Java

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# JSR 292 Cookbook: Fresh Recipes with New Ingredients

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# Overview

Got a language cooking on the JVM?

JSR 292, a set of major changes to the JVM architecture, provides you with some exciting new ingredients.

# Agenda

- A Discourse on Methods
  - discussion of compiled code
- Recipes (= use cases):
  - calling Java
  - Curry
  - Fast-and-slow
- (…with JSR 292 API elements sprinkled in)

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# What’s in a method call?

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- Naming — using a symbolic name
- Linking — reaching out somewhere else
- Selecting — deciding which one to call
- Adapting — agreeing on calling conventions

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- Selecting — deciding which one to call
- Adapting — agreeing on calling conventions

- *(…and finally, a parameterized control transfer)*

# A connection from caller A to target B

- Including naming, linking, selecting, adapting:
- …where B might be known to A only by a name
- …and A and B might be far apart
- …and B might depend on arguments passed by A
- …and a correct call to B might require adaptations

a) names are subjected to Java scoping & access

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- …where B might be known to A only by a name
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- …and B might depend on arguments passed by A
- …and a correct call to B might require adaptations

- *(After everything is decided, A jumps to B’s code.)*

# Example: Fully static invocation

- For this source code

```
String s = System.getProperty("java.home");
```

The compiled byte code looks like

```
0:   ldc #2            //String ”java.home”
2:   invokestatic #3   //Method java/lang/System.getProperty:
                        (Ljava/lang/String;)Ljava/lang/String;
5:   astore_1
```

# Example: Fully static invocation

> For this source code

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The compiled byte code looks like

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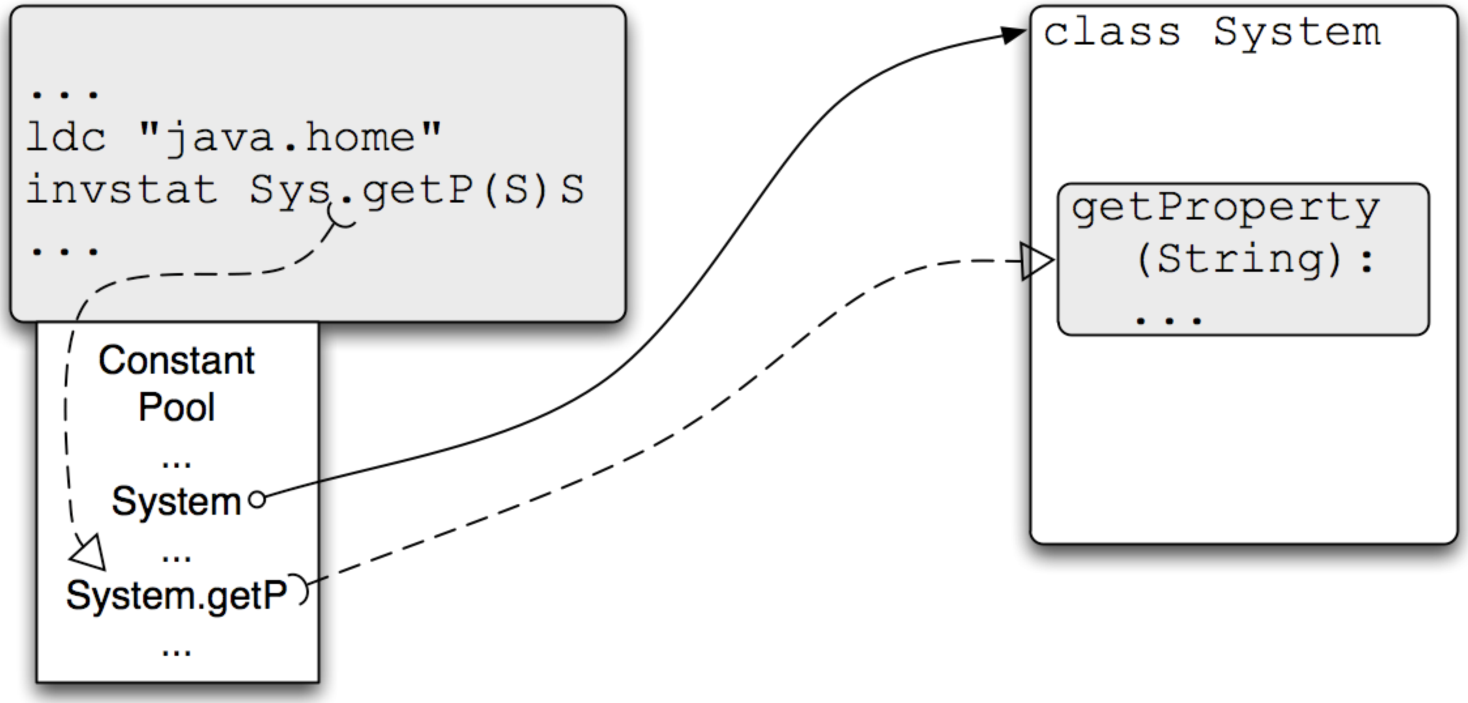
                         (Ljava/lang/String;)Ljava/lang/String;
5:   astore_1
```

a) Names are embedded in the bytecode
b) Linking handled by the JVM with fixed Java rules
c) Target method selection is not dynamic at all
d) No adaptation:  Signatures must match exactly

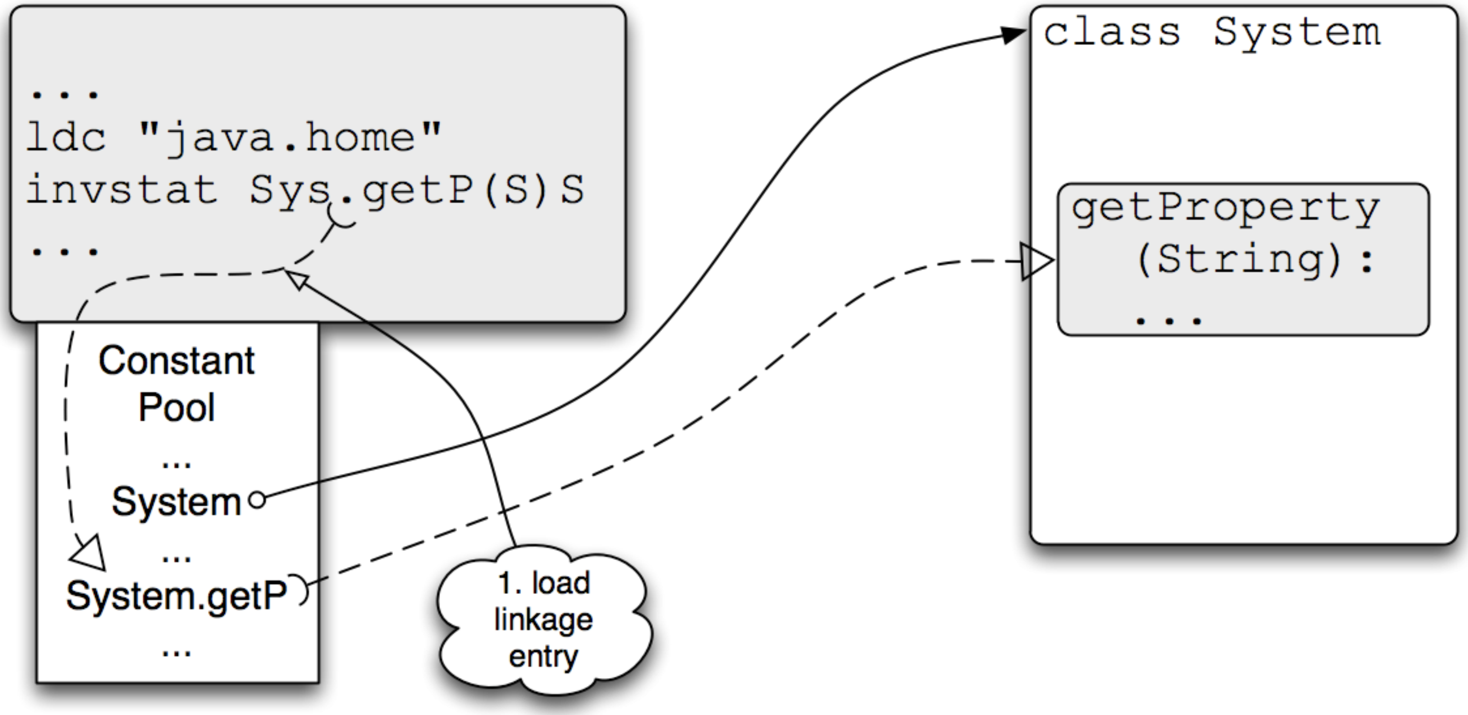
# How the VM sees it:



```
...
ldc "java.home"
invstat Sys.getP(S)S
...
```

*(Note: This implementation is typical; VMs vary.)*

# How the VM sees it:



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ldc "java.home"
invstat Sys.getP(S)S
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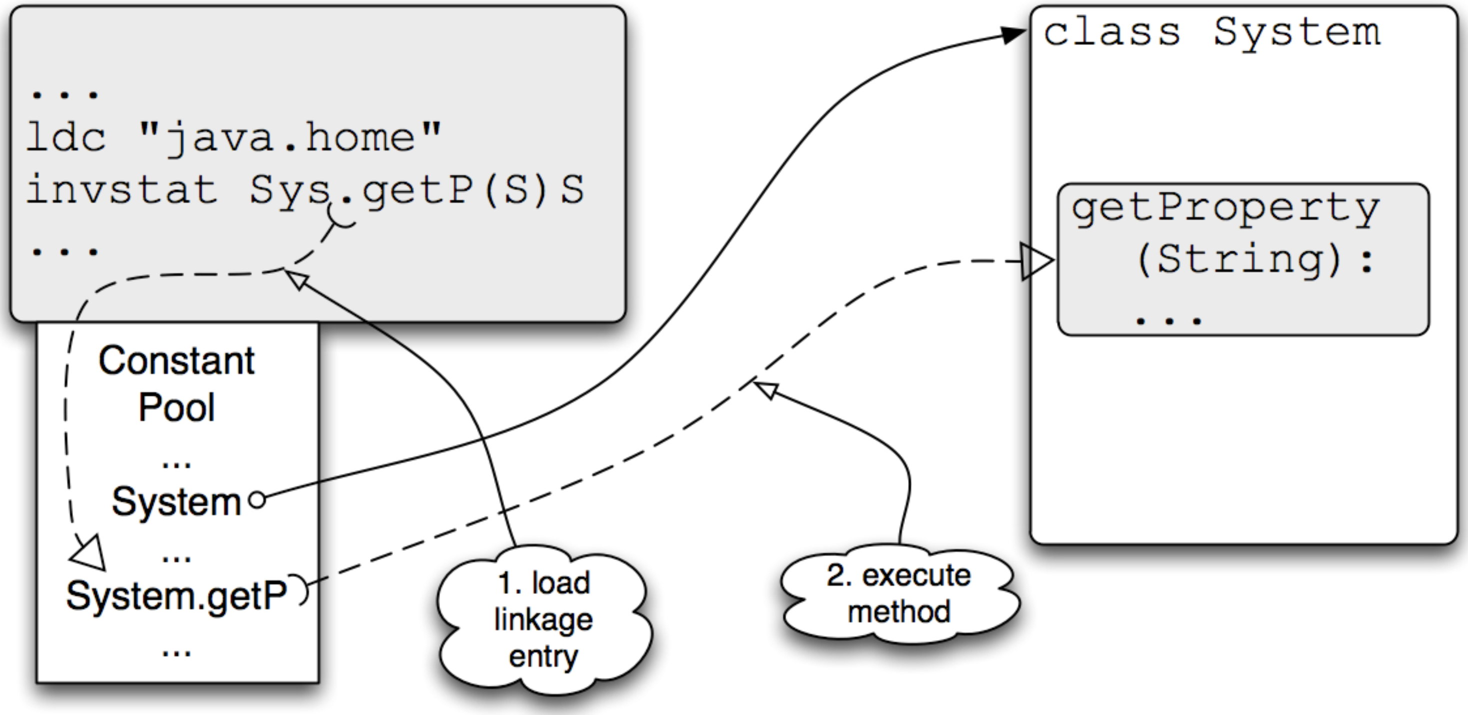
*(Note: This implementation is typical; VMs vary.)*

# How the VM sees it:



```
...
ldc "java.home"
invstat Sys.getP(S)S
...
```

Constant Pool

...

System

...

System.getP

...

```
class System
```

```
getProperty
  (String):
  ...
```

1. load linkage entry

2. execute method

*(Note: This implementation is typical; VMs vary.)*

# Example: Class-based single dispatch

- For this source code

```
//PrintStream out = System.out;
out.println("Hello World");
```

The compiled byte code looks like

```
4:    aload_1
5:    ldc #2                //String "Hello World”
7:    invokevirtual #4      //Method java/io/PrintStream.println:
                                       (Ljava/lang/String;)V
```

# Example: Class-based single dispatch

- For this source code

```
//PrintStream out = System.out;
out.println("Hello World");
```

The compiled byte code looks like

```
4:   aload_1
5:   ldc #2                //String "Hello World”
7:   invokevirtual #4      //Method java/io/PrintStream.println:
                                       (Ljava/lang/String;)V
```

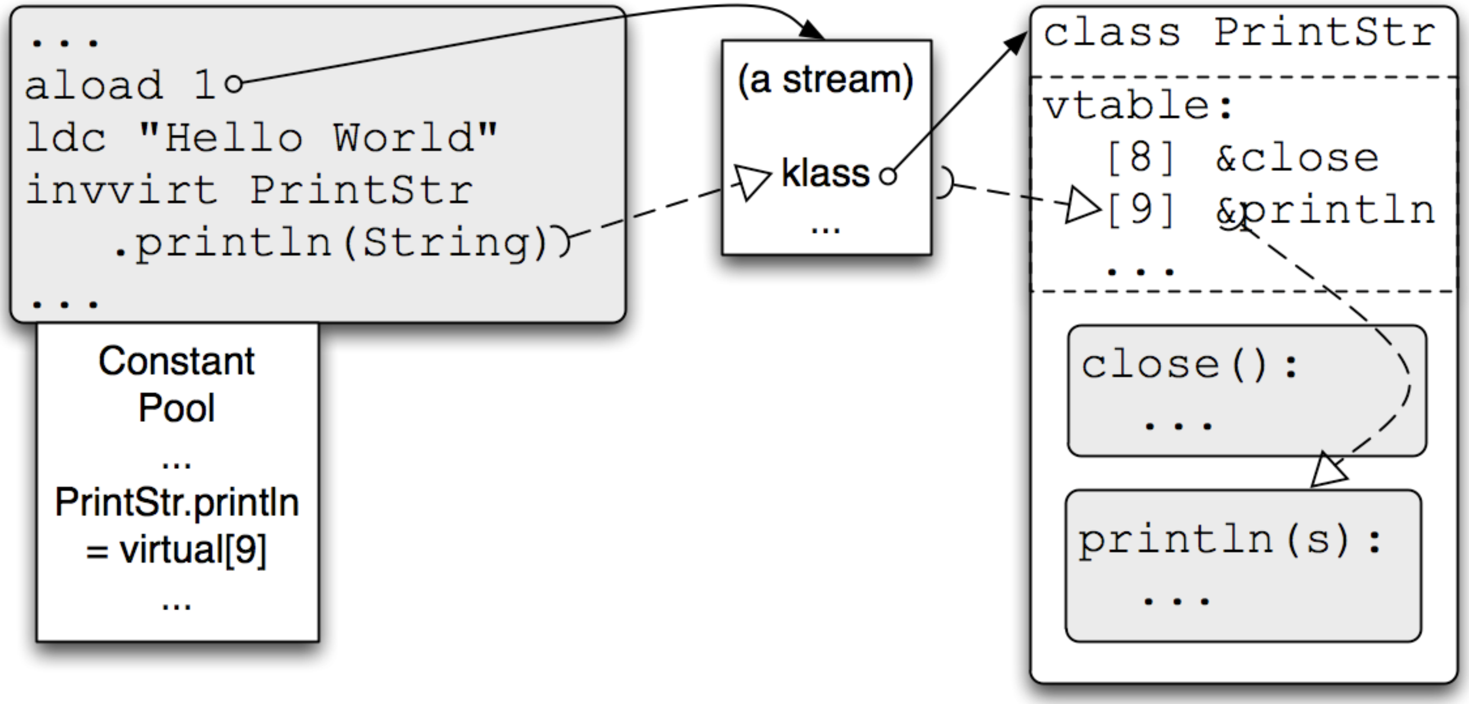
a) Again, names in bytecode

b) Again, linking fixed by JVM

c) *Only* the receiver type determines method selection

d) *Only* the receiver type can be adapted (narrowed)

# How the VM selects the target method:



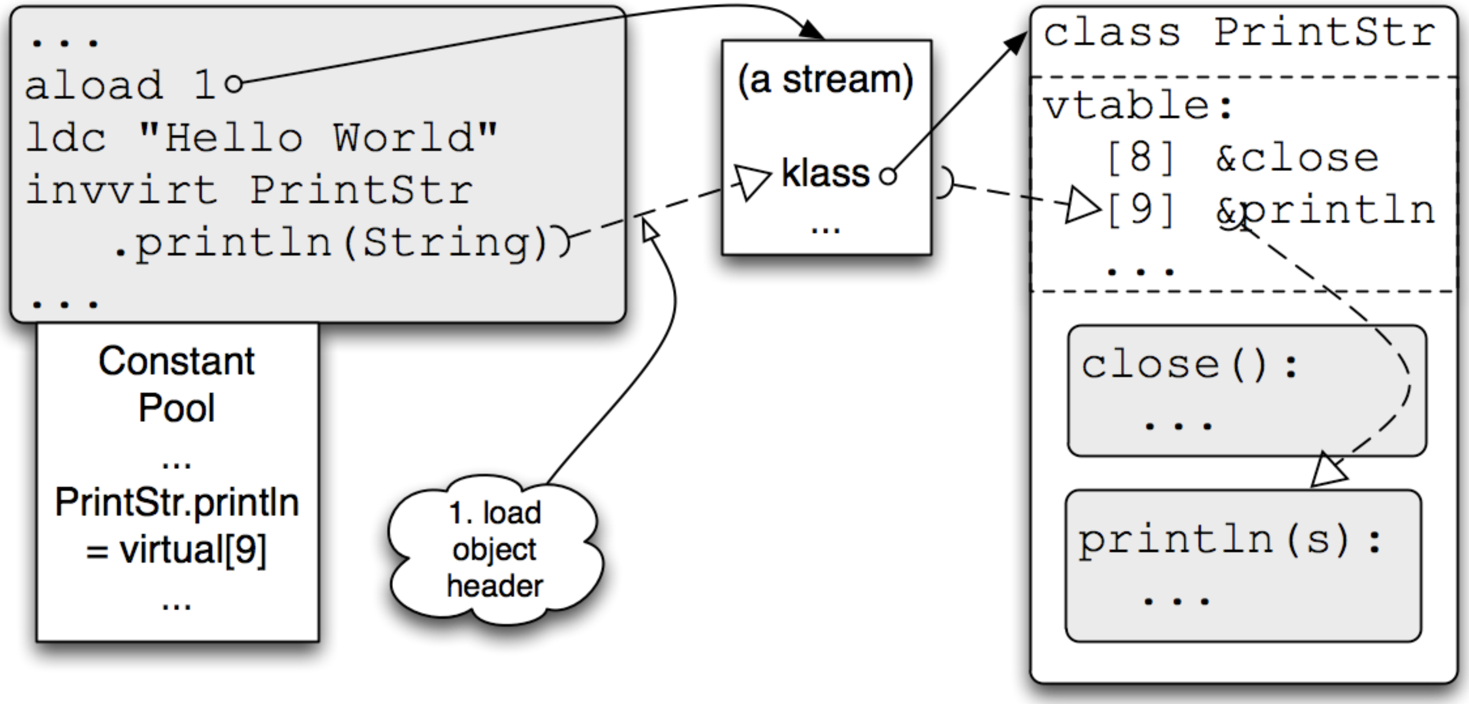
```
...
aload 1
ldc "Hello World"
invvirt PrintStr
    .println(String)
...
```

Constant Pool
...
PrintStr.println
= virtual[9]
...

```
class PrintStr
vtable:
   [8] &close
   [9] &println
   ...
close():
   ...
println(s):
   ...
```

- *(Note: This implementation is typical; VMs vary.)*

# How the VM selects the target method:



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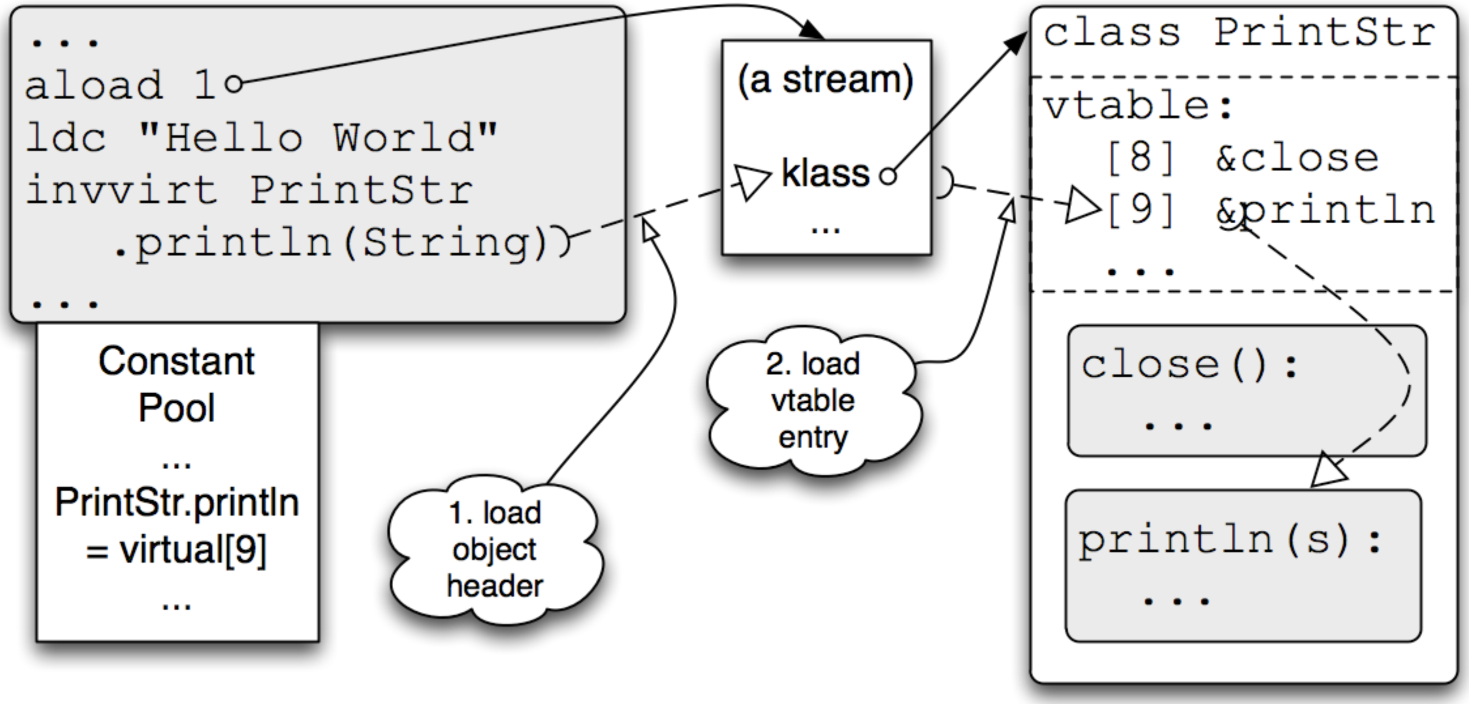

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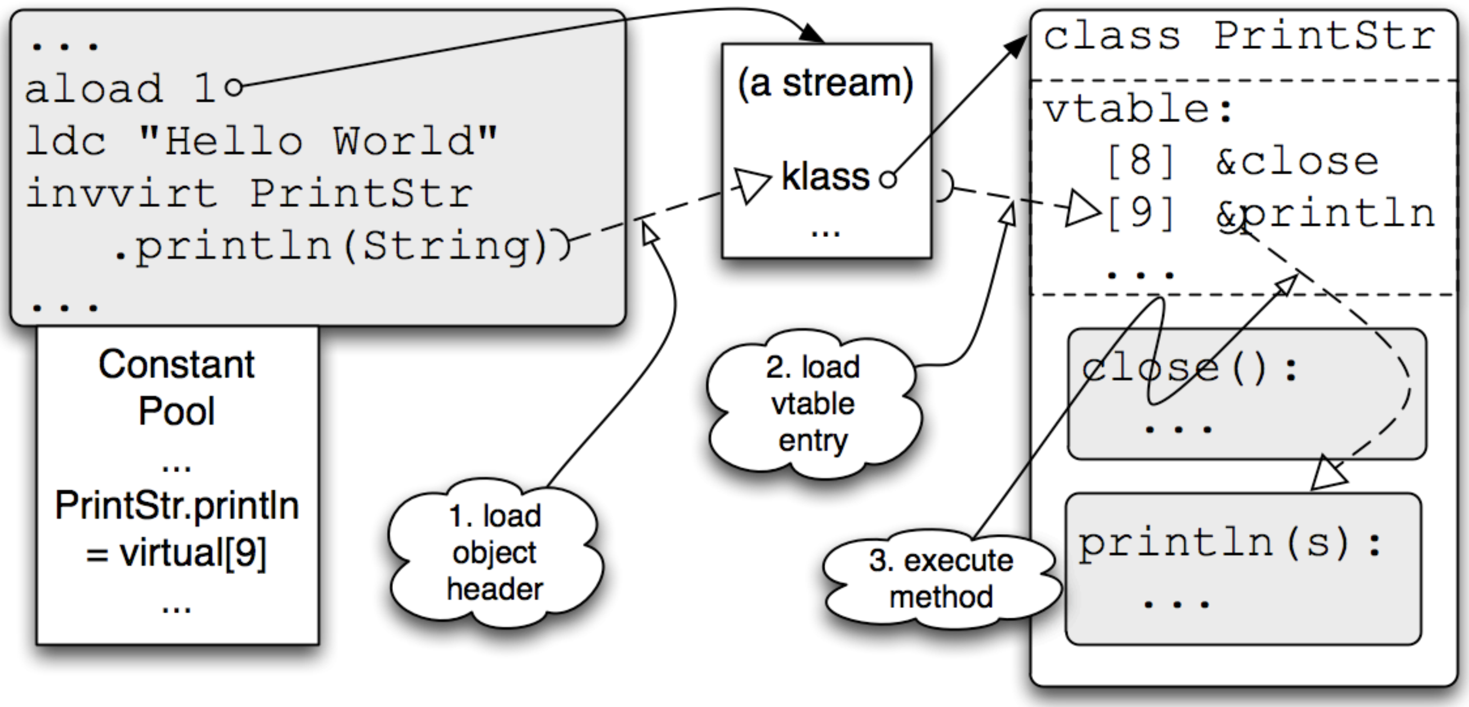


```
...
aload 1
ldc "Hello World"
invvirt PrintStr
    .println(String)
...
```

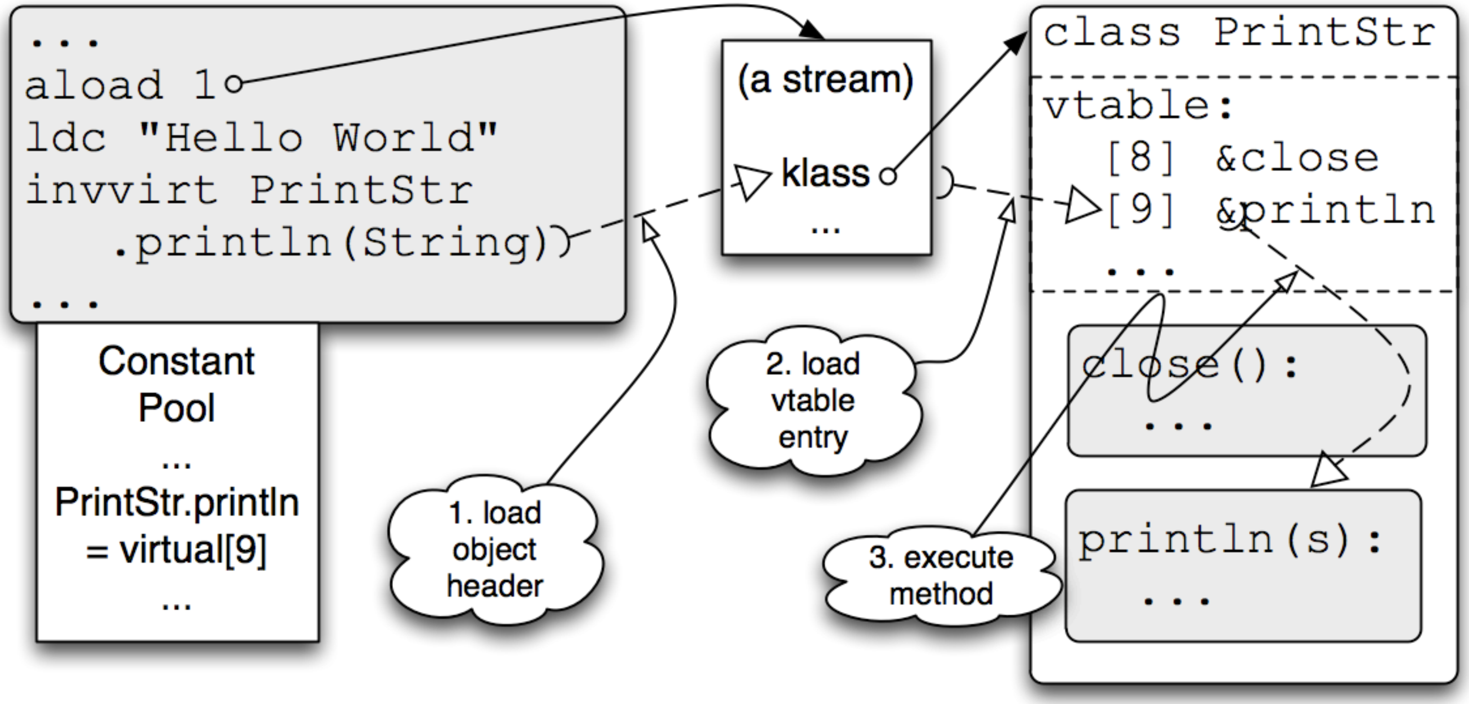
Constant Pool
...
PrintStr.println
= virtual[9]
...

(a stream)
klass
...

```
class PrintStr
vtable:
  [8] &close
  [9] &println
  ...
close():
  ...
println(s):
  ...
```

> *(Note: This implementation is typical; VMs vary.)*

# How the VM selects the target method:



```
...
aload 1
ldc "Hello World"
invvirt PrintStr
    .println(String)
...
```

*(Note: This implementation is typical; VMs vary.)*

# Dynamic method invocation

- For this source code

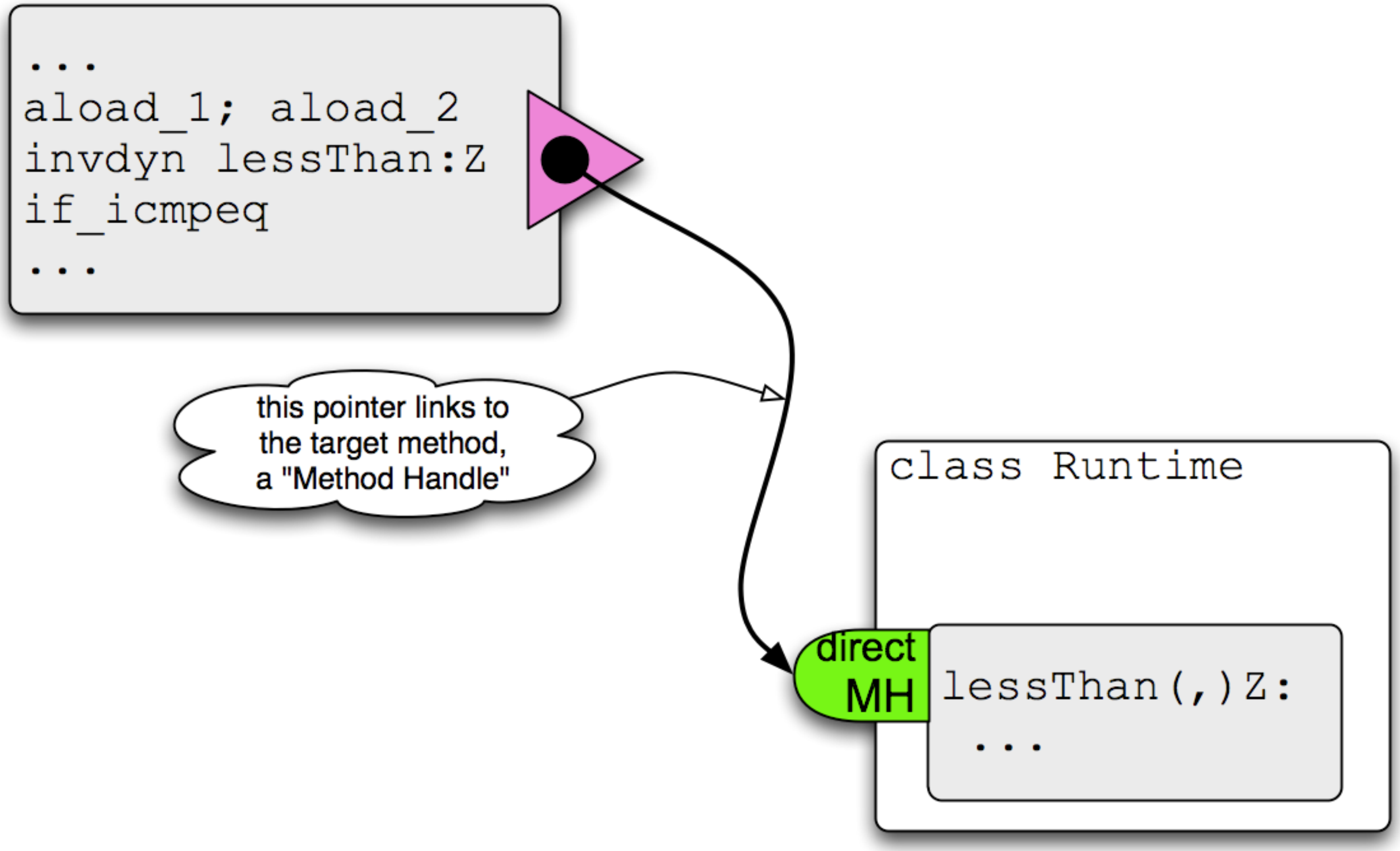
```
//Object x; Integer y;
if (InvokeDynamic.<boolean>lessThan(x, y))
```

A new option:

```
0:   aload_1; aload_2
2:   invokedynamic #3  //NameAndType lessThan:
                    (Ljava/lang/Object;Ljava/lang/Integer;)Z
5:   if_icmpeq
```

- Advantages:
  - Compact representation
  - Local argument & return types recorded accurately
  - (Flexibility from ***signature polymorphism***.)

# How the VM finds the target method:

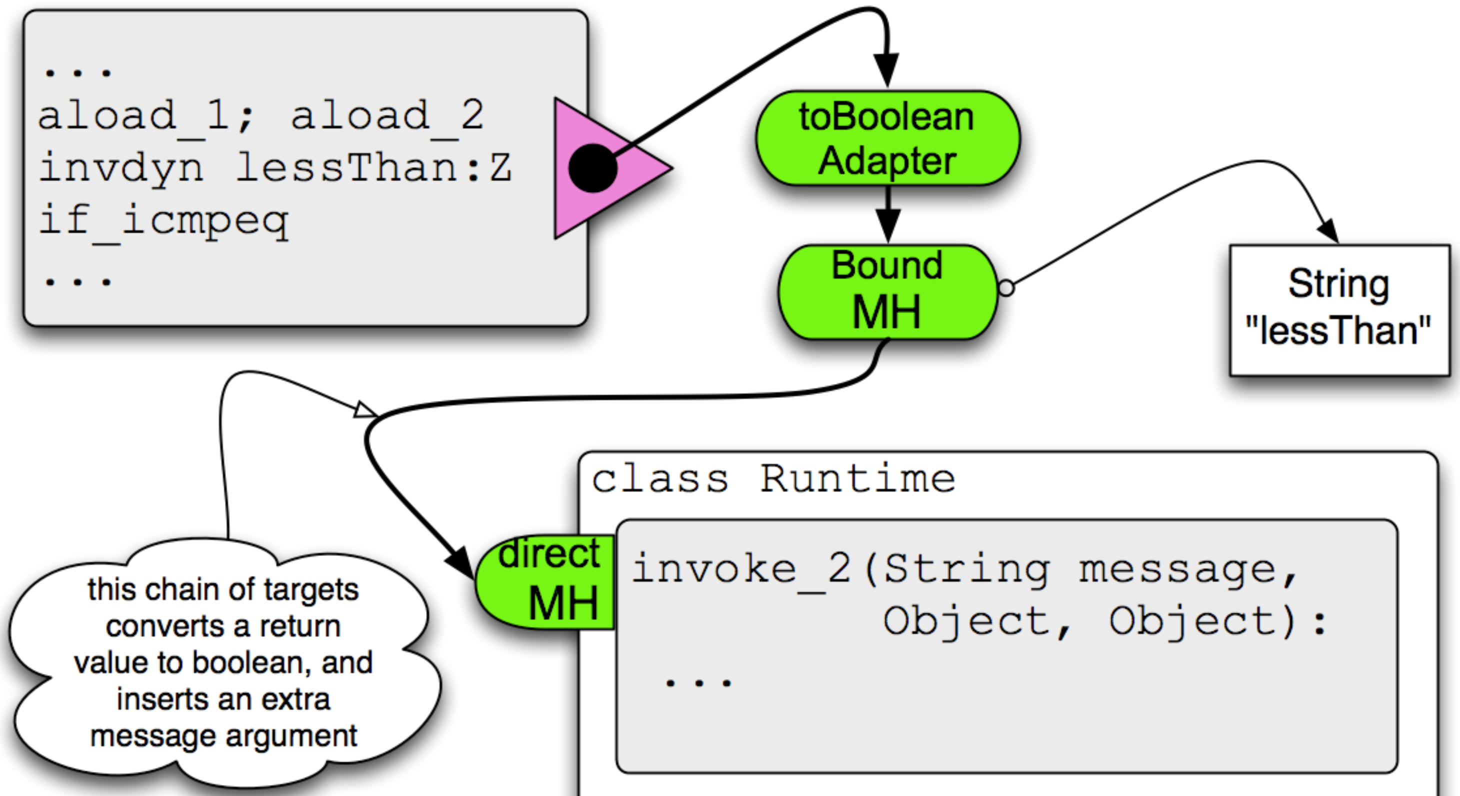


```
...
aload_1; aload_2
invdyn lessThan:Z
if_icmpeq
...
```

this pointer links to the target method, a "Method Handle"

```
class Runtime
lessThan(,)Z:
  ...
```

# The target method can be a chain:

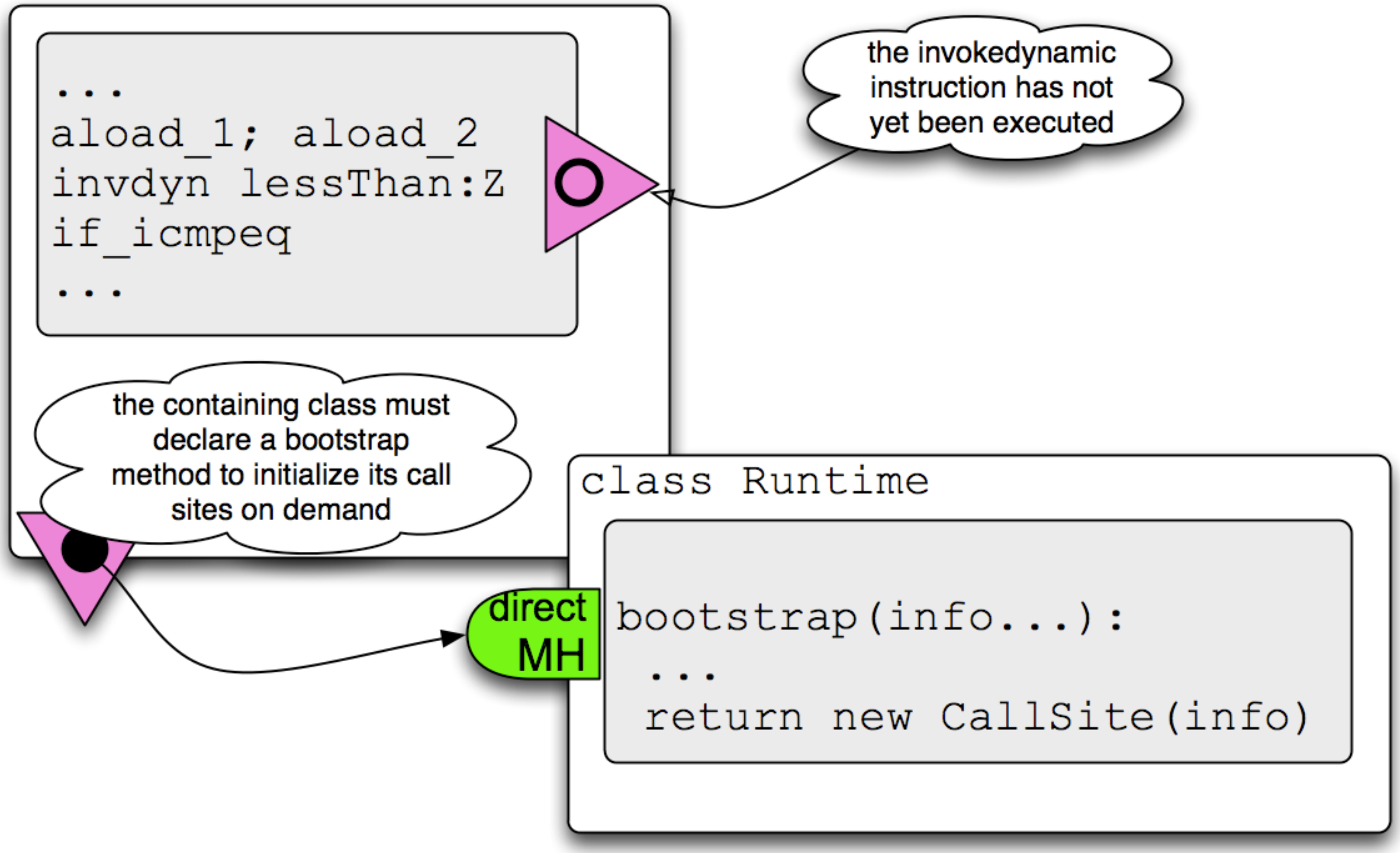


```
...
aload_1; aload_2
invdyn lessThan:Z
if_icmpeq
...
```

```
class Runtime
invoke_2(String message,
         Object, Object):
  ...
```

this chain of targets converts a return value to boolean, and inserts an extra message argument

# invokedynamic bootstrap logic:



```
...
aload_1; aload_2
invdyn lessThan:Z
if_icmpeq
...
```

the invokedynamic instruction has not yet been executed

the containing class must declare a bootstrap method to initialize its call sites on demand

```
class Runtime

bootstrap(info...):
 ...
 return new CallSite(info)
```

# Method handles

- An object of static type **`java.dyn.MethodHandle`**
- Like methods, can have any function type
- Unlike (other) objects, signature-polymorphic
- Like methods, can be virtual, static, or “special”
- Unlike methods, not named
- Invoked like methods:

```
  MethodHandle.invoke(args)
```

# An invokedynamic call site

- An invokedynamic call site contains
  - A method signature (immutable)
  - A method name (arbitrary)
  - The enclosing caller class
  - A class-specific bootstrap method
  - A site-specific target method *(the payload!)*
  - A CallSite which reifies it all
- All immutable, except for target method

# An invokedynamic call site (target)

- The linkage state consists only of the current target
- Target is a *method handle*
  - May point directly to a Java method
  - Can optionally test or adjust arguments
- Mutable property of the instruction
  - (May be managed via a reified **`CallSite`** object)
  - May be set at any time, but few changes expected
  - Changing a target *may* affect compilation, etc.

# Bootstrap methods

- The per-class “plug in” is the *bootstrap method*
- Its job is to build a reified call site on first execution
  - We consult the bootstrap *once,*
  - And then it gets out of the way
- Call site must have call-ready target from the start
  - target can be eagerly or lazily linked
  - can be a method handle for an inline cache
  - …can re-link the call site if prediction fails

# An invokedynamic call site

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# Let’s talk about compiled code

# A Simple Ruby method

- For this source code

```
def myadd(a, b)
   return a + b
end
```

consider the untyped plus “+” operation…

# Not-so-simple compiled code

- The JVM compiles and inlines these methods:

# Not-so-simple compiled code

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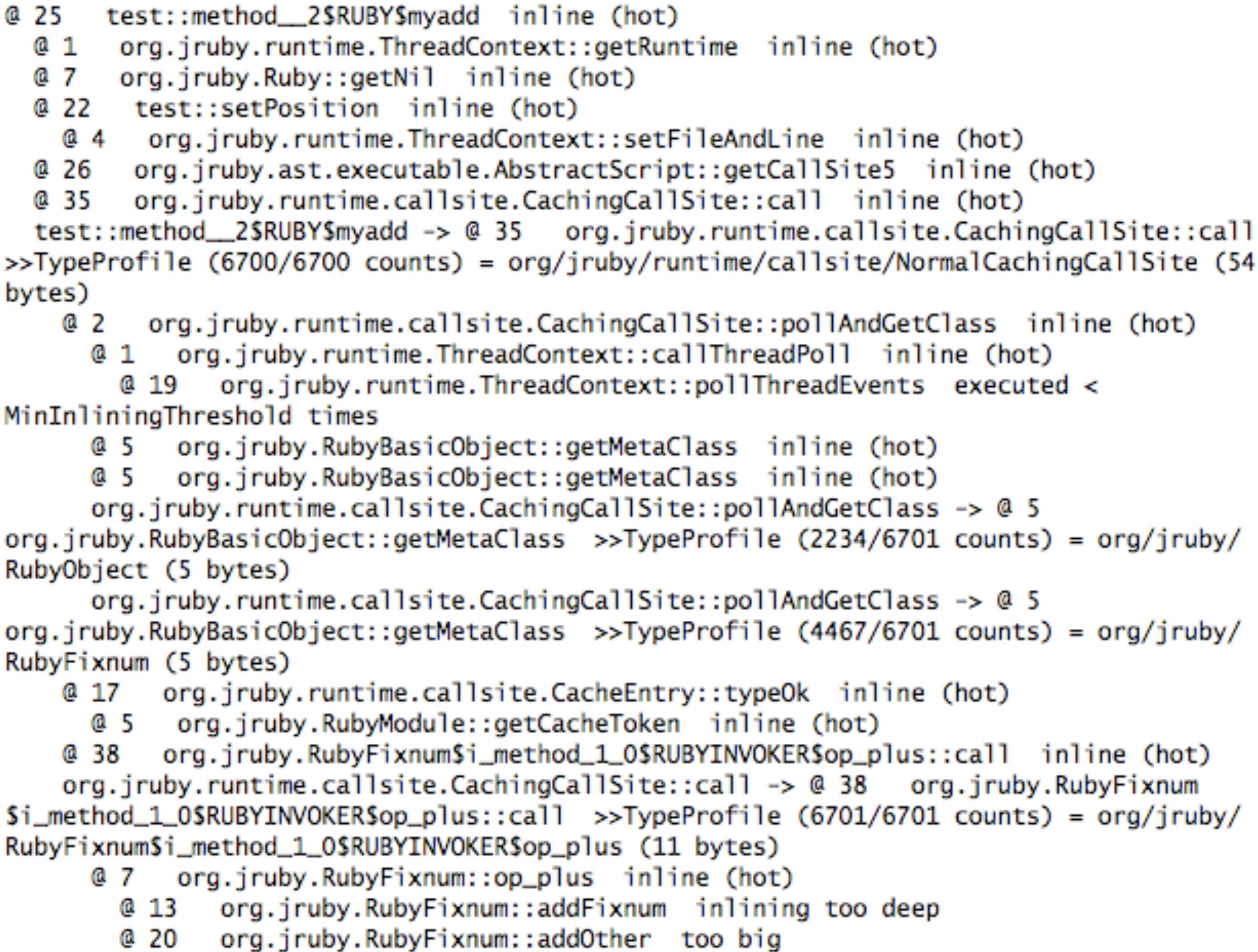
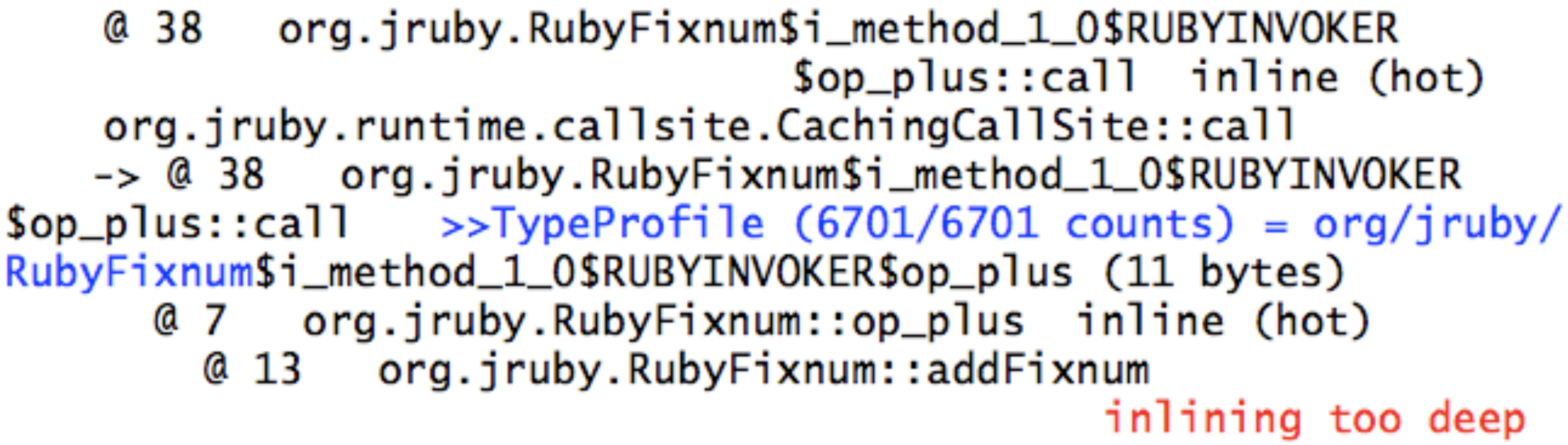


```
@ 25   test::method__2$RUBY$myadd  inline (hot)
  @ 1   org.jruby.runtime.ThreadContext::getRuntime  inline (hot)
  @ 7   org.jruby.Ruby::getNil  inline (hot)
  @ 22   test::setPosition  inline (hot)
    @ 4   org.jruby.runtime.ThreadContext::setFileAndLine  inline (hot)
  @ 26   org.jruby.ast.executable.AbstractScript::getCallSite5  inline (hot)
  @ 35   org.jruby.runtime.callsite.CachingCallSite::call  inline (hot)
  test::method__2$RUBY$myadd -> @ 35   org.jruby.runtime.callsite.CachingCallSite::call
>>TypeProfile (6700/6700 counts) = org/jruby/runtime/callsite/NormalCachingCallSite (54
bytes)
    @ 2   org.jruby.runtime.callsite.CachingCallSite::pollAndGetClass  inline (hot)
      @ 1   org.jruby.runtime.ThreadContext::callThreadPoll  inline (hot)
        @ 19   org.jruby.runtime.ThreadContext::pollThreadEvents  executed <
MinInliningThreshold times
      @ 5   org.jruby.RubyBasicObject::getMetaClass  inline (hot)
      @ 5   org.jruby.RubyBasicObject::getMetaClass  inline (hot)
      org.jruby.runtime.callsite.CachingCallSite::pollAndGetClass -> @ 5
org.jruby.RubyBasicObject::getMetaClass  >>TypeProfile (2234/6701 counts) = org/jruby/
RubyObject (5 bytes)
      org.jruby.runtime.callsite.CachingCallSite::pollAndGetClass -> @ 5
org.jruby.RubyBasicObject::getMetaClass  >>TypeProfile (4467/6701 counts) = org/jruby/
RubyFixnum (5 bytes)
    @ 17   org.jruby.runtime.callsite.CacheEntry::typeOk  inline (hot)
      @ 5   org.jruby.RubyModule::getCacheToken  inline (hot)
    @ 38   org.jruby.RubyFixnum$i_method_1_0$RUBYINVOKER$op_plus::call  inline (hot)
    org.jruby.runtime.callsite.CachingCallSite::call -> @ 38   org.jruby.RubyFixnum
$i_method_1_0$RUBYINVOKER$op_plus::call  >>TypeProfile (6701/6701 counts) = org/jruby/
RubyFixnum$i_method_1_0$RUBYINVOKER$op_plus (11 bytes)
      @ 7   org.jruby.RubyFixnum::op_plus  inline (hot)
        @ 13   org.jruby.RubyFixnum::addFixnum  inlining too deep
        @ 20   org.jruby.RubyFixnum::addOther  too big
```

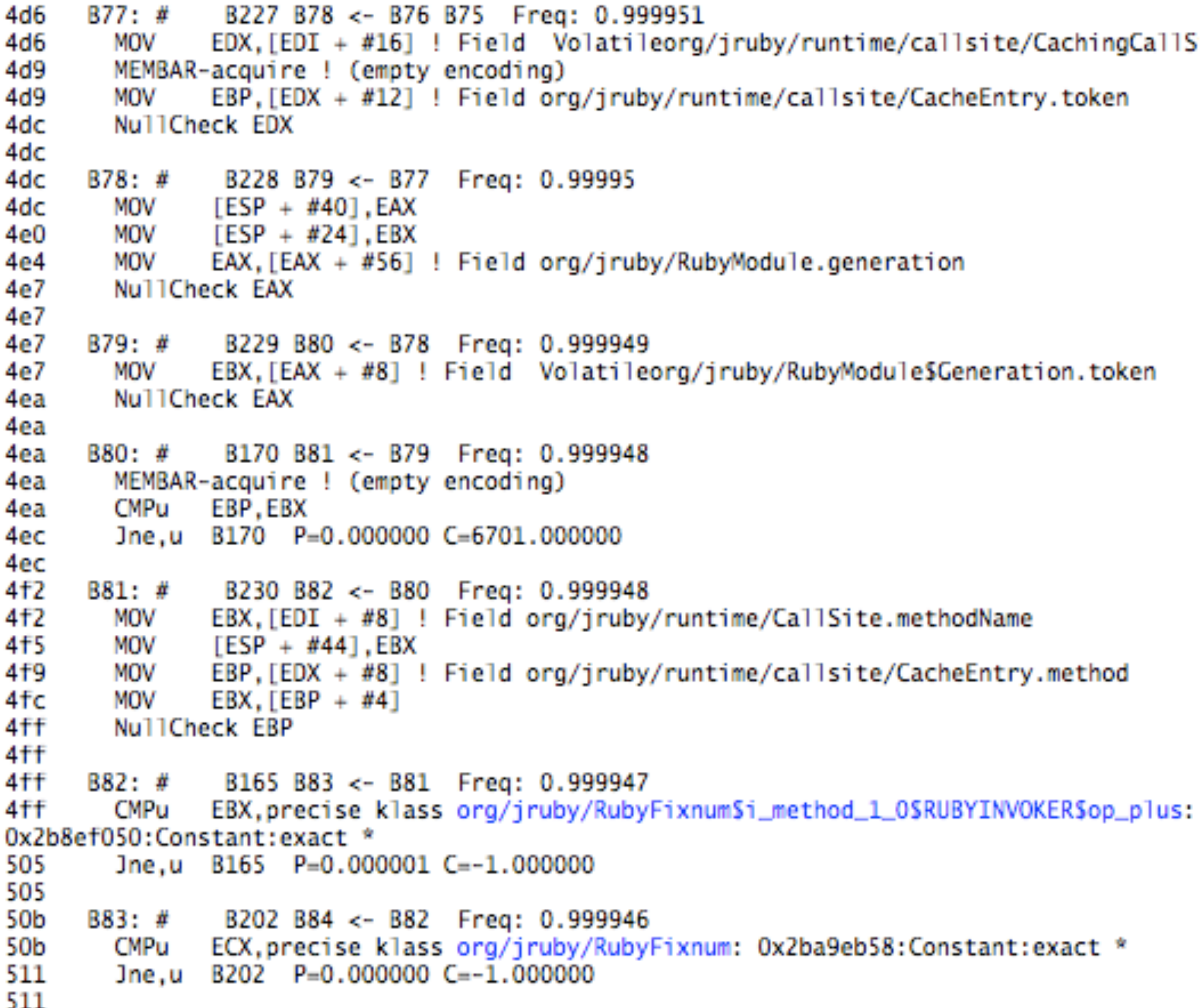
# Not-so-simple compiled code

- The JVM compiles and inlines these methods:



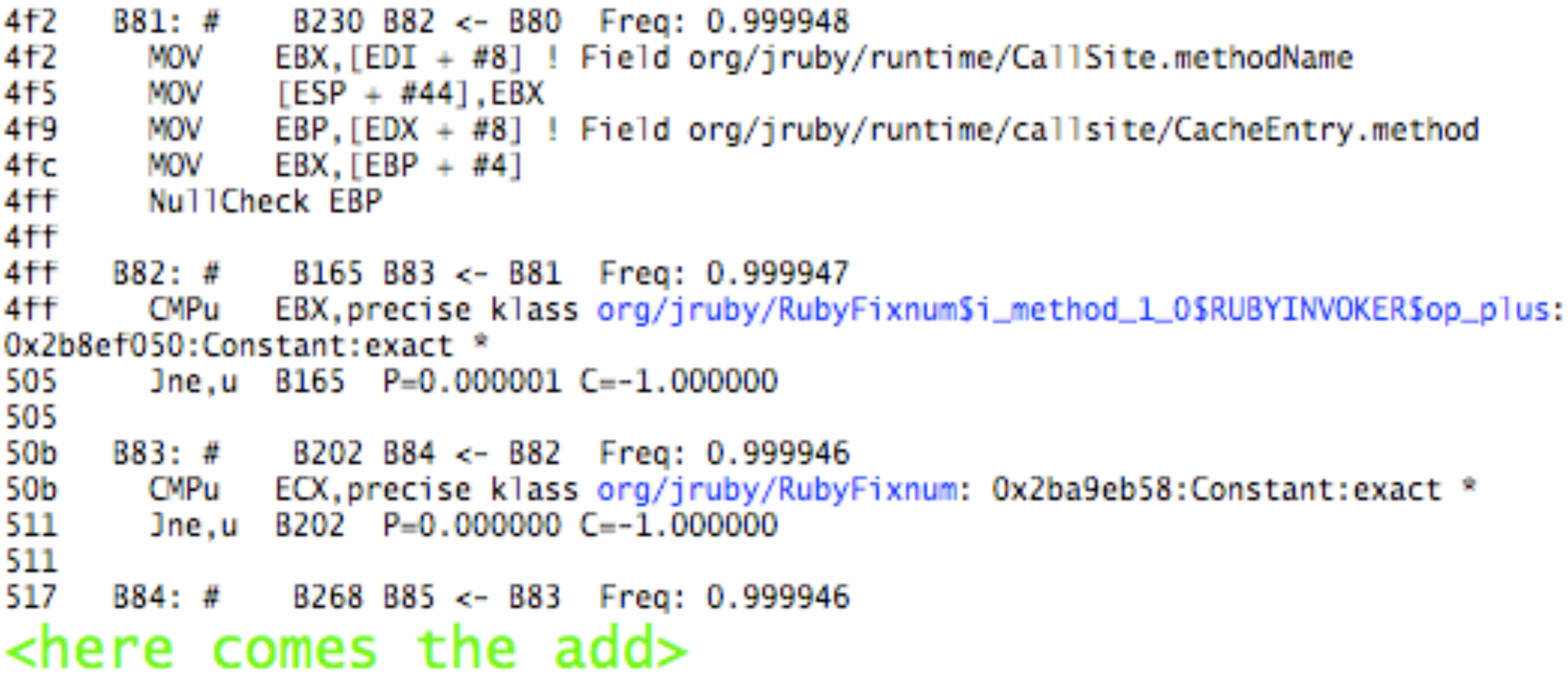
```
  @ 38  org.jruby.RubyFixnum$i_method_1_0$RUBYINVOKER
                  $op_plus::call  inline (hot)
  org.jruby.runtime.callsite.CachingCallSite::call
  -> @ 38  org.jruby.RubyFixnum$i_method_1_0$RUBYINVOKER
$op_plus::call   >>TypeProfile (6701/6701 counts) = org/jruby/
RubyFixnum$i_method_1_0$RUBYINVOKER$op_plus (11 bytes)
   @ 7  org.jruby.RubyFixnum::op_plus  inline (hot)
    @ 13  org.jruby.RubyFixnum::addFixnum
                      inlining too deep
```

# After optimization, optimistic type checks



```
4d6   B77: #    B227 B78 <- B76 B75  Freq: 0.999951
4d6     MOV    EDX,[EDI + #16] ! Field  Volatileorg/jruby/runtime/callsite/CachingCallS
4d9     MEMBAR-acquire ! (empty encoding)
4d9     MOV    EBP,[EDX + #12] ! Field org/jruby/runtime/callsite/CacheEntry.token
4dc     NullCheck EDX
4dc
4dc   B78: #    B228 B79 <- B77  Freq: 0.99995
4dc     MOV    [ESP + #40],EAX
4e0     MOV    [ESP + #24],EBX
4e4     MOV    EAX,[EAX + #56] ! Field org/jruby/RubyModule.generation
4e7     NullCheck EAX
4e7
4e7   B79: #    B229 B80 <- B78  Freq: 0.999949
4e7     MOV    EBX,[EAX + #8] ! Field  Volatileorg/jruby/RubyModule$Generation.token
4ea     NullCheck EAX
4ea
4ea   B80: #    B170 B81 <- B79  Freq: 0.999948
4ea     MEMBAR-acquire ! (empty encoding)
4ea     CMPu   EBP,EBX
4ec     Jne,u  B170  P=0.000000 C=6701.000000
4ec
4f2   B81: #    B230 B82 <- B80  Freq: 0.999948
4f2     MOV    EBX,[EDI + #8] ! Field org/jruby/runtime/CallSite.methodName
4f5     MOV    [ESP + #44],EBX
4f9     MOV    EBP,[EDX + #8] ! Field org/jruby/runtime/callsite/CacheEntry.method
4fc     MOV    EBX,[EBP + #4]
4ff     NullCheck EBP
4ff
4ff   B82: #    B165 B83 <- B81  Freq: 0.999947
4ff     CMPu   EBX,precise klass org/jruby/RubyFixnum$i_method_1_0$RUBYINVOKER$op_plus:
0x2b8ef050:Constant:exact *
505     Jne,u  B165  P=0.000001 C=-1.000000
505
50b   B83: #    B202 B84 <- B82  Freq: 0.999946
50b     CMPu   ECX,precise klass org/jruby/RubyFixnum: 0x2ba9eb58:Constant:exact *
511     Jne,u  B202  P=0.000000 C=-1.000000
511
```

# After optimization, optimistic type checks



```
4f2   B81: #    B230 B82 <- B80   Freq: 0.999948
4f2     MOV    EBX,[EDI + #8] ! Field org/jruby/runtime/CallSite.methodName
4f5     MOV    [ESP + #44],EBX
4f9     MOV    EBP,[EDX + #8] ! Field org/jruby/runtime/callsite/CacheEntry.method
4fc     MOV    EBX,[EBP + #4]
4ff     NullCheck EBP
4ff
4ff   B82: #    B165 B83 <- B81   Freq: 0.999947
4ff     CMPu   EBX,precise klass org/jruby/RubyFixnum$i_method_1_0$RUBYINVOKER$op_plus:
0x2b8ef050:Constant:exact *
505     Jne,u  B165  P=0.000001 C=-1.000000
505
50b   B83: #    B202 B84 <- B82   Freq: 0.999946
50b     CMPu   ECX,precise klass org/jruby/RubyFixnum: 0x2ba9eb58:Constant:exact *
511     Jne,u  B202  P=0.000000 C=-1.000000
511
517   B84: #    B268 B85 <- B83   Freq: 0.999946
<here comes the add>
```

# So, what can indy do?

- Currently only interpreted invokedynamic supported
  - It's 5 to 25% slower than “normal” Jruby
  - Compiled invokedynamic is almost there
  - but there are still some issues (we are currently working on that)

# JRuby is very smart!

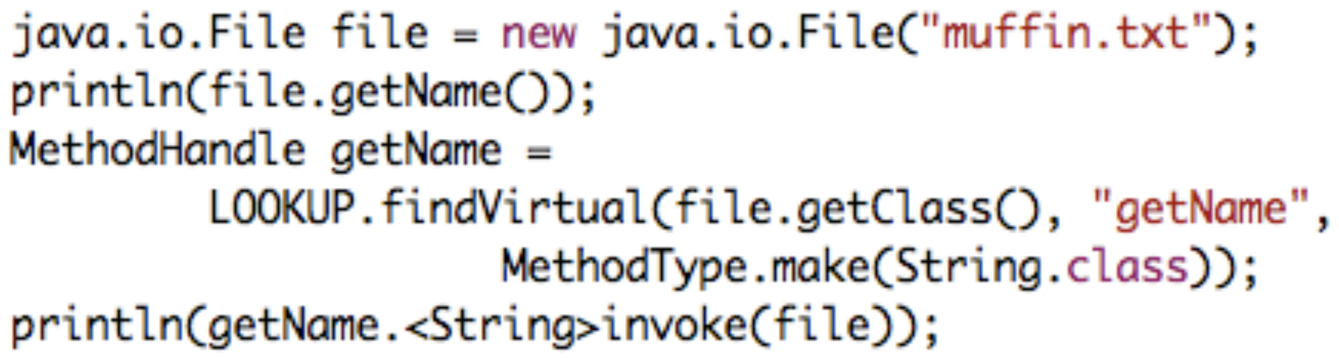
- Generated “invoker” methods are inlined perfectly
- but you have to generate them
- these are a lot of bytecodes
  - Makes your implementation complex
  - Default inlining depth can be (and is) hit
  - Linear dispatching pattern hidden in call tree (?)

# MethodHandles does that for you

- You get the speed of JRuby out-of-the-box
- Your language implementation is much simpler
  - you can concentrate on other things
- Compiled invokedynamic is very likely to have the same performance as JRuby's invoker methods
  - (but maybe some other compiler optimizations kick in that we currently don't think about)
  - method handle chains are a clear signal of linear control flow to the inliner

# Some code examples…

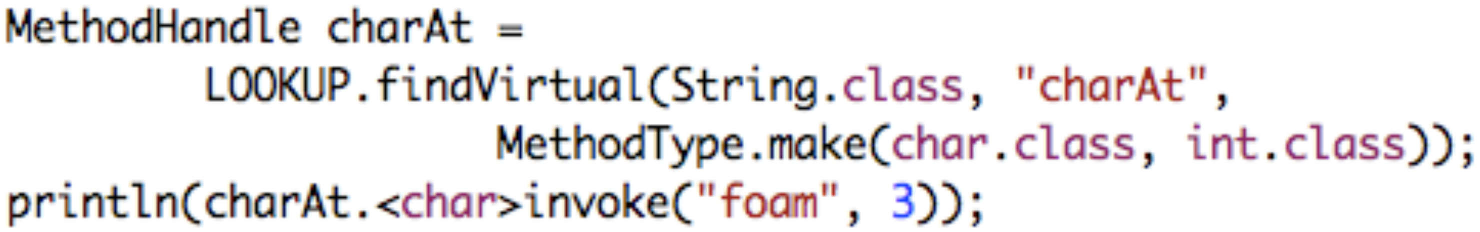
# Plain old Java



```
java.io.File file = new java.io.File("muffin.txt");
println(file.getName());
MethodHandle getName =
        LOOKUP.findVirtual(file.getClass(), "getName",
                    MethodType.make(String.class));
println(getName.<String>invoke(file));
```

Method handles can access any method in any Java API.

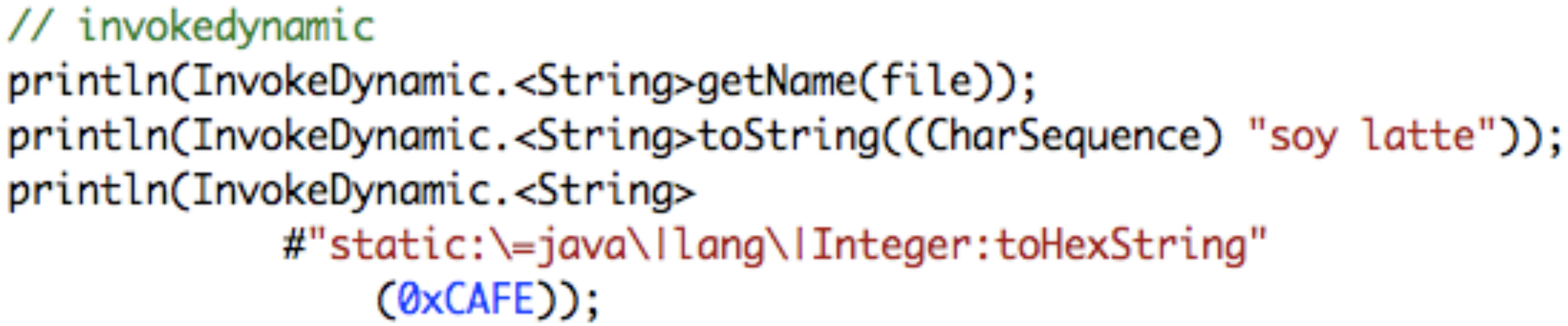
# Plain old Java



```
MethodHandle charAt =
        LOOKUP.findVirtual(String.class, "charAt",
                    MethodType.make(char.class, int.class));
println(charAt.<char>invoke("foam", 3));
```

Primitive types (like int, char) work just fine.

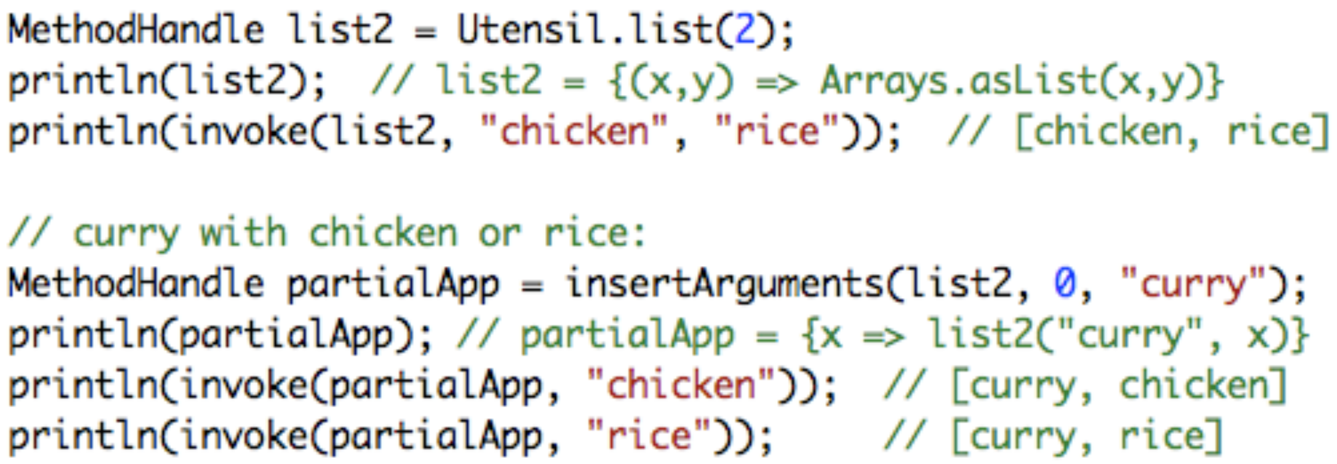
# Plain old Java



```
// invokedynamic
println(InvokeDynamic.<String>getName(file));
println(InvokeDynamic.<String>toString((CharSequence) "soy latte"));
println(InvokeDynamic.<String>
            #"static:\=java\|lang\|Integer:toHexString"
                (0xCAFE));
```

Invokedynamic sites can be bound to Java methods.

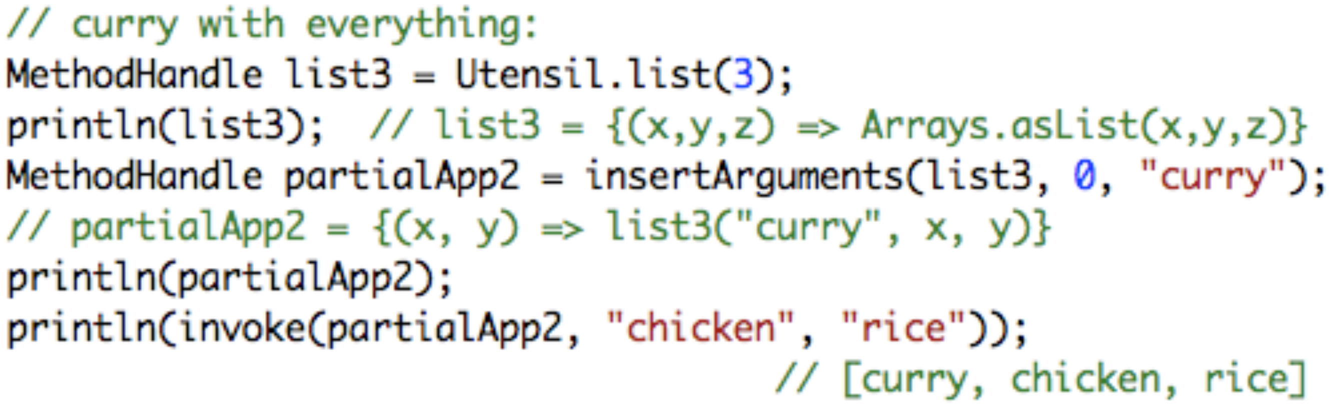
# Curry  (chicken or rice)



```
MethodHandle list2 = Utensil.list(2);
println(list2);  // list2 = {(x,y) => Arrays.asList(x,y)}
println(invoke(list2, "chicken", "rice"));  // [chicken, rice]

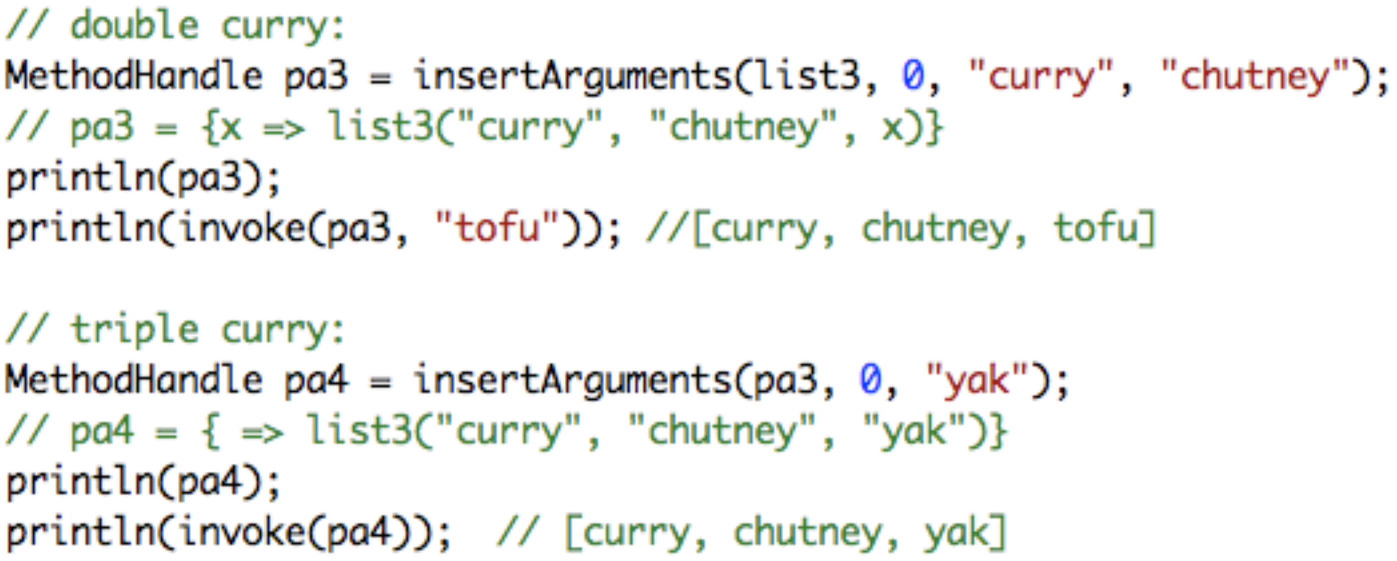
// curry with chicken or rice:
MethodHandle partialApp = insertArguments(list2, 0, "curry");
println(partialApp); // partialApp = {x => list2("curry", x)}
println(invoke(partialApp, "chicken"));  // [curry, chicken]
println(invoke(partialApp, "rice"));     // [curry, rice]
```

# Curry (with everything)



```
// curry with everything:
MethodHandle list3 = Utensil.list(3);
println(list3);  // list3 = {(x,y,z) => Arrays.asList(x,y,z)}
MethodHandle partialApp2 = insertArguments(list3, 0, "curry");
// partialApp2 = {(x, y) => list3("curry", x, y)}
println(partialApp2);
println(invoke(partialApp2, "chicken", "rice"));
                                    // [curry, chicken, rice]
```

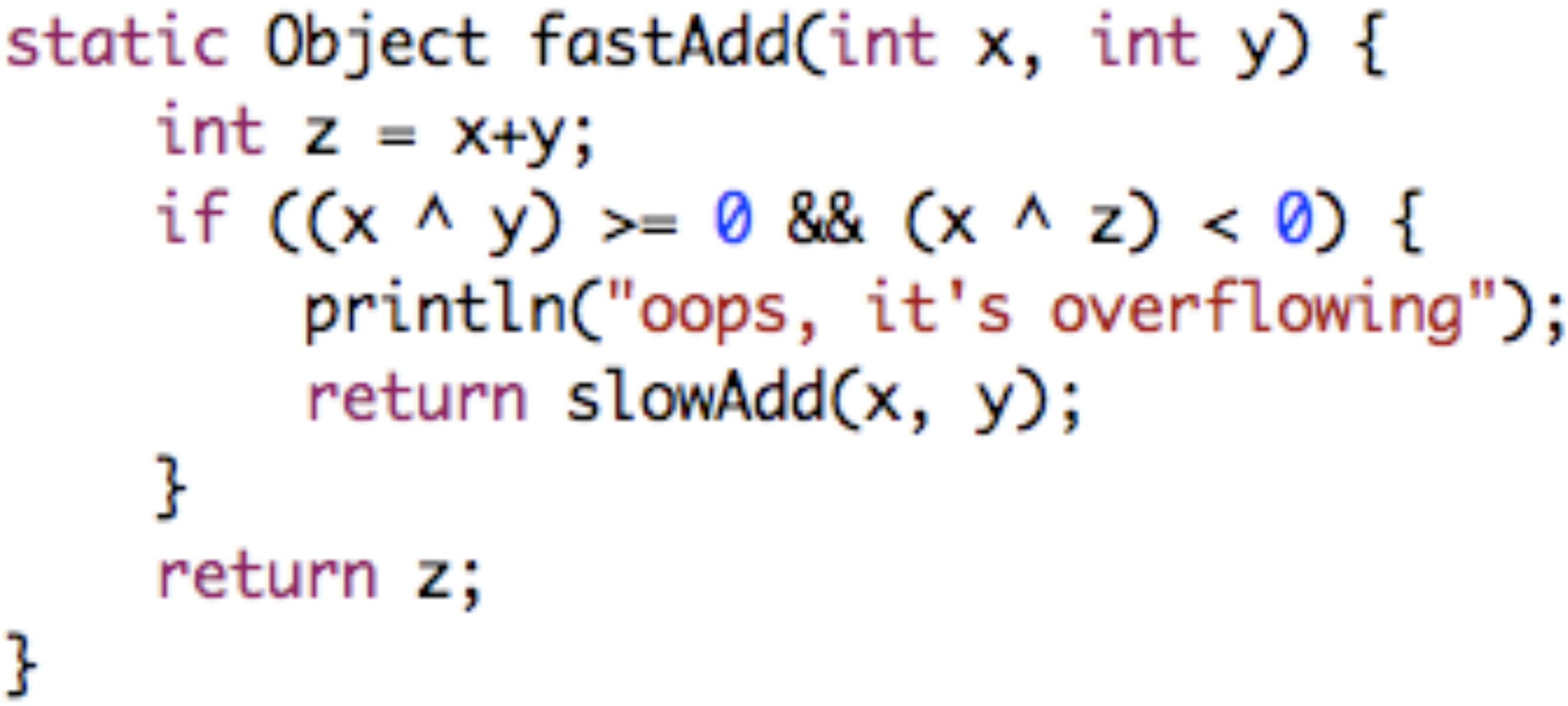
# Curry (in cascade)



```
// double curry:
MethodHandle pa3 = insertArguments(list3, 0, "curry", "chutney");
// pa3 = {x => list3("curry", "chutney", x)}
println(pa3);
println(invoke(pa3, "tofu")); //[curry, chutney, tofu]

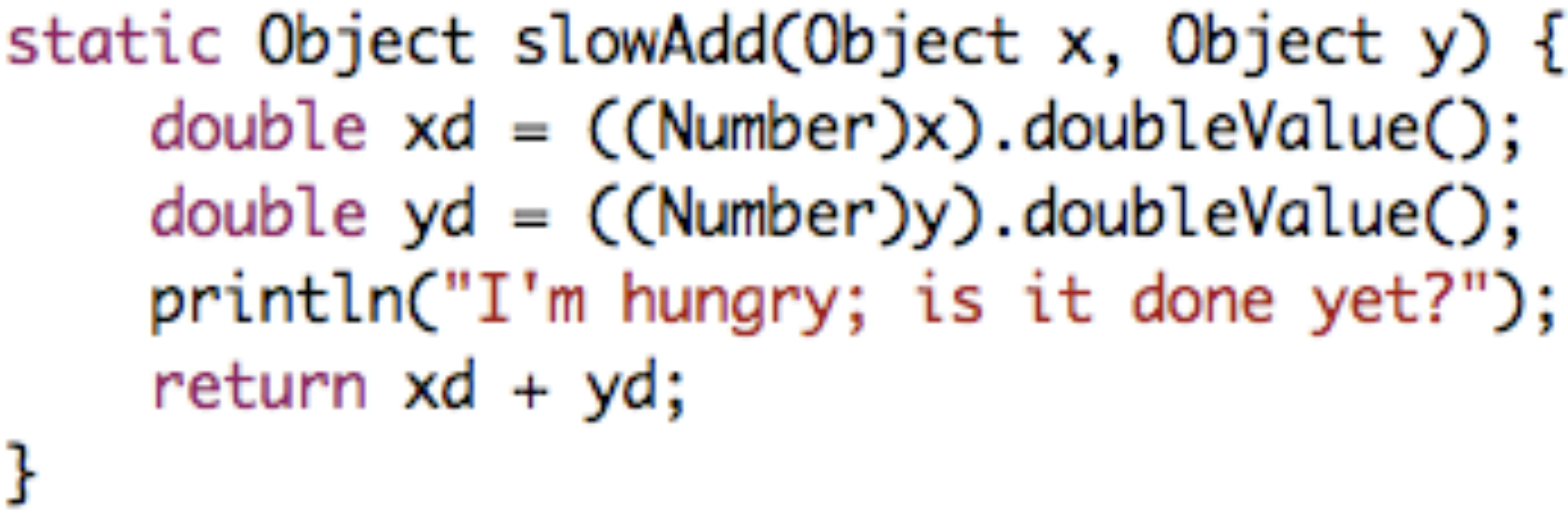
// triple curry:
MethodHandle pa4 = insertArguments(pa3, 0, "yak");
// pa4 = { => list3("curry", "chutney", "yak")}
println(pa4);
println(invoke(pa4));  // [curry, chutney, yak]
```

# Fast food!



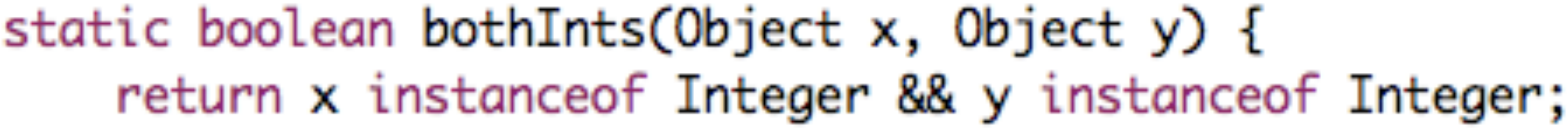
```
static Object fastAdd(int x, int y) {
    int z = x+y;
    if ((x ^ y) >= 0 && (x ^ z) < 0) {
        println("oops, it's overflowing");
        return slowAdd(x, y);
    }
    return z;
}
```

# Slowly brewed



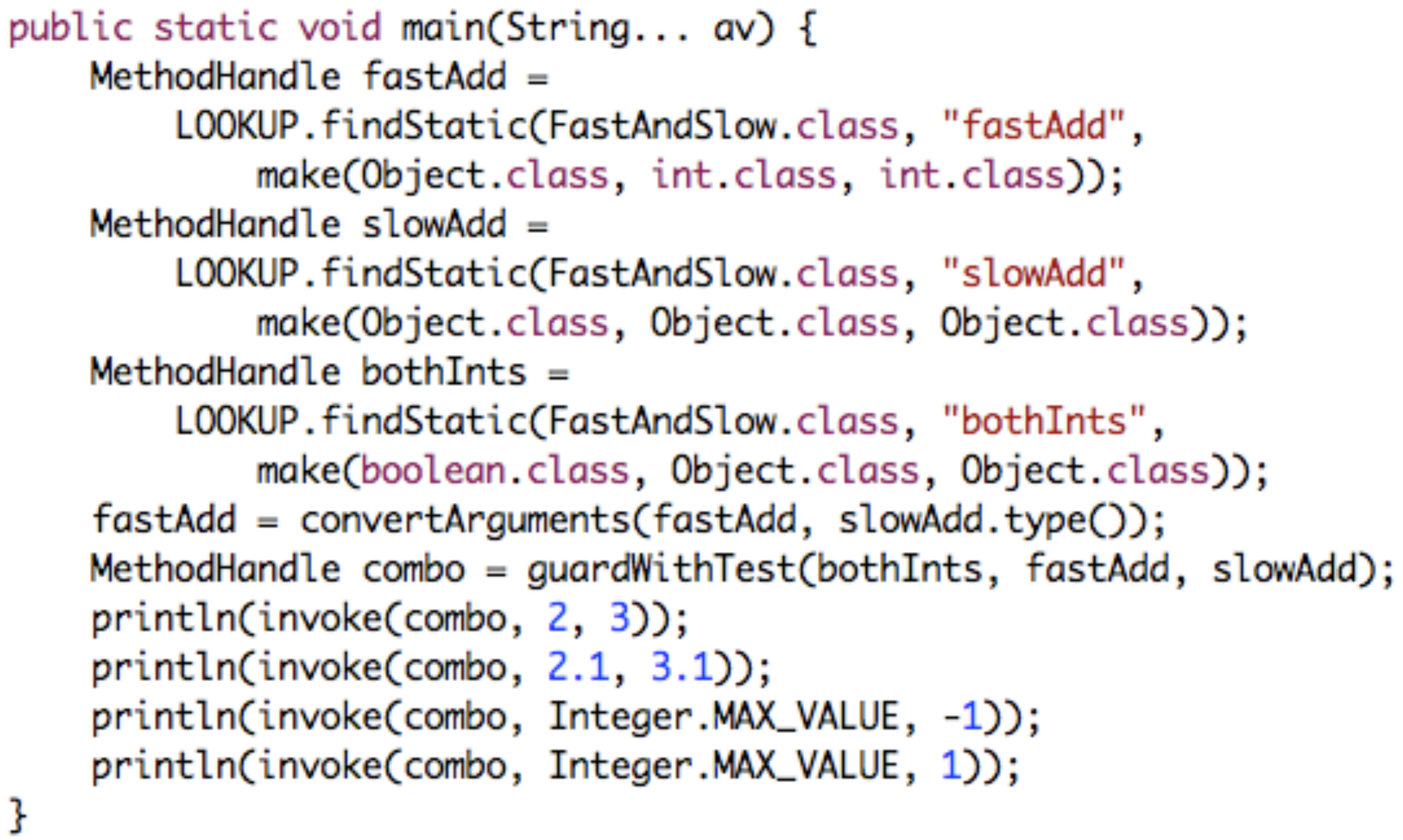
```
static Object slowAdd(Object x, Object y) {
    double xd = ((Number)x).doubleValue();
    double yd = ((Number)y).doubleValue();
    println("I'm hungry; is it done yet?");
    return xd + yd;
}
```

# Moment of decision



```
static boolean bothInts(Object x, Object y) {
    return x instanceof Integer && y instanceof Integer;
```

# Mixing it all together



```
public static void main(String... av) {
    MethodHandle fastAdd =
        LOOKUP.findStatic(FastAndSlow.class, "fastAdd",
            make(Object.class, int.class, int.class));
    MethodHandle slowAdd =
        LOOKUP.findStatic(FastAndSlow.class, "slowAdd",
            make(Object.class, Object.class, Object.class));
    MethodHandle bothInts =
        LOOKUP.findStatic(FastAndSlow.class, "bothInts",
            make(boolean.class, Object.class, Object.class));
    fastAdd = convertArguments(fastAdd, slowAdd.type());
    MethodHandle combo = guardWithTest(bothInts, fastAdd, slowAdd);
    println(invoke(combo, 2, 3));
    println(invoke(combo, 2.1, 3.1));
    println(invoke(combo, Integer.MAX_VALUE, -1));
    println(invoke(combo, Integer.MAX_VALUE, 1));
}
```

# Demo sources…

NetBeans™ code demos are online here:

```
http://hg.openjdk.java.net/mlvm/mlvm/file/tip/
  netbeans/indy-demo
```

Outline of use:

```
hg clone http://hg.openjdk.java.net/mlvm/mlvm

cd mlvm/netbeans/indy-demo

vi nbproject/project.properties

ant run
```

JavaOne

# Thank You

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http://openjdk.java.net/projects/mlvm