

## 2 The Virtual Machine Instruction Set

### Pushing Constants onto the Stack

#### **bipush**

Push one-byte signed integer

Syntax:

<i>bipush</i> = 16
<i>byte1</i>

Stack: ... => ..., *value*

*byte1* is interpreted as a signed 8-bit *value*. This *value* is expanded to an integer and pushed onto the operand stack.

#### **sipush**

Push two-byte signed integer

Syntax:

<i>sipush</i> = 17
<i>byte1</i>
<i>byte2</i>

Stack: ... => ..., *item*

*byte1* and *byte2* are assembled into a signed 16-bit *value*. This *value* is expanded to an integer and pushed onto the operand stack.

#### **ldc1**

Push item from constant pool

Syntax:

<i>ldc1</i> = 18
<i>indexbyte1</i>

Stack: ... => ..., *item*

*indexbyte1* is used as an unsigned 8-bit index into the constant pool of the current class. The *item* at that index is resolved and pushed onto the stack.

**ldc2**

Push item from constant pool

Syntax:

<i>ldc2</i> = 19
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ... => ..., *item*

*indexbyte1* and *indexbyte2* are used to construct an unsigned 16-bit index into the constant pool of the current class. The *item* at that index is resolved and pushed onto the stack.

**ldc2w**

Push long or double from constant pool

Syntax:

<i>ldc2w</i> = 20
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ... => ..., *constant-word1*, *constant-word2*

*indexbyte1* and *indexbyte2* are used to construct an unsigned 16-bit index into the constant pool of the current class. The two-word *constant* at that index is resolved and pushed onto the stack.

**aconst\_null**

Push null object

Syntax:

<i>aconst_null</i> = 1
------------------------

Stack: ... => ..., *null*

Push the *null* object onto the stack.

**iconst\_m1**

Push integer constant -1

Syntax:

<i>iconst_m1</i> = 2
----------------------

Stack: ... => ..., -1

Push the integer -1 onto the stack.

**iconst\_<n>**

Push integer constant <n>

Syntax:

<i>iconst_&lt;n&gt;</i>
-------------------------

Stack: ... => ..., <n>

Forms: *iconst\_0* = 3, *iconst\_1* = 4, *iconst\_2* = 5, *iconst\_3* = 6, *iconst\_4* = 7, *iconst\_5* = 8

Push the integer <n> onto the stack.

**lconst\_<l>**

Push long integer constant

Syntax:

<i>lconst_&lt;l&gt;</i>
-------------------------

Stack: ... =&gt; ..., &lt;l&gt;-word1, &lt;l&gt;-word2

Forms: *lconst\_0* = 9, *lconst\_1* = 10

Push the long integer &lt;l&gt; onto the stack.

**fconst\_<f>**

Push single float

Syntax:

<i>fconst_&lt;f&gt;</i>
-------------------------

Stack: ... =&gt; ..., &lt;f&gt;

Forms: *fconst\_0* = 11, *fconst\_1* = 12, *fconst\_2* = 13

Push the single precision floating point number &lt;f&gt; onto the stack.

**dconst\_<d>**

Push double float

Syntax:

<i>dconst_&lt;d&gt;</i>
-------------------------

Stack: ... =&gt; ..., &lt;d&gt;-word1, &lt;d&gt;-word2

Forms: *dconst\_0* = 14, *dconst\_1* = 15

Push the double precision floating point number &lt;d&gt; onto the stack.

**Loading Local Variables Onto the Stack****iload**

Load integer from local variable

Syntax:

<i>iload</i> = 21
-------------------

<i>vindex</i>
---------------

Stack: ... => ..., *value*Local variable *vindex* in the current Java frame should contain an integer. The *value* of that variable is pushed onto the operand stack.

**iload\_<n>**

Load integer from local variable

Syntax:

<i>iload_&lt;n&gt;</i>
------------------------

Stack: ... => ..., *value*

Forms: *iload\_0* = 27, *iload\_1* = 27, *iload\_2* = 28, *iload\_3* = 29

Local variable <*n*> in the current Java frame should contain an integer. The *value* of that variable is pushed onto the operand stack.

This instruction is the same as *iload* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**lload**

Load long integer from local variable

Syntax:

<i>lload</i> = 22
<i>vindex</i>

Stack: ... => ..., *value-word1*, *value-word2*

Local variables *vindex* and *vindex*+1 in the current Java frame should together contain a long integer. The *value* contained in those variables is pushed onto the operand stack.

**lload\_<n>**

Load long integer from local variable

Syntax:

<i>lload_&lt;n&gt;</i>
------------------------

Stack: ... => ..., *value-word1*, *value-word2*

Forms: *lload\_0* = 30, *lload\_1* = 31, *lload\_2* = 32, *lload\_3* = 33

Local variables <*n*> and <*n*>+1 in the current Java frame should together contain a long integer. The *value* contained in those variables is pushed onto the operand stack.

This opcode is the same as *lload* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**fload**

Load single float from local variable

Syntax:

<i>fload</i> = 23
<i>vindex</i>

Stack: ... => ..., *value*

Local variable *vindex* in the current Java frame should contain a single precision floating point number. The *value* of that variable is pushed onto the operand stack.

**fload\_<n>**

Load single float from local variable

Syntax:

<i>fload_&lt;n&gt;</i>
------------------------

Stack: ... => ..., *value*

Forms: *fload\_0* = 34, *fload\_1* = 35, *fload\_2* = 36, *fload\_3* = 37

Local variable <*n*> in the current Java frame should contain a single precision floating point number. The *value* of that variable is pushed onto the operand stack.

This opcode is the same as *fload* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**dload**

Load double float from local variable

Syntax:

<i>dload</i> = 24
<i>vindex</i>

Stack: ... => ..., *value-word1*, *value-word2*

Local variables *vindex* and *vindex*+1 in the current Java frame should together contain a double precision float point number. The *value* contained in those variables is pushed onto the operand stack.

**dload\_<n>**

Load double float from local variable

Syntax:

<i>dload_&lt;n&gt;</i>
------------------------

Stack: ... => ..., *value-word1*, *value-word2*

Forms: *dload\_0* = 38, *dload\_1* = 39, *dload\_2* = 40, *dload\_3* = 41

Local variables <*n*> and <*n*>+1 in the current Java frame should together contain a double precision floating point number. The *value* contained in those variables is pushed onto the operand stack.

This opcode is the same as *dload* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**aload**

Load local object variable

Syntax:

<i>aload</i> = 25
<i>vindex</i>

Stack: ... => ..., *value*

Local variable *vindex* in the current Java frame should contain a handle to an object or to an array. The *value* of that variable is pushed onto the operand stack.

**aload\_<n>**

Load object reference from local variable

Syntax:

<i>aload_&lt;n&gt;</i>
------------------------

Stack: ... => ..., *value*

Forms: *aload\_0* = 42, *aload\_1* = 43, *aload\_2* = 44, *aload\_3* = 45

Local variable *n* in the current Java frame should contain a handle to an object or to an array. The *value* of that variable is pushed onto the operand stack.

This opcode is the same as *aload* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

## Storing Stack Values into Local Variables

**istore**

Store integer into local variable

Syntax:

<i>istore</i> = 54
<i>vindex</i>

Stack: ..., *value* => ...

*value* should be an integer. Local variable *vindex* in the current Java frame is set to *value*.

**istore\_<n>**

Store integer into local variable

Syntax:

<i>istore_&lt;n&gt;</i>
-------------------------

Stack: ..., *value* => ...

Forms: *istore\_0* = 59, *istore\_1* = 60, *istore\_2* = 61, *istore\_3* = 62

*value* should be an integer. Local variable <*n*> in the current Java frame is set to *value*.

This instruction is the same as *istore* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**lstore**

Store long integer into local variable

Syntax:

<i>lstore</i> = 55
<i>vindex</i>

Stack: ..., *value-word1*, *value-word2* => ...

*value* should be a long integer. Local variables *vindex* and *vindex*+1 in the current Java frame are set to *value*.

**lstore\_<n>**

Store long integer into local variable

Syntax:

<i>lstore_&lt;n&gt;</i>
-------------------------

Stack: ..., *value-word1*, *value-word2* => ...

Forms: *lstore\_0* = 63, *lstore\_1* = 64, *lstore\_2* = 65, *lstore\_3* = 66

*value* should be a long integer. Local variables <*n*> and <*n*>+1 in the current Java frame are set to *value*.

This instruction is the same as *lstore* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**fstore**

Store single float into local variable

Syntax:

<i>fstore</i> = 56
<i>vindex</i>

Stack: ..., *value* => ...

*value* should be a single precision floating point number. Local variable *vindex* in the current Java frame is set to *value*.

**fstore\_<n>**

Store single float into local variable

Syntax:

<i>fstore_&lt;n&gt;</i>
-------------------------

Stack: ..., *value* => ...

Possible Instructions:

*fstore\_0* = 67, *fstore\_1* = 68, *fstore\_2* = 69, *fstore\_3* = 70

*value* should be a single precision floating point number. Local variable <*n*> in the current Java frame is set to *value*.

This instruction is the same as *fstore* with a *vindex* of <*n*>, except that the operand <*n*> is implicit.

**dstore**

Store double float into local variable

Syntax:

<i>dstore</i> = 57
<i>vindex</i>

Stack: ..., *value-word1*, *value-word2* => ...

*value* should be a double precision floating point number. Local variables *vindex* and *vindex*+1 in the current Java frame are set to *value*.

**dstore\_<n>**

Store double float into local variable

Syntax:

<i>dstore_&lt;n&gt;</i>
-------------------------

Stack: ..., *value-word1*, *value-word2* => ...

Forms: *dstore\_0* = 71, *dstore\_1* = 72, *dstore\_2* = 73, *dstore\_3* = 74

*value* should be an double precision floating point number. Local variables *<n>* and *<n>+1* in the current Java frame are set to *value*.

This instruction is the same as *dstore* with a *vindex* of *<n>*, except that the operand *<n>* is implicit.

**astore**

Store object reference into local variable

Syntax:

<i>astore</i> = 58
<i>vindex</i>

Stack: ..., *value* => ...

*value* should be a handle to an array or to an object. Local variable *vindex* in the current Java frame is set to *value*.

**astore\_<n>**

Store object reference into local variable

Syntax:

<i>astore_&lt;n&gt;</i>
-------------------------

Stack: ..., *value* => ...

Forms: *astore\_0* = 75, *astore\_1* = 76, *astore\_2* = 77, *astore\_3* = 78

*value* should be a handle to an array or to an object. Local variable *<n>* in the current Java frame is set to *value*.

This instruction is the same as *astore* with a *vindex* of *<n>*, except that the operand *<n>* is implicit.

**iinc**

Increment local variable by constant

Syntax:

<i>iinc</i> = 132
<i>vindex</i>
<i>const</i>

Stack: no change

Local variable *vindex* in the current Java frame should contain an integer. Its value is incremented by the value *const*, where *const* is treated as a signed 8-bit quantity.

## Managing Arrays

### **newarray**

Allocate new array

Syntax:

<i>newarray</i> = <i>l88</i>
<i>atype</i>

Stack: ..., *size* => *result*

*size* should be an integer. It represents the number of elements in the new array.

*atype* is an internal code that indicates the type of array to allocate. Possible values for *atype* are as follows:

<b>T_ARRAY</b>	1
<b>T_BOOLEAN</b>	4
<b>T_CHAR</b>	5
<b>T_FLOAT</b>	6
<b>T_DOUBLE</b>	7
<b>T_BYTE</b>	8
<b>T_SHORT</b>	9
<b>T_INT</b>	10
<b>T_LONG</b>	11

A new array of the indicated or computed *atype*, capable of holding *size* elements, is allocated. Allocation of an array large enough to contain *nelem* items of *atype* is attempted. All elements of the array are initialized to zero.

If *size* is less than zero, a `NegativeArraySizeException` is thrown. If there is not enough memory to allocate the array, an `OutOfMemoryException` is thrown.

**anewarray**

Allocate new array of objects

Syntax:

<i>anewarray</i> = <i>189</i>
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *size* => *result*

*size* should be an integer. It represents the number of elements in the new array.

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index is resolved. The resulting entry should be a class.

A new array of the indicated class type and capable of holding *size* elements is allocated. Allocation of an array large enough to contain *size* items of the given class type is attempted. All elements of the array are initialized to zero.

If *size* is less than zero, a `NegativeArraySizeException` is thrown. If there is not enough memory to allocate the array, an `OutOfMemoryException` is thrown.

`anewarray` is used to create a single dimension of an array of objects. For example, to create

```
new Thread[7]
```

the following code is used:

```
bipush 7
anewarray <Class "java.lang.Thread">
```

`anewarray` can also be used to create the outermost dimension of a multi-dimensional array. For example, the following array declaration:

```
new int[6][ ]
```

is created with the following code:

```
bipush 6
anewarray <Class "[I">
```

See `CONSTANT_Class` in the *Class File Format* chapter for information on array class names.

**multianewarray**

Allocate new multi-dimensional array

Syntax:

<i>anewarray</i> = <i>198</i>
<i>indexbyte1</i>
<i>indexbyte2</i>
<i>dimensions</i>

Stack: ..., *size1 size2...sizen* => *result*

Each *size* should be an integer. Each represents the number of elements in a dimension of the array.

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index is resolved. The resulting entry should be a class.

*dimensions* has the following aspects:

- It should be an integer  $\geq 1$ .
- It represents the number of dimensions being created. It must be  $\leq$  the number of dimensions of the array class.
- It represents the number of elements that are popped off the stack. All must be integers greater than or equal to zero. These are used as the sizes of the dimension. For example, to create:

```
new int[6][3][ ]
```

the following code is used:

```
bipush 6
bipush 3
multianewarray <Class "[[I"> 2
```

If any of the *size* arguments on the stack is less than zero, a `NegativeArraySizeException` is thrown. If there is not enough memory to allocate the array, an `OutOfMemoryException` is thrown.

**Note:** It is more efficient to use `newarray` or `anewarray` when creating a single dimension.

See `CONSTANT_Class` in the *Class File Format* chapter for information on array class names.

## arraylength

Get length of array

Syntax:

```
arraylength = 190
```

Stack: ..., *handle* => ..., *length*

*handle* should be the *handle* of an array. The length of the array is determined and replaces *handle* on the top of the stack.

If the *handle* is null, a `NullPointerException` is thrown.

## iaload

Load integer from array

Syntax:

```
iaload = 46
```

Stack: ..., *array*, *index* => ..., *value*

*array* should be an array of integers. *index* should be an integer. The integer *value* at position number *index* in *array* is retrieved and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

## laload

Load long integer from array

Syntax:

```
laload = 47
```

Stack: ..., *array*, *index* => ..., *value-word1*, *value-word2*

*array* should be an array of long integers. *index* should be an integer. The long integer *value* at position number *index* in *array* is retrieved and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**faload**

Load single float from array

Syntax:

<i>faload</i> = 48
--------------------

Stack: ..., *array*, *index* => ..., *value*

*array* should be an array of single precision floating point numbers. *index* should be an integer. The single precision floating point number *value* at position number *index* in *array* is retrieved and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**daload**

Load double float from array

Syntax:

<i>daload</i> = 49
--------------------

Stack: ..., *array*, *index* => ..., *value-word1*, *value-word2*

*array* should be an array of double precision floating point numbers. *index* should be an integer. The double precision floating point number *value* at position number *index* in *array* is retrieved and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**aaload**

Load object reference from array

Syntax:

<i>aaload</i> = 50
--------------------

Stack: ..., *array*, *index* => ..., *value*

*array* should be an array of handles to objects or arrays. *index* should be an integer. The object or array value at position number *index* in *array* is retrieved and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**baload**

Load signed byte from array

Syntax:

<i>baload</i> = 51
--------------------

Stack: ..., *array*, *index* => ..., *value*

*array* should be an array of signed bytes. *index* should be an integer. The signed byte value at position number *index* in *array* is retrieved, expanded to an integer, and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**caload**

Load character from array

Syntax:

<i>caload</i> = 52
--------------------

Stack: ..., *array*, *index* => ..., *value*

*array* should be an array of characters. *index* should be an integer. The character value at position number *index* in *array* is retrieved, expanded to an integer, and pushed onto the top of the stack.

If *array* is null a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**saload**

Load short from array

Syntax:

<i>saload</i> = 53
--------------------

Stack: ..., *array*, *index* => ..., *value*

*array* should be an array of (signed) short integers. *index* should be an integer. The short integer value at position number *index* in *array* is retrieved, expanded to an integer, and pushed onto the top of the stack.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**iastore**

Store into integer array

Syntax:

<i>iastore</i> = 79
---------------------

Stack: ..., *array*, *index*, *value* => ...

*array* should be an array of integers, *index* should be an integer, and *value* an integer. The integer *value* is stored at position *index* in *array*.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**lastore**

Store into long integer array

Syntax:

<i>lastore</i> = 80
---------------------

Stack: ..., *array*, *index*, *value-word1*, *value-word2* => ...

*array* should be an array of long integers, *index* should be an integer, and *value* a long integer. The long integer *value* is stored at position *index* in *array*.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**fastore**

Store into single float array

Syntax:

<i>fastore</i> = 81
---------------------

Stack: ..., *array*, *index*, *value* => ...

*array* should be an array of single precision floating point numbers, *index* should be an integer, and *value* a single precision floating point number. The single float *value* is stored at position *index* in *array*.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**dastore**

Store into double float array

Syntax:

<i>dastore</i> = 82
---------------------

Stack: ..., *array*, *index*, *value-word1*, *value-word2* => ...

*array* should be an array of double precision floating point numbers, *index* should be an integer, and *value* a double precision floating point number. The double float *value* is stored at position *index* in *array*.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**aastore**

Store into object reference array

Syntax:

<i>aastore</i> = 83
---------------------

Stack: ..., *array*, *index*, *value* => ...

*array* should be an array of handles to objects or to arrays, *index* should be an integer, and *value* a handle to an object or array. The handle *value* is stored at position *index* in *array*.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

The actual type of *value* should be conformable with the actual type of the elements of the array. For example, it is legal to store an instance of class `Thread` in an array of class `Object`, but not vice versa. An `IncompatibleTypeException` is thrown if an attempt is made to store an incompatible object reference.

**bastore**

Store into signed byte array

Syntax:

<i>bastore</i> = 84
---------------------

Stack: ..., *array*, *index*, *value* => ...

*array* should be an array of signed bytes, *index* should be an integer, and *value* an integer. The integer *value* is stored at position *index* in *array*. If *value* is too large to be a signed byte, it is truncated.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**castore**

Store into character array

Syntax:

<i>castore</i> = 85
---------------------

Stack: ..., *array*, *index*, *value* => ...

*array* should be an array of characters, *index* should be an integer, and *value* an integer. The integer *value* is stored at position *index* in *array*. If *value* is too large to be a character, it is truncated.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array*, an `ArrayIndexOutOfBoundsException` is thrown.

**sastore**

Store into short array

Syntax:

<i>sastore</i> = 86
---------------------

Stack: ..., *array*, *index*, *value* => ...

*array* should be an array of shorts, *index* should be an integer, and *value* an integer. The integer *value* is stored at position *index* in *array*. If *value* is too large to be a short, it is truncated.

If *array* is null, a `NullPointerException` is thrown. If *index* is not within the bounds of *array* an `ArrayIndexOutOfBoundsException` is thrown.

**Stack Instructions****nop**

Do nothing.

Syntax:

<i>nop</i> = 0
----------------

Stack: no change

Do nothing.

**pop**

Pop top stack word

Syntax:

<i>pop</i> = 87
-----------------

Stack: ..., *any* => ...

Pop the top word from the stack.

**pop2**

Pop top two stack words

Syntax:

<i>pop2</i> = 88
------------------

Stack: ..., *any2*, *any1* => ...

Pop the top two words from the stack.

**dup**

Duplicate top stack word

Syntax:

<i>dup</i> = 89
-----------------

Stack: ..., *any* => ..., *any*, *any*

Duplicate the top word on the stack.

**dup2**

Duplicate top two stack words

Syntax:

<i>dup2</i> = 92
------------------

Stack: ..., *any2*, *any1* => ..., *any2*, *any1*, *any2*, *any1*

Duplicate the top two words on the stack.

**dup\_x1**

Duplicate top stack word and put two down

Syntax:

<i>dup_x1</i> = 90
--------------------

Stack: ..., *any2*, *any1* => ..., *any1*, *any2*, *any1*

Duplicate the top word on the stack and insert the copy two words down in the stack.

**dup2\_x1**

Duplicate top two stack words and put two down

Syntax:

<i>dup2_x1</i> = 93
---------------------

Stack: ..., *any3*, *any2*, *any1* => ..., *any2*, *any1*, *any3*, *any2*, *any1*

Duplicate the top two words on the stack and insert the copies two words down in the stack.

**dup\_x2**

Duplicate top stack word and put three down.

Syntax:

<i>dup_x2 = 91</i>
--------------------

Stack: ..., *any3*, *any2*, *any1* => ..., *any1*, *any3*, *any2*, *any1*

Duplicate the top word on the stack and insert the copy three words down in the stack.

**dup2\_x2**

Duplicate top two stack words and put three down

Syntax:

<i>dup2_x2 = 94</i>
---------------------

Stack: ..., *any4*, *any3*, *any2*, *any1* => ..., *any2*, *any1*, *any4*, *any3*, *any2*, *any1*

Duplicate the top two words on the stack and insert the copies three words down in the stack.

**swap**

Swap top two stack words

Syntax:

<i>swap = 95</i>
------------------

Stack: ..., *any2*, *any1* => ..., *any2*, *any1*

Swap the top two elements on the stack.

**Arithmetic Instructions****iadd**

Integer add

Syntax:

<i>iadd = 96</i>
------------------

Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be integers. The values are added and are replaced on the stack by their integer sum.

**ladd**

Long integer add

Syntax:

<i>ladd = 97</i>
------------------

Stack: ..., *value1-word1*, *value1-word2*, *value2-word1*, *value2-word2* => ..., *result-word1*, *result-word2*

*value1* and *value2* should be long integers. The values are added and are replaced on the stack by their long integer sum.

**fadd**

Single float add

Syntax:

*fadd* = 98Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should be single precision floating point numbers. The values are added and are replaced on the stack by their single precision floating point sum.**dadd**

Double float add

Syntax:

*dadd* = 99Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should be double precision floating point numbers. The values are added and are replaced on the stack by their double precision floating point sum.**isub**

Integer subtract

Syntax:

*isub* = 100Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should be integers. *value2* is subtracted from *value1*, and both values are replaced on the stack by their integer difference.**lsub**

Long integer subtract

Syntax:

*lsub* = 101Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should be long integers. *value2* is subtracted from *value1*, and both values are replaced on the stack by their long integer difference.**fsub**

Single float subtract

Syntax:

*fsub* = 102Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should be single precision floating point numbers. *value2* is subtracted from *value1*, and both values are replaced on the stack by their single precision floating point difference.

**dsub**

Double float subtract

Syntax:

*dsub = 103*Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should be double precision floating point numbers. *value2* is subtracted from *value1*, and both values are replaced on the stack by their double precision floating point difference.**imul**

Integer multiply

Syntax:

*imul = 104*Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should be integers. Both values are replaced on the stack by their integer product.**lmul**

Long integer multiply

Syntax:

*lmul = 105*Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should be long integers. Both values are replaced on the stack by their long integer product.**fmul**

Single float multiply

Syntax:

*fmul = 106*Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should be single precision floating point numbers. Both values are replaced on the stack by their single precision floating point product.**dmul**

Double float multiply

Syntax:

*dmul = 107*Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should be double precision floating point numbers. Both values are replaced on the stack by their double precision floating point product.

**idiv**

Integer divide

Syntax:

<i>idiv</i> = 108
-------------------

Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be integers. *value1* is divided by *value2*, and both values are replaced on the stack by their integer quotient.

The result is truncated to the nearest integer that is between it and 0. An attempt to divide by zero results in a “/ by zero” `ArithmeticException` being thrown.

**ldiv**

Long integer divide

Syntax:

<i>ldiv</i> = 109
-------------------

Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2

*value1* and *value2* should be long integers. *value1* is divided by *value2*, and both values are replaced on the stack by their long integer quotient.

The result is truncated to the nearest integer that is between it and 0. An attempt to divide by zero results in a “/ by zero” `ArithmeticException` being thrown.

**fdiv**

Single float divide

Syntax:

<i>fdiv</i> = 110
-------------------

Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be single precision floating point numbers. *value1* is divided by *value2*, and both values are replaced on the stack by their single precision floating point quotient.

Divide by zero results in the quotient being NaN.

**ddiv**

Double float divide

Syntax:

<i>ddiv</i> = 111
-------------------

Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2

*value1* and *value2* should be double precision floating point numbers. *value1* is divided by *value2*, and both values are replaced on the stack by their double precision floating point quotient.

Divide by zero results in the quotient being NaN.

**imod**

Integer mod

Syntax:

*imod* = 112Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should both be integers. *value1* is divided by *value2*, and both values are replaced on the stack by their integer remainder.

An attempt to divide by zero results in a “/ by zero” `ArithmeticException` being thrown.

**lmod**

Long integer mod

Syntax:

*lmod* = 113Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2

*value1* and *value2* should both be long integers. *value1* is divided by *value2*, and both values are replaced on the stack by their long integer remainder.

An attempt to divide by zero results in a “/ by zero” `ArithmeticException` being thrown.

**fmod**

Single float mod

Syntax:

*fmod* = 114Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should both be single precision floating point numbers. *value1* is divided by *value2*, and the quotient is truncated to an integer, and then multiplied by *value2*. The product is subtracted from *value1*. The result, as a single precision floating point number, replaces both values on the stack. That is,  $result = value1 - ((int)(value1 / value2)) * value2$ .

An attempt to divide by zero results in NaN.

**dmod**

Double float mod

Syntax:

*dmod* = 115Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2

*value1* and *value2* should both be double precision floating point numbers. *value1* is divided by *value2*, and the quotient is truncated to an integer, and then multiplied by *value2*. The product is subtracted from *value1*. The result, as a double precision floating point number, replaces both values on the stack. That is,  $result = value1 - ((int)(value1 / value2)) * value2$ .

An attempt to divide by zero results in NaN.

**ineg**

Integer negate

Syntax:

*ineg* = 116Stack: ..., *value* => ..., *result**value* should be an integer. It is replaced on the stack by its arithmetic negation.**lneg**

Long integer negate

Syntax:

*lneg* = 117Stack: ..., *value-word1*, *value-word2* => ..., *result-word1*, *result-word2**value* should be a long integer. It is replaced on the stack by its arithmetic negation.**fneg**

Single float negate

Syntax:

*fneg* = 118Stack: ..., *value* => ..., *result**value* should be a single precision floating point number. It is replaced on the stack by its arithmetic negation.**dneg**

Double float negate

Syntax:

*dneg* = 119Stack: ..., *value-word1*, *value-word2* => ..., *result-word1*, *result-word2**value* should be a double precision floating point number. It is replaced on the stack by its arithmetic negation.**Logical Instructions****ishl**

Integer shift left

Syntax:

*ishl* = 120Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should be integers. *value1* is shifted left by the amount indicated by the low five bits of *value2*. The integer result replaces both values on the stack.

**ishr**

Integer arithmetic shift right

Syntax:

*ishr* = 122Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be integers. *value1* is shifted right arithmetically (with sign extension) by the amount indicated by the low five bits of *value2*. The integer result replaces both values on the stack.

**iushr**

Integer logical shift right

Syntax:

*iushr* = 124Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be integers. *value1* is shifted right logically (with no sign extension) by the amount indicated by the low five bits of *value2*. The integer result replaces both values on the stack.

**lshl**

Long integer shift left

Syntax:

*lshl* = 121Stack: ..., *value1*-word1, *value1*-word2, *value2* => ..., *result*-word1, *result*-word2

*value1* should be a long integer and *value2* should be an integer. *value1* is shifted left by the amount indicated by the low six bits of *value2*. The long integer result replaces both values on the stack.

**lshr**

Long integer arithmetic shift right

Syntax:

*lshr* = 123Stack: ..., *value1*-word1, *value1*-word2, *value2* => ..., *result*-word1, *result*-word2

*value1* should be a long integer and *value2* should be an integer. *value1* is shifted right arithmetically (with sign extension) by the amount indicated by the low six bits of *value2*. The long integer result replaces both values on the stack.

**lushr**

Long integer logical shift right

Syntax:

*lushr* = 125Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2

*value1* should be a long integer and *value2* should be an integer. *value1* is shifted right logically (with no sign extension) by the amount indicated by the low six bits of *value2*. The long integer result replaces both values on the stack.

**iand**

Integer boolean and

Syntax:

*iand* = 126Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should both be integers. They are replaced on the stack by their bitwise conjunction (AND).**land**

Long integer boolean and

Syntax:

*land* = 127Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should both be long integers. They are replaced on the stack by their bitwise conjunction (AND).**ior**

Integer boolean or

Syntax:

*ior* = 128Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should both be integers. They are replaced on the stack by their bitwise disjunction (OR).**lor**

Long integer boolean or

Syntax:

*lor* = 129Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should both be long integers. They are replaced on the stack by their bitwise disjunction (OR).**ixor**

Integer boolean xor

Syntax:

*ixor* = 130Stack: ..., *value1*, *value2* => ..., *result**value1* and *value2* should both be integers. They are replaced on the stack by their bitwise exclusive disjunction (XOR).

**l xor**

Long integer boolean xor

Syntax:

*l xor* = 131Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word2 => ..., *result*-word1, *result*-word2*value1* and *value2* should both be long integers. They are replaced on the stack by their bitwise exclusive disjunction (XOR).**Conversion Operations****i2l**

Integer to long integer conversion

Syntax:

*i2l* = 132Stack: ..., *value* => ..., *result*-word1, *result*-word2*value* should be an integer. It is converted to a long integer. The result replaces *value* on the stack.**i2f**

Integer to single float

Syntax:

*i2f* = 133Stack: ..., *value* => ..., *result**value* should be an integer. It is converted to a single precision floating point number. The result replaces *value* on the stack.**i2d**

Integer to double float

Syntax:

*i2d* = 134Stack: ..., *value* => ..., *result*-word1, *result*-word2*value* should be an integer. It is converted to a double precision floating point number. The result replaces *value* on the stack.**l2i**

Long integer to integer

Syntax:

*l2i* = 136Stack: ..., *value*-word1, *value*-word2 => ..., *result**value* should be a long integer. It is converted to an integer. The result replaces *value* on the stack.

**l2f**

Long integer to single float

Syntax:

 $l2f = 137$ Stack: ..., *value-word1*, *value-word2* => ..., *result**value* should be a long integer. It is converted to a single precision floating point number. The result replaces *value* on the stack.**l2d**

Long integer to double float

Syntax:

 $l2d = 138$ Stack: ..., *value-word1*, *value-word2* => ..., *result-word1*, *result-word2**value* should be a long integer. It is converted to a double precision floating point number. The result replaces *value* on the stack.**f2i**

Single float to integer

Syntax:

 $f2i = 139$ Stack: ..., *value* => ..., *result**value* should be a single precision floating point number. It is converted to an integer. The result replaces *value* on the stack.**f2l**

Single float to long integer

Syntax:

 $f2l = 140$ Stack: ..., *value* => ..., *result-word1*, *result-word2**value* should be a single precision floating point number. It is converted to a long integer. The result replaces *value* on the stack.**f2d**

Single float to double float

Syntax:

 $f2d = 141$ Stack: ..., *value* => ..., *result-word1*, *result-word2**value* should be a single precision floating point number. It is converted to a double precision floating point number. The result replaces *value* on the stack.

**d2i**

Double float to integer

Syntax:

 $d2i = 142$ Stack: ..., *value-word1*, *value-word2* => ..., *result**value* should be a double precision floating point number. It is converted to an integer. The result replaces *value* on the stack.**d2l**

Double float to long integer

Syntax:

 $d2l = 143$ Stack: ..., *value-word1*, *value-word2* => ..., *result-word1*, *result-word2**value* should be a double precision floating point number. It is converted to a long integer. The result replaces *value* on the stack.**d2f**

Double float to single float

Syntax:

 $d2f = 144$ Stack: ..., *value-word1*, *value-word2* => ..., *result**value* should be a double precision floating point number. It is converted to a single precision floating point number. The result replaces *value* on the stack.**int2byte**

Integer to signed byte

Syntax:

 $int2byte = 145$ Stack: ..., *value* => ..., *result-word1*, *result-word2**value* should be an integer. It is truncated to a signed 8-bit result, then sign extended to an integer. The result replaces *value* on the stack.**int2char**

Integer to char

Syntax:

 $int2char = 146$ 

Stack: ..., &lt;int&gt; =&gt; ..., &lt;result&gt;

*value* should be an integer. It is truncated to an unsigned 16-bit result, then sign extended to an integer. The result replaces *value* on the stack.

**int2short**

Integer to char

Syntax:

<i>int2short</i> = 147
------------------------

Stack: ..., &lt;int&gt; =&gt; ..., &lt;result&gt;

*value* should be an integer. It is truncated to a signed 16-bit result, then sign extended to an integer. The result replaces *value* on the stack.

**Control Transfer Instructions****ifeq**

Branch if equal to 0

Syntax:

<i>ifeq</i> = 153
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value* => ...

*value* should be an integer or a handle to an object or to an array. It is popped from the stack. If *value* is equal to zero, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *ifeq*.

**iflt**

Branch if less than 0

Syntax:

<i>iflt</i> = 155
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value* => ...

*value* should be an integer. It is popped from the stack. If *value* is less than zero, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *iflt*.

**ifle**

Branch if less than or equal to 0

Syntax:

<i>ifle</i> = 158
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value* => ...

*value* should be an integer. It is popped from the stack. If *value* is less than or equal to zero, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *ifle*.

**ifne**

Branch if not equal to 0

Syntax:

<i>ifne</i> = 154
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value* => ...

*value* should be an integer or a handle to an object or to an array. It is popped from the stack. If *value* is not equal to zero, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *ifne*.

**ifgt**

Branch if greater than 0

Syntax:

<i>ifgt</i> = 157
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value* => ...

*value* should be an integer. It is popped from the stack. If *value* is greater than zero, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *ifgt*.

**ifge**

Branch if greater than or equal to 0

Syntax:

<i>ifge</i> = 156
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value* => ...

*value* should be an integer. It is popped from the stack. If *value* is greater than or equal to zero, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *ifge*.

**if\_icmpeq**

Branch if integers equal

Syntax:

<i>if_icmpeq</i> = 159
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be integers. They are both popped from the stack. If *value1* is equal to *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_icmpeq*.

**if\_icmpne**

Branch if integers not equal

Syntax:

<i>if_icmpne</i> = 160
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be integers. They are both popped from the stack. If *value1* is not equal to *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_icmpne*.

**if\_icmplt**

Branch if integer less than

Syntax:

<i>if_icmplt</i> = 161
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be integers. They are both popped from the stack. If *value1* is less than *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_icmplt*.

**if\_icmpgt**

Branch if integer greater than

Syntax:

<i>if_icmpgt</i> = 163
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be integers. They are both popped from the stack. If *value1* is greater than *value2* (C's >), *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_icmpgt*.

**if\_icmple**

Branch if integer less than or equal to

Syntax:

<i>if_icmple</i> = 164
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be integers. They are both popped from the stack. If *value1* is less than or equal to *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_icmple*.

**if\_icmpge**

Branch if integer greater than or equal to

Syntax:

<i>if_icmpge</i> = 162
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be integers. They are both popped from the stack. If *value1* is greater than or equal to *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_icmpge*.

**lcmp**

Long integer compare

Syntax:

<i>lcmp</i> = 148
-------------------

Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word1 => ..., *result*

*value1* and *value2* should be long integers. They are both popped from the stack and compared. If *value1* is greater than *value2*, the integer value 1 is pushed onto the stack. If *value1* is equal to *value2*, the value 0 is pushed onto the stack. If *value1* is less than *value2*, the value -1 is pushed onto the stack.

**fcmpl**

Single float compare (-1 on incomparable)

Syntax:

<i>fcmpl</i> = 149
--------------------

Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be single precision floating point numbers. They are both popped from the stack and compared. If *value1* is greater than *value2*, the integer value 1 is pushed onto the stack. If *value1* is equal to *value2*, the value 0 is pushed onto the stack. If *value1* is less than *value2*, the value -1 is pushed onto the stack.

If either *value1* or *value2* is NaN, the value -1 is pushed onto the stack.

**fcmpg**

Single float compare (1 on incomparable)

Syntax:

<i>fcmpg</i> = 150
--------------------

Stack: ..., *value1*, *value2* => ..., *result*

*value1* and *value2* should be single precision floating point numbers. They are both popped from the stack and compared. If *value1* is greater than *value2*, the integer value 1 is pushed onto the stack. If *value1* is equal to *value2*, the value 0 is pushed onto the stack. If *value1* is less than *value2*, the value -1 is pushed onto the stack.

If either *value1* or *value2* is NaN, the value 1 is pushed onto the stack.

**dcmpl**

Double float compare (-1 on incomparable)

Syntax:

<i>dcmpl</i> = 151
--------------------

Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word1 => ..., *result*

*value1* and *value2* should be double precision floating point numbers. They are both popped from the stack and compared. If *value1* is greater than *value2*, the integer value 1 is pushed onto the stack. If *value1* is equal to *value2*, the value 0 is pushed onto the stack. If *value1* is less than *value2*, the value -1 is pushed onto the stack.

If either *value1* or *value2* is NaN, the value -1 is pushed onto the stack.

**dcmpg**

Double float compare (1 on incomparable)

Syntax:

<i>dcmpg</i> = 152
--------------------

Stack: ..., *value1*-word1, *value1*-word2, *value2*-word1, *value2*-word1 => ..., *result*

*value1* and *value2* should be double precision floating point numbers. They are both popped from the stack and compared. If *value1* is greater than *value2*, the integer value 1 is pushed onto the stack. If *value1* is equal to *value2*, the value 0 is pushed onto the stack. If *value1* is less than *value2*, the value -1 is pushed onto the stack.

If either *value1* or *value2* is NaN, the value 1 is pushed onto the stack.

**if\_acmpeq**

Branch if objects same

Syntax:

<i>if_acmpeq</i> = 165
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be handles to objects or arrays. They are both popped from the stack. If *value1* is equal to *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_acmpeq*.

**if\_acmpne**

Branch if objects not same

Syntax:

<i>if_acmpne</i> = 166
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ..., *value1*, *value2* => ...

*value1* and *value2* should be handles to objects or arrays. They are both popped from the stack. If *value1* is not equal to *value2*, *branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc. Otherwise execution proceeds at the instruction following the *if\_acmpne*.

**goto**

Branch always

Syntax:

<i>goto</i> = 167
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: no change

*branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. Execution proceeds at that offset from the pc.

**jsr**

Jump subroutine

Syntax:

<i>jsr</i> = 168
<i>branchbyte1</i>
<i>branchbyte2</i>

Stack: ... => ..., *return-address*

*branchbyte1* and *branchbyte2* are used to construct a signed 16-bit offset. The address of the instruction immediately following the *jsr* is pushed onto the stack. Execution proceeds at the offset from the current pc.

The *jsr* instruction is used in the implementation of Java's **finally** keyword.

**ret**

Return from subroutine

Syntax:

<i>ret</i> = 169
<i>vindex</i>

Stack: no change

Local variable *vindex* in the current Java frame should contain a return address. The contents of the local variable are written into the pc.

Note that *jsr* pushes the address onto the stack, and *ret* gets it out of a local variable. This asymmetry is intentional.

The *ret* instruction is used in the implementation of Java's **finally** keyword.

## Function Return

### **ireturn**

Return integer from function

Syntax:

<i>ireturn</i> = 172
----------------------

Stack: ..., *value* => [empty]

*value* should be an integer. The value *value* is pushed onto the stack of the previous execution environment. Any other values on the operand stack are discarded. The interpreter then returns control to its caller.

[Note: this may be confusing to people expecting that the stack is like the C stack. However, the operand stack should be seen as consisting of a number of discontinuous segments, each corresponding to a method invocation. A return instruction empties the Java operand stack segment corresponding to the activity of the returning invocation, but does not affect the segment of any parent invocations.]]

### **lreturn**

Return long integer from function

Syntax:

<i>lreturn</i> = 173
----------------------

Stack: ..., *value-word1*, *value-word2* => [empty]

*value* should be a long integer. The value *value* is pushed onto the stack of the previous execution environment. Any other values on the operand stack are discarded. The interpreter then returns control to its caller.

### **freturn**

Return single float from function

Syntax:

<i>freturn</i> = 174
----------------------

Stack: ..., *value* => [empty]

*value* should be a single precision floating point number. The value *value* is pushed onto the stack of the previous execution environment. Any other values on the operand stack are discarded. The interpreter then returns control to its caller.

### **dreturn**

Return double float from function

Syntax:

<i>dreturn</i> = 175
----------------------

Stack: ..., *value-word1*, *value-word2* => [empty]

*value* should be a double precision floating point number. The value *value* is pushed onto the stack of the previous execution environment. Any other values on the operand stack are discarded. The interpreter then returns control to its caller.

**areturn**

Return object reference from function

Syntax:

<i>areturn</i> = 176
----------------------

Stack: ..., *value* => [empty]

*value* should be a handle to an object or an array. The value *value* is pushed onto the stack of the previous execution environment. Any other values on the operand stack are discarded. The interpreter then returns control to its caller.

**return**

Return (void) from procedure

Syntax:

<i>return</i> = 177
---------------------

Stack: ... => [empty]

All values on the operand stack are discarded. The interpreter then returns control to its caller.

**Table Jumping****tableswitch**

Access jump table by index and jump

Syntax:

<i>tableswitch</i> = 170
...0-3 byte pad...
<i>default-offset1</i>
<i>default-offset2</i>
<i>default-offset3</i>
<i>default-offset4</i>
<i>low1</i>
<i>low2</i>
<i>low3</i>
<i>low4</i>
<i>high1</i>
<i>high2</i>
<i>high3</i>
<i>high4</i>
...jump offsets...

Stack: ..., *index* => ...

*tableswitch* is a variable length instruction. Immediately after the *tableswitch* opcode, between zero and three 0's are inserted as padding so that the next byte begins at an address that is a multiple of four. After the padding follow a series of signed 4-byte quantities: *default-offset*, *low*, *high*, and then *high-low+1* further signed 4-byte offsets. The *high-low+1* signed 4-byte offsets are treated as a 0-based jump table.

The *index* should be an integer. If *index* is less than *low* or *index* is greater than *high*, then *default-offset* is added to the pc. Otherwise, *low* is subtracted from *index*, and the *index-low*'th element of the jump table is extracted, and added to the pc.

## lookupswitch

Access jump table by key match and jump

Syntax:

<i>lookupswitch</i> = 171
...0-3 byte pad...
<i>default-offset1</i>
<i>default-offset2</i>
<i>default-offset3</i>
<i>default-offset4</i>
<i>npairs1</i>
<i>npairs2</i>
<i>npairs3</i>
<i>npairs4</i>
..match-offset pairs..

Stack: ..., *key* => ...

*lookupswitch* is a variable length instruction. Immediately after the *lookupswitch* opcode, between zero and three 0's are inserted as padding so that the next byte begins at an address that is a multiple of four.

Immediately after the padding are a series of pairs of signed 4-byte quantities. The first pair is special. The first item of that pair is the default offset, and the second item of that pair gives the number of pairs that follow. Each subsequent pair consists of a *match* and an *offset*.

The *key* should be an integer. The integer *key* on the stack is compared against each of the *matches*. If it is equal to one of them, the *offset* is added to the pc. If the *key* does not match any of the *matches*, the default offset is added to the pc.

## Manipulating Object Fields

### putfield

Set field in object

Syntax:

<i>putfield</i> = 181
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *handle*, *value* => ...

OR

Stack: ..., *handle*, *value-word1*, *value-word2* => ...

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The constant pool item will be a field reference to a class name and a field name. The item is resolved to a field block pointer which has both the field width (in bytes) and the field offset (in bytes).

The field at that *offset* from the start of the instance pointed to by *handle* will be set to the *value* on the top of the stack.

This instruction handles both 32-bit and 64-bit wide fields.

If *handle* is null, a `NullPointerException` exception is generated.

If the specified field is a static field, a `DynamicRefOfStaticField` exception is generated.

**getfield**

Fetch field from object

Syntax:

<i>getfield</i> = 180
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *handle* => ..., *value*

OR

Stack: ..., *handle* => ..., *value-word1*, *value-word2*

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The constant pool item will be a field reference to a class name and a field name. The item is resolved to a field block pointer which has both the field width (in bytes) and the field *offset* (in bytes).

*handle* should be a handle to an object. The value at *offset* into the object referenced by *handle* replaces *handle* on the top of the stack.

This instruction handles both 32-bit and 64-bit wide fields.

If the specified field is a static field, a `DynamicRefOfStaticField` exception is generated.

**putstatic**

Set static field in class

Syntax:

<i>putstatic</i> = 179
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *value* => ...

OR

Stack: ..., *value-word1*, *value-word2* => ...

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The constant pool item will be a field reference to a static field of a class. That field will be set to have the value on the top of the stack.

This instruction works for both 32-bit and 64-bit wide fields.

If the specified field is a dynamic field, a `StaticRefOfDynamicFieldException` is generated.

**getstatic**

Get static field from class

Syntax:

<i>getstatic</i> = 178
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., => ..., *value*

OR

Stack: ..., => ..., *value-word1*, *value-word2*

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The constant pool item will be a field reference to a static field of a class. The value of that field will replace *handle* on the stack.

This instruction handles both 32-bit and 64-bit wide fields.

If the specified field is a dynamic field, a `StaticRefOfDynamicFieldException` is generated.

## Method Invocation

There are four instructions that implement different flavors of method invocation. At first glance their descriptions look very similar but they are all slightly different.

<code>invokevirtual</code>	Searches for a non-static method through an object instance, taking into account the runtime type of the object being referenced. It's behavior is similar to that of virtual methods in C++.
<code>invokenonvirtual</code>	Searches for a non-static method beginning in a particular class. Behaves like non-virtual methods in C++.
<code>invokestatic</code>	Searches for a static method in a particular class.
<code>invokeinterface</code>	Begins searching with the most derived class of the object, like <i>invokemethod</i> , but it does not presume to know which slot the method will be found in. It's behavior is similar to multiply-inherited virtual methods in C++.

### `invokevirtual`

Invoke class method

Syntax:

<i>invokevirtual</i> = 182
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *object*, [*arg1*, [*arg2* ...]], ... => ...

The operand stack is assumed to contain a handle to an object or to an array and some number of arguments. *indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index in the constant pool contains the complete method signature. A pointer to the object's method table is retrieved from the object handle. The method signature is looked up in the method table. The method signature is guaranteed to exactly match one of the method signatures in the table.

The result of the lookup is an index into the method table of the named class, where a pointer to the method block for the matched method is found. The method block indicates the type of method (native, synchronized, etc.) and the number of arguments (nargs) expected on the operand stack.

If the method is marked synchronized the monitor associated with handle is entered. The exact behavior of monitors and their interactions with threads is a runtime issue.

The base of the local variables array for the new Java stack frame is set to point to handle on the stack, making handle and the supplied arguments (*arg1*, *arg2*, ...) the first nargs local variables of the new frame. The total number of local variables used by the method is determined, and the execution environment of the new frame is pushed after leaving sufficient room for the locals. The base of the operand stack for this method invocation is set to the first word after the execution environment. Finally, execution continues with the first instruction of the matched method.

If the object handle on the operand stack is null, a `NullPointerException` is thrown. If during the method invocation a stack overflow is detected, a `StackOverflowException` is thrown.

**invokenonvirtual**

Invoke non-virtual method

Syntax:

<i>invokenonvirtual</i> = 183
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *object*, *nargs*, ... => ...

The operand stack is assumed to contain a handle to an object and some number of arguments. *indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index in the constant pool contains the complete method signature. A pointer to the object's method table is retrieved from the object handle. The method signature is looked up in the the method table. The method signature is guaranteed to exactly match one of the method signatures in the table.

The result of the lookup is a method block. The method block indicates the type of method (native, synchronized, etc.) and the number of arguments (*nargs*) expected on the operand stack.

If the method is marked *synchronized* the monitor associated with *handle* is entered. The exact behavior of monitors and their interactions with threads is a runtime issue.

The base of the local variables array for the new Java stack frame is set to point to handle on the stack, making handle and the supplied arguments (*arg1*, *arg2*, ...) the first *nargs* local variables of the new frame. The total number of local variables used by the method is determined, and the execution environment of the new frame is pushed after leaving sufficient room for the locals. The base of the operand stack for this method invocation is set to the first word after the execution environment. Finally, execution continues with the first instruction of the matched method.

If the object handle on the operand stack is null, a `NullPointerException` is thrown. If during the method invocation a stack overflow is detected, a `StackOverflowException` is thrown.

**invokestatic**

Invoke a static method

Syntax:

<i>invokestatic</i> = 184
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *nargs*, ... => ...

The operand stack is assumed to contain some number of arguments. *indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index in the constant pool contains the complete method signature and class. The method signature is looked up in the the method table of the class indicated. The method signature is guaranteed to exactly match one of the method signatures in the class's method table.

The result of the lookup is a method block. The method block indicates the type of method (native, synchronized, etc.) and the number of arguments (*nargs*) expected on the operand stack.

If the method is marked *synchronized* the monitor associated with the class is entered. The exact behavior of monitors and their interactions with threads is a runtime issue.

The base of the local variables array for the new Java stack frame is set to point to the first argument on the stack, making the supplied arguments (*arg1*, *arg2*, ...) the first *nargs* local variables of the new frame. The total number of local variables used by the method is determined, and the execution environment of the new frame is pushed after leaving sufficient room for the locals. The base of the operand stack for this method invocation is set to the first word after the execution environment. Finally, execution continues with the first instruction of the matched method.

If during the method invocation a stack overflow is detected, a `StackOverflowException` is thrown.

**invokeinterface**

Invoke interface method

Syntax:

<i>invokeinterface</i> = 185
<i>indexbyte1</i>
<i>indexbyte2</i>
<i>nargs</i>
<i>reserved</i>

Stack: ..., *object*, [*arg1*, [*arg2* ...]], ... => ...

The operand stack is assumed to contain a handle to an object and *nargs*-1 arguments. *indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index in the constant pool contains the complete method signature. A pointer to the object's method table is retrieved from the object handle. The method signature is looked up in the method table. The method signature is guaranteed to exactly match one of the method signatures in the table.

The result of the lookup is a method block. The method block indicates the type of method (native, synchronized, etc.) but unlike *invokemethod* and *invokesuper*, the number of available arguments (*nargs*) is taken from the bytecode.

If the method is marked *synchronized* the monitor associated with handle is entered. The exact behavior of monitors and their interactions with threads is a runtime issue.

The base of the local variables array for the new Java stack frame is set to point to handle on the stack, making handle and the supplied arguments (*arg1*, *arg2*, ...) the first *nargs* local variables of the new frame. The total number of local variables used by the method is determined, and the execution environment of the new frame is pushed after leaving sufficient room for the locals. The base of the operand stack for this method invocation is set to the first word after the execution environment. Finally, execution continues with the first instruction of the matched method.

If the object handle on the operand stack is null, a *NullPointerException* is thrown. If during the method invocation a stack overflow is detected, a *StackOverflowException* is thrown.

## Exception Handling

The virtual machine support for exceptions documented here is likely to change in the near future but reflects the current Java implementation. The instructions here also assume that asynchronous exceptions are not supported.

### athrow

Throw exception

Syntax:

<i>athrow</i> = 191
---------------------

Stack: ..., *handle* => [undefined]

*handle* should be a handle to an object. The *handle* should be of an exception object, which is thrown. The current Java stack frame is searched for the most recent catch clause that handles this exception. A catch clause can handle an exception if the object in the constant pool at for that entry is a superclass of the thrown object.) If a matching catch list entry is found, the pc is reset to the address indicated by the catch-list pointer, and execution continues there.

If no appropriate catch clause is found in the current stack frame, that frame is popped and the exception is rethrown. If one is found, it contains the location of the code for this exception. The pc is reset to that location and execution continues. If no appropriate catch is found in the current stack frame, that frame is popped and the exception is rethrown.

If *handle* is null, then a `NullPointerException` is thrown instead.

## Miscellaneous Object Operations

### new

Create new object

Syntax:

<i>new</i> = 187
------------------

<i>indexbyte1</i>
-------------------

<i>indexbyte2</i>
-------------------

Stack: ... => ..., *handle*

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The item at that index should be a class name that can be resolved to a class pointer, *class*. A new instance of that class is then created and a *handle* for it is pushed on the stack.

### newfromname

Create new object from name

Syntax:

<i>newfromname</i> = 186
--------------------------

Stack: ..., *handle* => ..., *new-handle*

*handle* should be a handle to a character array. The class whose name is the string represented by the character array is determined. A new object of that class is created, and a handle *new-handle* for that object replaces the character array *handle* on the top of the stack.

If the handle is null, a `NullPointerException` is thrown. If no such class can be found, a `NoClassDefFoundException` is thrown.

**checkcast**

Make sure object is of given type

Syntax:

<i>checkcast</i> = 192
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *handle* => ..., [*handle* | ...]

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The string at that index of the constant pool is presumed to be a class name which can be resolved to a class pointer, *class*. *handle* should be a handle to an object.

*checkcast* determines whether *handle* can be cast to an object of class *class*. A null *handle* can be cast to any *class*. Otherwise *handle* must be an instance of *class* or one of its superclasses. If *handle* can be cast to *class* execution proceeds at the next instruction, and the handle for *handle* remains on the stack.

If *handle* cannot be cast to *class*, a `ClassCastException` is thrown.

**instanceof**

Determine if object is of given type

Syntax:

<i>instanceof</i> = 193
<i>indexbyte1</i>
<i>indexbyte2</i>

Stack: ..., *handle* => ..., *result*

*indexbyte1* and *indexbyte2* are used to construct an index into the constant pool of the current class. The string at that index of the constant pool is presumed to be a class name which can be resolved to a class pointer, *class*. *handle* should be a handle to an object.

*instanceof* determines whether *handle* can be cast to an object of the class *class*. This instruction will overwrite *handle* with 1 if *handle* is null or if it is an instance of *class* or one of its superclasses. Otherwise, *handle* is overwritten by 0.

**verifystack**

Verify stack empty

Syntax:

<i>verifystack</i> = 196
--------------------------

Stack: ... => [empty stack]

This instruction is only generated if the code was compiled using a debugging version of the compiler. This instruction indicates that the compiler expects the operand stack to be empty at this point.

If the stack is not currently empty, it will be set to empty. In addition, if running a debugging version of the interpreter, an error message is printed out warning that something is seriously wrong.

## Monitors

### monitorenter

Enter monitored region of code

Syntax:

<i>monitorenter</i> = 194
---------------------------

Stack: ..., *handle* => ...

*handle* should be a handle to an object.

The interpreter attempts to obtain exclusive access via a lock mechanism to *handle*. If another process already has *handle* locked, then the current process waits until the handle is unlocked. If the current process already has *handle* locked, then continue execution. If *handle* has no lock on it, then obtain an exclusive lock.

### monitorexit

Exit monitored region of code

Syntax:

<i>monitorexit</i> = 195
--------------------------

Stack: ..., *handle* => ...

*handle* should be a handle to an object.

The lock on *handle* is released. If this is the last lock that this process has on that handle (one process is allowed to have multiple locks on a single handle), then other processes that are waiting for *handle* to be free are allowed to proceed.

## Debugging

### breakpoint

Call breakpoint handler

Syntax:

<i>breakpoint</i> = 197
-------------------------

The *breakpoint* instruction is used to temporarily overwrite an instruction causing a break to the debugger prior to the effect of the overwritten instruction. The original instruction's operands (if any) are not overwritten, and the original instruction can be restored when the *breakpoint* instruction is removed.