpot
- III: The Scala 2.12 Optimizer
- IV: New Bytecode in Scala 2.12
  - InvokeDynamic for Lambdas
  - Default Methods for Traits

Lambdas for SAM Types

- SAM = "Single Abstract Method"
- Lambda syntax to create SAM type instances

```
scala> new Thread(() => println("hi")).run
hi
```

- Same as in Java 8, mostly useful for interop

Interop Example: Streams

```
scala> val myList = java.util.Arrays.asList(
     |  "a1", "a2", "b1", "c2", "c1")

scala> myList.stream.
     |  filter(_.startsWith("c")).
     |  map(_.toUpperCase).
     |  sorted.
     |  forEach(println)
C1
C2
```

Scaladoc's New Look

http://www.scala-lang.org/api/2.12.0-RC2

REPL tab-completion

- Available in 2.11.8, 2.12.0
- Uses the presentation compiler (Scala IDE, ensime)

```
scala> List("a", "b").map(_.to<TAB>
...
toDouble       toLowerCase    toUpperCase

scala> List("a", "b").map(_.touc<TAB>
scala> List("a", "b").map(_.toUpperCase<TAB>

def toUpperCase(): String
def toUpperCase(x$1: java.util.Locale): String
```

Right-Biased Either

```
scala> def toInt(s: String): Either[MyError, Int] =
     |   ...

scala> def sum(a: String, b: String) = for {
     |   x <- toInt(a)
     |   y <- toInt(b)
     | } yield x + y
sum: (a: String, b: String)Either[MyError,Int]

scala> sum("1", "2")
res1: Either[MyError,Int] = Right(3)
```

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Changes to the Library

- A `mutable.TreeMap` (sorted map)
- Deprecated `JavaConversions`: only explicit `asScala` / `asJava` using `JavaConverters`
- Various minor performance improvements

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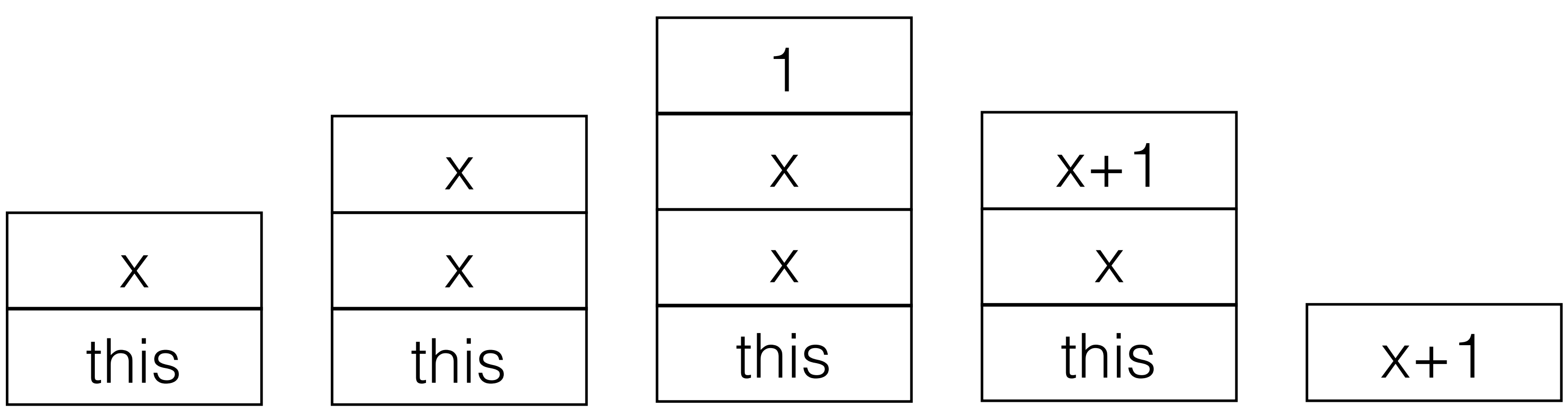
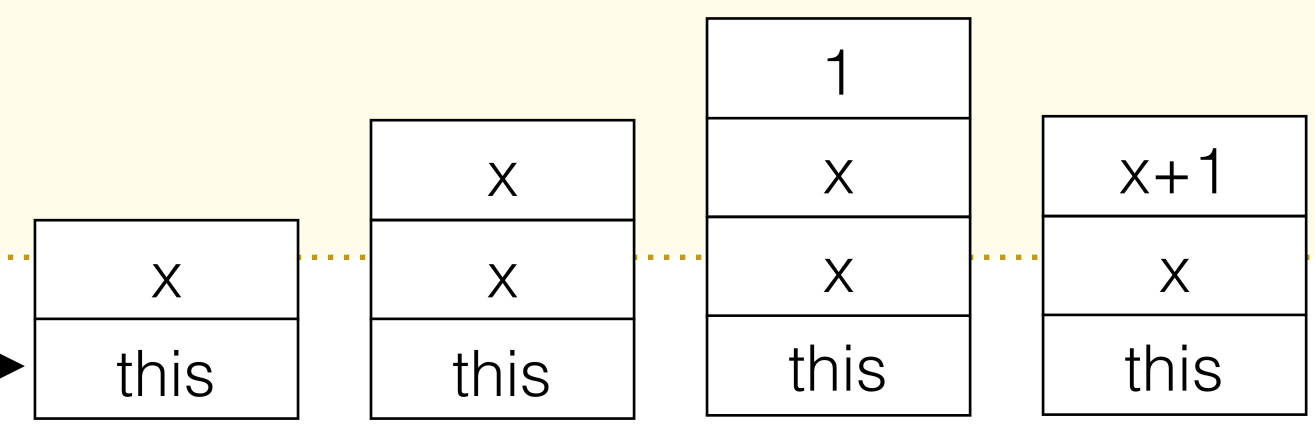
Java Bytecode Example

```
// def f(x: Int) = x + 1

  public f(I)I
    ILOAD 1
    ICONST_1
    IADD
    IRETURN
```



Interpretation

```scala
val stack: Stack[Any]
val frameIdx: Stack[Int]

def intp(code: List[Instr]) = {
  code.head match {
    case IConst(n) => stack.push(n)
    case ILoad(n) => stack.push(stack(frameIdx.head + n))
    case IAdd => stack.push(stack.pop() + stack.pop())
    ...
  }
  intp(code.tail)
}
```



Making it Fast

- Bytecode that is executed "many" times is compiled to native code (assembly)
- Two compilers in JDK 7+
    - C1 ("client" compiler in JDK 6): fast
    - C2 ("server"): advanced optimisations, slower

"Many" Executions

- Method invocation counter: 2k → C1, 15k → C2
  - C1 assembly is *instrumented*: update invocation counter, other metrics
- Loop counter: 60k iterations → C1, ... → C2
  - Assembly entrypoint at the loop start
  - Switch to the assembly code: "on-stack replacement" (OSR)

Optimizations

"JVM JIT compilation overview" by Vladimir Ivanov

http://www.slideshare.net/ZeroTurnaround/vladimir-ivanovjvmjitcompilationoverview-24613146

- compiler tactics
  - delayed compilation
  - tiered compilation
  - on-stack replacement
  - delayed reoptimization
  - program dependence graph rep.
  - static single assignment rep.
- proof-based techniques
  - exact type inference
  - memory value inference
  - memory value tracking
  - constant folding
  - reassociation
  - operator strength reduction
  - null check elimination
  - type test strength reduction
  - type test elimination
  - algebraic simplification
  - common subexpression elimination
  - integer range typing
- flow-sensitive rewrites
  - conditional constant propagation
  - dominating test detection
  - flow-carried type narrowing
  - dead code elimination
- language-specific techniques
  - class hierarchy analysis
  - devirtualization
  - symbolic constant propagation
  - autobox elimination
  - escape analysis
  - lock elision
  - lock fusion
  - de-reflection
- speculative (profile-based) techniques
  - optimistic nullness assertions
  - optimistic type assertions
  - optimistic type strengthening
  - optimistic array length strengthening
  - untaken branch pruning
  - optimistic N-morphic inlining
  - branch frequency prediction
  - call frequency prediction
- memory and placement transformation
  - expression hoisting
  - expression sinking
  - redundant store elimination
  - adjacent store fusion
  - card-mark elimination
  - merge-point splitting
- loop transformations
  - loop unrolling
  - loop peeling
  - safepoint elimination
  - iteration range splitting
  - range check elimination
  - loop vectorization
- global code shaping
  - inlining (graph integration)
  - global code motion
  - heat-based code layout
  - switch balancing
  - throw inlining
- control flow graph transformation
  - local code scheduling
  - local code bundling
  - delay slot filling
  - graph-coloring register allocation
  - linear scan register allocation
  - live range splitting
  - copy coalescing
  - constant splitting
  - copy removal
  - address mode matching
  - instruction peepholing
  - DFA-based code generator

Inlining

- Inlining enables most other optimizations
  - Duplicated code can be specialized
- Heuristics decide what to inline:
  - Small methods (35 bytes) are inlined
  - "Hot" callsites are inlined (up to 325 bytes)
  - Max depth of 9

Inlining Virtual Methods

- Java / Scala has virtual methods by default
- Many callsites are *monomorphic*
  - Class Hierarchy Analysis (CHA): a virtual method with no overrides can be inlined (C1, C2)
  - Profile-based inlining (C2): inline if the receiver at a callsite is always the same
  - Profiles collected by interpreter and C1 assembly

Speculative Inlining

- Assumptions can invalidate compiled code
    - A method gets an override when a new class is loaded
    - A new receiver type reaches a (previously monomorphic) callsite
- Deoptimization: the assembly is discarded, the interpreter takes over

Learn (a lot) More

- "JVM Mechanics", talk by Doug Hawkins (Azul)
  - Slides: http://www.slideshare.net/dougqh/jvm-mechanics-when-does-the
  - Video: https://www.youtube.com/watch?v=E9i9NJeXGmM

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Megamorphic Callsites

```
class Range {
  def foreach(f: Int => Unit) = {
    while(..) { .. f.apply(i) .. }
  }
}

(1 to 10) foreach (x => foo)
(2 to 20) foreach (x => bar)
(3 to 30) foreach (x => baz)
```

Virtual call:

- Run-time type of `f` defines which code to run
- Megamorphic callsite, varying targets
- Method lookup on every loop iteration

Solution: Inlining

```
(1 to 10) foreach (x => foo)
```

Scala optimizer inlines `foreach`

```
val _this = 1 to 10
val _f = (x: Int) => foo
while(..) { .. _f.apply(i) .. }
```

Monomorphic callsite enables JVM optimizations:

- Skip method lookup
- Inlining `apply` enables further optimizations

Value Boxing

```scala
var r = 0
(1 to 10000) foreach { x => r += x }
```

```scala
val r = IntRef(0)
val f = new anonfun(r)
(1 to 10000) foreach f
```

Slow

- Why? Not obvious..

```scala
class anonfun(r: IntRef) {
  def apply(x: Int) {
    r.elem += x
  }
}
```

Inlining

```scala
val r = IntRef(0)
val f = new anonfun(r)
(1 to 10000) foreach f
```

Inline `foreach` and function body

```scala
val r = IntRef(0)
val f = new anonfun(r)
var x = 0
while (x < 10000) {
  r.elem += x
}
```

Still slow (same as before)!

- Why? `IntRef`
- Escape analysis fails..

Closure Elimination

```scala
val r = IntRef(0)
val f = new anonfun(r)
var x = 0
while (x < 10000) {
  r.elem += x
}
```

Eliminate the closure allocation

```scala
val r = IntRef(0)
var x = 0
while (x < 10000) {
  r.elem += x
}
```

Fast! JVM escape analysis kicks in.

Scala

Typesafe

Box Elimination

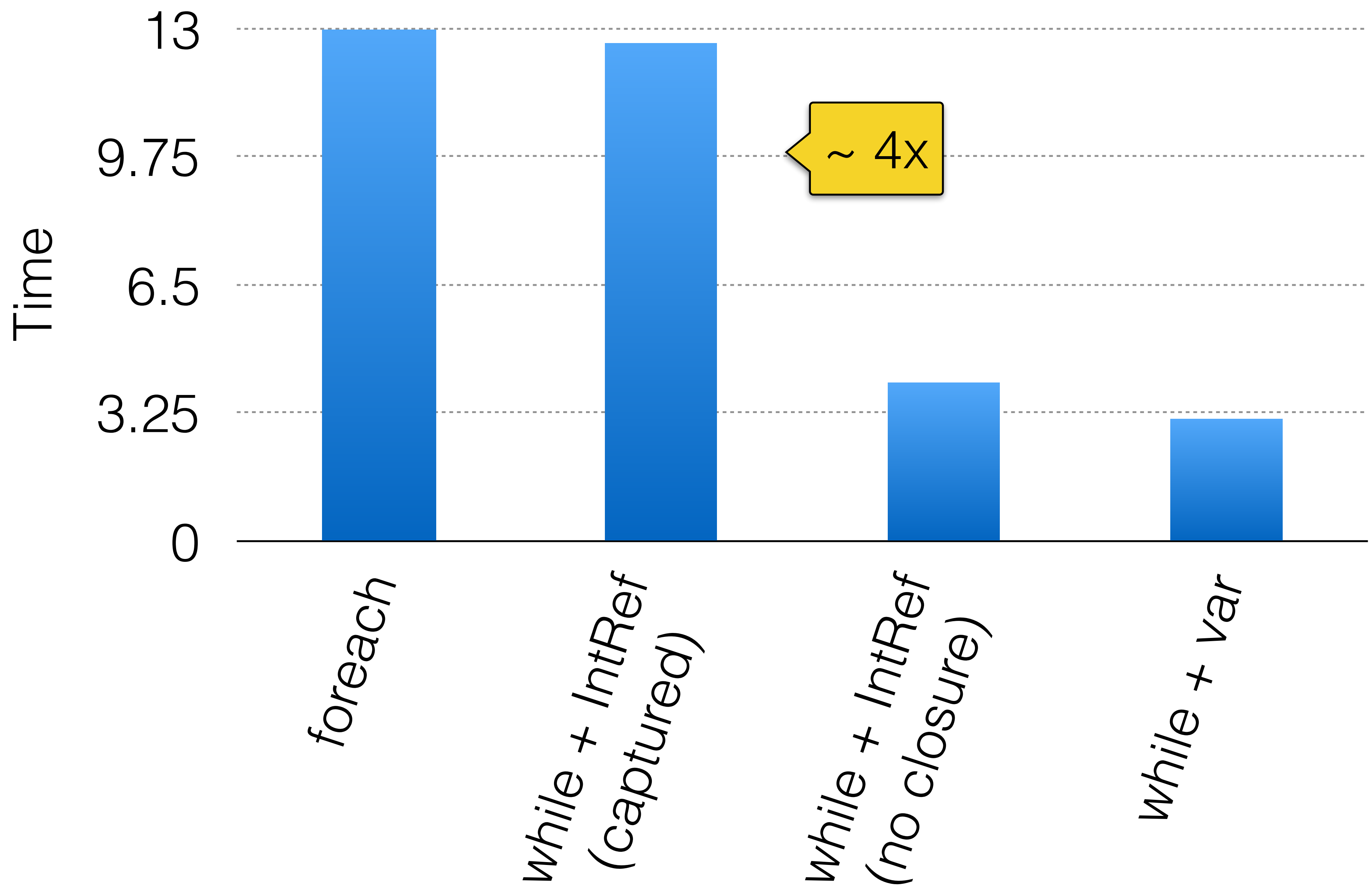
```scala
val r = IntRef(0)
var x = 0
while (x < 10000) {
  r.elem += x
}
```

Local `var` instead of `IntRef`

```scala
var r = 0
var x = 0
while (x < 10000) {
  r += x
}
```

Same as before!
JVM optimizes the IntRef just fine.

Bars


13
9.75
6.5
3.25
0
Time
~ 4x
foreach
while + IntRef (captured)
while + IntRef (no closure)
while + var

Compile-time Optimizer

- Goal: transform the code to make it please the JVM
- Don't perform optimizations that the JVM does well
- Avoid fruitless inlining: degrades performance
  - JVM optimizer is sensitive to method size

Scala

Typesafe

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InvokeDynamic (indy)

- Bootstrap method
  - Runs *once*, when indy is first executed
  - Arguments from the bytecode descriptor
- Target method
  - Invoked on each indy execution
  - Acts on the ordinary JVM stack

InvokeDynamic (indy)

```
invokedynamic name(argTps)resTp bsRef bsArgs
```

`MethodHandle` reference to bootstrap method

```scala
def myBootstrap(predefArgs, customArgs): CallSite
```

```scala
class CallSite {
  val/var target: MethodHandle // invoked method
}
```

Indy-Lambda

```
(s: String) => s.trim
```

```
def $anonfun(s: String) = s.trim
```

SAM name

SAM interface

```
invokedynamic apply()Lscala/Function1;
  LambdaMetafactory.altMetafactory     // bootstrap
  (Lj/l/Object;)Lj/l/Object;           // SAM type
  A.$anonfun(Lj/l/String;)Lj/l/String // body meth
```

LambdaMetaFactory

- Synthesizes and loads a new class that implements the SAM interface
- Returns a `CallSite` with a target that creates a new instance
  - If nothing is captured, the `CallSite` target returns a singleton instance

LMF 📦 Boxing Adaptation

Erasure: `(Obect)String`

```
trait T[T] { def apply(x: T): String }

val f: T[Int] = (x: Int) => "x:" + x

<synth> def anonfun$f(x: Int) = "x:" + x
```

LMF supports such differences, adds an unboxing conversion

Boxing 📦 Scala vs Java

```
val a: Int = (null: Integer) // 0 in Scala
int a      = (Integer) null; // NPE in Java
```

```
trait T[T] { def apply(x: T): String }
val f: T[Int] = (x: Int) => "x:" + x

f.asInstanceOf[T[Any]].apply(null)
```

```
<synth> def anonfun$f$adapted(x: Object) =
  anonfun$f(unboxToInt(x))
```

Specialization

```
trait A[@spec(Int) T]  { def apply(x: T): Int }
class C extends A[Int] { def apply(x: Int) = x }
```

```
trait A {
  def apply(x: Object): Object
  def apply$mcI$sp(x: Int): String = apply(box(x))
}
class C extends A {
  def apply(x: Object) = apply$mcI$sp(unbox(x))
  def apply$mcI$sp(x: Int) = x
}
```

LMF 💔 Specialization

```
trait A[@spec(Int) T] { def apply(x: T): Int }

val f: T[Int] = x => x
```

Should not box

This is the SAM,
LMF will implement it

```
trait A {
  def apply(x: Object): Object
  def apply$mcI$sp(x: Int): String = apply(box(x))
}
```

Don't subvert `@spec`

- `FunctionN`: hand-written specializations where the specialized method is abstract

- User-defined SAM types: don't use LMF, create an anonymous class at compile-time

$outer 📤 for local classes

```
class A {
  def f = () => { class C; serialize(new C) }
}
```

```
class $anofun { // 2.11
  def apply() = { class C; serialize(new C) }
}

class A { // 2.12
  def $anonfun { class C; serialize(new C) }
}
```

$outer is $anonfun

$outer is A

A Final's Secret 💌

```
class A {
  class B
  final class C
}

scala> classOf[A#B].getDeclaredFields.toList
List(public final A A$B.$outer)

scala> classOf[A#C].getDeclaredFields.toList
List()

scala> (new a1.C:Any) match {case _:a2.C => "OK"}
OK
```

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Fix `$outer` Capture 🎣

- Mark local classes with no subclasses `final`
- The existing logic eliminates the `$outer` field if it is not needed

More `$outer` Capture

```
class A {
  val f = () => { def local = 1; local }
}
```

- 2.11: `local` is lifted to the `$anonfun` class
- 2.12: `local` ends up in `A`, the closure needs to capture and store the outer A
  - Emit local methods static when possible

Lazy Val Init Lock 🔐

```
class A {
  def f = () => { lazy val x = 1; x }
}

// generates
def x(v: IntRef) = { if(!init) lzyCompute(v) .. }
def lzyCompute(v: IntRef) = this.synchronized{..}
```

- 2.11: methods generated in `$anonfun`. 2.12: in `A`
- Contention on the A instance, deadlocks

Local Lazies à la Dotty 🔘

- Observation: local lazies are boxed anyway
- Synchronize initialization on the box itself

```
def f = () => { lazy val x = 1; x }

// generates
def x(v: LazyInt) =
  if (v.init) v.value else lzyCompute(v)

def lzyCompute(v: LazyInt) = v.synchronized{..}
```

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Default Methods

- Looks like it could be simple:

```
trait T { def f = 1 }

interface T { default int f() { return 1; } }
```

- Challenges
  - Super calls
  - Multiple inheritance / linearization
  - Performance

Invokespecial 💍

- Used for private methods, constructors, super calls
- Method lookup is dynamic!

```
class C extends B {.. invokespecial A.f ..}
```

  - If A is a superclass (transitive) of C, lookup starts at B, otherwise it starts at A
  - Method lookup in superclasses, then interfaces

Bug in 2.11 🐛

```scala
class A { def f = 1 }
class B extends A { override def f = 2 }
trait T extends A
class C extends B with T {
  def t = super[T].f // should be 1
}

// invokespecial A.f in class C
// Lookup for f starts in B (not A)

// 2.12: "error: cannot emit super call"
```

Invokespecial 👨‍👩‍👧 Parents

```
trait T { def f = 1 }
trait U extends T
class C extends U { def t = super.f }
```

invokespecial T.f is not allowed unless C implements T

```
trait T {
  default int f() { return 1; }
  static int f$($this: T) {
    $this.f();
  }
}
class C { def t = T.f$(this) }
```

invokespecial T.f

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Forwarders ↪️ 2.11

```
trait T { def f = 1 }
class C extends T

interface T {
  int f();
}
class T$class {
  public static int f(T $this) { return 1; }
}
class C implements T {
  public int f() { return T$class.f(this); }
}
```

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Forwarders ↪️ 2.12

```scala
class A { def f = 1 }
trait T extends A { override def f = 2 }
class C extends A
```

T and A are unrelated

```java
interface T { default int f() { return 2; } }

class C extends A implements T {
  public int f() { T.super.f(); }
}
```

invokespecial

JUnit 4 💔 Default Methods

```
trait T { @Test def runMe() { .. } }
@RunWith(..) class C extends T

// Test C failed: No runnable methods
```

- `-Xmixin-force-forwarders:junit`
  - Enabled by default
- JUnit 5 will support default methods

Default Methods Perf 🏎

- Observation: using default methods degrades startup performance
- Compiling a simple `HelloWorld.scala`
  - Relying on default methods: 3.9s
  - With mixin forwarders: 2.9s
- Hot performance (sbt) is not affected

Mixin Forwarders in RC2

```
trait T { def f = 1 }
class C extends T

interface T {
  default public static int f$(T $this) {
    return $this.f();
  }
  default public int f() { return 1; }
}
class C implements T {
  public int f() { return T.f$(this); }
}
```

JVM and Default Methods

- Class Hierarchy Analysis is disabled for default methods
  - Prevents inlining in C1, likely other optimizations
- Class loading: populating class vtables with default methods is slow
  - Search through all ancestors
  - Mixin forwarders avoid this for classes; 60% speedup on `scala -version`
  - Still a hotspot in `generate_default_methods`, when loading interfaces

Thank You!

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