Cheatsheet: Java Functional Interfaces

by Tony Tapper · Mar. 09, 18 · Java Zone · Presentation

Looking at the alphabetical list of 43 functional interfaces in java.util.function is a bit overwhelming. Trying to learn and remember them all is going to be a challenge!

Luckily Joshua Bloch came to the rescue in his 3rd edition of Effective Java.

Item 44: Favor the use of standard functional interfaces.

I really recommend you read this!

It's unlikely that you will need to write your own, except in the cases that Prof. Bloch describes:

- Will be often used and a descriptive name is helpful
- Has a strong contract associated with it
- Would benefit from custom default methods

My goal is to produce a cheat sheet based on his work for easy reference (or your next interview!).

Remember (covers 39 of the 43 functional interfaces)

- Predicate, Unary Operator, BinaryOperator, Function, Supplier, and Consumer operate on reference types. Each has 3 variants, which operate on double, int, or long respectively

- BiPredicate, BiFunction, BiConsumer accept two reference types as arguments

- Function has six variants, which can accept a primitive and return a different primitive, and six (inc.

- Each of the six basic types has three variants that accept a primitive: double, int, or long
- Variants of the three basic types accept two arguments: BiPredicate, BiFunction, BiConsumer
- Function has 6 variants that convert one of the primitives (double, int, long) to a different primitive.
- Function and BiFunction each have 3 variants that take a reference type and return a primitive double, int, or long
- iant that returns a boolean
- hree variants that accept a reference type and a primitive: double, int, or long

Basic Types

PREDICATE	takes one (or two) argument(s) and returns a boolean (5 variants)
UNARY OPERATOR	result and the single argument types are the same (4 variants)
BINARY OPERATOR	result and both argument types are the same (4 variants)
FUNCTION	result and one (or two) argument(s) types are different (17 variants)
SUPPLIER	takes no arguments, returns a value (5 variants)
CONSUMER	takes one (or two) arguments and returns no value (8 variants)

Notation

If the interface accepts primitive arguments: prefixed Double, Int, Long, e.g. DoubleConsumer
If the interface produces a primitive result: prefixed ToDouble, ToInt, ToLong, e.g. ToDoubleFunction

Package Summary

https://docs.oracle.com/javase/8/docs/api/java/util/function/package-summary.html

Predicate

Predicate<T>	Represents a predicate (boolean-valued function) of one argument (reference type)
DoublePredicate	Accepts one double-valued argument
IntPredicate	Accepts one int-valued argument.
LongPredicate	Accepts one long-valued argument
BiPredicate<T,U>	Accepts two arguments (reference types)

Unary Operator

UnaryOperator<T>	Represents an operation on a single operand that produces a result of the same type as its operand (reference type)
DoubleUnaryOperator	Accepts single double-valued operand and produces a double-valued result
IntUnaryOperator	Accepts a single int-valued operand and produces an int-valued result
LongUnaryOperator	Accepts a single long-valued operand and produces a long-valued result

Binary Operator

BinaryOperator<T>	Represents an operation upon two operands of the same type, producing a result of the same type as the operands (reference type)
DoubleBinaryOperator	Accepts two double-valued operands and produces a double-valued result

Function

Function<T,R>	Represents a function that accepts one argument and produces a result (reference type)
DoubleFunction<R>	Accepts a double-valued argument and produces a result
IntFunction<R>	Accepts an int-valued argument and produces a result
LongFunction<R>	Accepts a long-valued argument and produces a result
DoubleToIntFunction	Accepts a double-valued argument and produces an int-valued result
DoubleToLongFunction	Accepts a double-valued argument and produces a long-valued result
IntToDoubleFunction	Accepts an int-valued argument and produces a double-valued result
IntToLongFunction	Accepts an int-valued argument and produces a long-valued result
LongToIntFunction	Accepts a long-valued argument and produces an int-valued result
LongToDoubleFunction	Accepts a long-valued argument and produces a double-valued result.
ToDoubleFunction<T>	Accepts a reference type and produces an int-valued result
ToIntFunction<T>	Accepts a reference type and produces an int-valued result
ToLongFunction<T>	Accepts a reference type and produces a long-valued result.
BiFunction<T,U,R>	Represents a function that accepts two arguments and produces a result (reference type)
ToDoubleBiFunction<T,U>	Accepts two reference type arguments and produces a double-valued result
ToIntBiFunction<T,U>	Accepts two reference type arguments and produces an int-valued result
ToLongBiFunction<T,U>	Accepts two reference type arguments and produces a long-valued result

IntSupplier	A supplier of int-valued results
LongSupplier	A supplier of long-valued results
BooleanSupplier	A supplier of boolean-valued results

Consumer

Consumer<T>	Represents an operation that accepts a single (reference type) input argument and returns no result
DoubleConsumer	Accepts a single double-valued argument and returns no result
IntConsumer	Accepts a single int-valued argument and returns no result
LongConsumer	Accepts a single long-valued argument and returns no result
BiConsumer<T,U>	Represents an operation that accepts two (reference type) input arguments and returns no result
ObjDoubleConsumer<T>	Accepts an object-valued and a double-valued argument, and returns no result
ObjIntConsumer<T>	Accepts an object-valued and an int-valued argument, and returns no result
ObjLongConsumer<T>	Accepts an object-valued and a long-valued argument, and returns no result

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Introduction to Java Bytecode

by Mahmoud Anouti MVB · Mar 25, 18 · Java Zone · Tutorial

Reading compiled Java bytecode can be tedious, even for experienced Java developers. Why do we need to know about such low-level stuff in the first place? Here is a simple scenario that happened to me last week: I had made some code changes on my machine a long time ago, compiled a JAR, and deployed it on a server to test a potential fix for a performance issue. Unfortunately, the code was never checked into a version control system, and for whatever reason, the local changes were deleted without a trace. After a couple of months, I needed those changes in source form again (which took quite an effort to come up with), but I could not find them!

Luckily the compiled code still existed on that remote server. So with a sigh of relief, I fetched the JAR again and opened it using a decompiler editor... Only one problem: The decompiler GUI is not a flawless tool, and out of the many classes in that JAR, for some reason, only the specific class I was looking to decompile caused a bug in the UI whenever I opened it, and the decompiler to crash!

Desperate times call for desperate measures. Fortunately, I was familiar with raw bytecode, and I'd rather take some time manually decompiling some pieces of the code rather than work through the changes and testing them again. Since I still remembered at least where to look in the code, reading bytecode helped me pinpoint the exact

Before learning about the bytecode instruction set though, let's get familiar with a few things about the JVM that are needed as a prerequisite.

JVM Data Types

Java is statically typed, which affects the design of the bytecode instructions such that an instruction expects itself to operate on values of specific types. For example, there are several add instructions to add two numbers: `iadd` , `ladd` , `fadd` , `dadd` . They expect operands of type, respectively, int, long, float, and double. The majority of bytecode has this characteristic of having different forms of the same functionality depending on the operand types.

The data types defined by the JVM are:

1. Primitive types:
   - Numeric types: `byte` (8-bit 2's complement), `short` (16-bit 2's complement), `int` (32-bit 2's complement), `long` (64-bit 2's complement), `char` (16-bit unsigned Unicode), `float` (32-bit IEEE 754 single precision FP), `double` (64-bit IEEE 754 double precision FP)
   - `boolean` type
   - `returnAddress` : pointer to instruction
2. Reference types:
   - Class types
   - Array types
   - Interface types

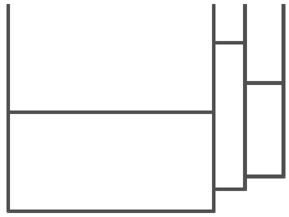
The `boolean` type has limited support in bytecode. For example, there are no instructions that directly operate on `boolean` values. Boolean values are instead converted to `int` by the compiler and the corresponding `int` instruction is used.

Java developers should be familiar with all of the above types, except `returnAddress` , which has no equivalent programming language type.

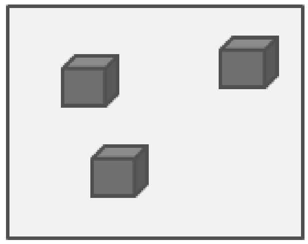
Stack-Based Architecture

The simplicity of the bytecode instruction set is largely due to Sun having designed a stack-based VM architecture, as opposed to a register-based one. There are various memory components used by a JVM process, but only the *JVM stacks* need to be examined in detail to essentially be able to follow bytecode instructions:

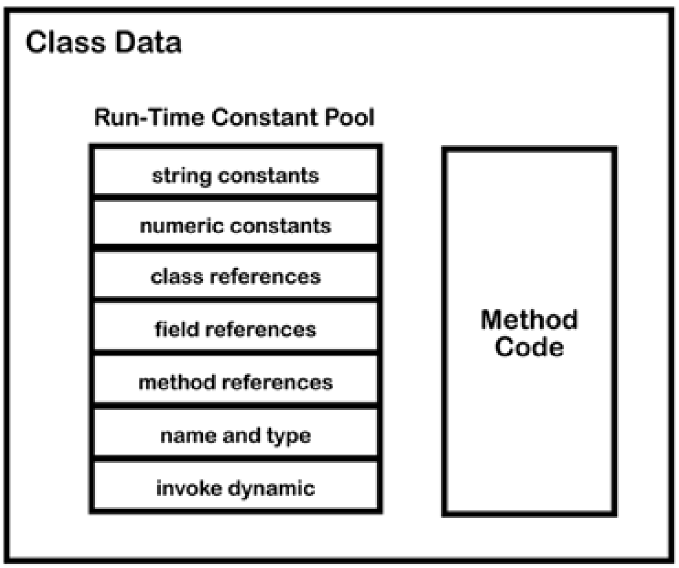
PC register: for each thread running in a Java program, a PC register stores the address of the current



Heap: memory shared by all threads and storing objects (class instances and arrays). Object deallocation is managed by a garbage collector.

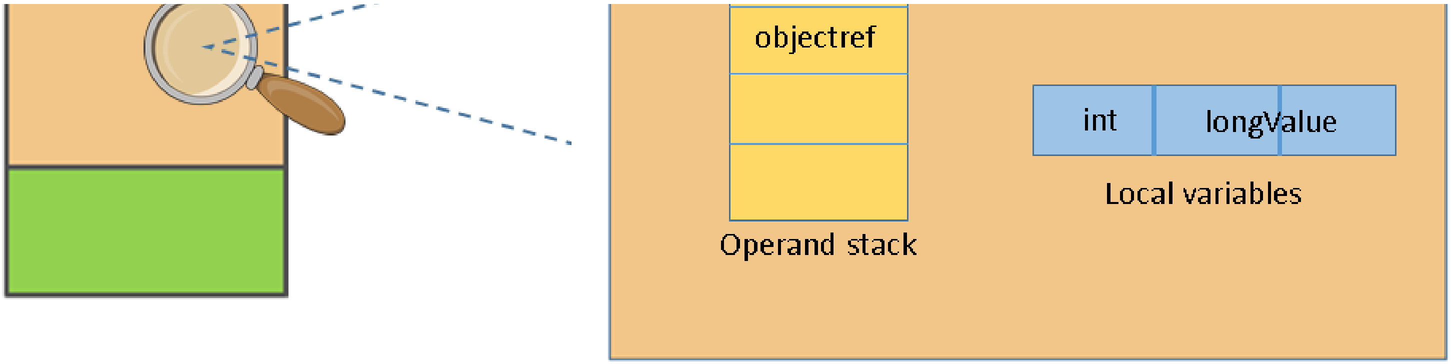


Method area: for each loaded class, it stores the code of methods and a table of symbols (e.g. references to fields or methods) and constants known as the constant pool.



A JVM stack is composed of *frames*, each pushed onto the stack when a method is invoked and popped from the stack when the method completes (either by returning normally or by throwing an exception). Each frame further consists of:

1. An array of *local variables*, indexed from 0 to its length minus 1. The length is computed by the compiler. A local variable can hold a value of any type, except `long` and `double` values, which occupy two local variables



Bytecode Explored

With an idea about the internals of a JVM, we can look at some basic bytecode example generated from sample code. Each method in a Java class file has a code segment that consists of a sequence of instructions, each having the following format:

opcode (1 byte) operand1 (optional) operand2 (optional) ...

That is an instruction that consists of one-byte opcode and zero or more operands that contain the data to operate.

Within the stack frame of the currently executing method, an instruction can push or pop values onto the operand stack, and it can potentially load or store values in the array local variables. Let's look at a simple example:

```
public static void main(String[] args) {
    int a = 1;
    int b = 2;
    int c = a + b;
}
```

In order to print the resulting bytecode in the compiled class (assuming it is in a file `Test.class`), we can run the `javap` tool:

```
javap -v Test.class
```

And we get:

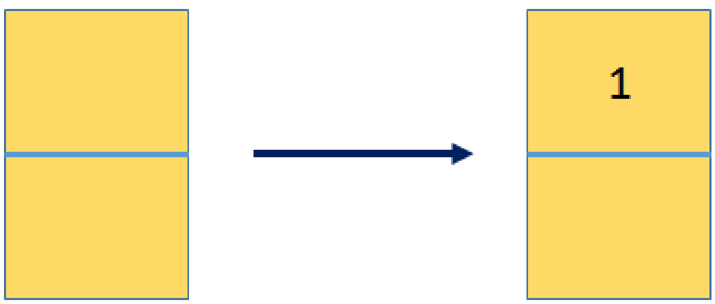
```
4: iload_1
5: iload_2
6: iadd
7: istore_3
8: return
...
```

We can see the method signature for the `main` method, a descriptor that indicates that the method takes an array of Strings (`[Ljava/lang/String;`), and has a void return type (`V`). A set of flags follow that describe the method as public (`ACC_PUBLIC`) and static (`ACC_STATIC`).

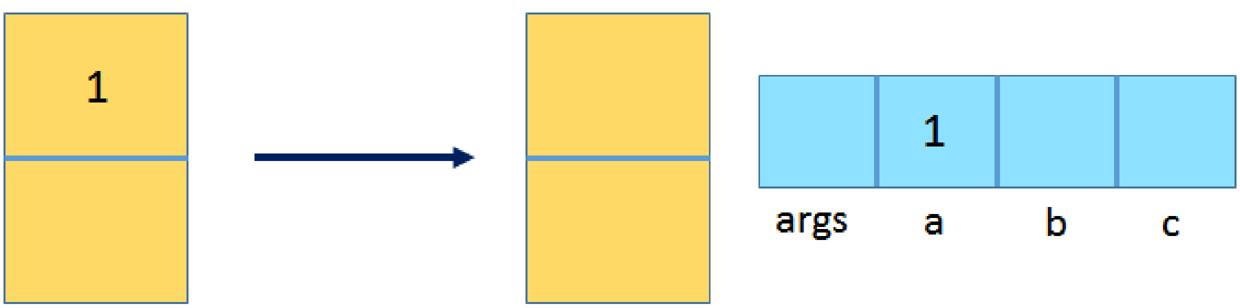
The most important part is the `Code` attribute, which contains the instructions for the method along with information such as the maximum depth of the operand stack (2 in this case), and the number of local variables allocated in the frame for this method (4 in this case). All local variables are referenced in the above instructions except the first one (at index 0), which holds the reference to the `args` argument. The other 3 local variables correspond to variables `a` , `b` and `c` in the source code.

The instructions from address 0 to 8 will do the following:

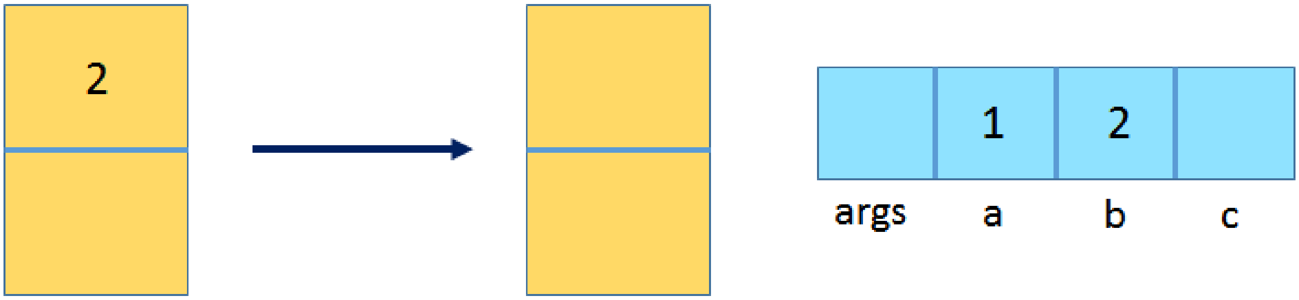
`iconst_1` : Push the integer constant 1 onto the operand stack.



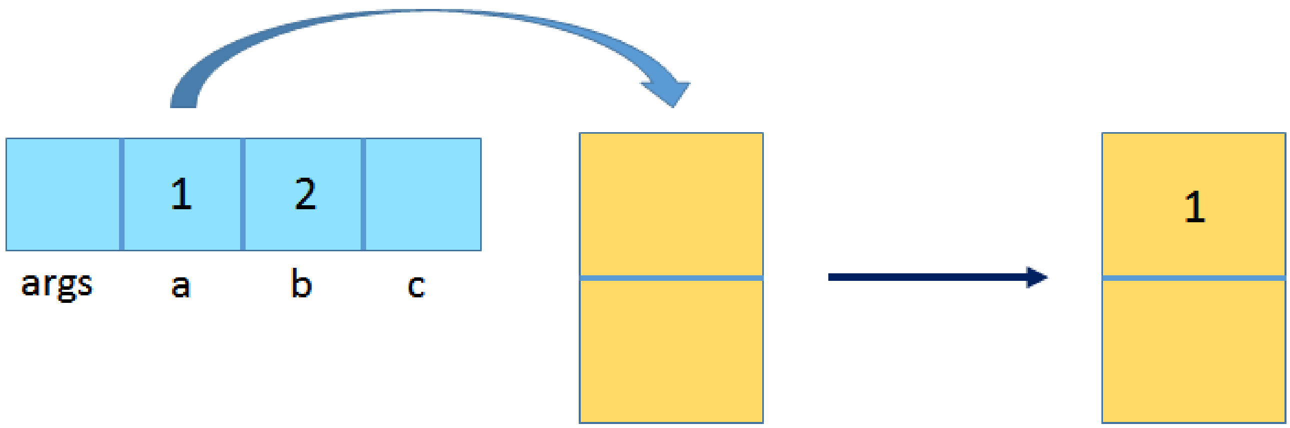
`istore_1` : Pop the top operand (an int value) and store it in local variable at index 1, which corresponds to variable `a` .



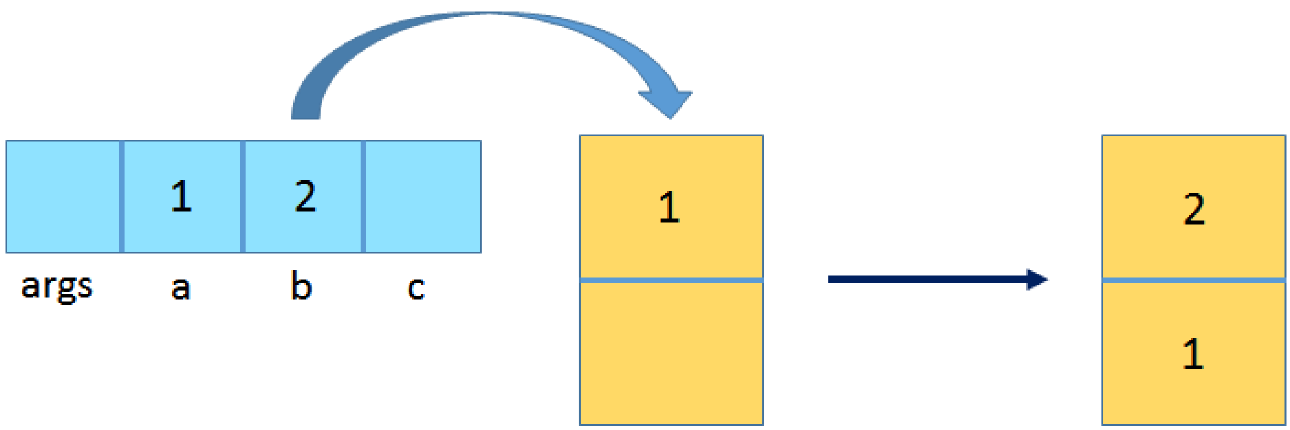
`istore_2` : Pop the top operand int value and store it in local variable at index 2, which corresponds to variable `b`.



`iload_1` : Load the int value from local variable at index 1 and push it onto the operand stack.

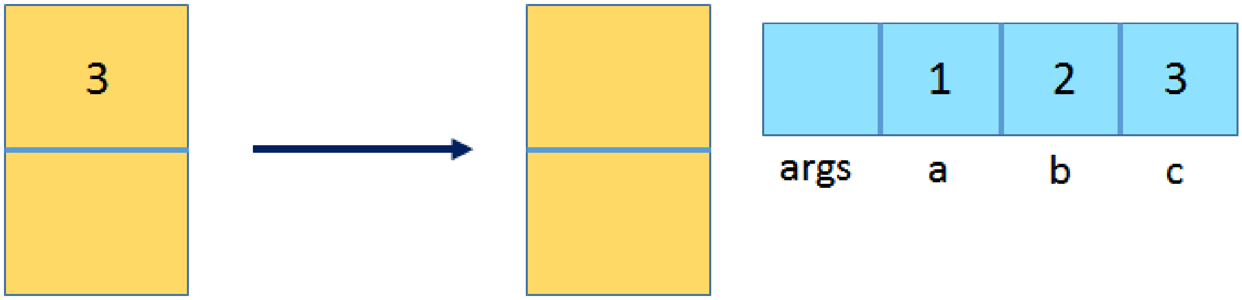


`iload_2` : Load the int value from the local variable at index 1 and push it onto the operand stack.



`iadd` : Pop the top two int values from the operand stack, add them, and push the result back onto the operand stack.

`istore_3` : Pop the top operand int value and store it in local variable at index 3, which corresponds to variable `c` .



`return` : Return from the void method.

Each of the above instructions consists of only an opcode, which dictates exactly the operation to be executed by the JVM.

Method Invocations

In the above example, there is only one method, the main method. Let's assume that we need to a more elaborate computation for the value of variable `c` , and we decide to place that in a new method called `calc` :

```
public static void main(String[] args) {
    int a = 1;
    int b = 2;
    int c = calc(a, b);
}

static int calc(int a, int b) {
    return (int) Math.sqrt(Math.pow(a, 2) + Math.pow(b, 2));
}
```

Let's see the resulting bytecode:

```
public static void main(java.lang.String[]);
  descriptor: ([Ljava/lang/String;)V
  flags: (0x0009) ACC_PUBLIC, ACC_STATIC
  Code:
    stack=2, locals=4, args_size=1
       0: iconst_1
       1: istore_1
```

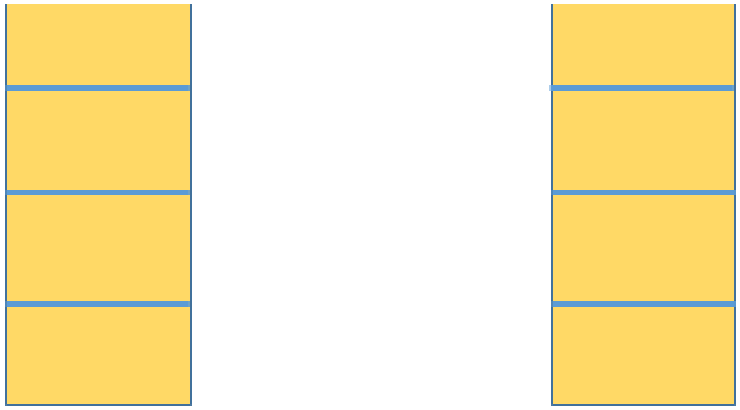
```
static int calc(int, int);
  descriptor: (II)I
  flags: (0x0008) ACC_STATIC
  Code:
    stack=6, locals=2, args_size=2
       0: iload_0
       1: i2d
       2: ldc2_w        #3          // double 2.0d
       5: invokestatic  #5          // Method java/lang/Math.pow:(DD)D
       8: iload_1
       9: i2d
      10: ldc2_w        #3          // double 2.0d
      13: invokestatic  #5          // Method java/lang/Math.pow:(DD)D
      16: dadd
      17: invokestatic  #6          // Method java/lang/Math.sqrt:(D)D
      20: d2i
      21: ireturn
```

The only difference in the main method code is that instead of having the `iadd` instruction, we now an `invokestatic` instruction, which simply invokes the static method `calc`. The key thing to note is that the operand stack contained the two arguments that are passed to the method `calc`. In other words, **the calling method prepares all arguments of the to-be-called method by pushing them onto the operand stack in the correct order. `invokestatic` (or a similar invoke instruction, as will be seen later) will subsequently pop these arguments, and a new frame is created for the invoked method where the arguments are placed in its local variable array.**

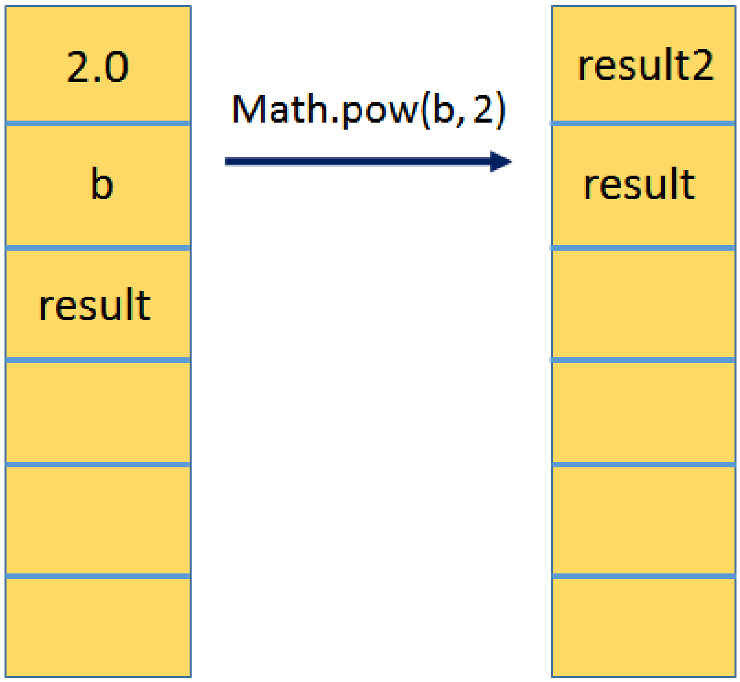
We also notice that the `invokestatic` instruction occupies 3 bytes by looking at the address, which jumped from 6 to 9. This is because, unlike all instructions seen so far, `invokestatic` includes two additional bytes to construct the reference to the method to be invoked (in addition to the opcode). The reference is shown by javap as `#2`, which is a symbolic reference to the `calc` method, which is resolved from the constant pool described earlier.

The other new information is obviously the code for the `calc` method itself. It first loads the first integer argument onto the operand stack (`iload_0`). The next instruction, `i2d`, converts it to a double by applying widening conversion. The resulting double replaces the top of the operand stack.

The next instruction pushes a double constant `2.0d` (taken from the constant pool) onto the operand stack. Then the static `Math.pow` method is invoked with the two operand values prepared so far (the first argument to `calc` and the constant `2.0d`). When the `Math.pow` method returns, its result will be stored on the operand stack



The same procedure is applied to compute `Math.pow(b, 2)` :



The next instruction, `dadd` , pops the top two intermediate results, adds them, and pushes the sum back to the top. Finally, invokestatic invokes `Math.sqrt` on the resulting sum, and the result is cast from double to int using narrowing conversion (`d2i`). The resulting int is returned to the main method, which stores it back to `c` (`istore_3`).

Instance Creations

Let's modify the example and introduce a class `Point` to encapsulate XY coordinates.

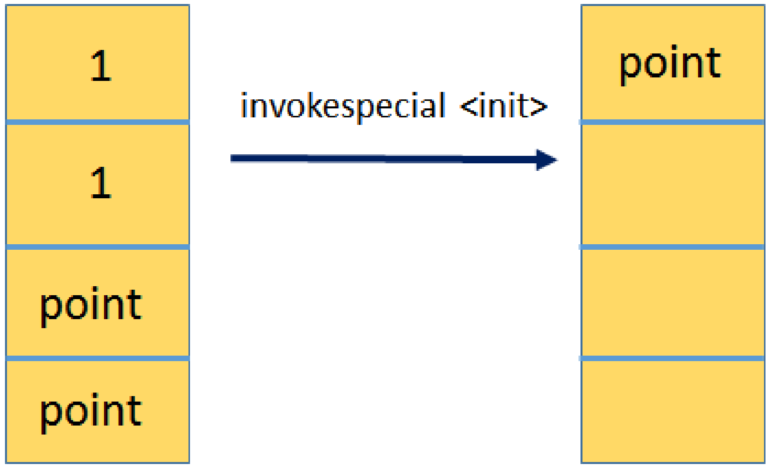
```
public class Test {
    public static void main(String[] args) {
```

```

    Point(int x, int y) {
        this.x = x;
        this.y = y;
    }

    public int area(Point b) {
        int length = Math.abs(b.y - this.y);
        int width = Math.abs(b.x - this.x);
        return length * width;
    }
}
```

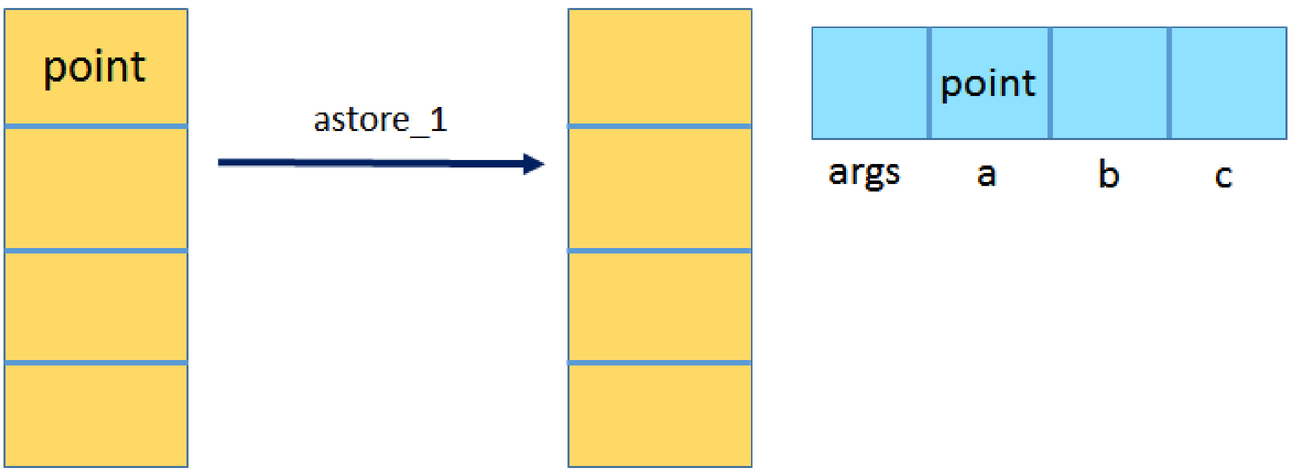
The compiled bytecode for the `main` method is shown below:

```
public static void main(java.lang.String[]);
  descriptor: ([Ljava/lang/String;)V
  flags: (0x0009) ACC_PUBLIC, ACC_STATIC
  Code:
    stack=4, locals=4, args_size=1
       0: new           #2       // class test/Point
       3: dup
       4: iconst_1
       5: iconst_1
       6: invokespecial #3       // Method test/Point."<init>":(II)V
       9: astore_1
      10: new           #2       // class test/Point
      13: dup
      14: iconst_5
      15: iconst_3
      16: invokespecial #3       // Method test/Point."<init>":(II)V
      19: astore_2
      20: aload_1
      21: aload_2
      22: invokevirtual #4       // Method test/Point.area:(Ltest/Point;)I
      25: istore_3
      26: return
```

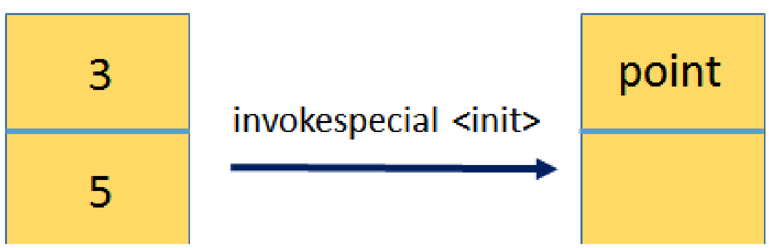
initialize the object) onto the operand stack, and then invoke a special initialization method, which corresponds with the constructor. The next method is where the fields `x` and `y` will get initialized. After the method is finished, the top three operand stack values are consumed, and what remains is the original reference to the created object (which is, by now, successfully initialized).

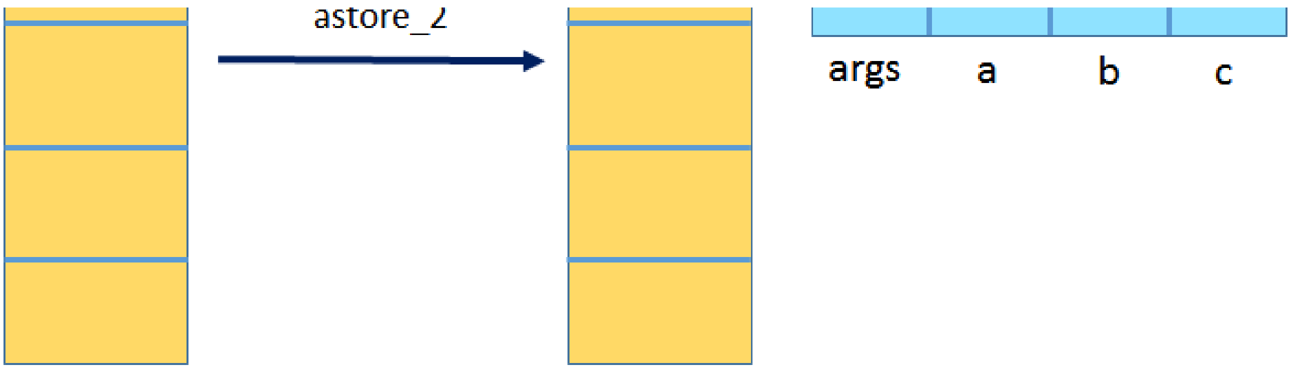


Next, `astore_1` pops that `Point` reference and assigns it to the local variable at index 1 (the `a` in `astore_1` indicates this is a reference value).

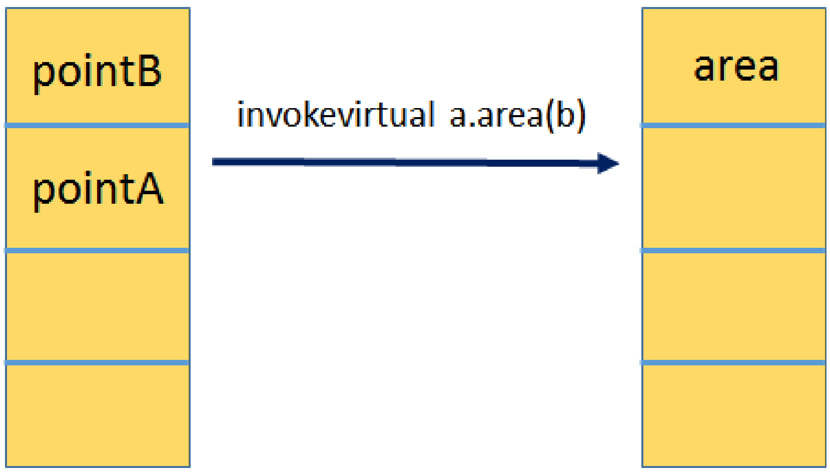


The same procedure is repeated for creating and initializing the second `Point` instance, which is assigned to variable `b`.





The last step loads the references to the two Point objects from local variables at indexes 1 and 2 (using `aload_1` and `aload_2` respectively), and invokes the `area` method using `invokevirtual` , which handles dispatching the call to the appropriate method based on the actual type of the object. For example, if the variable `a` contained an instance of type `SpecialPoint` that extends `Point` , and the subtype overrides the `area` method, then the overriden method is invoked. In this case, there is no subclass, and hence only one `area` method is available.



Note that even though the `area` method accepts one argument, there are *two* `Point` references on the top of the stack. The first one (`pointA` , which comes from variable `a`) is actually the instance on which the method is invoked (otherwise referred to as `this` in the programming language), and it will be passed in the first local variable of the new frame for the `area` method. The other operand value (`pointB`) is the argument to the `area` method.

The Other Way Around

You don't need to master the understanding of each instruction and the exact flow of execution to gain an idea about what the program does based on the bytecode at hand. For example, in my case, I wanted to check if the code employed a Java stream to read a file, and whether the stream was properly closed. Now given the following bytecode, it is relatively easy to determine that indeed a stream is used and most likely it is being closed as part of

```
         4: invokevirtual #4                  // Method java/lang/Class.getResource:(Ljava/lan
         7: invokevirtual #5                  // Method java/net/URL.toURI:()Ljava/net/URI;
        10: invokestatic  #6                  // Method java/nio/file/Paths.get:(Ljava/net/URI
        13: astore_1
        14: new           #7                  // class java/lang/StringBuilder
        17: dup
        18: invokespecial #8                  // Method java/lang/StringBuilder."<init>":()V
        21: astore_2
        22: aload_1
        23: invokestatic  #9                  // Method java/nio/file/Files.lines:(Ljava/nio/f
        26: astore_3
        27: aconst_null
        28: astore        4
        30: aload_3
        31: aload_2
        32: invokedynamic #10,  0             // InvokeDynamic #0:accept:(Ljava/lang/StringBui
        37: invokeinterface #11,  2           // InterfaceMethod java/util/stream/Stream.forEa
        42: aload_3
        43: ifnull        131
        46: aload         4
        48: ifnull        72
        51: aload_3
        52: invokeinterface #12,  1           // InterfaceMethod java/util/stream/Stream.close
        57: goto          131
        60: astore        5
        62: aload         4
        64: aload         5
        66: invokevirtual #14                 // Method java/lang/Throwable.addSuppressed:(Lja
        69: goto          131
        72: aload_3
        73: invokeinterface #12,  1           // InterfaceMethod java/util/stream/Stream.close
        78: goto          131
        81: astore        5
        83: aload         5
        85: astore        4
        87: aload         5
        89: athrow
        90: astore        6
```

```
     114: aload         7
     116: invokevirtual #14                 // Method java/lang/Throwable.addSuppressed:(Lja
     119: goto          128
     122: aload_3
     123: invokeinterface #12,  1           // InterfaceMethod java/util/stream/Stream.close
     128: aload         6
     130: athrow
     131: getstatic     #15                 // Field java/lang/System.out:Ljava/io/PrintStre
     134: aload_2
     135: invokevirtual #16                 // Method java/lang/StringBuilder.toString:()Lja
     138: invokevirtual #17                 // Method java/io/PrintStream.println:(Ljava/lan
     141: return
    ...
```

We see occurrences of `java/util/stream/Stream` where `forEach` is called, preceded by a call to `InvokeDynamic` with a reference to a `Consumer`. And then we see a chunk of bytecode that calls Stream.close along with branches that call `Throwable.addSuppressed`. This is the basic code that gets generated by the compiler for a try-with-resources statement.

Here's the original source for completeness:

```
public static void main(String[] args) throws Exception {
    Path path = Paths.get(Test.class.getResource("input.txt").toURI());
    StringBuilder data = new StringBuilder();
    try(Stream lines = Files.lines(path)) {
        lines.forEach(line -> data.append(line).append("\n"));
    }

    System.out.println(data.toString());
}
```

Conclusion

Thanks to the simplicity of the bytecode instruction set and the near absence of compiler optimizations when generating its instructions, disassembling class files could be one way to examine changes into your application code without having the source, if that ever becomes a need.

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