@takesection

JVMアセンブリ言語

2017年7月20日

自己紹介

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Java/Scalaエンジニア

ArduinoやPICのような組込系のASM、C、C++も好き

JVMの特徴

- スケーラビリティ
- マルチOS
- マルチプラットフォーム
- **スタックマシン**

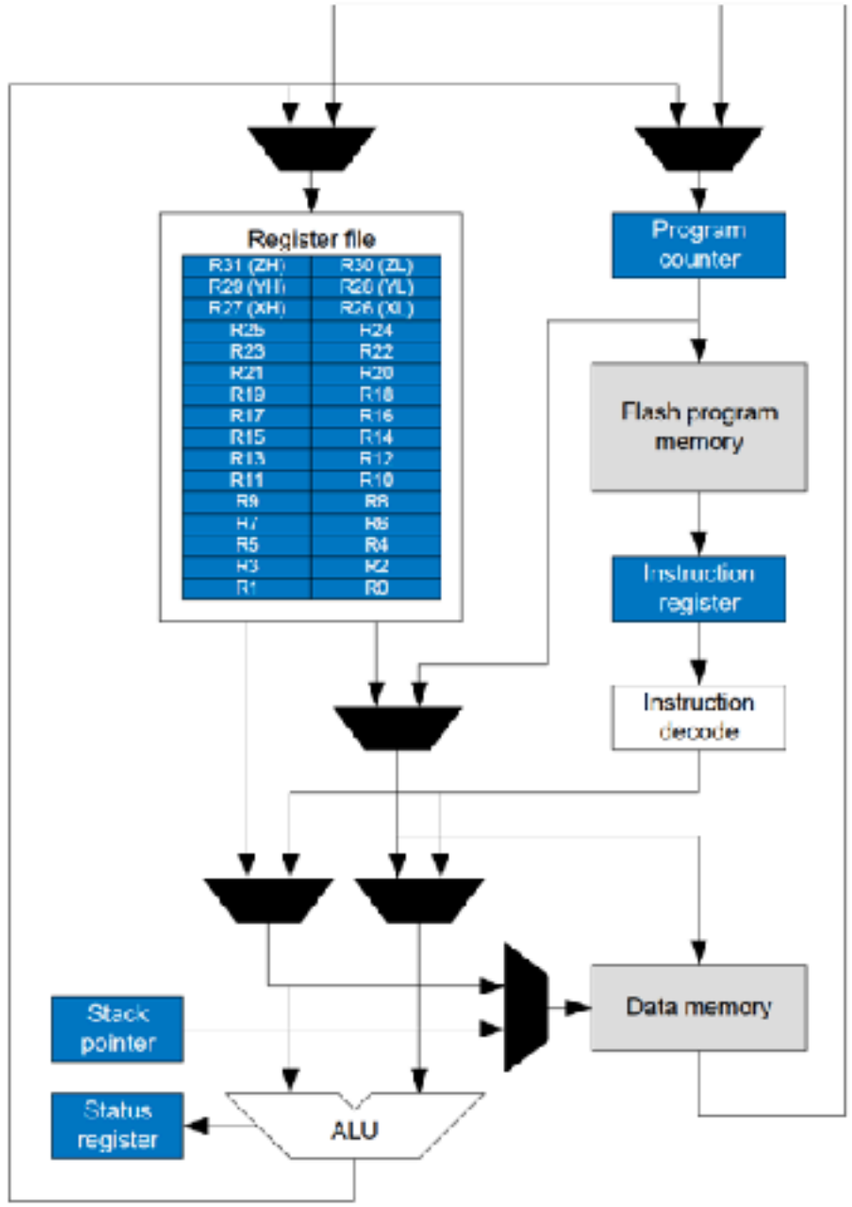
スタック言語

- FORTH, PostScript

```
%!
% PostScript
100 200 moveto
300 600 lineto
500 200 lineto
stroke
```

- リアルなCPUの場合、PC(Program Counter)、Stack Pointer、**Register**、ALU(Arithmetic Logic Unit)を持っている

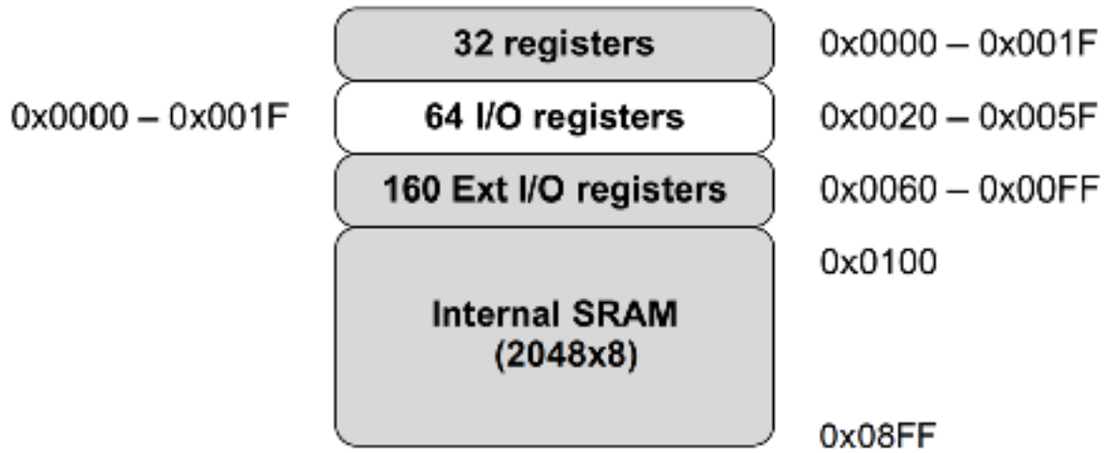
Figure 9-1. Block Diagram of the AVR Architecture



スタックとは

スタックデータ構造は、サブルーチンコールや割込時の状態を保存するのに適していて古から使われてきた構造。

Figure 10-2. Data Memory Map with 2048 byte Internal data SRAM



9.5 Stack Pointer

The Stack is mainly used for storing temporary data, for storing local variables and for storing return addresses after interrupts and subroutine calls. The Stack is implemented as growing from higher to lower memory locations. The Stack Pointer Register always points to the top of the Stack.

The Stack Pointer points to the data SRAM Stack area where the Subroutine and Interrupt Stacks are located. A Stack PUSH command will decrease the Stack Pointer. The Stack in the data SRAM must be defined by the program before any subroutine calls are executed or interrupts are enabled. Initial Stack Pointer value equals the last address of the internal SRAM and the Stack Pointer must be set to point above start of the SRAM. See the table for Stack Pointer details.

Table 9-1. Stack Pointer Instructions

Instruction	Stack pointer	Description
PUSH	Decremented by 1	Data is pushed onto the stack
CALL ICALL RCALL	Decremented by 2	Return address is pushed onto the stack with a subroutine call or interrupt
POP	Incremented by 1	Data is popped from the stack
RET RETI	Incremented by 2	Return address is popped from the stack with return from subroutine or return from interrupt

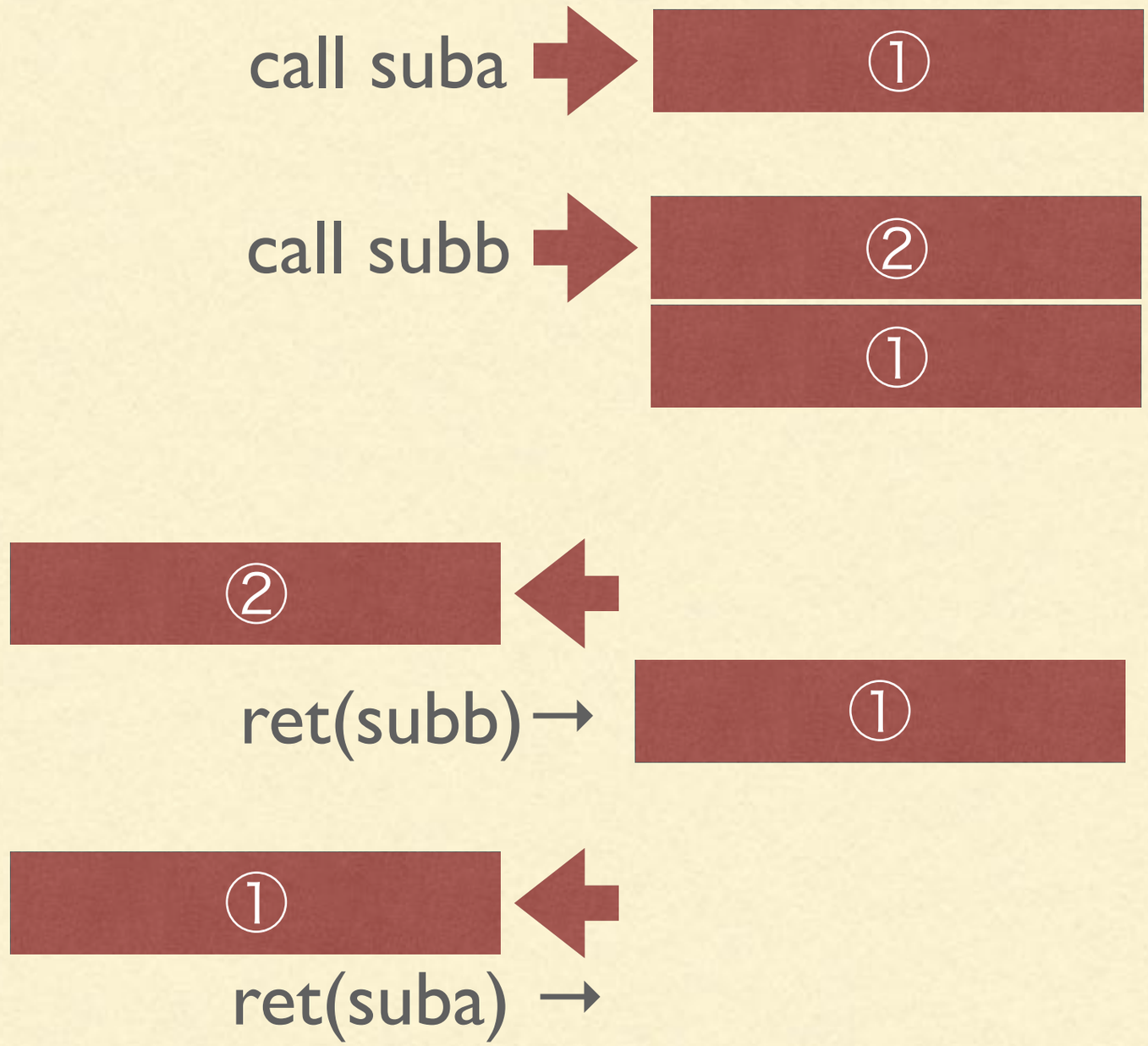
The AVR Stack Pointer is implemented as two 8-bit registers in the I/O space. The number of bits actually used is implementation dependent. Note that the data space in some implementations of the AVR architecture is so small that only SPL is needed. In this case, the SPH Register will not be present.

サブルーチンコール

```
loop:
  call suba
  jmp loop; ①

suba:
  call subb
  ret; ②

subb:
  ret
```



JVMのデータ領域

- **The pc Register** - 各スレッド単位で保持される
- **Java Virtual Machine Stacks** - スレッドはスレッドの生成と同時に生成されるプライベートなJava Virtual Machine Stackを持つ。このスタックにはFrameが格納される
- **Run-Time Constant Pool** - 実行時コンスタント・プール
- Method Area
- Heap
- Native Method Stacks

FRAME

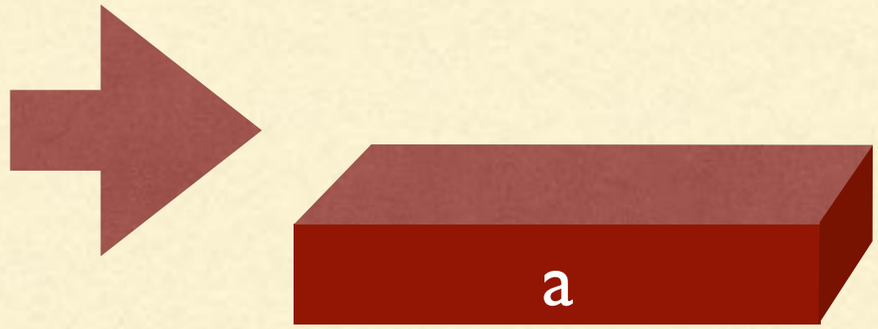
- メソッドが起動されるたびに生成され、起動されたメソッドの終了（正常・途中終了に関係なく）で破棄される
- Local Variables - ローカル変数やサブルーチンコールのアドレスを保持する
- Operand Stacks - オペコードは演算対象の値をLIFOのスタックを主に使用する
- Dynamic Linking - 実行時コンスタント・プールへの参照を保持する
- Normal Method Invocation Completion
- Abrupt Method Invocation Completion

スタックの基本的操作

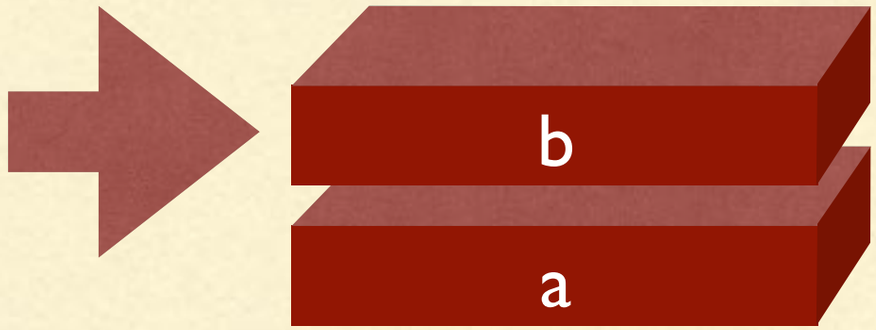
- PUSH
- POP
- DUP
- SWAP

PUSH

push a

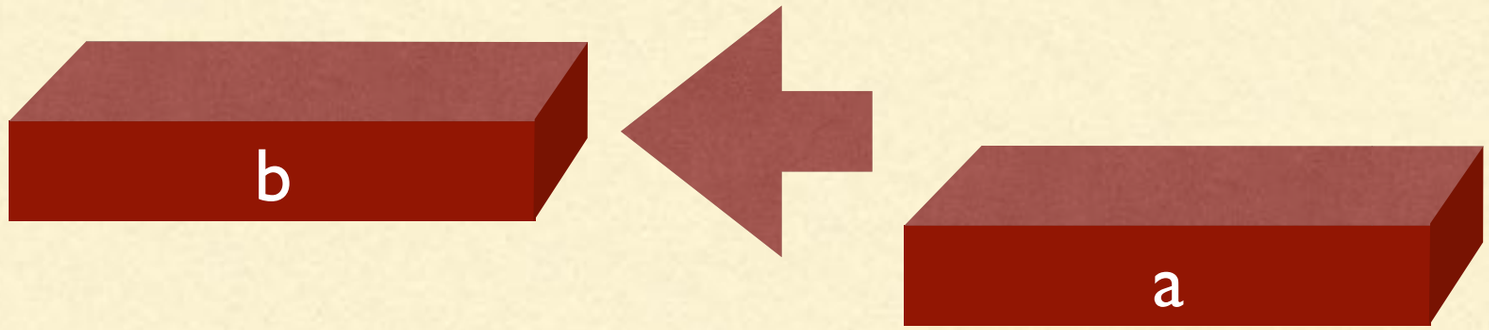


push b



POP

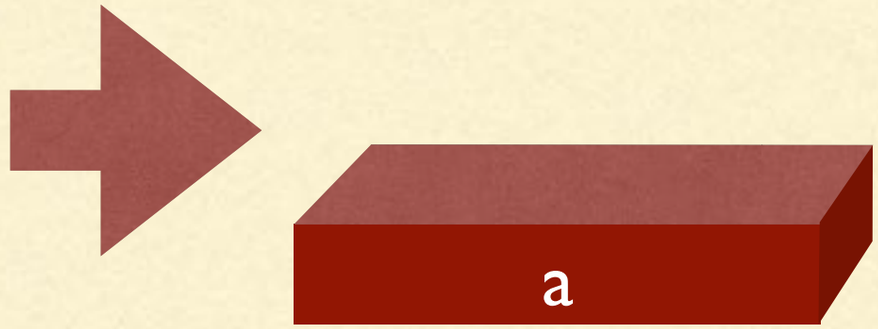
pop



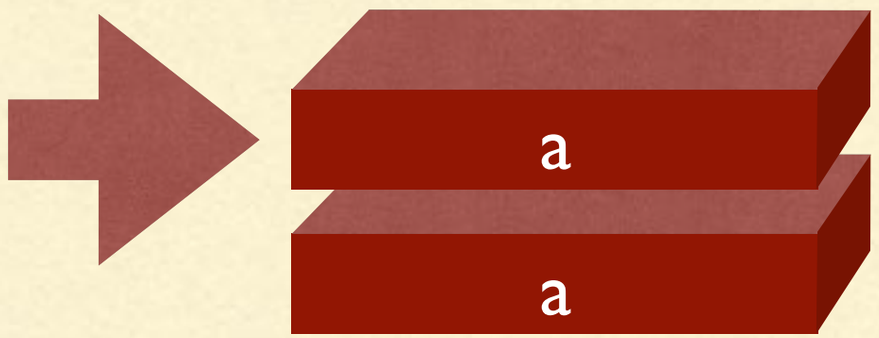
pop

DUP

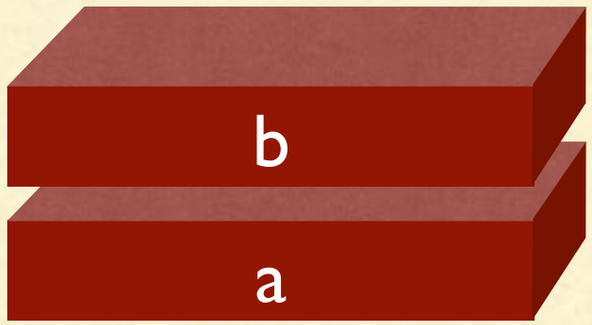
push a



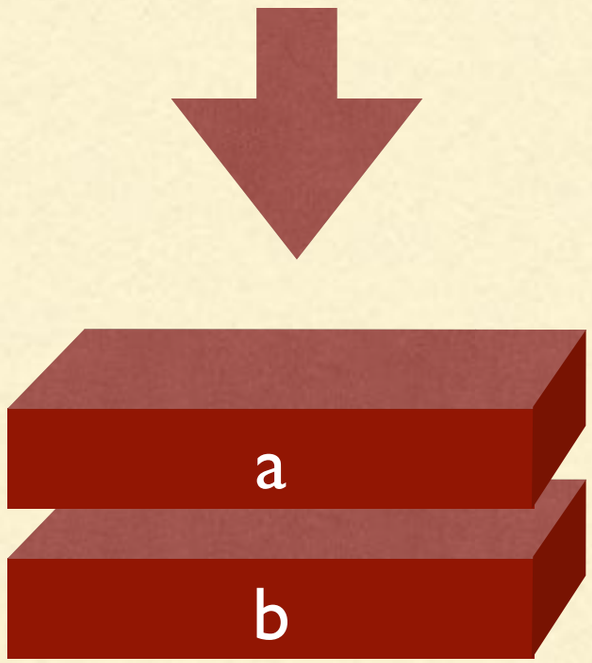
dup



SWAP

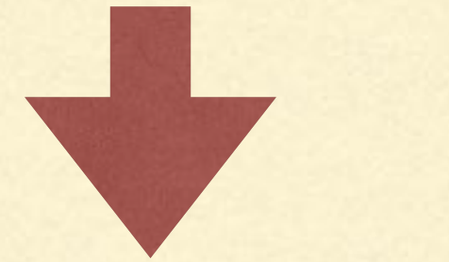


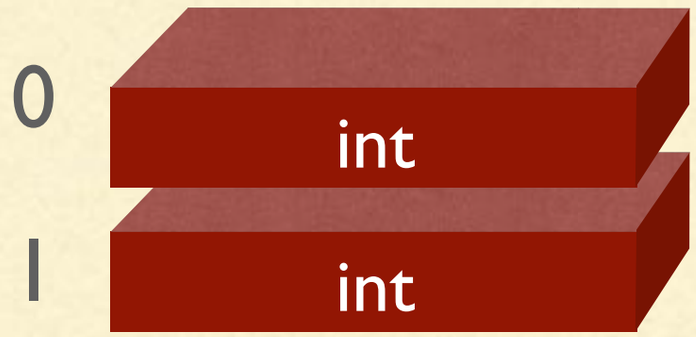
swap



例

```
int add(int a, int b) {
        return a + b;
}
```






```
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01:   public Foo();
02:     Code:
03:       0: aload_0
04:       1: invokespecial #1
05:       4: return
06:
07:   static int add(int, int);
08:     Code:
09:       0: iload_0
10:       1: iload_1
11:       2: iadd
12:       3: ireturn
13:
14: }
```

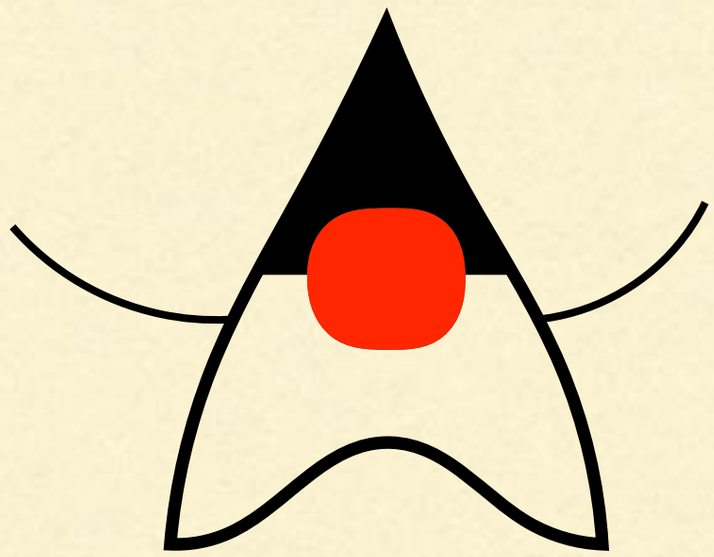

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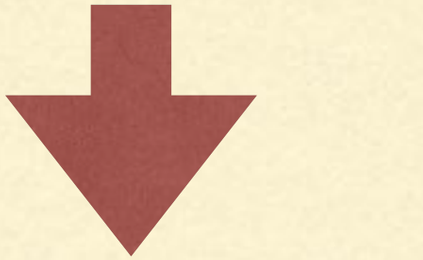

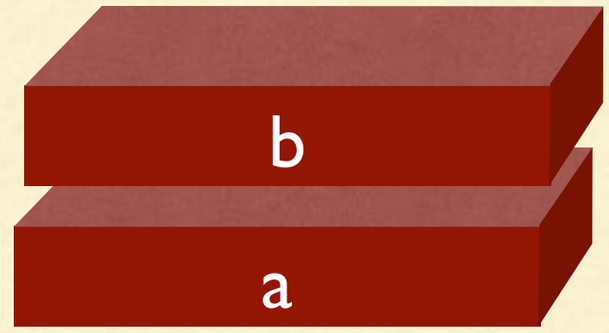


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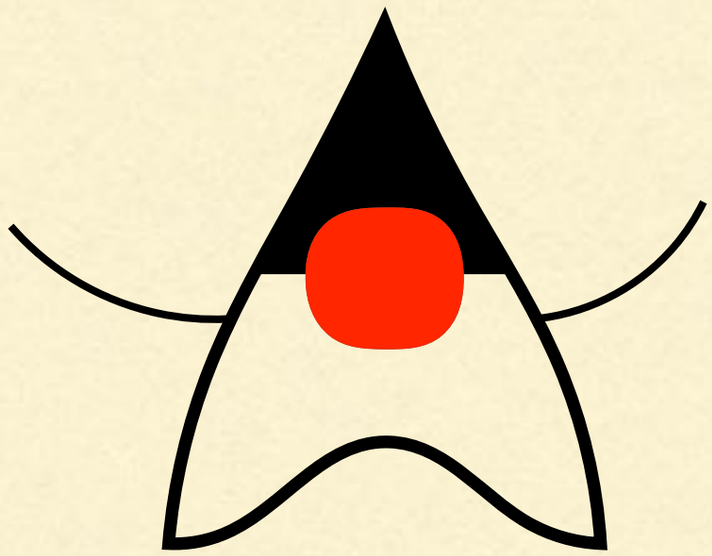

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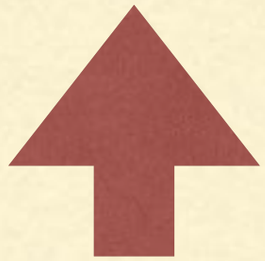


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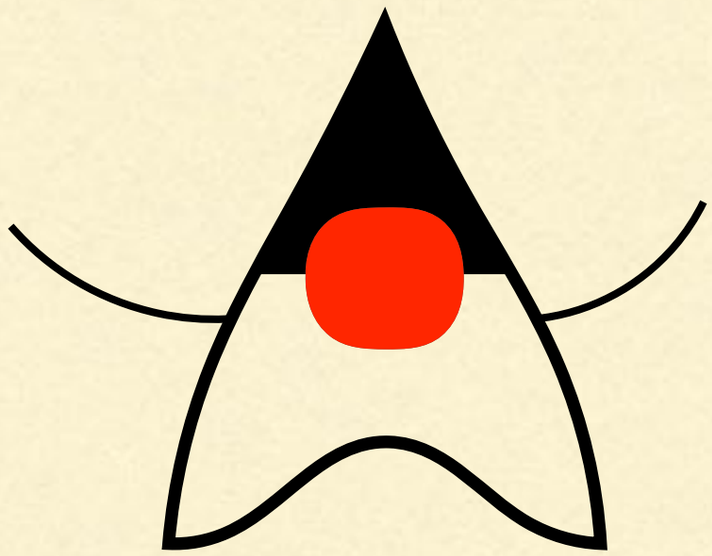

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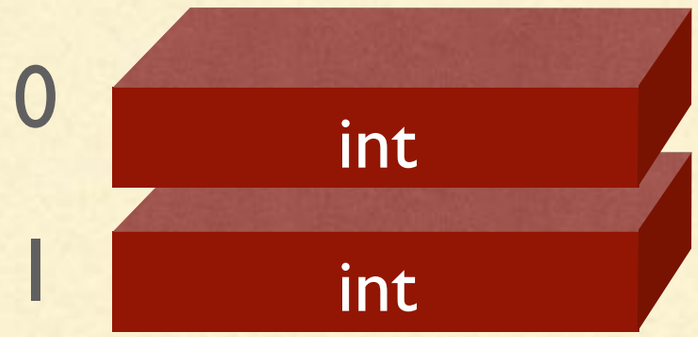

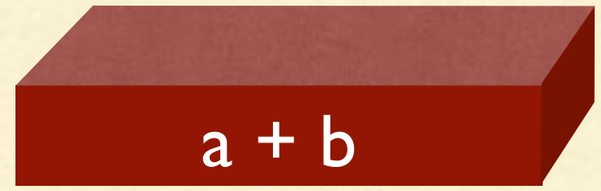


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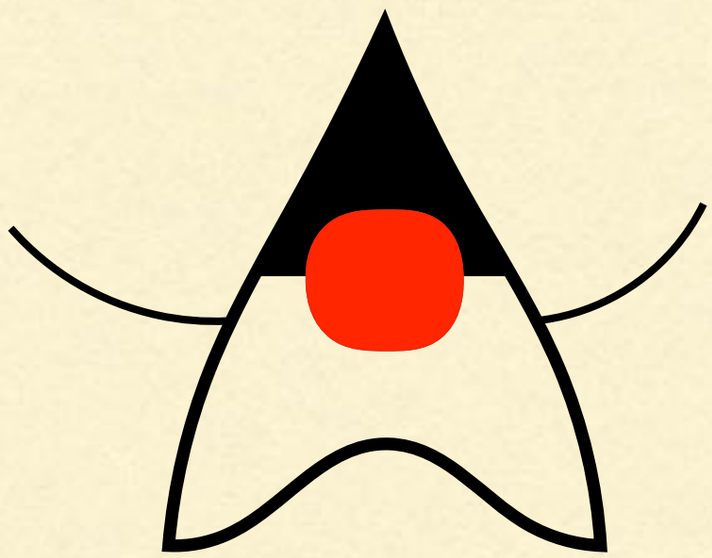

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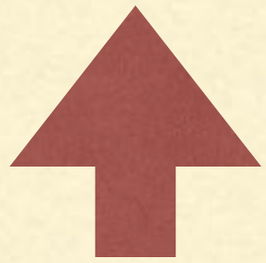

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03:       0: aload_0
04:       1: invokespecial #1
05:       4: return
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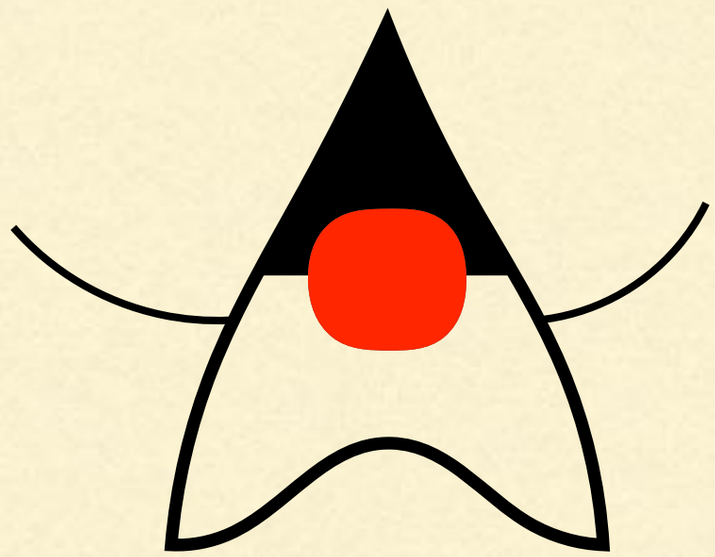


Note:

int型のreturn(ireturn)は、スタックからint値をpopし、呼び出し側のフレームにpushする

INVOKE OVERVIEW

- invokevirtual - C++におけるバーチャルメソッドの呼び出しと同様に、対象クラスの適切なメソッドを起動
- invokeintetface - インターフェースメソッドを起動する
- invokedynamic - 動的なクラス生成とインスタンス生成を実行する
- invokestatic - クラス(static)メソッドを起動
- invokespecial - スーパークラス、プライベートメソッド、インスタンス初期化メソッド(<init>)を起動

例外

- catchやfinallyが実行するハンドラーの開始pcアドレスはclassファイル中のCodeアトリビュートに定義されるexception_table配列に記述される
- Java Virutual Machineはチェック例外とランタイム例外やエラーを区別していない、またクラスファイルロード時にもこのことによるチェックを行わない。したがって、throwsやcatchがない場合でもどんな例外をスローしても問題はない。Scalaはそのためthrows宣言にあたるものがない(31.2.2 投げられた例外『Scalaスケーラブルプログラミング第3版』)

JSR, JSR_W, RET

- jsr, jsr_w - メソッド内のサブルーチンコールのためのインストラクション(returnAddress型をOperand Stacksにpushする)
- ret - サブルーチンコールからの復帰のためのインストラクション(returnAddressをLocal Variablesから取得する)
- finally節の実装中でつかわれている

スタックマシンで扱える型

- 32bitの値を扱うCategory 1と64bitの値を扱うCategory 2がある
- オブジェクトのインスタンスはCategory 1のreference型で表される

実際の型 (ACTUAL TYPE)	計算上の型 (COMPUTATIONAL TYPE)	CATEGORY
boolean	int	1
byte	int	1
char	int	1
short	int	1
int	int	1
float	float	1
reference	reference	1
returnAddress	returnAddress	1
long	long	2
double	double	2

NEW

- **new -** 新たなオブジェクトを生成する(このインストラクションは新たなインスタンスを完全に生成するものではない)

配列

- 配列の生成はインストラクションで特別扱いされている
  (anewarray, newarray, multianewarray)

アセンブラコード

```
package com.pigumer;

public class Foo {

  static int add(int a, int b) throws java.lang.RuntimeException {
    return a + b;
  }

  void foo() {
  }

  public void bar(int a, int b) {
    try {
      add(a, b);
    } finally {
      foo();
    }
  }
}
```

```
Compiled from "Foo.java"
public class com.pigumer.Foo {
  public com.pigumer.Foo();
    Code:
      0: aload_0
      1: invokespecial #1                  // Method java/lang/Object."<init>":()V
      4: return
    LineNumberTable:
      line 3: 0
    LocalVariableTable:
      Start  Length  Slot  Name   Signature
          0       5     0  this   Lcom/pigumer/Foo;

  static int add(int, int) throws java.lang.RuntimeException;
    Code:
      0: iload_0
      1: iload_1
      2: iadd
      3: ireturn
    LineNumberTable:
      line 6: 0
    LocalVariableTable:
      Start  Length  Slot  Name   Signature
          0       4     0     a   I
          0       4     1     b   I

  void foo();
    Code:
      0: return
    LineNumberTable:
      line 10: 0
    LocalVariableTable:
      Start  Length  Slot  Name   Signature
          0       1     0  this   Lcom/pigumer/Foo;
```

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

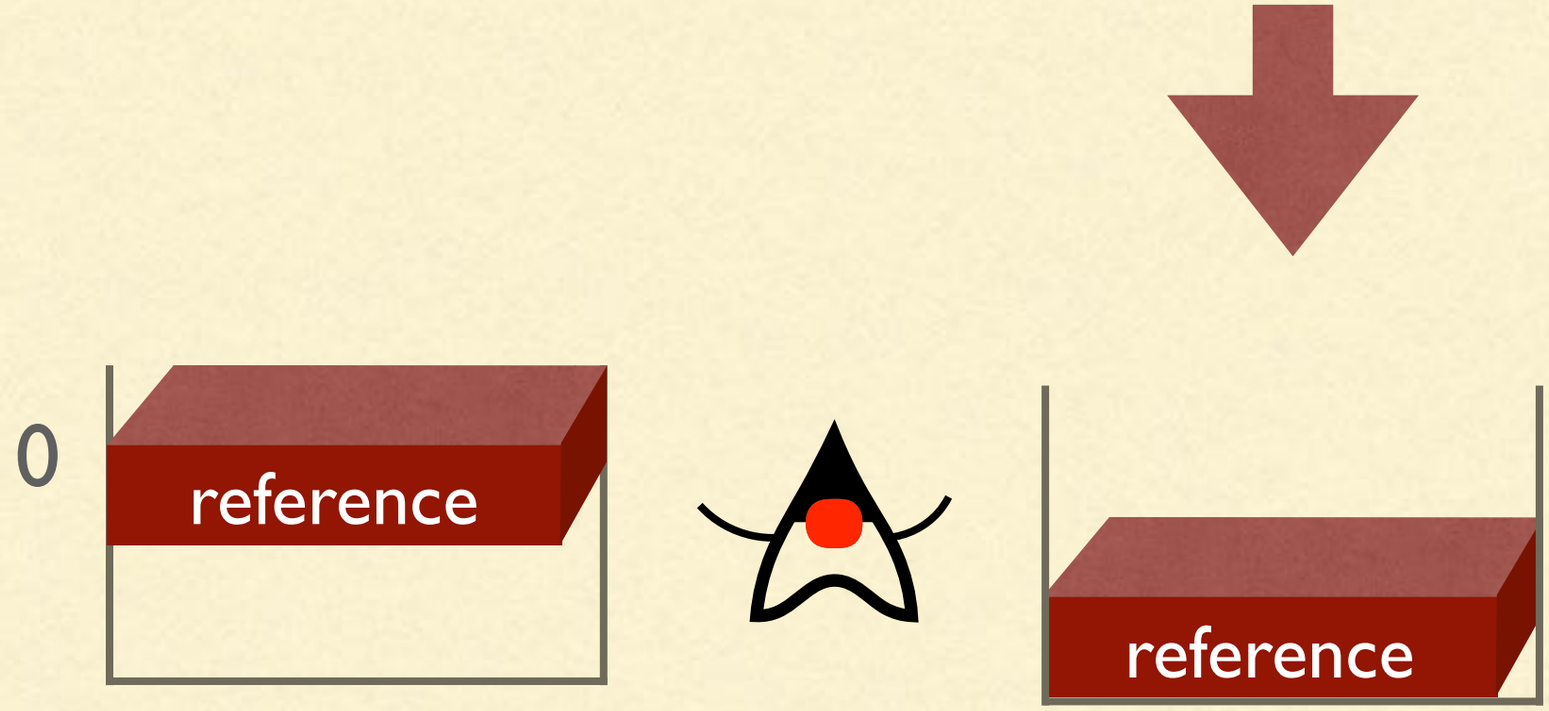
ADD(例参照)

```
static int add(int, int) throws java.lang.RuntimeException;
  Code:
     0: iload_0
     1: iload_1
     2: iadd
     3: ireturn
LineNumberTable:
  line 6: 0
LocalVariableTable:
  Start  Length  Slot  Name   Signature
      0       4     0     a   I
      0       4     1     b   I
```

コンストラクタ

```
public com.pigumer.Foo();
  Code:
     0: aload_0
     1: invokespecial #1                  // Method java/lang/Object."<init>":()V
     4: return
  LineNumberTable:
    line 3: 0
LocalVariableTable:
  Start  Length  Slot  Name   Signature
      0       5     0  this   Lcom/pigumer/Foo;
```

```
public com.pigumer.Foo();
  Code:
     0: aload_0
     1: invokespecial #1                  // Method java/lang/Object."<init>":()V
     4: return
  LineNumberTable:
    line 3: 0
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0       5     0  this   Lcom/pigumer/Foo;
```



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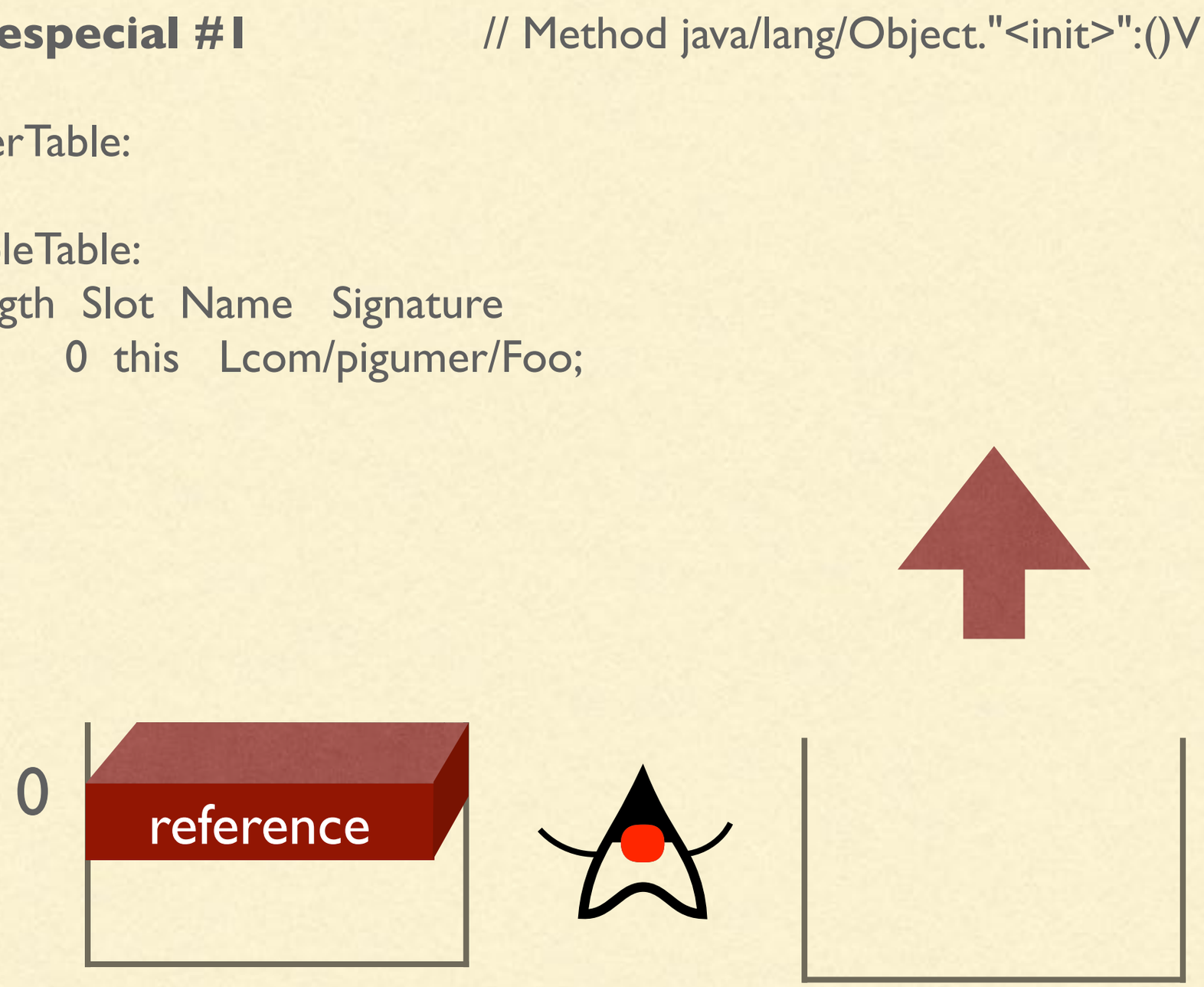
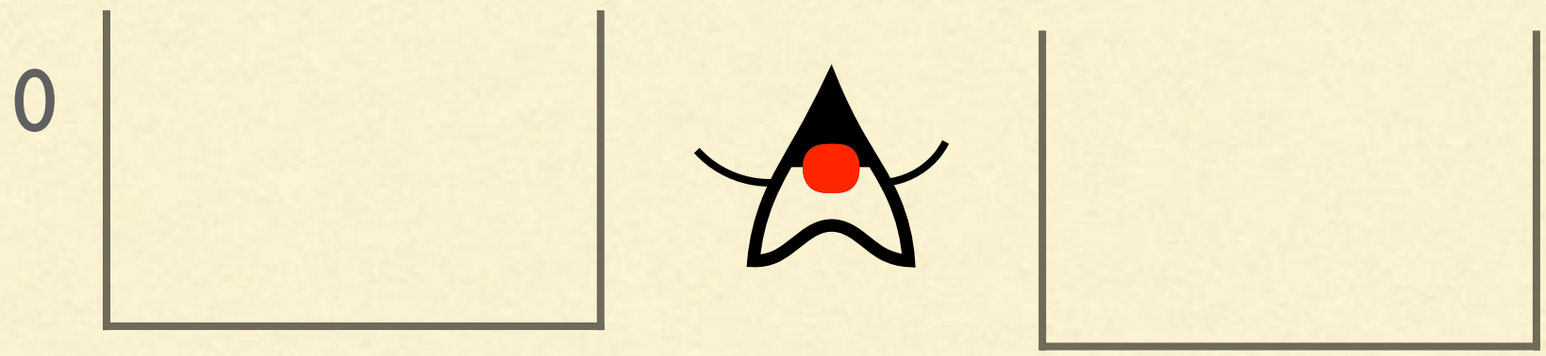
public com.pigumer.Foo();
  Code:
     0: aload_0
     1: invokespecial #1                  // Method java/lang/Object."<init>":()V
     4: return
  LineNumberTable:
    line 3: 0
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0       5     0  this   Lcom/pigumer/Foo;
```




```
#1 = Methodref          #5.#27         // java/lang/Object."<init>":()V
```

```
public com.pigumer.Foo();
  Code:
     0: aload_0
     1: invokespecial #1                  // Method java/lang/Object."<init>":()V
     4: return
  LineNumberTable:
    line 3: 0
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0       5     0  this   Lcom/pigumer/Foo;
```



STATICメソッドの実行

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
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        0      21     1     a   I
        0      21     2     b   I
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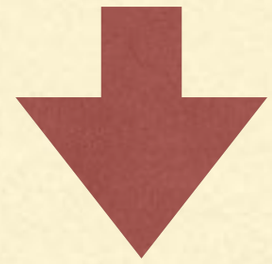
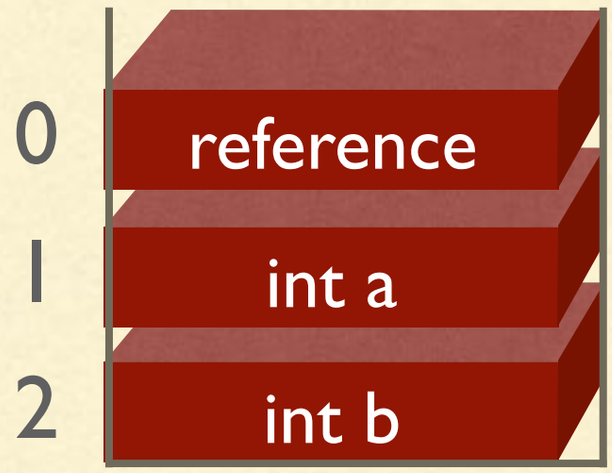
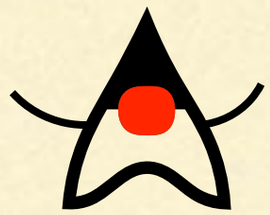
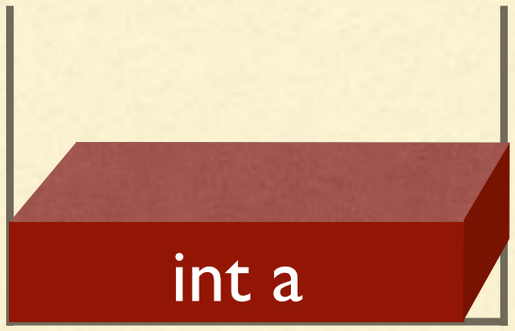
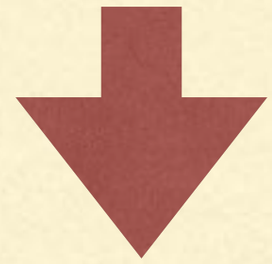


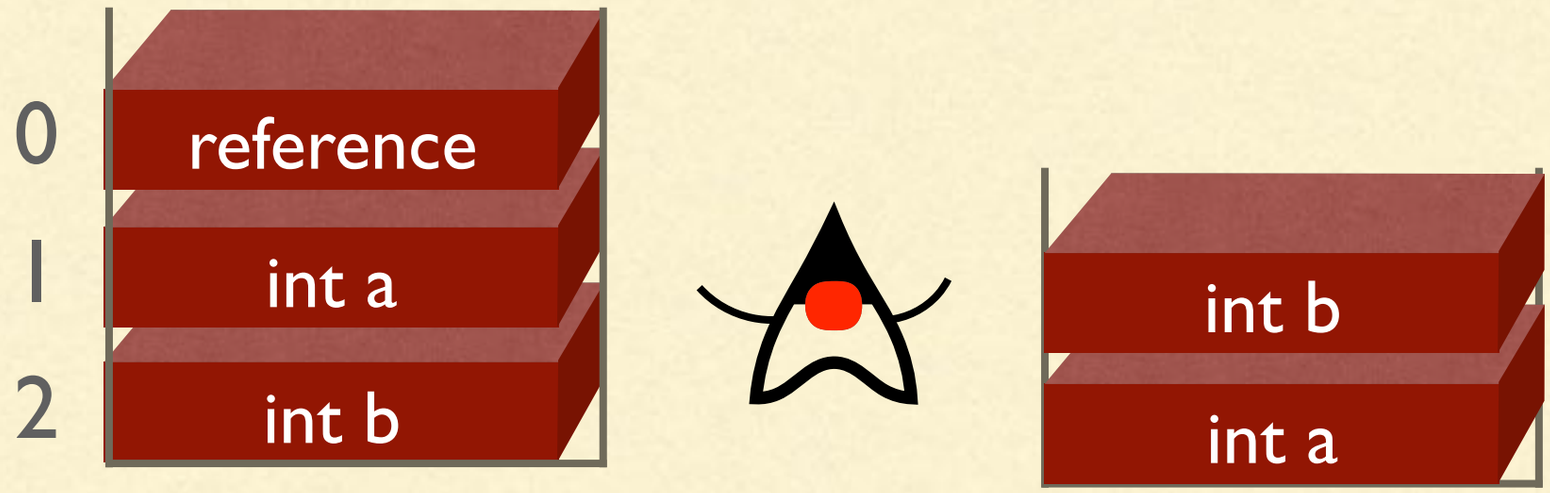






```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```





```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
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    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```
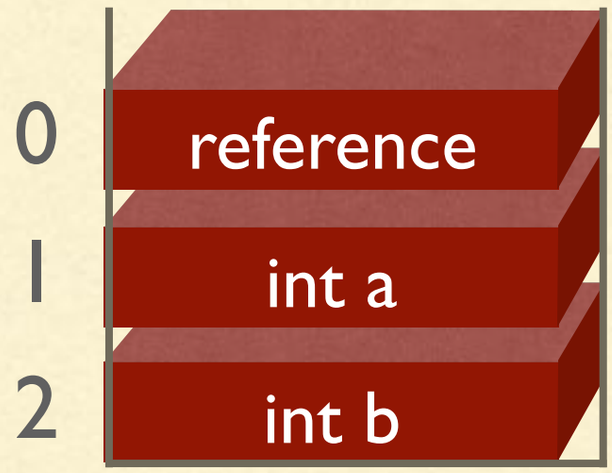
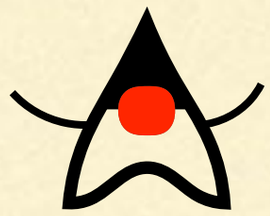
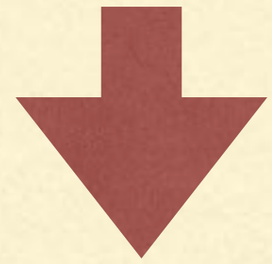
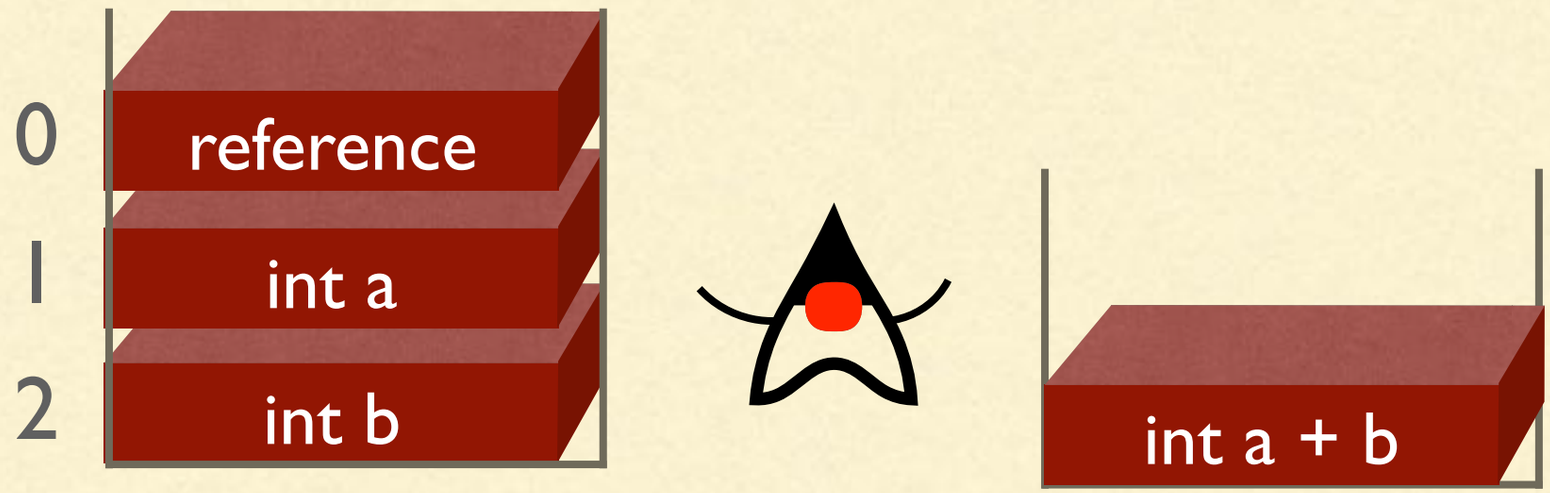





#2 = Methodref #4.#28 // com/pigumer/Foo.add:(II)I

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```





#2 = Methodref #4.#28 // com/pigumer/Foo.add:(II)I

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
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     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```
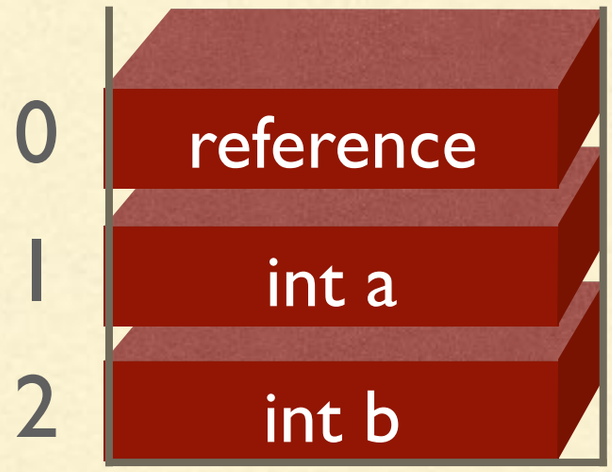
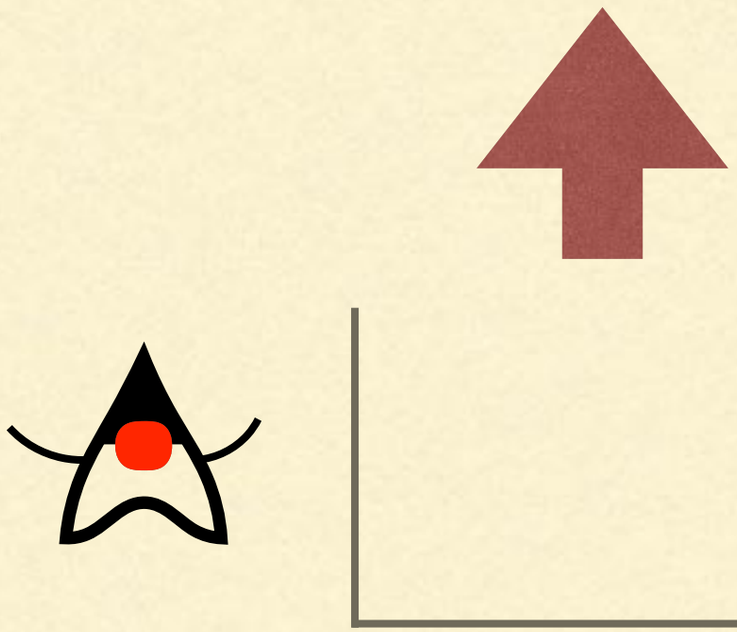

```
public void bar(int a, int b) {
  try {
    add(a, b);
  } finally {
    foo();
  }
}
```

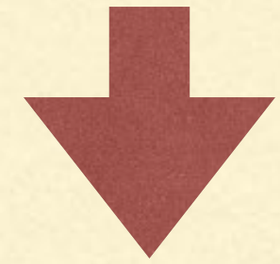


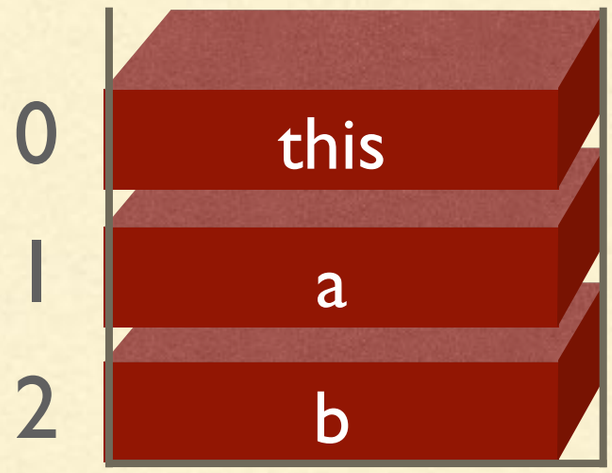


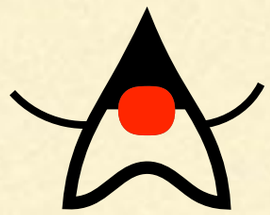
VIRTUALメソッドの実行

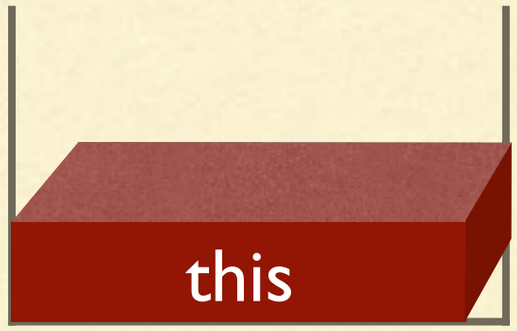
- InvokeVirtual

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

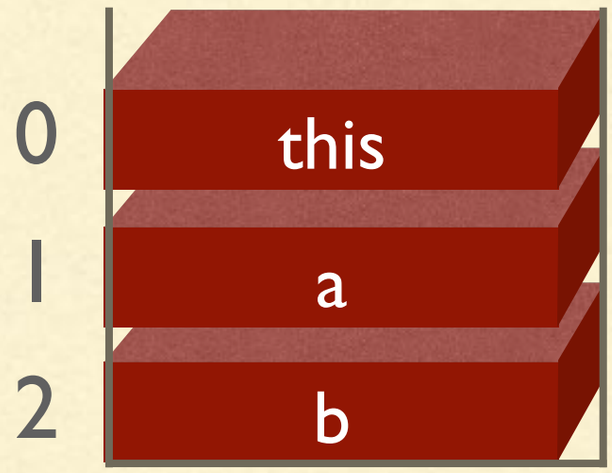


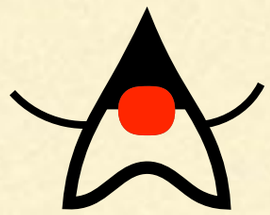






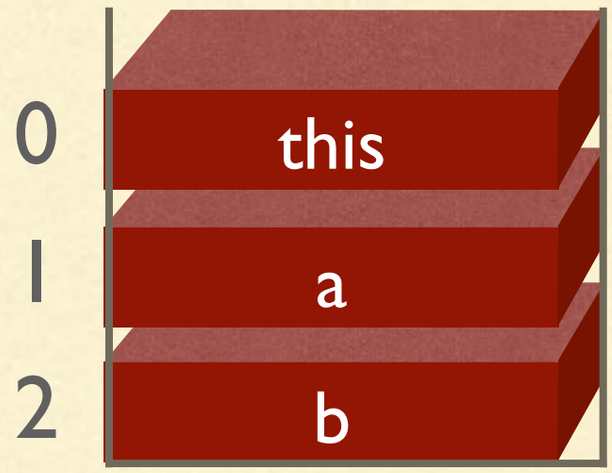
```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

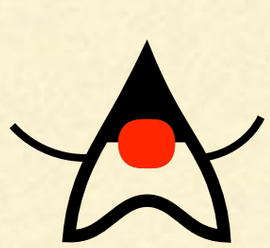




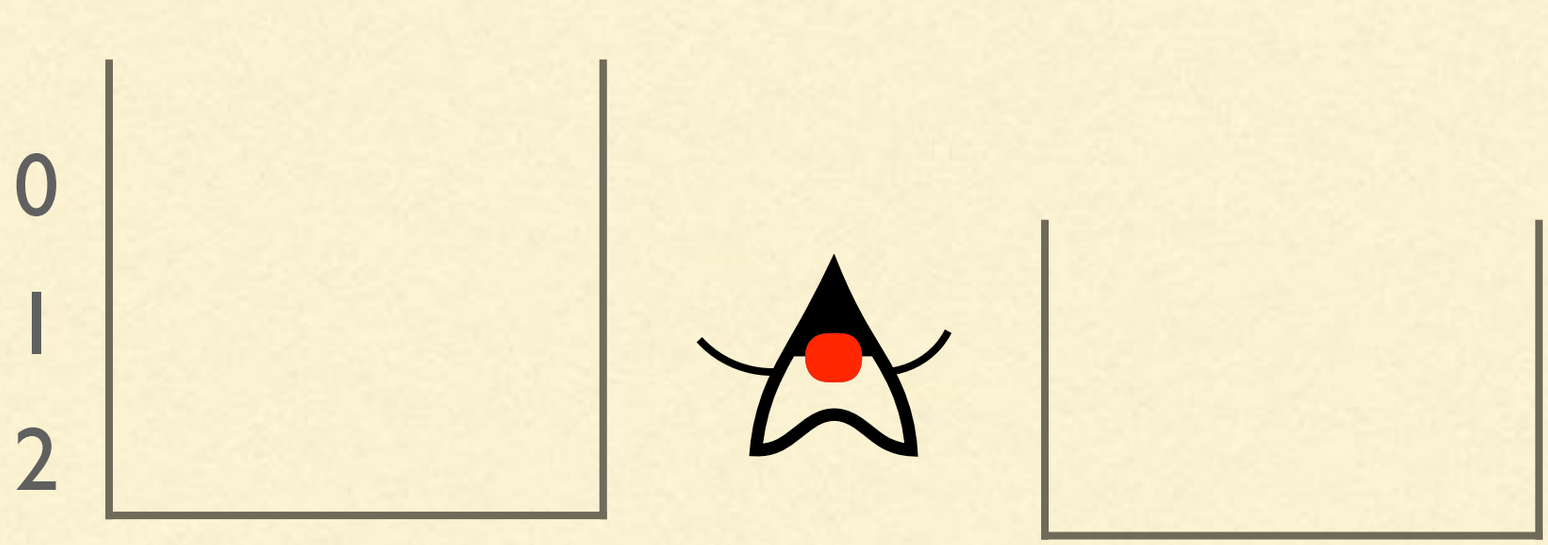
3 = Methodref #4.#29 // com/pigumer/Foo.foo:()V

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```





```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```



```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
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    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

```
public void bar(int a, int b) {
  try {
    add(a, b);
  } finally {
    foo();
  }
}
```

例外、FINALLY

- exception_table[]に指定されたアドレス内のコードでスローされた例外のハンドラーの指定により例外時のコードが実行される。

※ end_pcが自身の値を含んでいないのは、Java Virtual Machineの設計における歴史的な過ちとされている。

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
  LineNumberTable:
    line 14: 0
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    line 17: 10
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    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```
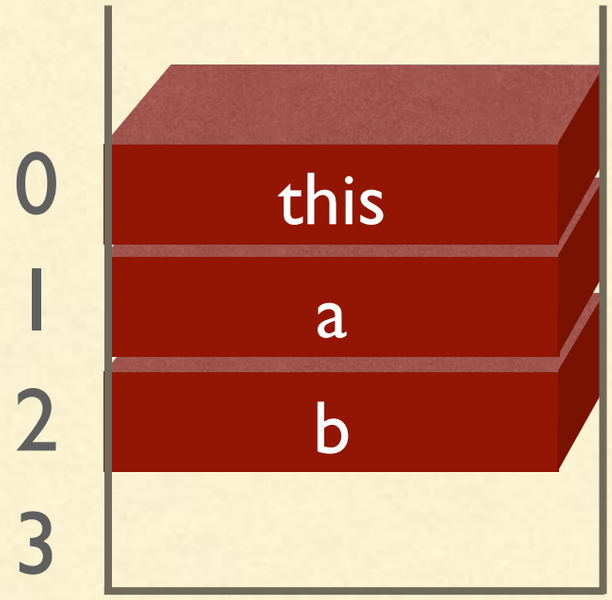
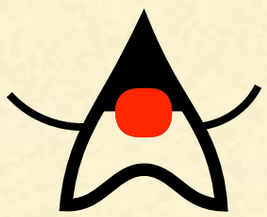
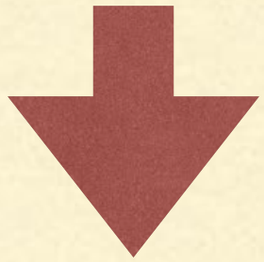

```
public void bar(int a, int b) {
  try {
    add(a, b);
  } finally {
    foo();
  }
}
```







```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
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         0     6    13   any
  LineNumberTable:
    line 14: 0
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    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

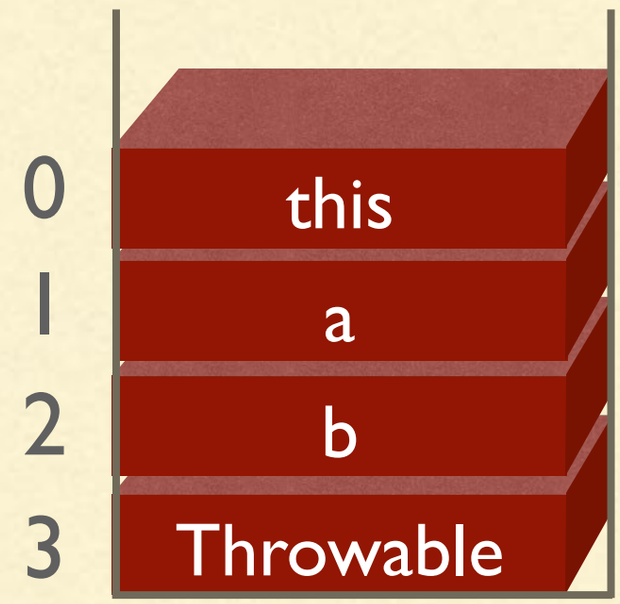

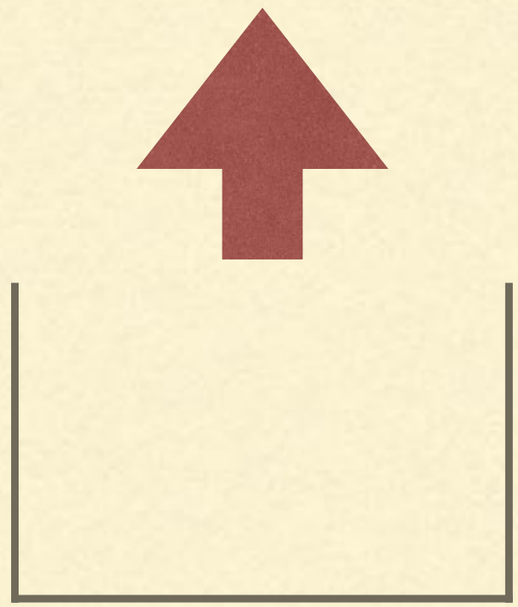

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
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  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

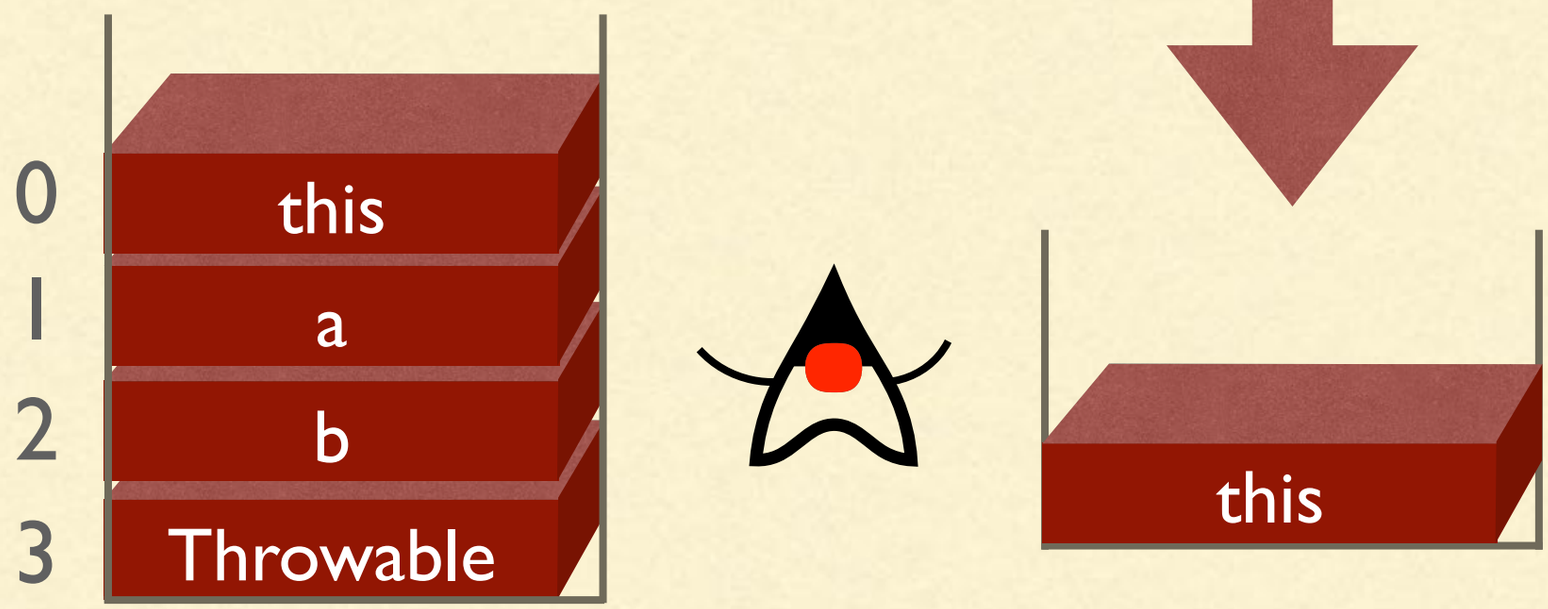

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
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  LineNumberTable:
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    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```

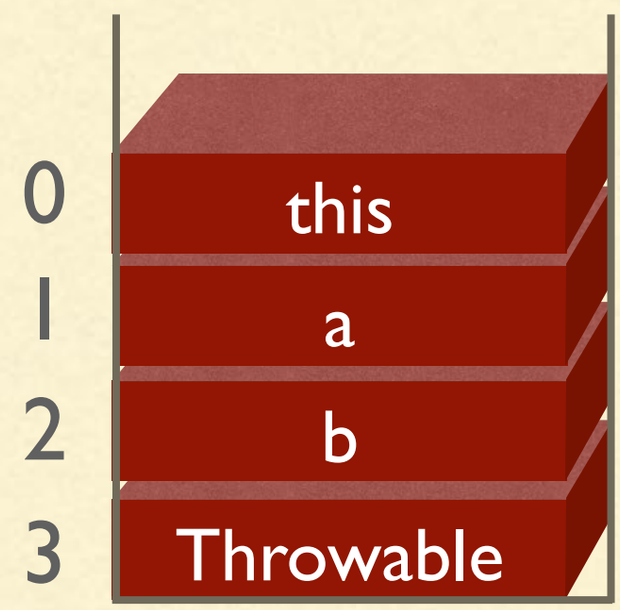

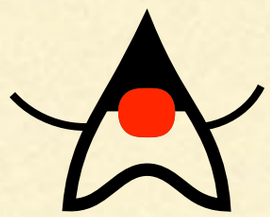

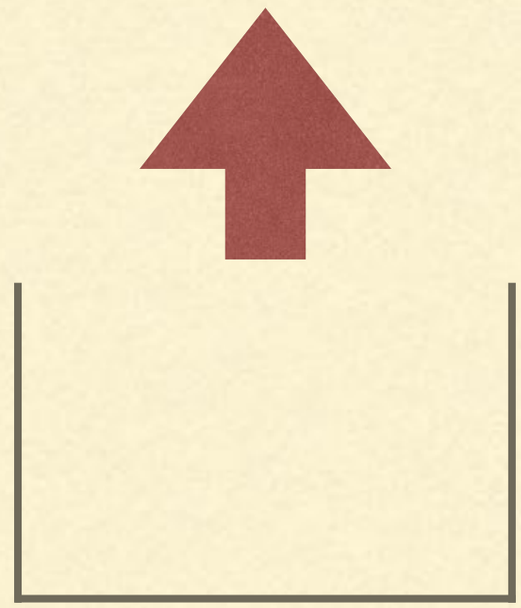

3 = Methodref #4.#29 // com/pigumer/Foo.foo:()V

```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
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         0     6    13   any
  LineNumberTable:
    line 14: 0
    line 16: 6
    line 17: 10
    line 16: 13
    line 18: 20
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      21     0  this   Lcom/pigumer/Foo;
        0      21     1     a   I
        0      21     2     b   I
}
```
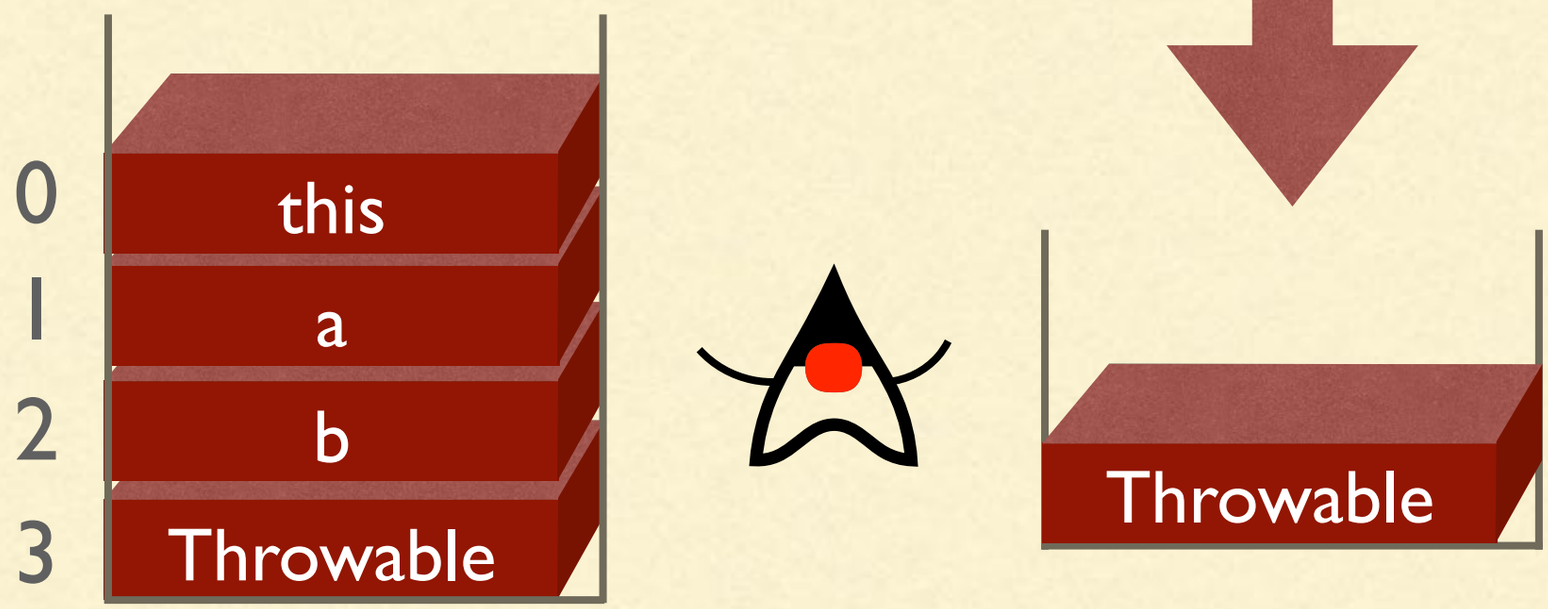
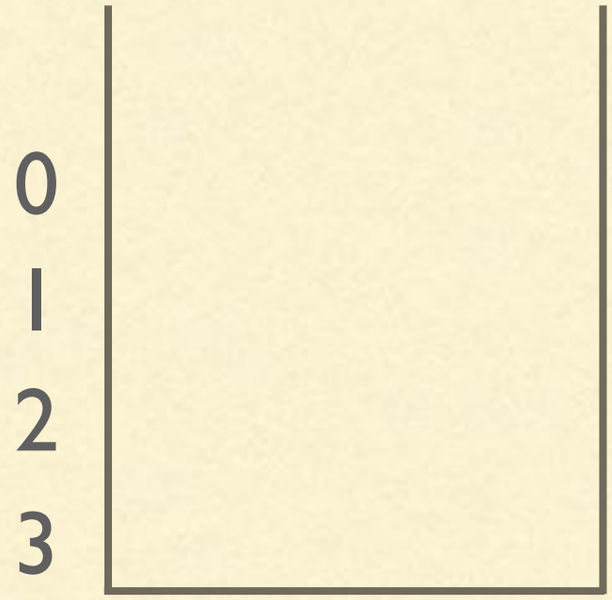
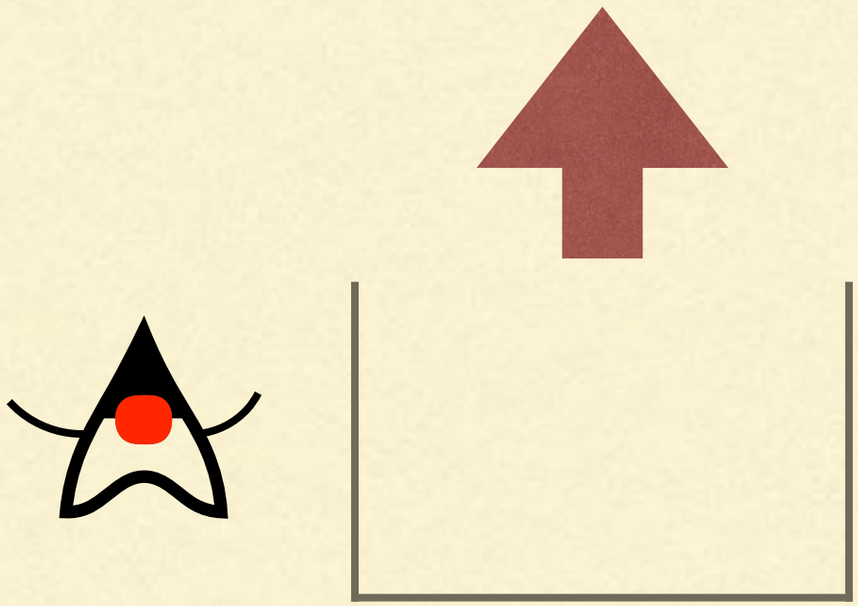



```
public void bar(int, int);
  Code:
     0: iload_1
     1: iload_2
     2: invokestatic  #2                  // Method add:(II)I
     5: pop
     6: aload_0
     7: invokevirtual #3                  // Method foo:()V
    10: goto          20
    13: astore_3
    14: aload_0
    15: invokevirtual #3                  // Method foo:()V
    18: aload_3
    19: athrow
    20: return
  Exception table:
     from    to  target type
         0     6    13   any
    LineNumberTable:
      line 14: 0
      line 16: 6
      line 17: 10
      line 16: 13
      line 18: 20
    LocalVariableTable:
      Start  Length  Slot  Name   Signature
          0      21     0  this   Lcom/pigumer/Foo;
          0      21     1     a   I
          0      21     2     b   I
}
```



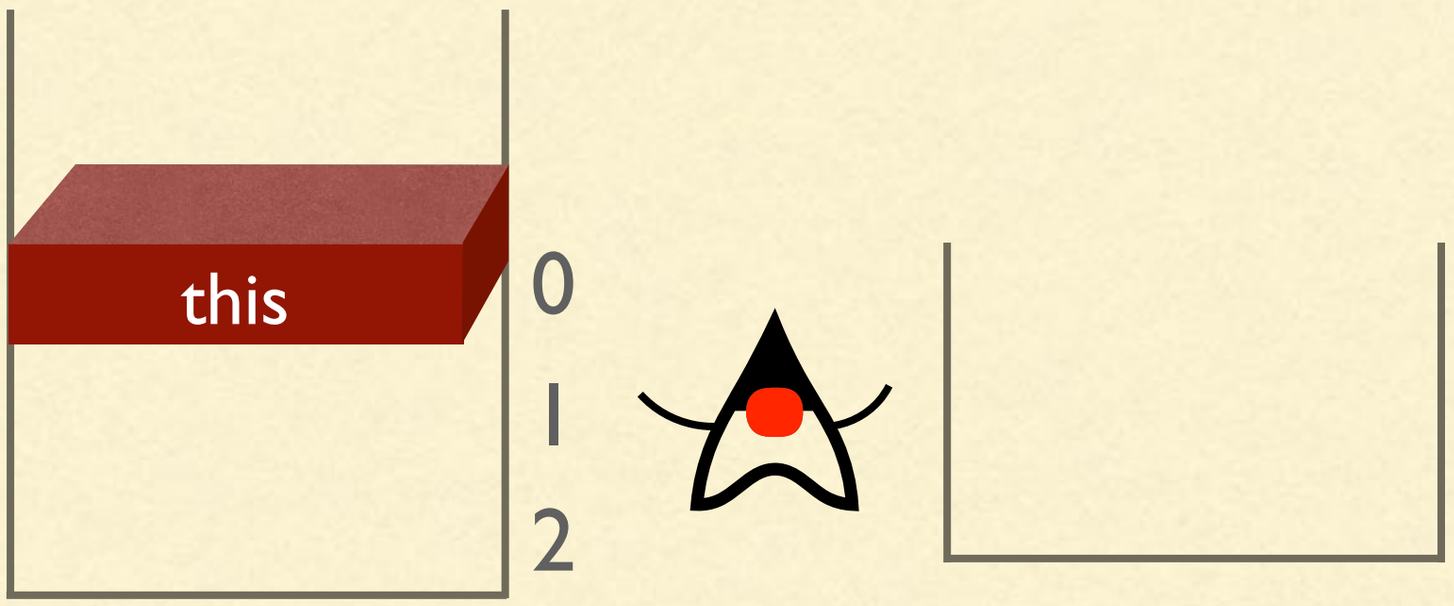


例外ハンドラー

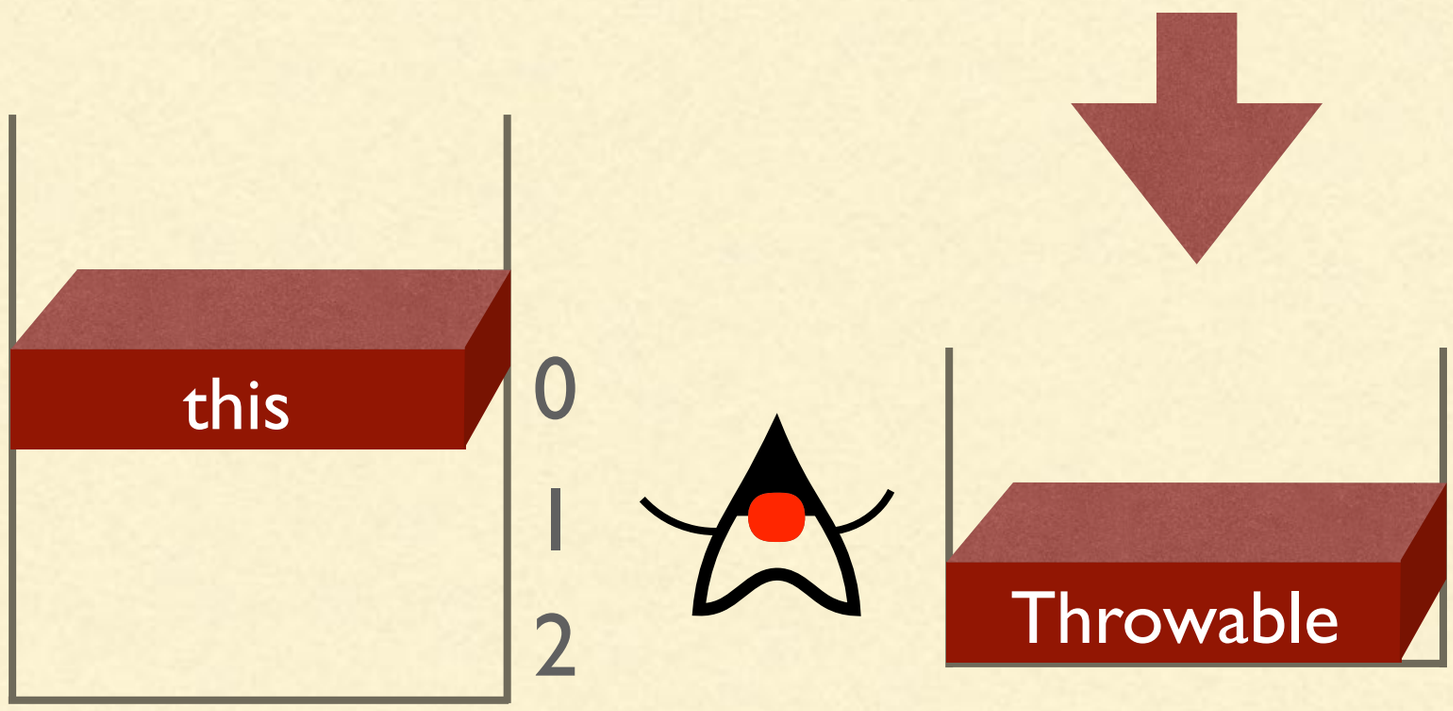
- The Java Virtual Machine Specification, Java SE 8 Edition に記載されている例

```
0   aload_0
1   invokevirtual #6
4   jsr 14
7   return
8   astore_1
9   jsr 14
12  aload_1
13  athrow
14  astore_2
15  aload_0
16  invokevirtual #5
19 ret 2
  Exception table:
  From   To     Target
  0      4      8          any
```

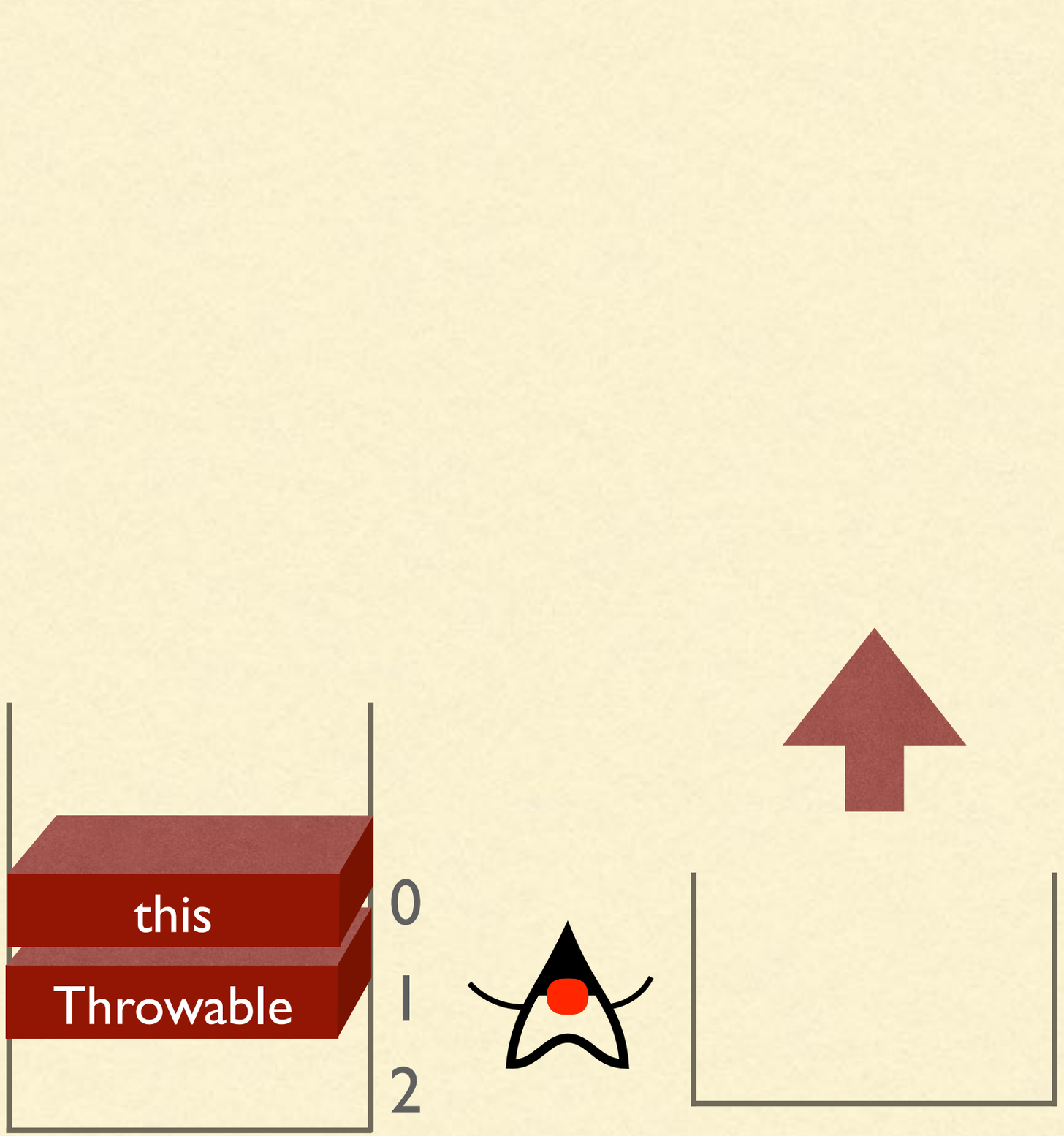
```
void tryFinally() {
        try {
            tryItOut();
        } finally {
            wrapItUp();
        }
}
```



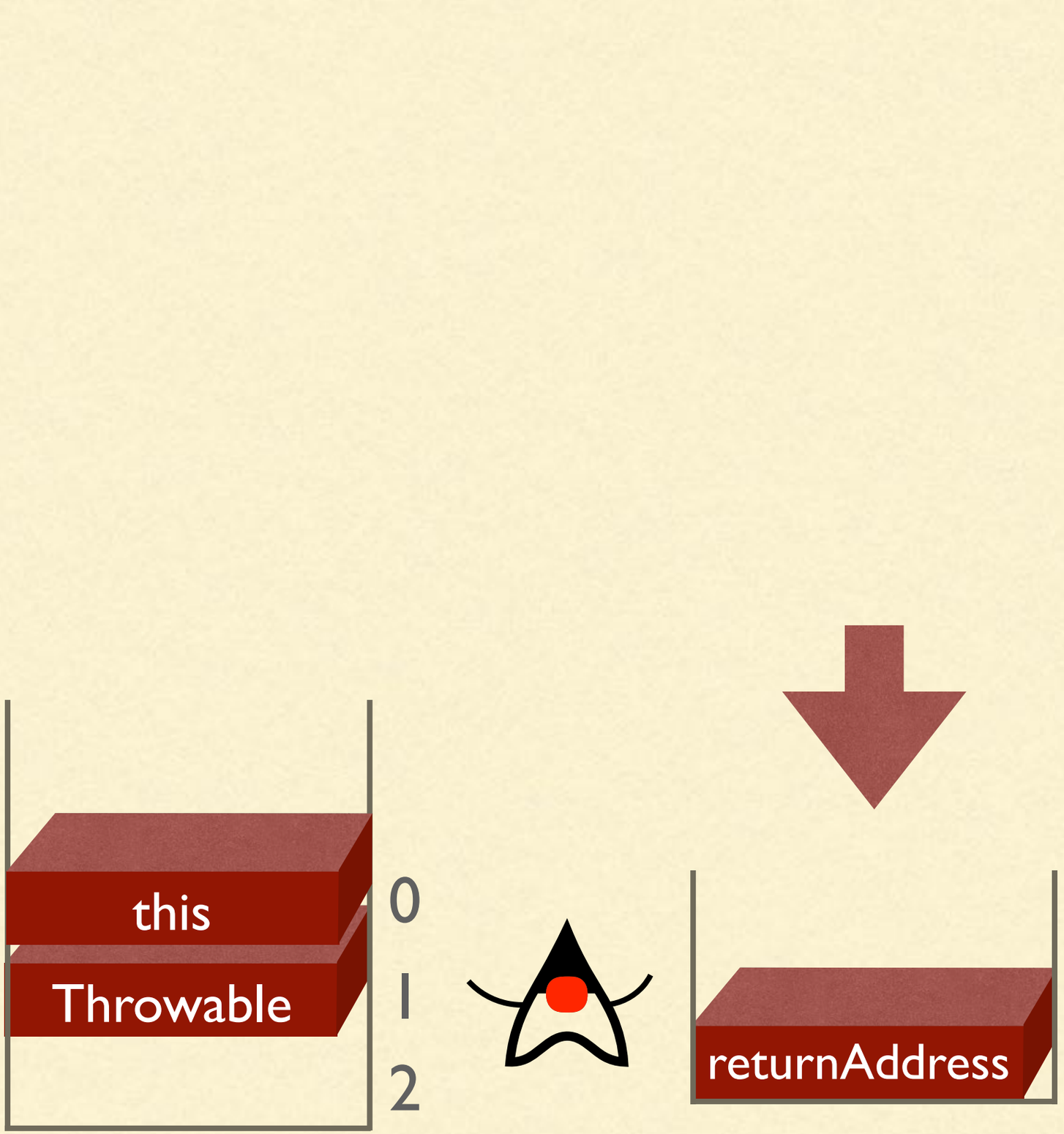
```
0   aload_0
1   invokevirtual #6
4   jsr 14
7   return
8   astore_1
9   jsr 14
12  aload_1
13  athrow
14  astore_2
15  aload_0
16  invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8           any
```



```
0    aload_0
1    invokevirtual #6
4    jsr 14
7    return
8    astore_1
9    jsr 14
12   aload_1
13   athrow
14   astore_2
15   aload_0
16   invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8          any
```

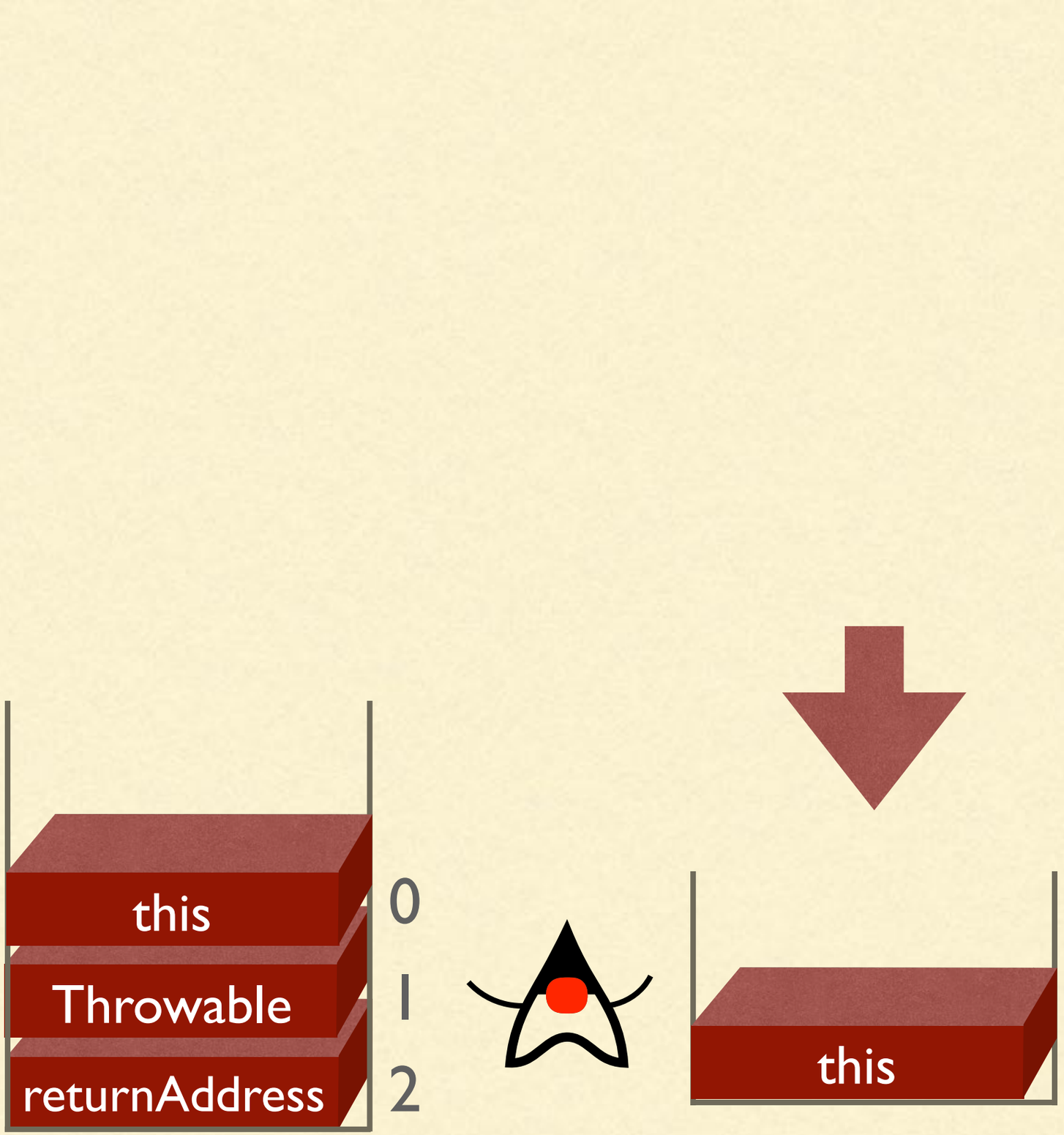


```
0    aload_0
1    invokevirtual #6
4    jsr 14
7    return
8    astore_1
9    jsr 14
12   aload_1
13   athrow
14   astore_2
15   aload_0
16   invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8           any
```

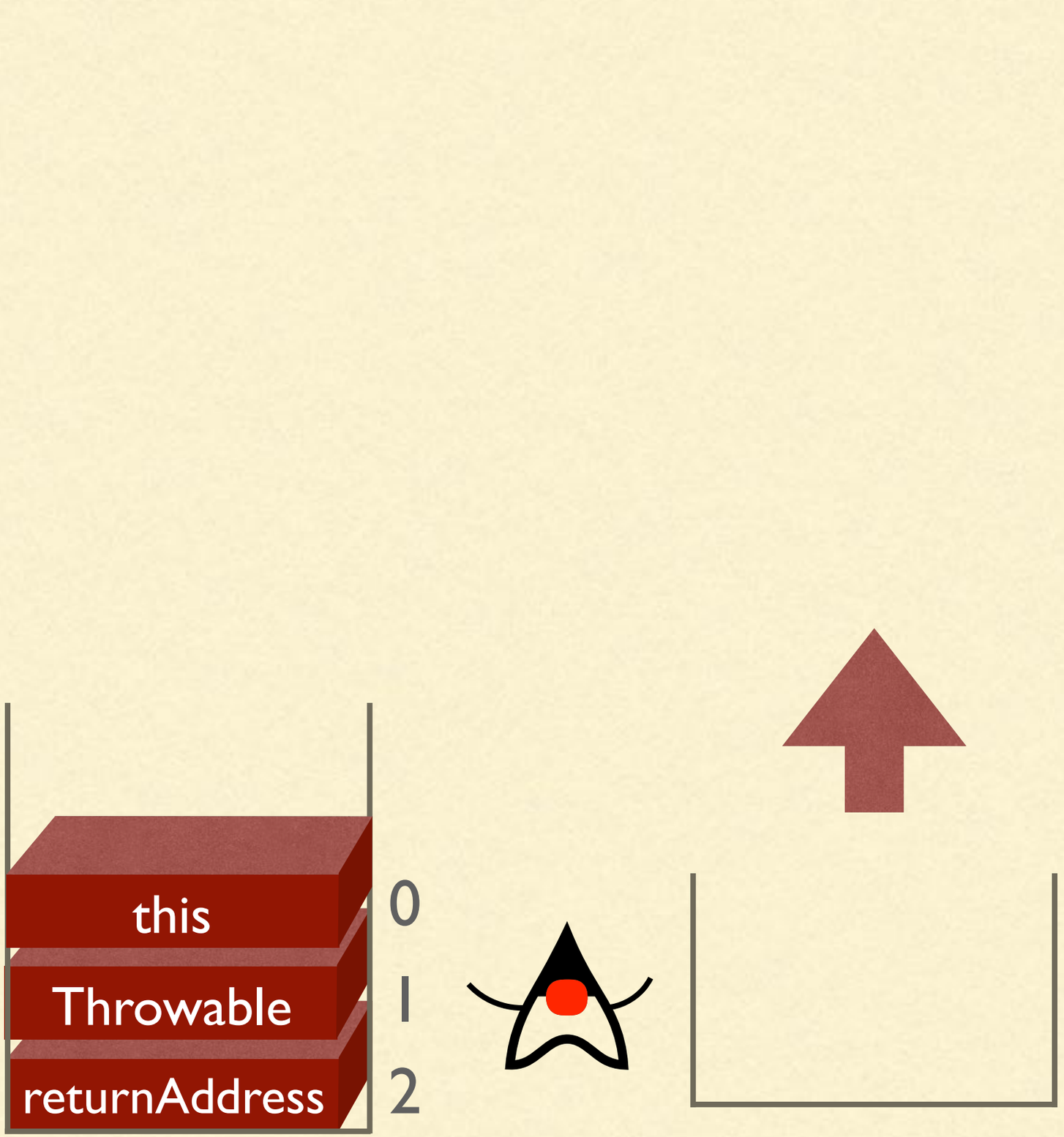


```
0    aload_0
1    invokevirtual #6
4    jsr 14
7    return
8    astore_1
9    jsr 14
12   aload_1
13   athrow
14   astore_2
15   aload_0
16   invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8          any
```

```
0   aload_0
1   invokevirtual #6
4   jsr 14
7   return
8   astore_1
9   jsr 14
12  aload_1
13  athrow
14  astore_2
15  aload_0
16  invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8           any
```



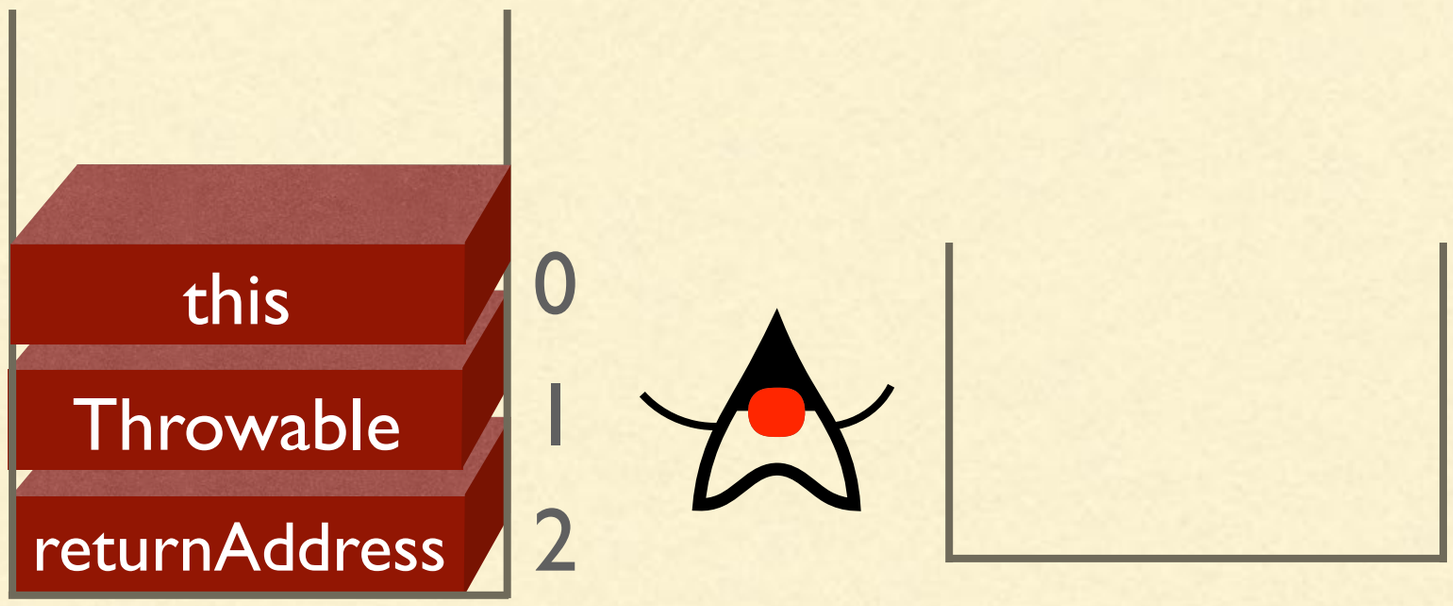
```
0    aload_0
1    invokevirtual #6
4    jsr 14
7    return
8    astore_1
9    jsr 14
12   aload_1
13   athrow
14   astore_2
15   aload_0
16   invokevirtual #5
19 ret 2
   Exception table:
   From   To     Target
   0      4      8          any
```



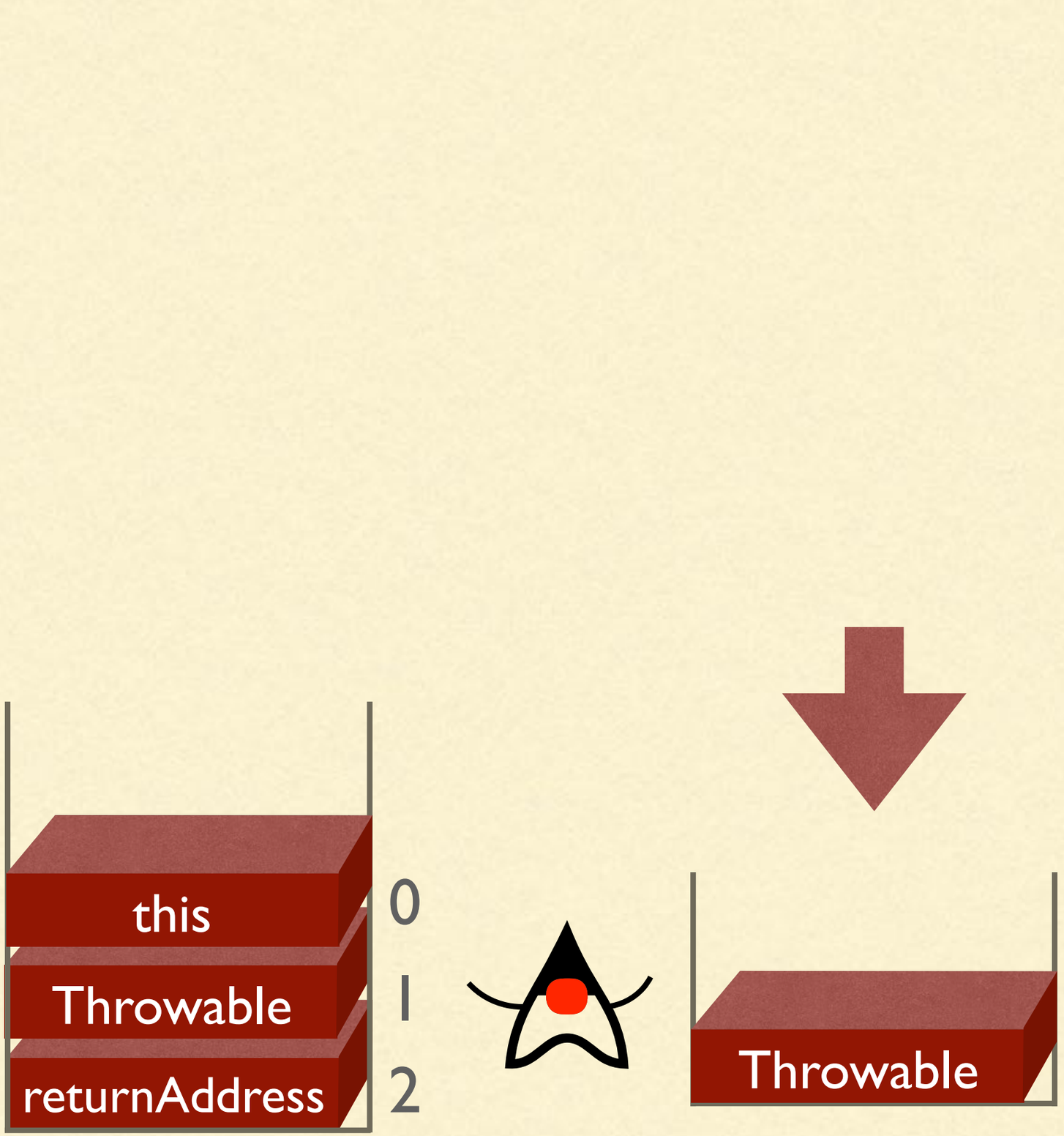
```
0   aload_0
1   invokevirtual #6
4   jsr 14
7   return
8   astore_1
9   jsr 14
12  aload_1
13  athrow
14  astore_2
15  aload_0
16  invokevirtual #5
19 ret 2
```

Exception table:

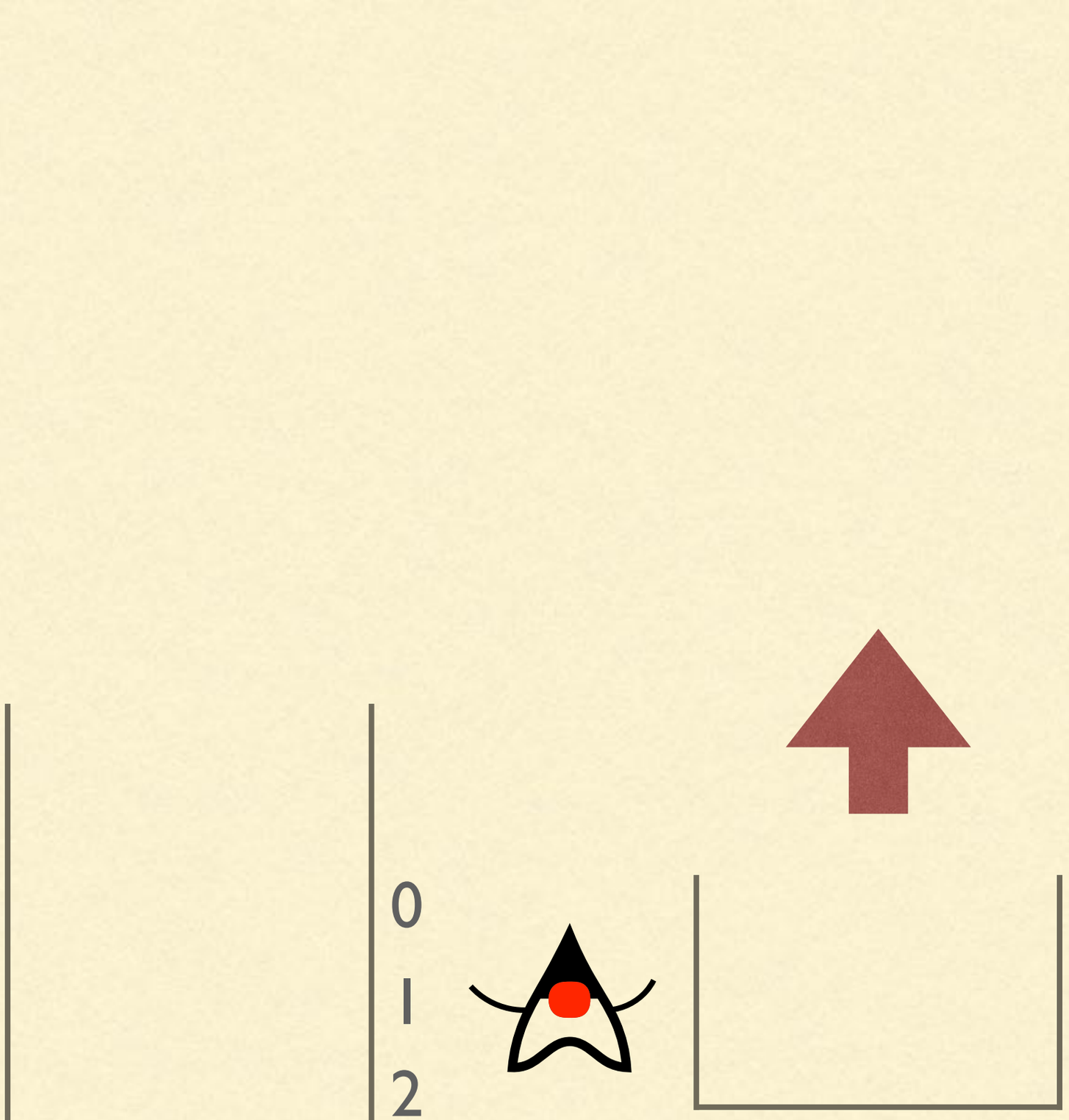
From	To	Target	
0	4	8	any



```
0   aload_0
1   invokevirtual #6
4   jsr 14
7   return
8   astore_1
9   jsr 14
12  aload_1
13  athrow
14  astore_2
15  aload_0
16  invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8           any
```



```
0    aload_0
1    invokevirtual #6
4    jsr 14
7    return
8    astore_1
9    jsr 14
12   aload_1
13   athrow
14   astore_2
15   aload_0
16   invokevirtual #5
19 ret 2
   Exception table:
   From    To      Target
   0       4       8          any
```



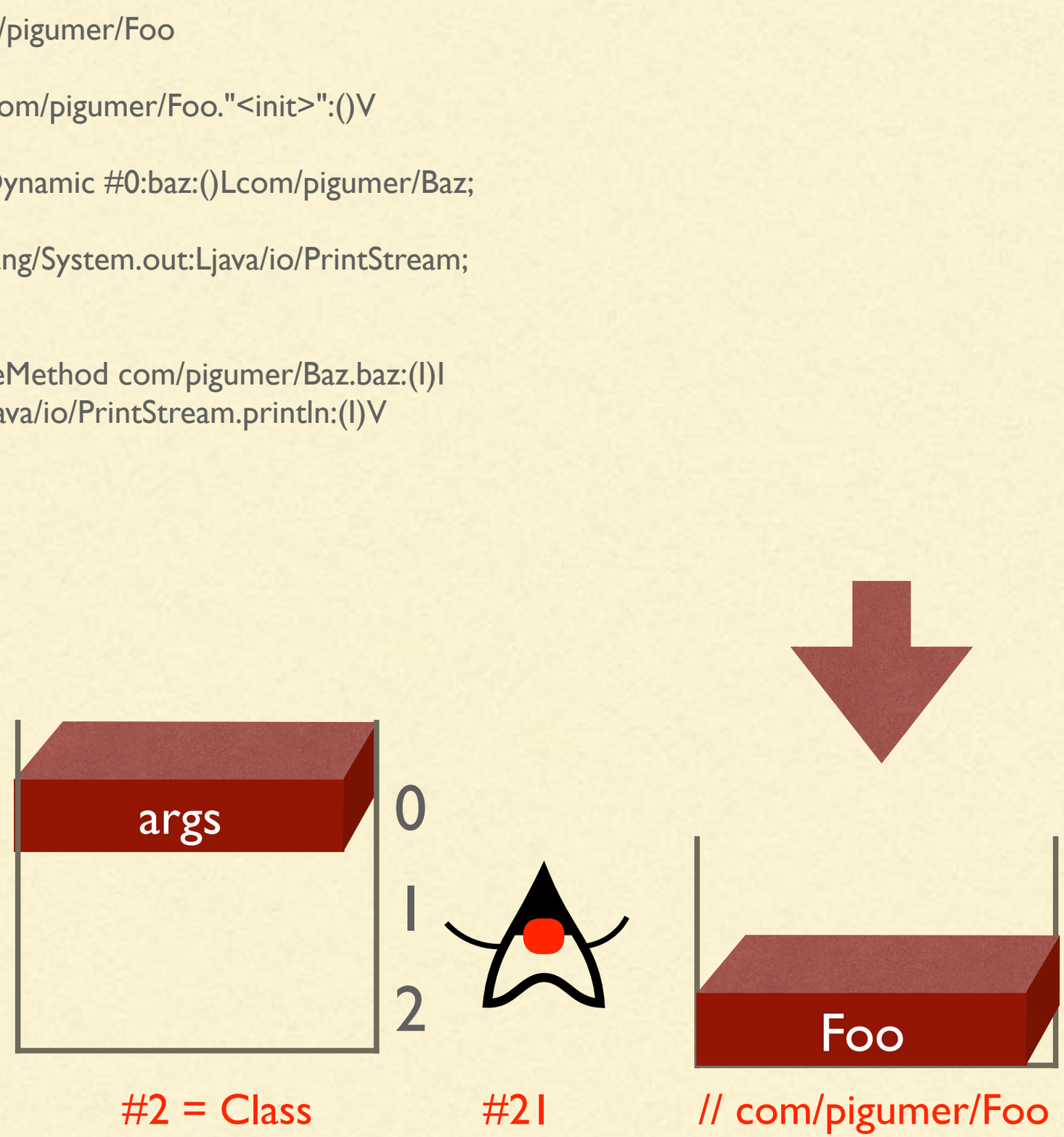
NEW

```
package com.pigumer;

public class Bar {

    public static void main(String[] args) {
        Foo foo = new Foo();

        Baz baz = a -> a + 1;
        System.out.println(baz.baz(3));
    }

}
```

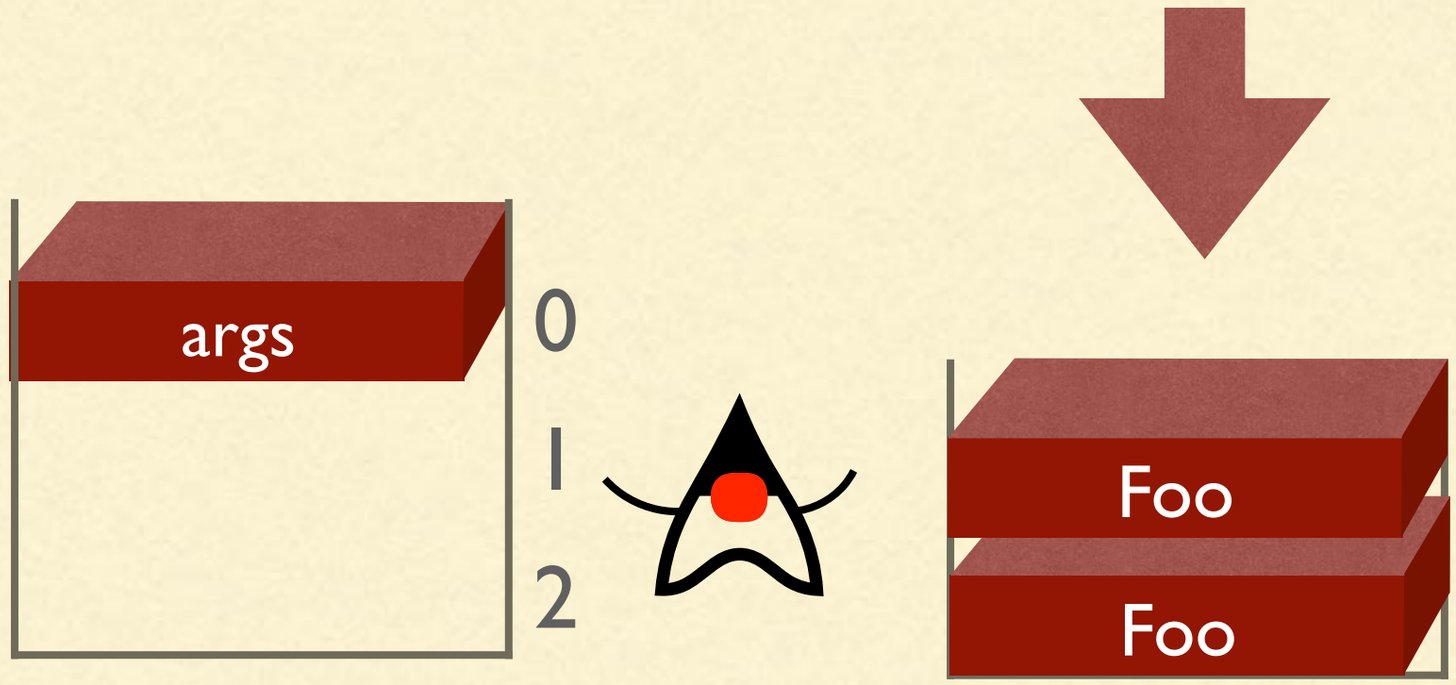
```
Compiled from "Bar.java"
public class com.pigumer.Bar {
  public com.pigumer.Bar();
    Code:
      0: aload_0
      1: invokespecial #1                  // Method java/lang/Object."<init>":()V
      4: return
    LineNumberTable:
      line 3: 0
    LocalVariableTable:
      Start  Length  Slot  Name   Signature
          0       5     0  this   Lcom/pigumer/Bar;

  public static void main(java.lang.String[]);
    Code:
      0: new           #2                  // class com/pigumer/Foo
      3: dup
      4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
      7: astore_1
      8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
     13: astore_2
     14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
     17: aload_2
     18: iconst_3
     19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
     24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
     27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```

```
  private static int lambda$main$0(int);
    Code:
       0: iload_0
       1: iconst_1
       2: iadd
       3: ireturn
    LineNumberTable:
      line 8: 0
    LocalVariableTable:
      Start  Length  Slot  Name   Signature
          0       4     0     a   I
}
```

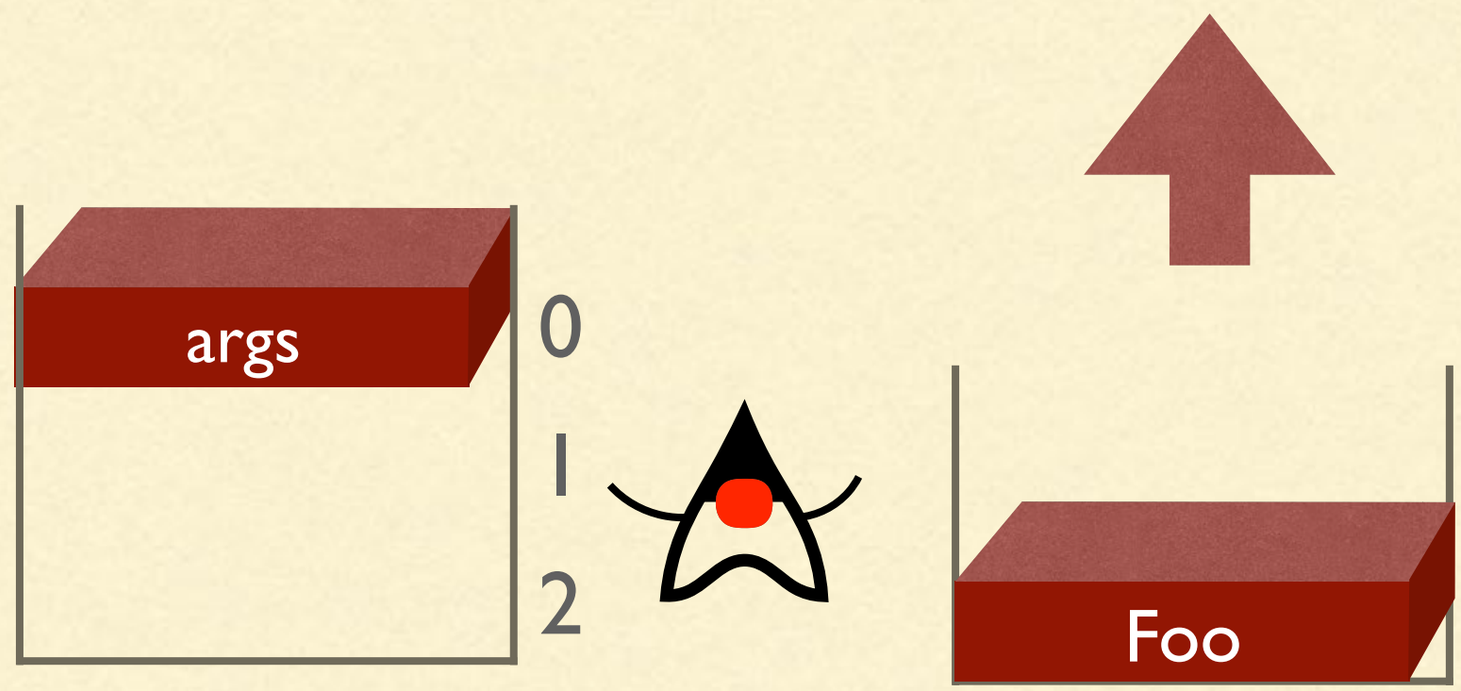
```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
LocalVariableTable:
  Start  Length  Slot  Name   Signature
      0      28     0  args   [Ljava/lang/String;
      8      20     1   foo   Lcom/pigumer/Foo;
     14      14     2   baz   Lcom/pigumer/Baz;
```



```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
LocalVariableTable:
  Start  Length  Slot  Name   Signature
      0      28     0  args   [Ljava/lang/String;
      8      20     1   foo   Lcom/pigumer/Foo;
     14      14     2   baz   Lcom/pigumer/Baz;
```

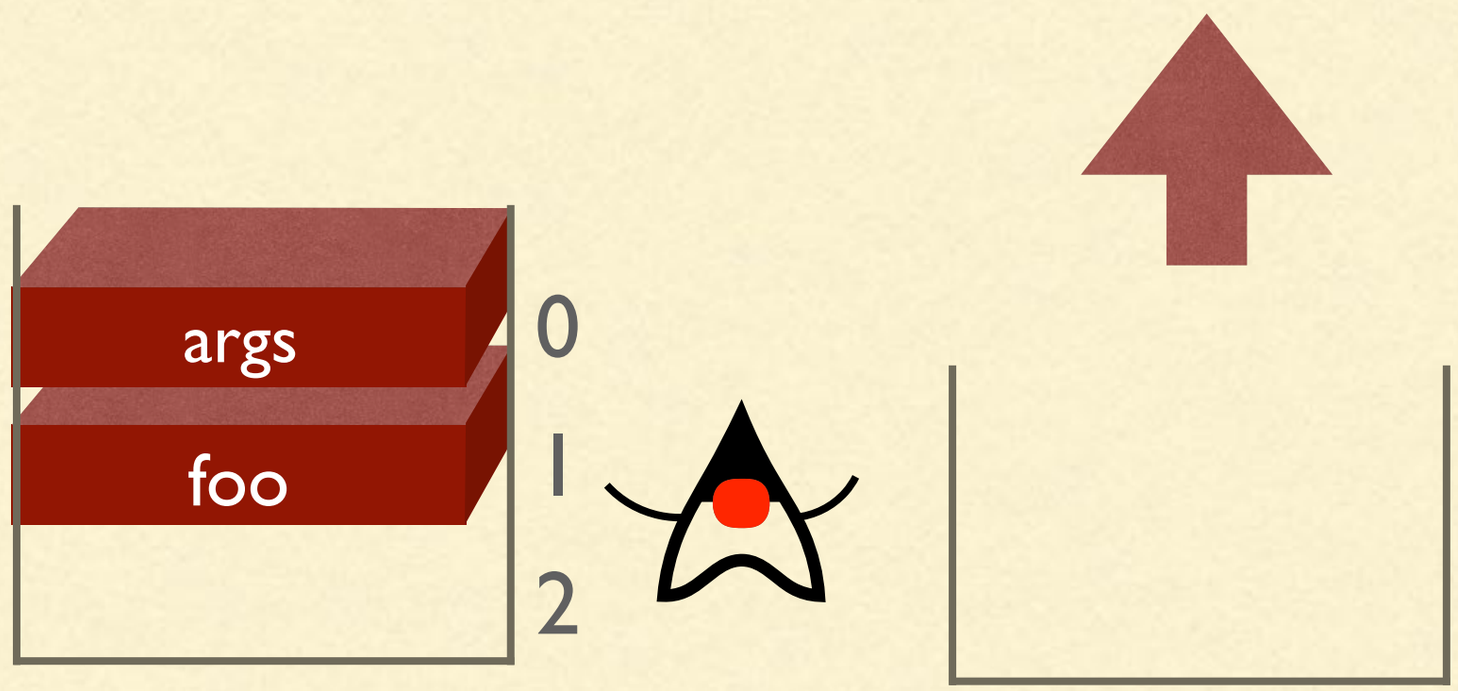


```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```



#3 = Methodref #2.#20 // com/pigumer/Foo."<init>":()V

```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
LocalVariableTable:
  Start  Length  Slot  Name   Signature
      0      28     0  args   [Ljava/lang/String;
      8      20     1   foo   Lcom/pigumer/Foo;
     14      14     2   baz   Lcom/pigumer/Baz;
```



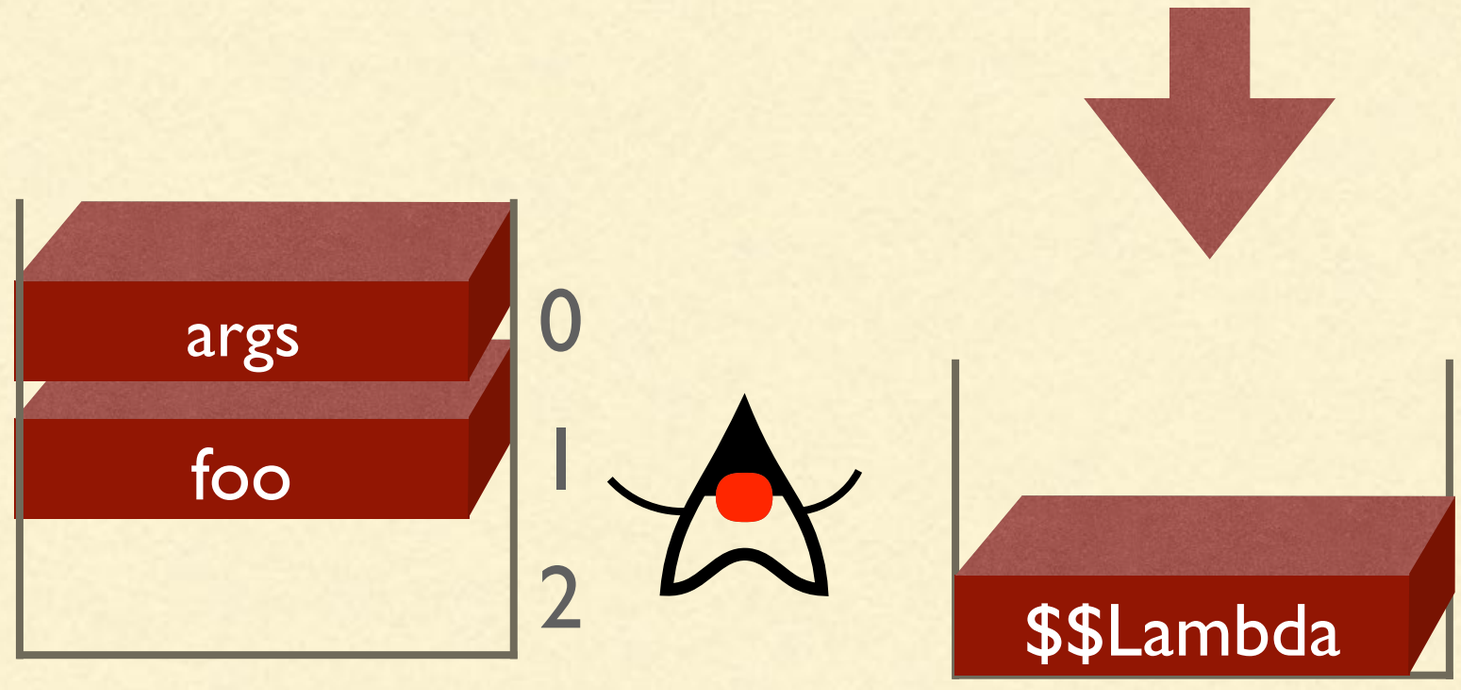
INVOKE

- InvokeDynamic
- InvokeInterface

```
InnerClasses:
     public static final #62= #61 of #65; //Lookup=class java/lang/invoke/
MethodHandles$Lookup of class java/lang/invoke/MethodHandles
BootstrapMethods:
  0: #34 invokestatic java/lang/invoke/LambdaMetafactory.metafactory:(Ljava/lang/invoke/
MethodHandles$Lookup;Ljava/lang/String;Ljava/lang/invoke/MethodType;Ljava/lang/invoke/
MethodType;Ljava/lang/invoke/MethodHandle;Ljava/lang/invoke/MethodType;)Ljava/lang/
invoke/CallSite;
    Method arguments:
      #35 (I)I
      #36 invokestatic com/pigumer/Bar.lambda$main$0:(I)I
      #35 (I)I
```

```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```

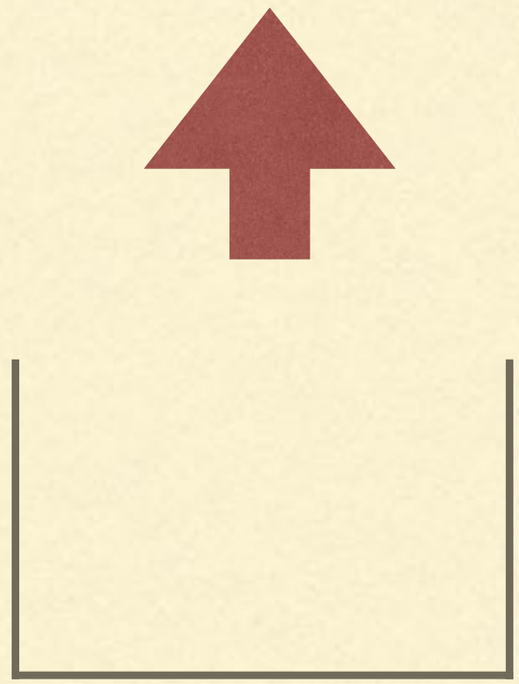
Baz baz = a -> a + 1;



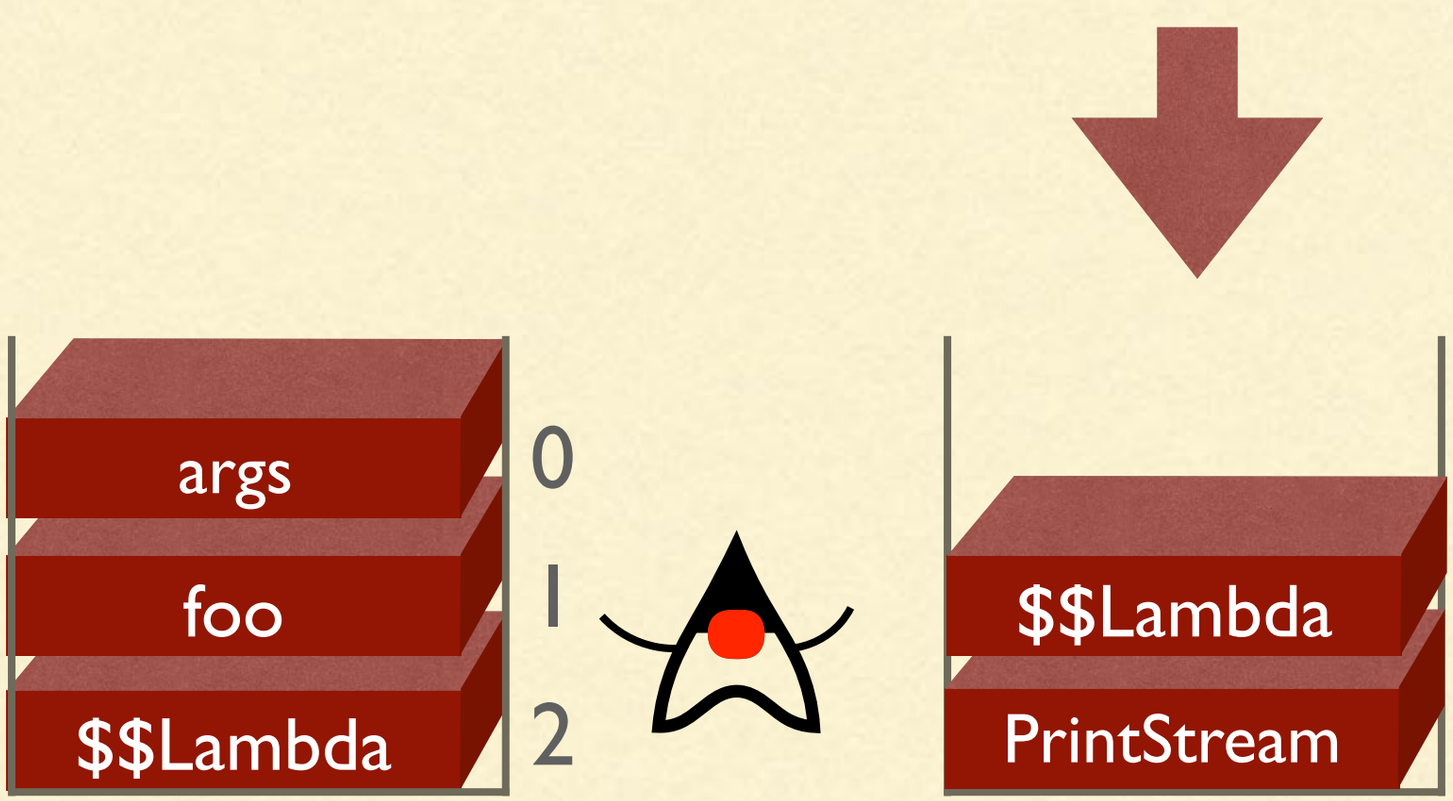
#4 = InvokeDynamic #0:#26 // #0:baz:()Lcom/pigumer/Baz;

```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```

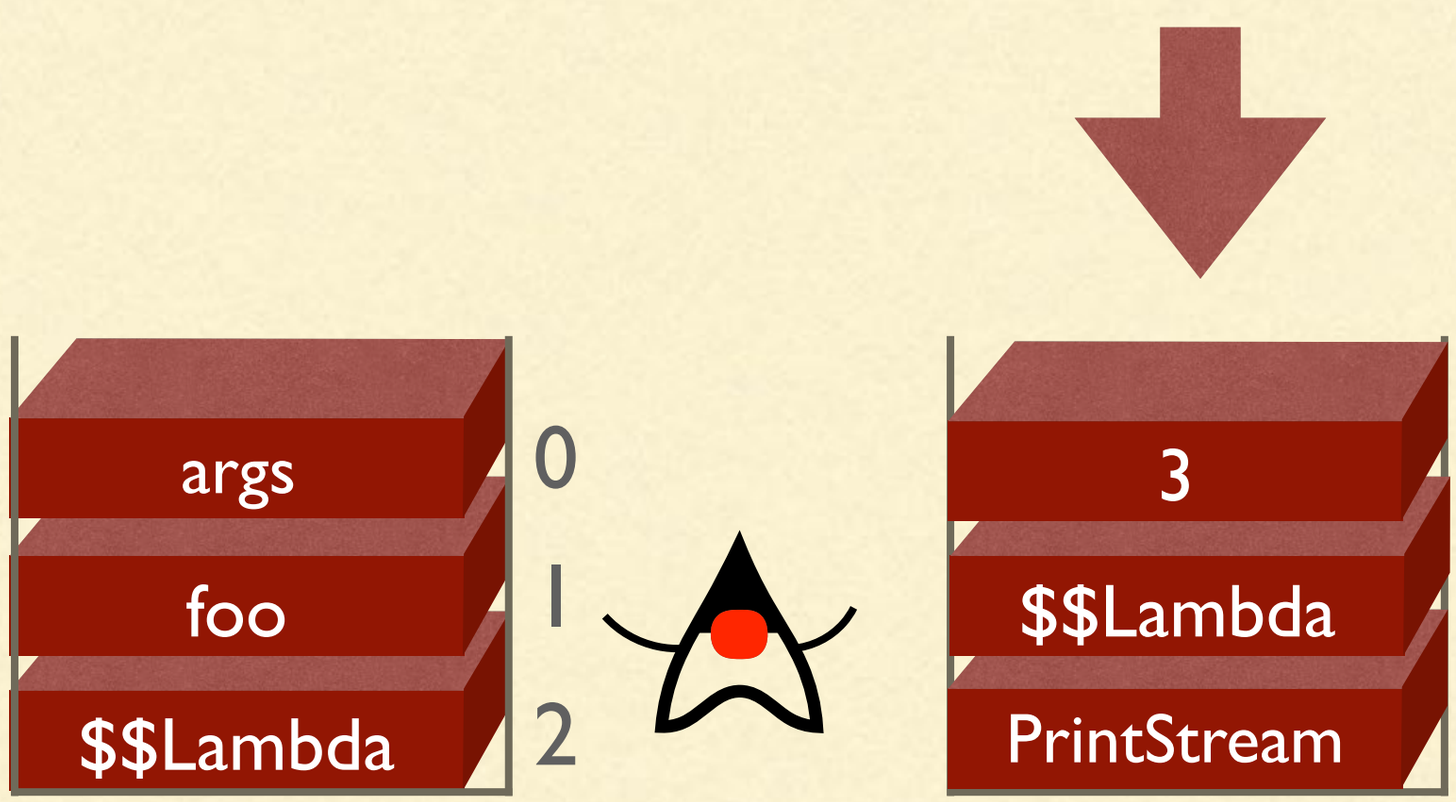
Baz baz = a -> a + 1;



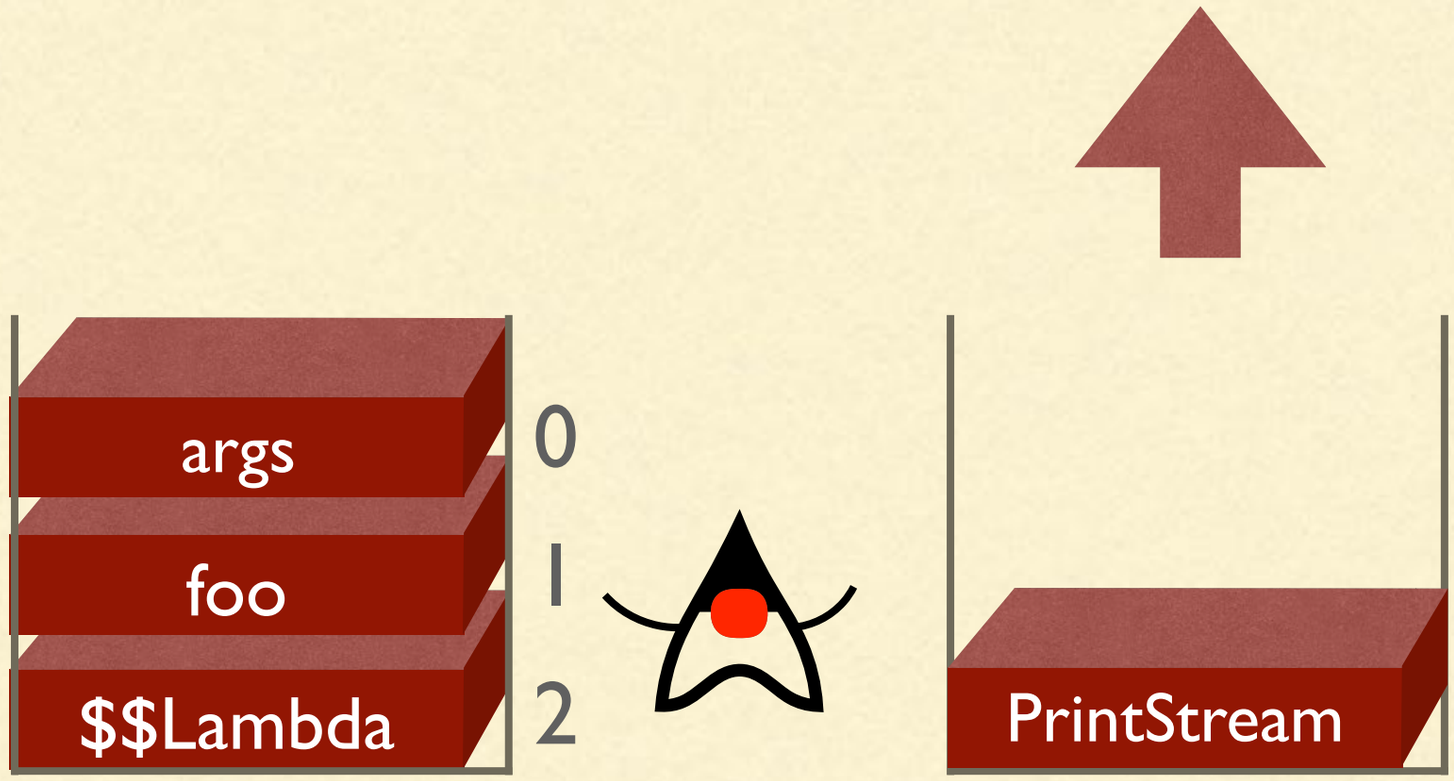
```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```



```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                 // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```

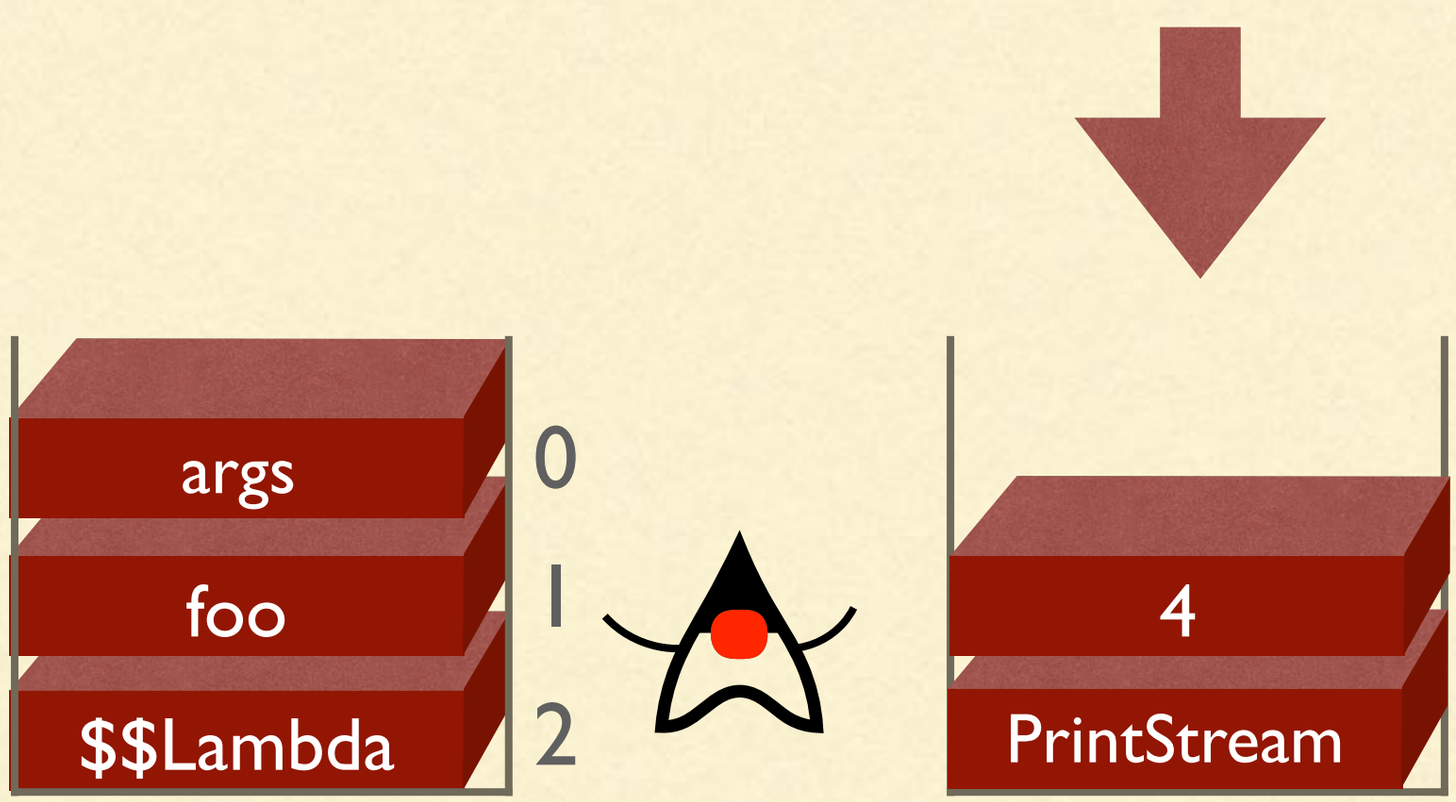


```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                  // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```



#6 = InterfaceMethodref #29.#30 // com/pigumer/Baz.baz:(I)I

```
public static void main(java.lang.String[]);
  Code:
     0: new           #2                  // class com/pigumer/Foo
     3: dup
     4: invokespecial #3                  // Method com/pigumer/Foo."<init>":()V
     7: astore_1
     8: invokedynamic #4,  0              // InvokeDynamic #0:baz:()Lcom/pigumer/Baz;
    13: astore_2
    14: getstatic     #5                  // Field java/lang/System.out:Ljava/io/PrintStream;
    17: aload_2
    18: iconst_3
    19: invokeinterface #6,  2           // InterfaceMethod com/pigumer/Baz.baz:(I)I
    24: invokevirtual #7                  // Method java/io/PrintStream.println:(I)V
    27: return
  LineNumberTable:
    line 6: 0
    line 8: 8
    line 9: 14
    line 10: 27
  LocalVariableTable:
    Start  Length  Slot  Name   Signature
        0      28     0  args   [Ljava/lang/String;
        8      20     1   foo   Lcom/pigumer/Foo;
       14      14     2   baz   Lcom/pigumer/Baz;
```



#6 = InterfaceMethodref #29.#30 // com/pigumer/Baz.baz:(I)I

- JVMアセンブラを扱うライブラリ
  - BCEL - https://commons.apache.org/proper/commons-bcel/
  - ASM - http://asm.ow2.org/
- invokedynamic 参考資料
  - https://www.slideshare.net/miyakawataku/lambda-meets-invokedynamic