

# **Barista 2.0-alpha3**

## Reference Manual

<http://barista.x9c.fr>

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# Abstract

This document presents Barista, the command-line program as well as the underlying OCaml library. The purpose of both is to allow easy manipulation of Java<sup>TM</sup> class files in their compiled (*a.k.a.* bytecode form).

The program allows one to assemble and disassemble class file, respectively from and to a source format called *assembler* (which is essentially a human-readable form of the bytecode). The program also allows one to retrieve information about a classfile, by printing either the contents of a class or the control flow of a method.

The OCaml library (upon which the program is built) allows more sophisticated analysis and manipulation of class file (and also package and module files). Its primary goal is to be used as the back-end for code generation in the OCaml-Java project (<http://ocamljava.x9c.fr>), which provides a compiler from OCaml sources into Java<sup>TM</sup> class files.

This manual is structured in five chapters, and four appendixes.

After a first chapter providing an overview of the Barista project, the second chapter explains how Barista can be built from sources and details its dependencies. Then, chapter three introduces the Barista program and how it can be executed, while chapter four introduces the format of so-called *assembler* source file. The last chapter sheds light on Barista as an OCaml library and provides entry points to its API. Finally, the three appendixes summarize all the instructions recognized by the Barista assembler, classified under three different ways (namely: alphabetically, by categories, and by opcode number) for easy reference. The fourth appendix presents the syntax extension used throughout the Barista sources.



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# Chapter 1

## Overview

This chapter presents some elements about the Barista project: its contents and objectives, its evolution, and also its management.

### 1.1 Current state

Barista is initially an OCaml<sup>1</sup> library designed to load, construct, manipulate and save Java<sup>TM</sup><sup>2</sup> class files. The library supports the whole class file format as defined by Oracle<sup>®</sup> (formerly Sun<sup>®</sup>). The Barista library was designed to be used in the OCaml-Java project (available at <http://ocamljava.x9c.fr>) for code generation.

Upon the library, a command-line utility (also named “barista”) has been developped: both an assembler and a disassembler for the Java<sup>TM</sup> platform. In its 2.0-alpha3 version, Barista supports Java<sup>TM</sup> 1.7 and needs OCaml 3.12.1 to build. Code sample 1 below shows the canonical basic example coded in the Barista assembler; the assembler will turn it into a class file to be run into a Java<sup>TM</sup> virtual machine. Chapter 4 describes the format of such assembler sources.

The disassembler does the same work in the opposite direction: it takes the fully qualified name of a Java<sup>TM</sup> bytecode class file present in the classpath, and transforms it into an assembler source. Two other utility allow to inspect the contents of a bytecode file; it is possible to just print the list of methods of a given class, and also to print the control flow of a given method as a graph.

### 1.2 Some history

From version 1.0 $\beta$  to 1.4, Barista also featured a Java<sup>TM</sup> API allowing to use Barista directly from Java<sup>TM</sup>. This API has been removed as of version 2.0. This removal was motivated by the following three reasons, sorted from most to least valuable. First, it introduced a circular dependency between Barista and the rest of the OCaml-Java project, intrincating both. Second, it was a burden to manually update the API in order to keep it a Java<sup>TM</sup> look and feel.

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<sup>1</sup>The official OCaml website can be reached at <http://caml.inria.fr> and contains the full development suite (compilers, tools, virtual machine, *etc.*) as well as links to third-party contributions.

<sup>2</sup>The official Java<sup>TM</sup> website can be reached at <http://java.sun.com> where most of official Java<sup>TM</sup> information can be found.

Third, it was pretty unused; those who actually want to use Barista from Java<sup>TM</sup> should take a look at the OCaml-Java project, and the ways it provides to interface OCaml and Java<sup>TM</sup> codes.

The 2.0 version of Barista is quite a leap forward: it claims full support for Java<sup>TM</sup> 1.7 (including serialization, various optimization on produced class files, and handling of package files), and has seen a major overhaul of the API to make it as simple, readable, and type-safe as can be. Of course, this induced backward-incompatible changes which motivated the jump in version numbering from 1.4 to 2.0.

### 1.3 Glimpse of the assembler syntax

Before dwelling upon technical issues in the next two chapters, here is the classical hello world example as it should be programmed in the Barista assembler (see code sample 1).

---

**Code sample 1** The classical “hello world” in Barista assembler.

---

```
.class public final pack.Test
.extends java.lang.Object

.method public static void main(java.lang.String[])
    getstatic java.lang.System.out : java.io.PrintStream
    ldc "hello world.\n"
    invokevirtual java.io.PrintStream.println(java.lang.String):void
```

---

As in most so-called assembly languages, the source format is line-oriented (meaning that in most cases an instruction cannot be split over multiple lines), and *directives* (how to interpret things) are discriminated from *instructions* (what things should be done) by prefixing the directive with a “.” character (*i.e.* a dot).

To be able to use the assembler, and to understand this very manual, good familiarity with Java<sup>TM</sup> in general and with the class file format in particular is assumed. One should refer to the documentation published by Oracle<sup>®</sup> for more information (a good entry point for the JVM specification being <http://java.sun.com/docs/books/jvms/>).

### 1.4 Contributions

In order to improve the project, I am primarily looking for testers and bug reporters. Pointing errors in documentation and indicating where it should be enhanced is also very helpful.

Bug reports can be made at <http://bugs.x9c.fr>.

Other requests can be sent to [barista@x9c.fr](mailto:barista@x9c.fr).



## Chapter 2

# Building Barista from sources

This chapter first lists the various libraries and tools Barista depends upon. Then, the following sections explain the steps to follow in order to build, and then install Barista (both the program and the library) from sources.

## 2.1 Dependencies

In order to compile the Barista sources, one needs OCaml 3.12.1, and GNU make 3.81. Compilation is actually realized by the `ocamlbuild` tool, although launched through the targets of a `Makefile`. Additionally, Barista depends upon the following OCaml libraries that should hence be installed before build:

- **bigarray**, **unix** available in the OCaml standard distribution;
- **camlzip** (zip/gzip/jar library), at least version 1.04  
available at: <http://cristal.inria.fr/~xleroy/software.html>;
- **camomile** (Unicode library), at least version 0.8.3  
available at: <http://camomile.sourceforge.net>.

## 2.2 Configuration

Before the actual compilation could be launched, it is necessary to configure the build process to the actual machine and system used. To this end, one should execute the `configure` script (*e.g.* by running `sh configure`). This script recognizes the following command-line options, that can be used to supersede the autodetection the script performs:

- `-ocaml-prefix` to indicate where OCaml should actually be found (it should hence be the same value as the one passed to OCaml's `configure` script through the `-prefix` option);
- `-ocamlfind` to indicate the path to the `ocamlfind`<sup>1</sup> program (setting it to the empty string will disable the use of `ocamlfind`).

Upon successful execution, a `Makefile.config` file is produced which contains the information either inferred by or passed to the script.

---

<sup>1</sup>Findlib, a library manager for OCaml, is available at <http://projects.camlcity.org/projects/findlib.html>

## 2.3 Compilation

Once configured, Barista can be built by calling the `make` program. It will first compile the syntax extension used for all sources (presented at appendix D), and then compile the actual sources.

The following targets are available:

- `all` compiles all files (bytecode and native versions)
- `doc` generates ocaml doc documentations
- `tests` runs tests
- `clean` deletes all produced files (excluding documentation)
- `veryclean` deletes all produced files (including documentation)
- `install` copies executable and library files
- `generate` generates files needed for build
- `ocamljava` compiles all files (ocamljava version)

## 2.4 Installation

Finally, as shown in the previous section, the installation of Barista is done by calling `make install`. However, two important things should be noted about installation.

First, the actual installation path depends on whether `ocamlfind` is enabled: if so, every file will be installed in the `ocamlfind` hierarchy; otherwise, the library will be installed in the `.../lib/ocaml/barista` directory, and the program executables will be installed in the same directory as the OCaml compilers.

Second, to install the files to their final destination, the user may need to have to acquire privileged rights; this is usually done through the `sudo` command, leading to a full installation command of `sudo make install`.

## Chapter 3

# Using Barista as a command-line program

The Barista program exists under two or three forms: `barista.byte`, `barista.native`, and optionally `barista.jar`. The first one is an OCaml bytecode file, the second one is a native executable, and the third one is an executable jar file compiled only if the `ocamljava` compiler is present. All three programs should behave the same way, only differing in execution speed.

For convenience, at installation a symbolic link is created from `barista` to either `barista.native` or `barista.byte` in the installation directory. This allows one to only refer to `barista` in order to launch the faster version of the program.

Since version 2.0, Barista uses the concept of *subcommands* (as usually found *e.g.* in version management systems) to let the user indicate which action to perform. As natural in this kind of settings, the command-line switches recognized depend on the subcommand that is passed immediatly after the name of the executable. As an example, this means that invoking Barista to assemble a file is done by the following command line:

```
barista assemble source.j
```

The following sections presents the various available commands. All commands involving a classpath set by default this value to the value of the environment variable named `CLASSPATH` if it exists, to “.” (*a.k.a.* dot) otherwise.

### 3.1 The assemble subcommand (alias: `asm`)

Assembles (*i.e.* compiles) the passed assembler files into Java<sup>TM</sup> bytecode class files.

The `assemble` subcommand recognizes the following parameters:

- `-cp` `<path>` add to classpath
- `-classpath` `<colon-separated-list>` set classpath
- `-compute-stacks` computes stack elements (`max_locals`, `max_stacks`, and frames)
- `-d` `<path>` output path for generated class files

- `-destination` `<path>` output path for generated class files
- `-optimize` optimize bytecode
- `-target` target version for generated class files (possible values being: 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8)

### 3.2 The disassemble subcommand (alias: `dasm`)

Disassembles (*i.e.* decompiles) the passed Java<sup>TM</sup> bytecode class files into assembler files.

The `disassemble` subcommand recognizes the following parameters:

- `-cp` `<path>` add to classpath
- `-classpath` `<colon-separated-list>` set classpath

### 3.3 The flow subcommand

Prints onto the standard output the control flow of the passed methods. The output format is the dot format<sup>1</sup>. The passed methods should follow the format for method signatures as presented in chapter 4. As an example, printing the control flow for the `toString` method is done by the following command line:

```
barista flow 'java.lang.Object.toString():java.lang.String'
```

It is important to enclose the signature of the method inside quotes, as otherwise the shell would interpret the parentheses.

The `flow` subcommand recognizes the following parameters:

- `-cp` `<path>` add to classpath
- `-classpath` `<colon-separated-list>` set classpath

### 3.4 The print subcommand

Prints the contents of the passed Java<sup>TM</sup> bytecode class files onto the standard output.

The `print` subcommand recognizes the following parameters:

- `-cp` `<path>` add to classpath
- `-classpath` `<colon-separated-list>` set classpath

### 3.5 The version subcommand

Prints the current Barista version onto the standard output.

The `version` subcommand recognizes no parameter.

---

<sup>1</sup><http://www.graphviz.org/doc/info/lang.html>

## 3.6 The **help** subcommand

The **help** subcommand basically writes on the standard error stream all the information contained in the previous sections of this chapter.



## Chapter 4

# Programming in Barista assembler language

This chapter describes the format of the source files that the Barista assembler accepts. The very same format is used by the Barista disassembler as its output format. This makes it easy to disassemble a class, modify the disassembled source, and then reassemble it. Each file will be assembled to a single class file.

### 4.1 Lexical elements

The source files used by the Barista assembler are line-oriented (this means that source elements are analyzed line by line). Over a line, elements are whitespace-separated, meaning that whitespaces are meaningful. The different lexical elements are presented below.

**Comments** are introduced by the `#` (sharp) character and terminate at the end of the line.

**Assembler directives** are introduced by the `.` (dot) character followed by a non-empty sequence of lowercase letters or underscores *e.g.* `.class`.

**Element attributes** are introduced by the `@` (at) character followed by a non-empty capitalized sequence of letters *e.g.* `@ConstantValue`.

**Labels** are non-empty sequences of letters and digits beginning with a letter and ending with a colon *e.g.* `aLabel13:.`

**Integer constants** follow the OCaml conventions and thus support decimal notation (*e.g.* `15`), hexadecimal notation (*e.g.* `0x0F`), octal notation (*e.g.* `0o17`) and binary notation (*e.g.* `0b1111`). All notations support embedded underscore characters used for increased readability (such underscore characters are ignored). Integer constants can also be defined using the character notation (*e.g.* `'a'`); this notation supports escaped sequence for ASCII characters (*e.g.* `'\t'`, `'\n'`, or `'\\'`) as well as for Unicode character in short (*e.g.* `'\u1234'`) and long formats (*e.g.* `'\U12345678'`).

**Floating-point constants** follow the OCaml conventions and thus consist of three part: an integral part, a decimal part and an optional exponent part (*e.g.* `-1.234e+2`). As for integer constants, embedded underscore characters can be used for readability.

**String constants** are presented between " quotes, and support the escaped sequences presented for integer character constants *e.g.* `"abc\tdef"`.

**Class names** should be given in *external* format, that is using dots between packages/classes and dollars between inner classes (*e.g.* `pack.Cls$Inn` for an inner-class *Inn* of a class named *Cls* in package *pack*).

**Primitive names** should appear as they would be in a Java<sup>TM</sup> source file (*e.g.* `boolean`).

**Array types** are either a class name or a primitive type name followed by a non-empty list of square brackets [] pairs (*e.g.* `int[] []` or `java.lang.String[]`).

**Field references** are defined by a qualified field name followed by a colon and the field type (*e.g.* `java.lang.String.CASE_SENSITIVE_ORDER:java.util.Comparator`).

**Dynamic method references** are defined by an unqualified method name followed by the parameters between parentheses, then followed by a colon and the return type  
*e.g.* `toString():java.lang.String`.

**Method references** are defined by a qualified method name followed by the parameter types between parentheses, then followed by a colon and the return type  
*e.g.* `java.lang.Object.toString():java.lang.String` or `int[].toString():java.lang.String`.

**Method signatures** are defined by an unqualified method name followed by the parameter types between parentheses *e.g.* `toString()`.

**Method types** are defined by the parameter types between parentheses, then followed by a colon and the return type *e.g.* `(int,int):void`.

**Method handles** are defined by a prefix and a suffix separated by a % character. The prefix defines the kind of entity pointed by the handle, while the suffix defines an actual reference to the entity. The possible prefix/suffix combinations are:

- `getField` followed by a field reference;
- `getStatic` followed by a field reference;
- `putField` followed by a field reference;
- `putStatic` followed by a field reference;
- `invokeVirtual` followed by a method reference;
- `invokeStatic` followed by a method reference;



- `invokeSpecial` followed by a method reference;
- `newInvokeSpecial` followed by a method reference;
- `invokeInterface` followed by a method reference.

Examples:

- `getStatic%java.lang.String.CASE_SENSITIVE_ORDER:java.util.Comparator`
- `invokeVirtual%java.lang.Object.toString():java.lang.String`

**Identifiers** are non-empty sequences of letters and digits beginning with a letter *e.g.* `anIdent2`.

**Arrows** are simply the character sequence `=>`, and are used for the encoding of the `lookupswitch`, and `tableswitch` cases.

**Tildes** are simply the character `~`, and are used as a separator between stack elements and locals in stack frames.

## 4.2 Assembler directives

The assembler directives define the elements of a Java<sup>TM</sup> class as well as their main properties. They are used by the programmer to tell the assembler which elements are part of a class file. The different assembler directives are presented below.

### 4.2.1 The class directive

Written `.class flags name` where *flags* is a list of class flags<sup>1</sup> (among `public`, `final`, `super`, `interface`, `abstract`, `synthetic`, `annotation`, `enum`), and *name* is a fully qualified class name. This directive should be the first one of the source file.

### 4.2.2 The extends directive

Written `.extends name` where *name* is a fully qualified class name. This directive sets the class parent and should be present even if the parent is `java.lang.Object`; this directive may be missing if and only if the class defined by the source file has no parent (it should only be true for the `java.lang.Object` class).

### 4.2.3 The implements directive

Written `.implements name` where *name* is a fully qualified class name (that should be an interface).

---

<sup>1</sup>One should notice that flags discussed in this document are JVM-level flags, and not Java<sup>TM</sup> language-level flags. Hence the presence of flag that cannot occur in Java<sup>TM</sup> sources.

#### 4.2.4 The field directive

Written `.field flags type name` where *flags* is a list of field flags (among `public`, `private`, `protected`, `static`, `final`, `volatile`, `transient`, `synthetic`, `enum`), *type* is either a primitive, a fully qualified class name or an array type, and *name* is a field name. This directive adds a field to the class.

#### 4.2.5 The method directive

Written `.method flags returntype signature` where *flags* is a list of method class flags (among `public`, `private`, `protected`, `static`, `final`, `synchronized`, `bridge`, `varargs`, `native`, `abstract`, `strict`, `synthetic`), *returntype* is either a primitive, a fully qualified class name, or an array type, and *signature* is a method signature. This directive adds a method to the class.

#### 4.2.6 The max\_stack directive

Written `.max_stack n` where *n* is an integer in the interval from 0 to 65535 (both inclusive). This directive sets the maximum stack size for the current method.

#### 4.2.7 The max\_locals directive

Written `.max_locals n` where *n* is an integer in the interval from 0 to 65535 (both inclusive). This directive sets the maximum local size for the current method.

#### 4.2.8 The catch directive

Written `.catch start end handler [name]` where *start*, *end* and *handler* are labels referring to respectively the begin and the end of the protected code area, and to the associated exception handler. The optional *name* is a fully qualified class name giving the name of the exception class to be handled by the code located at handler label; if this name is missing, all exceptions will be caught.

#### 4.2.9 The frame directive

Written `.frame l def` where *l* is the label where the frame definition *def* applies. This directive allows to specify elements for the `StackMapFrame` attributes of the class file. The frame definition (noted *def* above) can take of of the following forms:

- `same` to indicate that the frame definition is the same as the previous one;
- `same_locals t` to indicate that the frame definition is the same as the previous one regarding locals and has one element on the stack whose type is *t*;
- `chop n` to indicate that the frame definition is the same as the previous one, chopped by *n* elements (*n* should be 1, 2, or 3);
- `append t1 [t2 [t3]]` indicate that the frame definition is the same as the previous one, with one to three elements appended (whose types are given by the *t<sub>i</sub>*);
- `full t1 ... tn ~ t'1 ... t'm` to define a frame with no reference to the previous one, the *t<sub>i</sub>* are the types for locals while the *t'<sub>j</sub>* ones are the types for stack elements (the tilde symbol separating the two lists);

The  $t$ ,  $t_i$ , and  $t'_j$  are type definitions whose possible values are:

- `top` for the *top* type;
- `int` for the `int` type;
- `float` for the `float` type;
- `long` for the `long` type;
- `double` for the `double` type;
- `null` for the type associated to the *null* value;
- `uninit_this` for the uninitialized *this* reference;
- `uninit l` for an uninitialized reference whose related `new` instruction is located at the offset given by label  $l$ ;
- a fully-qualified class name for the type associated to this class.

## 4.3 Attributes

The assembler attributes define the properties of a Java<sup>TM</sup> element. An attribute is applied to the latest defined Java<sup>TM</sup> element by a `.class`, `.field` or `.method` directive. (one should notice that some attributes are only used inside a given element kind). The different elements attributes are presented below.

### 4.3.1 The ConstantValue attribute

Written `@ConstantValue value` (for fields only), it defines the initial value of the field. *value* should be compatible with the field type and can be a float, an integer or a string. A `false` boolean is coded by a 0 integer while every other values code a `true` boolean

### 4.3.2 The Exceptions attribute

Written `@Exceptions non-empty-list` (for methods only), it defines the list of exceptions (as fully qualified class names) that the method can throw

### 4.3.3 The InnerClasses attribute

Written `@InnerClasses ic oc n flags` (for classes only), it adds an inner-class information. *ic* is the fully qualified name of the inner-class (or 0 if this information is missing), *oc* is the fully qualified name of the outer-class (or 0 if this information is missing), *n* is the name of the inner-class in the outer-class (or 0 if this information is missing), *flags* is a list of inner-class flags (among `public`, `private`, `protected`, `static`, `final`, `super`, `interface`, `abstract`, `synthetic`, `annotation`, `enum`)

### 4.3.4 The EnclosingMethod attribute

Written `@EnclosingMethod name meth` (for classes only), it adds an enclosing-method information. *name* is the fully qualified name of the enclosed class, *meth* is the enclosing method specified as a dynamic method (or 0 if this information is missing)

#### 4.3.5 The Synthetic attribute

Written `@Synthetic` (for classes, fields, and methods), it marks the element as synthetic (*i.e.* compiler-generated)

#### 4.3.6 The Signature attribute

Written `@Signature` *string* (for classes, fields, and methods), it sets the signature of the element

#### 4.3.7 The SourceFile attribute

Written `@SourceFile` *string* (for classes only), it sets the source file name

#### 4.3.8 The SourceDebugExtension attribute

Written `@SourceDebugExtension` *string* (for classes only), it sets the source debug extension

#### 4.3.9 The Deprecated attribute

Written `@Deprecated` (for classes, fields, and methods), it marks the element as deprecated

#### 4.3.10 The RuntimeVisibleAnnotations attribute

Written `@RuntimeVisibleAnnotations` *elems* (for classes, fields, and methods), it adds an annotation to the element (the format of annotations is discussed below)

#### 4.3.11 The RuntimeInvisibleAnnotations attribute

Written `@RuntimeInvisibleAnnotations` *elems* (for classes, fields, and methods), it adds an annotation to the element (the format of annotations is discussed below)

#### 4.3.12 The RuntimeVisibleParameterAnnotations attribute

Written `@RuntimeVisibleParameterAnnotations` *n elems* (for methods only), it adds an annotation to the element for the parameter at index *n* (the format of annotations is discussed below)

#### 4.3.13 The RuntimeInvisibleParameterAnnotations attribute

Written `@RuntimeInvisibleParameterAnnotations` *n elems* (for methods only), it adds an annotation to the element for the parameter at index *n* (the format of annotations is discussed below)

#### 4.3.14 The AnnotationDefault attribute

Written `@AnnotationDefault` *elems* (for methods only), it adds an annotation default to the element (the format of annotation defaults is discussed below)

#### 4.3.15 The LineNumberTable attribute

Written `@LineNumberTable [n]` (for methods only), it maps the current code offset to a line number. The line number is *n* if provided, otherwise it is the current line of the Barista source file

#### 4.3.16 The LocalVariableTable attribute

Written `@LocalVariableTable start end id t idx` (for methods only), it adds a type information for a local variable. *id* and *t* are the variable identifier and type, *idx* is its position in the locals, and *start* (inclusive) and *end* (exclusive) are labels defining the portion of code where this variable is defined

#### 4.3.17 The LocalVariableTypeTable attribute

Written `@LocalVariableTypeTable start end id s idx` (for methods only), it adds a type information for a local variable. *id* and *s* are the variable identifier and signature, *idx* is its position in the locals, and *start* (inclusive) and *end* (exclusive) are labels defining the portion of code where this variable is defined

#### 4.3.18 The Unknown attribute

Written `@Unknown string1 string2` (for classes, fields, and methods), it adds an unknown (*i.e.* implementation-dependent) attributes to the element. *string1* is the identifier of the attribute while *string2* is its value

### 4.4 Annotations

Annotations with their key-value attributes and possibly embedded annotations form a tree-like structure. The Barista assembler sources being line-oriented, annotations are organized in a way such that lines with the same prefix gives informations for the same subtree.

On a line defining an annotation, the first element should be the class of the annotation. This fully qualified class name is followed by the key identifier and its associated value. The value is itself a couple; the first component is the value type while the second component is the actual value. Code sample 2 shows an annotation (whose class is `pack.AnnotationClass`) with two parameters:

- parameter *a* whose type is *string* and value "xyz";
- parameter *b* whose type is *float* and value 3.14.

---

#### Code sample 2 Annotation example.

---

```
@RuntimeVisibleAnnotation pack.AnnotationClass a string "xzy"
@RuntimeVisibleAnnotation pack.AnnotationClass b float 3.14
```

---

The possible types for an annotation attribute are the Java<sup>TM</sup> primitive types, extended with the following ones:

- **string** for string values (using the format of string constants discussed above);
- **enum** for enum values (defined by the fully qualified name of the enum class followed by the identifier of the enum value);
- **class** for reference to a given class (followed by the fully qualified name of the class);
- **annotation** for embedded annotation (followed by an annotation value using the format explained in this very section);
- an array is not introduced by any keyword, each value being introduced by its index<sup>2</sup> (as an integer). The type of each embedded element should be repeated.

Code sample 3 shows the previous annotation enriched with three values:

- parameter `c` whose type is *array* and value is a two-element array containing 5 and 7;
- parameter `d` whose type is *annotation* and value `java.lang.Deprecated`;
- parameter `e` whose type is *enum* and value `pack.EnumClass.E1`.

---

**Code sample 3** Annotation example.

---

```
@RuntimeVisibleAnnotation pack.AnnotationClass a string "xyz"  
@RuntimeVisibleAnnotation pack.AnnotationClass b float 3.14  
@RuntimeVisibleAnnotation pack.AnnotationClass c 0 int 5  
@RuntimeVisibleAnnotation pack.AnnotationClass c 1 int 7  
@RuntimeVisibleAnnotation pack.AnnotationClass d annotation java.lang.Deprecated  
@RuntimeVisibleAnnotation pack.AnnotationClass e enum pack.EnumClass E1
```

---

## 4.5 Annotation defaults

Annotation defaults closely follow the notation used for annotation, except that leading annotation class name as well as attribute name should be omitted. Code sample 4 defines an annotation default whose value is the "xyz" string.

---

**Code sample 4** Annotation default example.

---

```
@AnnotationDefault string "xyz"
```

---

---

<sup>2</sup>These indexes do not need to be successive, they are only used to sort the values in order to produce the array.

## 4.6 Instructions

Instructions may, of course, be used only inside methods. An instruction line may contain either a label, or an instruction (along with its parameters), or both. One should refer to the JVM specification for the list of available instructions; this specification also defines the parameters waited by each instruction. The translation of parameters from the specification to their Barista counterpart is straightforward and only detailed in the appendix (one may also read examples and tests cases for samples). When using the *wide* version of an instruction, one has to use the **wide** keyword before the instruction.

### 4.6.1 The switch instructions

Almost all instructions are declared on one line but *switch* instructions are multi-line ones. Code sample 5 shows the syntax used by the **tableswitch** and **lookupswitch** instructions. A **tableswitch** instruction accepts three parameters: a label, and lower and upper bounds. The label is the destination for the default case; the following lines define the destination for the lower bound, the lower bound plus one, and so on until the upper bound.

A **lookupswitch** instruction accepts two parameters: a label and a number of matchings. The label is the destination for the default case; the following lines define the matchings in the *value => label* form.

---

**Code sample 5** Switch examples.

---

```
tableswitch default: 0 2
    => zero:
    => one:
    => two:

lookupswitch default: 3
    0 => zero:
    1 => one:
    2 => two:
```

---

### 4.6.2 The invokedynamic instruction

The **invokedynamic** instruction is also different from the other ones. Although it is written on one single line, it is particular because unlike others it accepts a variable number of arguments.

$$\text{invokedynamic } bsm \ bsa_0 \dots bsa_n \ mr$$

where:

- *bsm* is a method handle to the bootstrap method;
- *bsa<sub>i</sub>* are arguments to the bootstrap method;
- *mr* is the method reference to be actually invoked.

## 4.7 Example

Code sample [6](#) shows an example of a Barista source file coding a Java<sup>™</sup> class named `pack.Test`. This class contains two fields (the constants named `PREFIX` and `SUFFIX`) as well as two methods (`print` and `main`). The `main` method prints the classical hello world message and then iterates over the elements of the passed string array by applying the `print` method to each element. In turn, the `print` method prints each string with the prefix and suffix specified by the `PREFIX` and `SUFFIX` field values.



---

**Code sample 6** Example of a Barista-coded class file.
 

---

```
.class public final pack.Test
.extends java.lang.Object

.field private static final java.lang.String PREFIX
    @ConstantValue " - << "

.field private static final java.lang.String SUFFIX
    @ConstantValue " >>"

.method public static void print(java.lang.String)
    getstatic java.lang.System.out:java.io.PrintStream
    dup
    dup
    getstatic pack.Test.PREFIX: java.lang.String
    invokevirtual java.io.PrintStream.print(java.lang.String): void
    aload_0
    invokevirtual java.io.PrintStream.print(java.lang.String) :void
    getstatic pack.Test.SUFFIX :java.lang.String
    invokevirtual java.io.PrintStream.println(java.lang.String) : void
    return

.method public static void main(java.lang.String[])
    nop
    getstatic java.lang.System.out : java.io.PrintStream
    ldc "hello\t... \n\t... \"world\""
    invokevirtual java.io.PrintStream.println(java.lang.String):void

    iconst_0
    istore_1
    aload_0
    arraylength
    istore_2
loop:
    iload_1
    iload_2
    if_icmpeq end:
    aload_0
    iload_1
    aaload
    invokestatic pack.Test.print(java.lang.String):void
    iinc 1 1
    goto loop:
end:
    return
```

---



## Chapter 5

# Using Barista as an OCaml library

This chapter sheds light on the way the Barista library is organized, and its main modules. First, it explain how to compile a Barista-based application. Then, the library contents is explored. Finally, a complete example demonstrates a practical use of the library.

### 5.1 Compilation

In order to use Barista as a library, it is sufficient to link the program with either `baristaLibrary.cma` (bytecode version), `baristaLibrary.cmxa` (native version), or `baristaLibrary.cmja` (Java<sup>TM</sup>-compiled version). These libraries are crafted in such a way that there is only one top-level module called `BaristaLibrary` that contains all the modules described by the `ocamldoc`-generated documentation.

As there are two ways to install Barista (classical installation, and `ocamlfind`-based installation), there are two ways to compile a program which are explained in the following two section.

#### 5.1.1 Under *classical* installation

In order to compile the source files presented in this chapter, one of the following commands should be used (where “`source.ml`” is the program to be compiled):

- `ocamlc -I +barista -I +zip bigarray.cma camomile.cma unix.cma zip.cma str.cma baristaLibrary.cma source.ml`
- `ocamlopt -I +barista -I +zip bigarray.cmxa camomile.cmxa unix.cmxa zip.cmxa str.cmxa baristaLibrary.cmxa source.ml`
- `ocamljava -I +barista -I +zip bigarray.cmja camomile.cmja unix.cmja zip.cmja str.cmja baristaLibrary.cmja source.ml`

#### 5.1.2 Under `ocamlfind` installation

In order to compile the source files presented in this chapter, one of the following commands should be used:

- `ocamlfind ocamlc -package bigarray,unix,str,camomile,zip,barista source.ml`

- `ocamlfind ocamlpt -package bigarray,unix,str,camomile,zip,barista source.ml`
- `ocamlfind ocamljava -package bigarray,unix,str,camomile,zip,barista source.ml`

## 5.2 Overview of the library

### 5.2.1 Organization of the source base

Although all modules are packed into one, namely `BaristaLibrary`, the source directory is organized in subdirectories corresponding to the areas covered by the library.

These directories are:

- `common` that contains various utility modules of general use;
- `helpers` that contains various utility modules for lexing and class loading;
- `classfile` that contains the modules defining class files;
- `analysis` that contains some modules for both analysis and optimization of bytecode;
- `commands`, and `driver` that contain the definition of command-line subcommands and the definition of main program;
- `tools` that contains the actual implementation of command-line subcommands;
- `utf8` that contains a Camomile-based UTF8 implementation.

### 5.2.2 Description of the main modules

The complete documentation for the library can be generated by issuing `make doc` after a successful compilation; the produced documentation is located in the `ocamldoc` subdirectory. The remainder of this section provides a quick overview of the main modules in the different areas.

The main utility modules in `common` are:

- `Utils` providing Unicode functions (based on the Camomile library);
- `InputStream` providing various implementation of input streams;
- `OutputStream` providing various implementation of output streams;
- `Consts` providing the Unicode constants for the whole project.

The main utility modules in `helpers` are:

- `ClassPath` providing definition for a classpath;
- `ClassLoader` providing functions for loading class, package, and module files.

The main utility modules in `classfile` are:

- `Name` defines the names for the various kinds of Java<sup>TM</sup> elements;

- **Descriptor** defines the descriptors (*i.e.* type informations) for the various kinds of Java<sup>TM</sup> elements;
- **Signature** defines the signature (*i.e.* type informations for *generic* types) for the various kinds of Java<sup>TM</sup> elements;
- **AccessFlag** defines the access flags for the various kinds of Java<sup>TM</sup> elements;
- **ConstantPool** defines the constant pools used for decoding/encoding of class files.

Additionally, other modules provide types representing the class file elements. Each class file element comes in two flavours: a low-level form (as close as possible to the class file format) and a high-level form (as expressive as can be). Table 5.1 gives the types for these elements.

Element	Low-level form	High-level form
Annotations	Annotation.info	Annotation.t
Attributes	Attribute.info	Attribute.t
Instructions	ByteCode.t	Instruction.t
Fields	Field.info	Field.t
Methods	Method.info	Method.t
Classes	ClassFile.t	ClassDefinition.t
Packages	ClassFile.t	PackageDefinition.t
Modules	ClassFile.t	ModuleDefinition.t

Table 5.1: Mapping of Java<sup>TM</sup> elements to Barista types.

The main utility modules in **analysis** are:

- **StackState** providing manipulation of locals and operand stacks;
- **ControlFlow** providing construction of the (hyper-)graph representing the control flow of a method;
- **Peephole** providing rewriting rules for *peephole* of instruction list in a control flow graph;
- **Code** providing various functions working on a control flow graph (*e.g.* computation of stack elements, that is `max_locals`, `max_stack`, and stack frames).

The main utility modules in **tools** are:

- **Assembler** providing the function called by the `assemble` subcommand;
- **ClassPrinter** providing the function called by the `print` subcommand;
- **Disassembler** providing the function called by the `disassemble` subcommand;
- **FlowPrinter** providing the function called by the `flow` subcommand.

### 5.3 Complete example

Code sample 7 shows an example of an OCaml program using Barista to produce a file named `Hello.class` containing the definition of a class named `example.Hello`. This class contains only a `main` method that prints “hello.” on the standard output.

Here are the key points of this example, in the order they appear in the source file:

- first, the Barista library and its `Utils` is open (the latter is especially useful to get access to the UTF8-related modules);
- then, some abbreviations are given to functions building UTF8 strings and class, field, and method names;
- from these shorthands, some constants denoting class field and methods are defined;
- `instructions` is bound to what will actually be executed by the `main` method of the class;
- `code` encapsulates `instructions`, as well as stack/local limits and possible exception table and attributes;
- `main_method` is defined as would be in a Java<sup>TM</sup> source file: flags, name, descriptor (*i.e.* signature), and attributes (here only its code);
- at this point, it is possible to build an actual class definition from flags, name, parent class, parent interfaces, embedded fields, embedded methods, and attributes;
- finally, the class definition is converted into a class file that is written to the file `‘Hello.class’`.

---

**Code sample 7** Using Barista to produce a class file from an OCaml program.

---

```

open BaristaLibrary
open Utils

let utf8 = UTF8.of_string
let utf8_for_class x = Name.make_for_class_from_external (utf8 x)
let utf8_for_field x = Name.make_for_field (utf8 x)
let utf8_for_method x = Name.make_for_method (utf8 x)

let example_Hello = utf8_for_class "example.Hello"
let java_lang_Object = utf8_for_class "java.lang.Object"
let java_lang_System = utf8_for_class "java.lang.System"
let java_lang_String = utf8_for_class "java.lang.String"
let java_io_PrintStream = utf8_for_class "java.io.PrintStream"
let out = utf8_for_field "out"
let println = utf8_for_method "println"
let main = utf8_for_method "main"

let () =
  let instructions = [
    Instruction.GETSTATIC (java_lang_System, out, 'Class java_io_PrintStream);
    Instruction.LDC ('String (utf8 "hello.");');
    Instruction.INVOKEVIRTUAL ('Class_or_interface java_io_PrintStream,
                              println,
                              ([ 'Class java_lang_String ], 'Void));
    Instruction.RETURN;
  ] in
  let code = {
    Attribute.max_stack = u2 2;
    Attribute.max_locals = u2 1;
    Attribute.code = instructions;
    Attribute.exception_table = [];
    Attribute.attributes = [];
  } in
  let main_method =
    Method.Regular { Method.flags = ['Public; 'Static];
                     Method.name = main;
                     Method.descriptor = ['Array ('Class java_lang_String)], 'Void;
                     Method.attributes = ['Code code] } in

  let hello = {
    ClassDefinition.access_flags = ['Public; 'Super];
    ClassDefinition.name = example_Hello;
    ClassDefinition.extends = Some java_lang_Object;
    ClassDefinition.implements = [];
    ClassDefinition.fields = [];
    ClassDefinition.methods = [main_method];
    ClassDefinition.attributes = [];
  } in
  let cf = ClassDefinition.encode hello in
  ClassFile.write cf (OutputStream.make_of_channel (open_out "Hello.class"))

```

---





## Appendix A

# Instructions and related parameters

This appendix summarizes, in alphabetical order, the instructions recognized by the Barista assembler. For a complete description, one should refer to the JVM documentation provided by Oracle<sup>®</sup>.

For various examples of actual uses, one is advised to check either the samples in the **examples** subdirectory, or the sources used as unit tests (they can be found in the **tests** subdirectory of the Barista source distribution).

---

**aaload** — load reference from array

*opcode: 0x32*

*no parameter*

---

---

**aastore** — store into reference array

*opcode: 0x53*

*no parameter*

---

---

**aconst\_null** — push null

*opcode: 0x01*

*no parameter*

---

---

**aload** — load reference from local variable

*opcode: 0x19*

*parameter #1: local index (unsigned 8-bit integer)*

---

---

**aload\_0** — load reference from local variable

*opcode:* 0x2A

*no parameter*

---

---

**aload\_1** — load reference from local variable

*opcode:* 0x2B

*no parameter*

---

---

**aload\_2** — load reference from local variable

*opcode:* 0x2C

*no parameter*

---

---

**aload\_3** — load reference from local variable

*opcode:* 0x2D

*no parameter*

---

---

**anewarray** — create new array of references

*opcode:* 0xBD

*parameter #1:* element type (class name, or array type)

---

---

**areturn** — return reference from method

*opcode:* 0xB0

*no parameter*

---

---

**arraylength** — get length of array

*opcode:* 0xBE

*no parameter*

---

---

**astore** — store reference into local variable

*opcode:* 0x3A

*parameter #1:* local index (unsigned 8-bit integer)

---

---

**astore\_0** — store reference into local variable

*opcode: 0x4B*

*no parameter*

---

---

**astore\_1** — store reference into local variable

*opcode: 0x4C*

*no parameter*

---

---

**astore\_2** — store reference into local variable

*opcode: 0x4D*

*no parameter*

---

---

**astore\_3** — store reference into local variable

*opcode: 0x4E*

*no parameter*

---

---

**athrow** — throw exception or error

*opcode: 0xBF*

*no parameter*

---

---

**baload** — load byte or boolean from array

*opcode: 0x33*

*no parameter*

---

---

**bastore** — store into byte or boolean array

*opcode: 0x54*

*no parameter*

---

---

**bipush** — push byte

*opcode: 0x10*

*parameter #1: byte value (signed 8-bit integer)*

---

---

**caload** — load char from array

*opcode: 0x34*

*no parameter*

---

---

**castore** — store into char array

*opcode: 0x55*

*no parameter*

---

---

**checkcast** — check whether object is of given type

*opcode: 0xC0*

*parameter #1: type to test against (class name, or array type)*

---

---

**d2f** — convert double to float

*opcode: 0x90*

*no parameter*

---

---

**d2i** — convert double to int

*opcode: 0x8E*

*no parameter*

---

---

**d2l** — convert double to long

*opcode: 0x8F*

*no parameter*

---

---

**dadd** — add double

*opcode: 0x63*

*no parameter*

---

---

**daload** — load double from array

*opcode: 0x31*

*no parameter*

---

---

**dastore** — store into double array

*opcode: 0x52*

*no parameter*

---

---

**dcmpg** — compare double

*opcode: 0x98*

*no parameter*

---

---

**dcmpl** — compare double

*opcode: 0x97*

*no parameter*

---

---

**dconst\_0** — push double

*opcode: 0x0E*

*no parameter*

---

---

**dconst\_1** — push double

*opcode: 0x0F*

*no parameter*

---

---

**ddiv** — divide double

*opcode: 0x6F*

*no parameter*

---

---

**dload** — load double from local variable

*opcode: 0x18*

*parameter #1: local index (unsigned 8-bit integer)*

---

---

**dload\_0** — load double from local variable

*opcode: 0x26*

*no parameter*

---

---

**dload\_1** — load double from local variable

*opcode: 0x27*

*no parameter*

---

---

**dload\_2** — load double from local variable

*opcode: 0x28*

*no parameter*

---

---

**dload\_3** — load double from local variable

*opcode: 0x29*

*no parameter*

---

---

**dmul** — multiply double

*opcode: 0x6B*

*no parameter*

---

---

**dneg** — negate double

*opcode: 0x77*

*no parameter*

---

---

**drem** — remainder double

*opcode: 0x73*

*no parameter*

---

---

**dreturn** — return double from method

*opcode: 0xAF*

*no parameter*

---

---

**dstore** — store double into local variable

*opcode: 0x39*

*parameter #1: local index (unsigned 8-bit integer)*

---

---

**dstore\_0** — store double into local variable

*opcode: 0x47*

*no parameter*

---

---

**dstore\_1** — store double into local variable

*opcode: 0x48*

*no parameter*

---

---

**dstore\_2** — store double into local variable

*opcode: 0x49*

*no parameter*

---

---

**dstore\_3** — store double into local variable

*opcode: 0x4A*

*no parameter*

---

---

**dsub** — subtract double

*opcode: 0x67*

*no parameter*

---

---

**dup** — duplicate the top operand stack value

*opcode: 0x59*

*no parameter*

---

---

**dup2** — duplicate the top one or two operand stack values

*opcode: 0x5C*

*no parameter*

---

---

**dup2\_x1** — duplicate the top one or two operand stack values and insert two or three values down

*opcode:* 0x5D

*no parameter*

---

---

**dup2\_x2** — duplicate the top one or two operand stack values and insert two, three, or four values down

*opcode:* 0x5E

*no parameter*

---

---

**dup\_x1** — duplicate the top operand stack value and insert two values down

*opcode:* 0x5A

*no parameter*

---

---

**dup\_x2** — duplicate the top operand stack value and insert two or three values down

*opcode:* 0x5B

*no parameter*

---

---

**f2d** — convert float to double

*opcode:* 0x8D

*no parameter*

---

---

**f2i** — convert float to int

*opcode:* 0x8B

*no parameter*

---

---

**f2l** — convert float to long

*opcode:* 0x8C

*no parameter*

---



---

**fadd** — add float

*opcode: 0x62*

*no parameter*

---

---

**faload** — load float from array

*opcode: 0x30*

*no parameter*

---

---

**fastore** — store into float array

*opcode: 0x51*

*no parameter*

---

---

**fcmpg** — compare float

*opcode: 0x96*

*no parameter*

---

---

**fcmpl** — compare float

*opcode: 0x95*

*no parameter*

---

---

**fconst\_0** — push float

*opcode: 0x0B*

*no parameter*

---

---

**fconst\_1** — push float

*opcode: 0x0C*

*no parameter*

---

---

**fconst\_2** — push float

*opcode: 0x0D*

*no parameter*

---

---

**fdiv** — divide float

*opcode:* 0x6E

*no parameter*

---

---

**fload** — load float from local variable

*opcode:* 0x17

*parameter #1:* local index (unsigned 8-bit integer)

---

---

**fload\_0** — load float from local variable

*opcode:* 0x22

*no parameter*

---

---

**fload\_1** — load float from local variable

*opcode:* 0x23

*no parameter*

---

---

**fload\_2** — load float from local variable

*opcode:* 0x24

*no parameter*

---

---

**fload\_3** — load float from local variable

*opcode:* 0x25

*no parameter*

---

---

**fmul** — multiply float

*opcode:* 0x6A

*no parameter*

---

---

**fneg** — negate float

*opcode:* 0x76

*no parameter*

---

---

**frem** — remainder float

*opcode: 0x72*

*no parameter*

---

---

**freturn** — return float from method

*opcode: 0xAE*

*no parameter*

---

---

**fstore** — store float into local variable

*opcode: 0x38*

*parameter #1: local index (unsigned 8-bit integer)*

---

---

**fstore\_0** — store float into local variable

*opcode: 0x43*

*no parameter*

---

---

**fstore\_1** — store float into local variable

*opcode: 0x44*

*no parameter*

---

---

**fstore\_2** — store float into local variable

*opcode: 0x45*

*no parameter*

---

---

**fstore\_3** — store float into local variable

*opcode: 0x46*

*no parameter*

---

---

**fsub** — subtract float

*opcode: 0x66*

*no parameter*

---

---

**getfield** — fetch field from object

*opcode:* 0xB4

*parameter #1:* field to get (field reference)

---

---

**getstatic** — get static field from class

*opcode:* 0xB2

*parameter #1:* field to get (field reference)

---

---

**goto** — branch always

*opcode:* 0xA7

*parameter #1:* destination offset (label)

---

---

**goto\_w** — branch always

*opcode:* 0xC8

*parameter #1:* destination offset (label)

---

---

**i2b** — convert int to byte

*opcode:* 0x91

*no parameter*

---

---

**i2c** — convert int to char

*opcode:* 0x92

*no parameter*

---

---

**i2d** — convert int to double

*opcode:* 0x87

*no parameter*

---

---

**i2f** — convert int to float

*opcode:* 0x86

*no parameter*

---

---

**i2l** — convert int to long

*opcode: 0x85*

*no parameter*

---

---

**i2s** — convert int to short

*opcode: 0x93*

*no parameter*

---

---

**iadd** — add int

*opcode: 0x60*

*no parameter*

---

---

**iaload** — load int from array

*opcode: 0x2E*

*no parameter*

---

---

**iand** — boolean AND int

*opcode: 0x7E*

*no parameter*

---

---

**iastore** — store into int array

*opcode: 0x4F*

*no parameter*

---

---

**iconst\_0** — push int constant

*opcode: 0x03*

*no parameter*

---

---

**iconst\_1** — push int constant

*opcode: 0x04*

*no parameter*

---

---

**iconst\_2** — push int constant

*opcode:* 0x05

*no parameter*

---

---

**iconst\_3** — push int constant

*opcode:* 0x06

*no parameter*

---

---

**iconst\_4** — push int constant

*opcode:* 0x07

*no parameter*

---

---

**iconst\_5** — push int constant

*opcode:* 0x08

*no parameter*

---

---

**iconst\_m1** — push int constant

*opcode:* 0x02

*no parameter*

---

---

**idiv** — divide int

*opcode:* 0x6C

*no parameter*

---

---

**if\_acmp<sub>eq</sub>** — branch if reference comparison succeeds

*opcode:* 0xA5

*parameter #1:* destination offset (label)

---

---

**if\_acmp<sub>pne</sub>** — branch if reference comparison succeeds

*opcode:* 0xA6

*parameter #1:* destination offset (label)

---

---

**if\_icmpeq** — branch if int comparison succeeds

*opcode:* 0x9F

*parameter #1:* destination offset (label)

---

---

**if\_icmpge** — branch if int comparison succeeds

*opcode:* 0xA2

*parameter #1:* destination offset (label)

---

---

**if\_icmpgt** — branch if int comparison succeeds

*opcode:* 0xA3

*parameter #1:* destination offset (label)

---

---

**if\_icmple** — branch if int comparison succeeds

*opcode:* 0xA4

*parameter #1:* destination offset (label)

---

---

**if\_icmplt** — branch if int comparison succeeds

*opcode:* 0xA1

*parameter #1:* destination offset (label)

---

---

**if\_icmpne** — branch if int comparison succeeds

*opcode:* 0xA0

*parameter #1:* destination offset (label)

---

---

**ifeq** — branch if int comparison with zero succeeds

*opcode:* 0x99

*parameter #1:* destination offset (label)

---

---

**ifge** — branch if int comparison with zero succeeds

*opcode:* 0x9C

*parameter #1:* destination offset (label)

---

---

**ifgt** — branch if int comparison with zero succeeds

*opcode:* 0x9D

*parameter #1:* destination offset (label)

---

---

**ifle** — branch if int comparison with zero succeeds

*opcode:* 0x9E

*parameter #1:* destination offset (label)

---

---

**iflt** — branch if int comparison with zero succeeds

*opcode:* 0x9B

*parameter #1:* destination offset (label)

---

---

**ifne** — branch if int comparison with zero succeeds

*opcode:* 0x9A

*parameter #1:* destination offset (label)

---

---

**ifnonnull** — branch if reference not null

*opcode:* 0xC7

*parameter #1:* destination offset (label)

---

---

**ifnull** — branch if reference not null

*opcode:* 0xC6

*parameter #1:* destination offset (label)

---

---

**inc** — increment local variable by constant

*opcode:* 0x84

*parameter #1:* local index (unsigned 8-bit integer)

*parameter #2:* increment value (signed 8-bit integer)

---



---

**iload** — load int from local variable  
*opcode:* 0x15  
*parameter #1:* local index (unsigned 8-bit integer)

---

---

**iload\_0** — load int from local variable  
*opcode:* 0x1A  
*no parameter*

---

---

**iload\_1** — load int from local variable  
*opcode:* 0x1B  
*no parameter*

---

---

**iload\_2** — load int from local variable  
*opcode:* 0x1C  
*no parameter*

---

---

**iload\_3** — load int from local variable  
*opcode:* 0x1D  
*no parameter*

---

---

**imul** — multiply int  
*opcode:* 0x68  
*no parameter*

---

---

**ineg** — negate int  
*opcode:* 0x74  
*no parameter*

---

---

**instanceof** — determine if object is of given type  
*opcode:* 0xC1  
*parameter #1:* type to test against (class name, or array type)

---

---

**invokedynamic** — invoke instance method; resolve and dispatch based on class

*opcode:* 0xBA

*parameter #1:* method to invoke (dynamic method reference)

---

---

**invokeinterface** — invoke interface method

*opcode:* 0xB9

*parameter #1:* method to invoke (method reference)

*parameter #2:* parameter count (unsigned 8-bit integer)

---

---

**invokespecial** — invoke instance method; special handling for superclass, private, and instance initialization method invocations

*opcode:* 0xB7

*parameter #1:* method to invoke (method reference)

---

---

**invokestatic** — invoke a class (static) method

*opcode:* 0xB8

*parameter #1:* method to invoke (method reference)

---

---

**invokevirtual** — invoke instance method; dispatch based on class

*opcode:* 0xB6

*parameter #1:* method to invoke (method reference)

---

---

**ior** — boolean OR int

*opcode:* 0x80

*no parameter*

---

---

**irem** — remainder int

*opcode:* 0x70

*no parameter*

---

**ireturn** — return int from method

*opcode: 0xAC*

*no parameter*

---

**ishl** — shift left int

*opcode: 0x78*

*no parameter*

---

**ishr** — arithmetic shift right int

*opcode: 0x7A*

*no parameter*

---

**istore** — store int into local variable

*opcode: 0x36*

*parameter #1: local index (unsigned 8-bit integer)*

---

**istore\_0** — store int into local variable

*opcode: 0x3B*

*no parameter*

---

**istore\_1** — store int into local variable

*opcode: 0x3C*

*no parameter*

---

**istore\_2** — store int into local variable

*opcode: 0x3D*

*no parameter*

---

**istore\_3** — store int into local variable

*opcode: 0x3E*

*no parameter*

---

---

**isub** — subtract int

*opcode: 0x64*

*no parameter*

---

---

**iushr** — logical shift right int

*opcode: 0x7C*

*no parameter*

---

---

**ixor** — boolean XOR int

*opcode: 0x82*

*no parameter*

---

---

**jsr** — jump subroutine

*opcode: 0xA8*

*parameter #1: destination offset (label)*

---

---

**jsr\_w** — jump subroutine (wide index)

*opcode: 0xC9*

*parameter #1: destination offset (label)*

---

---

**l2d** — convert long to double

*opcode: 0x8A*

*no parameter*

---

---

**l2f** — convert long to float

*opcode: 0x89*

*no parameter*

---

---

**l2i** — convert long to int

*opcode: 0x88*

*no parameter*

---

---

**ladd** — add long

*opcode: 0x61*

*no parameter*

---

---

**laload** — load long from array

*opcode: 0x2F*

*no parameter*

---

---

**land** — boolean AND long

*opcode: 0x7F*

*no parameter*

---

---

**lastore** — store into long array

*opcode: 0x50*

*no parameter*

---

---

**lcmp** — compare long

*opcode: 0x94*

*no parameter*

---

---

**lconst\_0** — push long constant

*opcode: 0x09*

*no parameter*

---

---

**lconst\_1** — push long constant

*opcode: 0x0A*

*no parameter*

---

---

**ldc** — push item from runtime constant pool

*opcode:* 0x12

*parameter #1:* value to be pushed (signed 32-bit integer, or float, or string literal, or class name, or array type, or method type constant, or method handle constant)

---

---

**ldc2\_w** — push long or double from runtime constant pool (wide index)

*opcode:* 0x14

*parameter #1:* value to be pushed (signed 64-bit integer, or float)

---

---

**ldc\_w** — push item from runtime constant pool (wide index)

*opcode:* 0x13

*parameter #1:* value to be pushed (signed 32-bit integer, or float, or string literal, or class name, or array type, or method type constant, or method handle constant)

---

---

**ldiv** — divide long

*opcode:* 0x6D

*no parameter*

---

---

**lload** — load long from local variable

*opcode:* 0x16

*parameter #1:* local index (unsigned 8-bit integer)

---

---

**lload\_0** — load long from local variable

*opcode:* 0x1E

*no parameter*

---

---

**lload\_1** — load long from local variable

*opcode:* 0x1F

*no parameter*

---

---

**lload.2** — load long from local variable

*opcode: 0x20*

*no parameter*

---

---

**lload.3** — load long from local variable

*opcode: 0x21*

*no parameter*

---

---

**lmul** — multiply long

*opcode: 0x69*

*no parameter*

---

---

**lneg** — negate long

*opcode: 0x75*

*no parameter*

---

---

**lookupswitch** — access jump table by key match and jump

*opcode: 0xAB*

*parameter #1: default destination offset (label)*

*parameter #2: number of key, offset pairs (signed 32-bit integer)*

*parameter #3: key, offset pairs (list of (match, label) pairs)*

---

---

**lor** — boolean OR long

*opcode: 0x81*

*no parameter*

---

---

**lrem** — remainder long

*opcode: 0x71*

*no parameter*

---

---

**lreturn** — return long from method

*opcode: 0xAD*

*no parameter*

---

---

**lshl** — shift left long

*opcode: 0x79*

*no parameter*

---

---

**lshr** — arithmetic shift right long

*opcode: 0x7B*

*no parameter*

---

---

**lstore** — store long into local variable

*opcode: 0x37*

*parameter #1: local index (unsigned 8-bit integer)*

---

---

**lstore\_0** — store long into local variable

*opcode: 0x3F*

*no parameter*

---

---

**lstore\_1** — store long into local variable

*opcode: 0x40*

*no parameter*

---

---

**lstore\_2** — store long into local variable

*opcode: 0x41*

*no parameter*

---

---

**lstore\_3** — store long into local variable

*opcode: 0x42*

*no parameter*

---



---

**lsub** — subtract long

*opcode: 0x65*

*no parameter*

---

---

**lushr** — logical shift right long

*opcode: 0x7D*

*no parameter*

---

---

**lxor** — boolean XOR long

*opcode: 0x83*

*no parameter*

---

---

**monitorenter** — enter monitor for object

*opcode: 0xC2*

*no parameter*

---

---

**monitorexit** — exit monitor for object

*opcode: 0xC3*

*no parameter*

---

---

**multianewarray** — create new multidimensional array

*opcode: 0xC5*

*parameter #1: element type (class name, or array type)*

*parameter #2: number of dimensions (unsigned 8-bit integer)*

---

---

**new** — create new object

*opcode: 0xBB*

*parameter #1: type to create (class name)*

---

---

**newarray** — create new arrayhandler

*opcode:* 0xBC

*parameter #1:* element type (primitive array type)

---

---

**nop** — do nothing

*opcode:* 0x00

*no parameter*

---

---

**pop** — pop the top operand stack value

*opcode:* 0x57

*no parameter*

---

---

**pop2** — pop the top one or two operand stack values

*opcode:* 0x58

*no parameter*

---

---

**putfield** — set field in object

*opcode:* 0xB5

*parameter #1:* field to set (field reference)

---

---

**putstatic** — set static field in class

*opcode:* 0xB3

*parameter #1:* field to set (field reference)

---

---

**ret** — return from subroutine

*opcode:* 0xA9

*parameter #1:* local index (unsigned 8-bit integer)

---

---

**return** — return void from method

*opcode:* 0xB1

*no parameter*

---

---

**saload** — load short from array

*opcode:* 0x35

*no parameter*

---

---

**sastore** — store into short array

*opcode:* 0x56

*no parameter*

---

---

**sipush** — push short

*opcode:* 0x11

*parameter #1:* short value (signed 16-bit integer)

---

---

**swap** — swap the top two operand stack values

*opcode:* 0x5F

*no parameter*

---

---

**tableswitch** — access jump table by index and jump

*opcode:* 0xAA

*parameter #1:* default destination offset (label)

*parameter #2:* lower bound (signed 32-bit integer)

*parameter #3:* higher bound (signed 32-bit integer)

*parameter #4:* destination offsets (list of labels)

---

---

**wide aload** — load reference from local variable

*opcode:* 0xC4 followed by 0x19

*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide astore** — store reference into local variable

*opcode:* 0xC4 followed by 0x3A

*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide dload** — load double from local variable  
*opcode:* 0xC4 followed by 0x18  
*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide dstore** — store double into local variable  
*opcode:* 0xC4 followed by 0x39  
*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide fload** — load float from local variable  
*opcode:* 0xC4 followed by 0x17  
*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide fstore** — store float into local variable  
*opcode:* 0xC4 followed by 0x38  
*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide iinc** — increment local variable by constant  
*opcode:* 0xC4 followed by 0x84  
*parameter #1:* local index (unsigned 16-bit integer)  
*parameter #2:* increment value (signed 16-bit integer)

---

---

**wide iload** — load int from local variable  
*opcode:* 0xC4 followed by 0x15  
*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide istore** — store int into local variable  
*opcode:* 0xC4 followed by 0x36  
*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide lload** — load long from local variable

*opcode:* 0xC4 followed by 0x16

*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide lstore** — store long into local variable

*opcode:* 0xC4 followed by 0x37

*parameter #1:* local index (unsigned 16-bit integer)

---

---

**wide ret** — return from subroutine

*opcode:* 0xC4 followed by 0xA9

*parameter #1:* local index (unsigned 16-bit integer)

---



## Appendix B

# Instructions by categories

This appendix lists the instructions grouped by categories, allowing easy search for a given operation. Categories overlaps, as a given instruction belongs to several categories; example: `fconst_0` is both related to constants and to floats.

Hyperlinks allow navigation to the previous appendix.

### Array creations and accesses

- [aaload](#) : load reference from array
- [aastore](#) : store into reference array
- [anewarray](#) : create new array of references
- [arraylength](#) : get length of array
- [baload](#) : load byte or boolean from array
- [bastore](#) : store into byte or boolean array
- [caload](#) : load char from array
- [castore](#) : store into char array
- [daload](#) : load double from array
- [dastore](#) : store into double array
- [faload](#) : load float from array
- [fastore](#) : store into float array
- [iaload](#) : load int from array
- [iastore](#) : store into int array
- [laload](#) : load long from array
- [lastore](#) : store into long array
- [multianewarray](#) : create new multidimensional array
- [newarray](#) : create new arrayhandler
- [saload](#) : load short from array
- [sastore](#) : store into short array

## Arithmetic operations

- `dadd` : add double
- `ddiv` : divide double
- `dmul` : multiply double
- `dneg` : negate double
- `drem` : remainder double
- `dsub` : subtract double
- `fadd` : add float
- `fdiv` : divide float
- `fmul` : multiply float
- `fneg` : negate float
- `frem` : remainder float
- `fsub` : subtract float
- `iadd` : add int
- `idiv` : divide int
- `iinc` : increment local variable by constant
- `imul` : multiply int
- `ineg` : negate int
- `irem` : remainder int
- `isub` : subtract int
- `ladd` : add long
- `ldiv` : divide long
- `lmul` : multiply long
- `lneg` : negate long
- `lrem` : remainder long
- `lsub` : subtract long
- `wide iinc` : increment local variable by constant

## Comparison operations

- `dcmpg` : compare double
- `dcmpl` : compare double
- `fcmpg` : compare float
- `fcmpl` : compare float
- `if_acmpeq` : branch if reference comparison succeeds
- `if_acmpne` : branch if reference comparison succeeds
- `if_icmpeq` : branch if int comparison succeeds



- `if_icmpge` : branch if int comparison succeeds
- `if_icmpgt` : branch if int comparison succeeds
- `if_icmple` : branch if int comparison succeeds
- `if_icmplt` : branch if int comparison succeeds
- `if_icmpne` : branch if int comparison succeeds
- `ifeq` : branch if int comparison with zero succeeds
- `ifge` : branch if int comparison with zero succeeds
- `ifgt` : branch if int comparison with zero succeeds
- `ifle` : branch if int comparison with zero succeeds
- `iflt` : branch if int comparison with zero succeeds
- `ifne` : branch if int comparison with zero succeeds
- `ifnonnull` : branch if reference not null
- `ifnull` : branch if reference not null
- `lcmp` : compare long
- `lookupswitch` : access jump table by key match and jump

## Control flow instructions

- `goto` : branch always
- `goto_w` : branch always
- `if_acmpeq` : branch if reference comparison succeeds
- `if_acmpne` : branch if reference comparison succeeds
- `if_icmpeq` : branch if int comparison succeeds
- `if_icmpge` : branch if int comparison succeeds
- `if_icmpgt` : branch if int comparison succeeds
- `if_icmple` : branch if int comparison succeeds
- `if_icmplt` : branch if int comparison succeeds
- `if_icmpne` : branch if int comparison succeeds
- `ifeq` : branch if int comparison with zero succeeds
- `ifge` : branch if int comparison with zero succeeds
- `ifgt` : branch if int comparison with zero succeeds
- `ifle` : branch if int comparison with zero succeeds
- `iflt` : branch if int comparison with zero succeeds
- `ifne` : branch if int comparison with zero succeeds
- `ifnonnull` : branch if reference not null
- `ifnull` : branch if reference not null
- `jsr` : jump subroutine
- `jsr_w` : jump subroutine (wide index)

- `lookupswitch` : access jump table by key match and jump
- `ret` : return from subroutine
- `tableswitch` : access jump table by index and jump
- `wide ret` : return from subroutine

## Conversions

- `checkcast` : check whether object is of given type
- `d2f` : convert double to float
- `d2i` : convert double to int
- `d2l` : convert double to long
- `f2d` : convert float to double
- `f2i` : convert float to int
- `f2l` : convert float to long
- `i2b` : convert int to byte
- `i2c` : convert int to char
- `i2d` : convert int to double
- `i2f` : convert int to float
- `i2l` : convert int to long
- `i2s` : convert int to short
- `l2d` : convert long to double
- `l2f` : convert long to float
- `l2i` : convert long to int

## Exception-related instructions

- `athrow` : throw exception or error

## Field-related instructions

- `getfield` : fetch field from object
- `getstatic` : get static field from class
- `putfield` : set field in object
- `putstatic` : set static field in class

## Constants

- `bipush` : push byte
- `dconst_0` : push double
- `dconst_1` : push double
- `fconst_0` : push float
- `fconst_1` : push float
- `fconst_2` : push float
- `iconst_0` : push int constant
- `iconst_1` : push int constant
- `iconst_2` : push int constant
- `iconst_3` : push int constant
- `iconst_4` : push int constant
- `iconst_5` : push int constant
- `iconst_m1` : push int constant
- `lconst_0` : push long constant
- `lconst_1` : push long constant
- `sipush` : push short

## Access to local variables

- `aload` : load reference from local variable
- `aload_0` : load reference from local variable
- `aload_1` : load reference from local variable
- `aload_2` : load reference from local variable
- `aload_3` : load reference from local variable
- `astore` : store reference into local variable
- `astore_0` : store reference into local variable
- `astore_1` : store reference into local variable
- `astore_2` : store reference into local variable
- `astore_3` : store reference into local variable
- `dload` : load double from local variable
- `dload_0` : load double from local variable
- `dload_1` : load double from local variable
- `dload_2` : load double from local variable
- `dload_3` : load double from local variable
- `dstore` : store double into local variable
- `dstore_0` : store double into local variable

- `dstore_1` : store double into local variable
- `dstore_2` : store double into local variable
- `dstore_3` : store double into local variable
- `fload` : load float from local variable
- `fload_0` : load float from local variable
- `fload_1` : load float from local variable
- `fload_2` : load float from local variable
- `fload_3` : load float from local variable
- `fstore` : store float into local variable
- `fstore_0` : store float into local variable
- `fstore_1` : store float into local variable
- `fstore_2` : store float into local variable
- `fstore_3` : store float into local variable
- `iinc` : increment local variable by constant
- `iload` : load int from local variable
- `iload_0` : load int from local variable
- `iload_1` : load int from local variable
- `iload_2` : load int from local variable
- `iload_3` : load int from local variable
- `istore` : store int into local variable
- `istore_0` : store int into local variable
- `istore_1` : store int into local variable
- `istore_2` : store int into local variable
- `istore_3` : store int into local variable
- `lload` : load long from local variable
- `lload_0` : load long from local variable
- `lload_1` : load long from local variable
- `lload_2` : load long from local variable
- `lload_3` : load long from local variable
- `lstore` : store long into local variable
- `lstore_0` : store long into local variable
- `lstore_1` : store long into local variable
- `lstore_2` : store long into local variable
- `lstore_3` : store long into local variable
- `wide aload` : load reference from local variable
- `wide astore` : store reference into local variable
- `wide dload` : load double from local variable

- `wide dstore` : store double into local variable
- `wide fload` : load float from local variable
- `wide fstore` : store float into local variable
- `wide iinc` : increment local variable by constant
- `wide iload` : load int from local variable
- `wide istore` : store int into local variable
- `wide lload` : load long from local variable
- `wide lstore` : store long into local variable

## Logical operations

- `iand` : boolean AND int
- `ior` : boolean OR int
- `ishl` : shift left int
- `ishr` : arithmetic shift right int
- `iushr` : logical shift right int
- `ixor` : boolean XOR int
- `land` : boolean AND long
- `lor` : boolean OR long
- `lshl` : shift left long
- `lshr` : arithmetic shift right long
- `lushr` : logical shift right long
- `lxor` : boolean XOR long

## Method calls

- `invokedynamic` : invoke instance method; resolve and dispatch based on class
- `invokeinterface` : invoke interface method
- `invokespecial` : invoke instance method; special handling for superclass, private, and instance initialization method invocations
- `invokestatic` : invoke a class (static) method
- `invokevirtual` : invoke instance method; dispatch based on class

## Instructions over monitors

- `monitorenter` : enter monitor for object
- `monitorexit` : exit monitor for object

## Method returns

- `areturn` : return reference from method
- `dreturn` : return double from method
- `freturn` : return float from method
- `ireturn` : return int from method
- `lreturn` : return long from method
- `return` : return void from method

## Stack manipulation

- `dup` : duplicate the top operand stack value
- `dup2` : duplicate the top one or two operand stack values
- `dup2_x1` : duplicate the top one or two operand stack values and insert two or three values down
- `dup2_x2` : duplicate the top one or two operand stack values and insert two, three, or four values down
- `dup_x1` : duplicate the top operand stack value and insert two values down
- `dup_x2` : duplicate the top operand stack value and insert two or three values down
- `ldc` : push item from runtime constant pool
- `ldc2_w` : push long or double from runtime constant pool (wide index)
- `ldc_w` : push item from runtime constant pool (wide index)
- `pop` : pop the top operand stack value
- `pop2` : pop the top one or two operand stack values
- `swap` : swap the top two operand stack values

## Operations over booleans

- `baload` : load byte or boolean from array
- `bastore` : store into byte or boolean array

## Operations over bytes

- `baload` : load byte or boolean from array
- `bastore` : store into byte or boolean array
- `bipush` : push byte
- `i2b` : convert int to byte

## Operations over chars

- `caload` : load char from array
- `castore` : store into char array
- `i2c` : convert int to char

## Operations over doubles

- `d2f` : convert double to float
- `d2i` : convert double to int
- `d2l` : convert double to long
- `dadd` : add double
- `daload` : load double from array
- `dastore` : store into double array
- `dcmpg` : compare double
- `dcmpl` : compare double
- `dconst_0` : push double
- `dconst_1` : push double
- `ddiv` : divide double
- `dload` : load double from local variable
- `dload_0` : load double from local variable
- `dload_1` : load double from local variable
- `dload_2` : load double from local variable
- `dload_3` : load double from local variable
- `dmul` : multiply double
- `dneg` : negate double
- `drem` : remainder double
- `dreturn` : return double from method
- `dstore` : store double into local variable
- `dstore_0` : store double into local variable
- `dstore_1` : store double into local variable
- `dstore_2` : store double into local variable
- `dstore_3` : store double into local variable
- `dsub` : subtract double
- `f2d` : convert float to double
- `i2d` : convert int to double
- `l2d` : convert long to double
- `wide dload` : load double from local variable
- `wide dstore` : store double into local variable

## Operations over floats

- `d2f` : convert double to float
- `f2d` : convert float to double
- `f2i` : convert float to int
- `f2l` : convert float to long
- `fadd` : add float
- `faload` : load float from array
- `fastore` : store into float array
- `fcmpg` : compare float
- `fcmpl` : compare float
- `fconst_0` : push float
- `fconst_1` : push float
- `fconst_2` : push float
- `fdiv` : divide float
- `fload` : load float from local variable
- `fload_0` : load float from local variable
- `fload_1` : load float from local variable
- `fload_2` : load float from local variable
- `fload_3` : load float from local variable
- `fmul` : multiply float
- `fneg` : negate float
- `frem` : remainder float
- `freturn` : return float from method
- `fstore` : store float into local variable
- `fstore_0` : store float into local variable
- `fstore_1` : store float into local variable
- `fstore_2` : store float into local variable
- `fstore_3` : store float into local variable
- `fsub` : subtract float
- `i2f` : convert int to float
- `l2f` : convert long to float
- `wide fload` : load float from local variable
- `wide fstore` : store float into local variable



## Operations over ints

- `d2i` : convert double to int
- `f2i` : convert float to int
- `i2b` : convert int to byte
- `i2c` : convert int to char
- `i2d` : convert int to double
- `i2f` : convert int to float
- `i2l` : convert int to long
- `i2s` : convert int to short
- `iadd` : add int
- `iaload` : load int from array
- `iand` : boolean AND int
- `iastore` : store into int array
- `iconst_0` : push int constant
- `iconst_1` : push int constant
- `iconst_2` : push int constant
- `iconst_3` : push int constant
- `iconst_4` : push int constant
- `iconst_5` : push int constant
- `iconst_m1` : push int constant
- `idiv` : divide int
- `if_icmpeq` : branch if int comparison succeeds
- `if_icmpge` : branch if int comparison succeeds
- `if_icmpgt` : branch if int comparison succeeds
- `if_icmple` : branch if int comparison succeeds
- `if_icmplt` : branch if int comparison succeeds
- `if_icmpne` : branch if int comparison succeeds
- `ifeq` : branch if int comparison with zero succeeds
- `ifge` : branch if int comparison with zero succeeds
- `ifgt` : branch if int comparison with zero succeeds
- `ifle` : branch if int comparison with zero succeeds
- `iflt` : branch if int comparison with zero succeeds
- `ifne` : branch if int comparison with zero succeeds
- `iinc` : increment local variable by constant
- `iload` : load int from local variable
- `iload_0` : load int from local variable
- `iload_1` : load int from local variable

- `iload_2` : load int from local variable
- `iload_3` : load int from local variable
- `imul` : multiply int
- `ineg` : negate int
- `ior` : boolean OR int
- `irem` : remainder int
- `ireturn` : return int from method
- `ishl` : shift left int
- `ishr` : arithmetic shift right int
- `istore` : store int into local variable
- `istore_0` : store int into local variable
- `istore_1` : store int into local variable
- `istore_2` : store int into local variable
- `istore_3` : store int into local variable
- `isub` : subtract int
- `iushr` : logical shift right int
- `ixor` : boolean XOR int
- `l2i` : convert long to int
- `lookupswitch` : access jump table by key match and jump
- `tableswitch` : access jump table by index and jump
- `wide iinc` : increment local variable by constant
- `wide iload` : load int from local variable
- `wide istore` : store int into local variable

## Operations over longs

- `d2l` : convert double to long
- `f2l` : convert float to long
- `i2l` : convert int to long
- `l2d` : convert long to double
- `l2f` : convert long to float
- `l2i` : convert long to int
- `ladd` : add long
- `laload` : load long from array
- `land` : boolean AND long
- `lastore` : store into long array
- `lcmp` : compare long
- `lconst_0` : push long constant

- `lconst_1` : push long constant
- `ldiv` : divide long
- `lload` : load long from local variable
- `lload_0` : load long from local variable
- `lload_1` : load long from local variable
- `lload_2` : load long from local variable
- `lload_3` : load long from local variable
- `lmul` : multiply long
- `lneg` : negate long
- `lor` : boolean OR long
- `lrem` : remainder long
- `lreturn` : return long from method
- `lshl` : shift left long
- `lshr` : arithmetic shift right long
- `lstore` : store long into local variable
- `lstore_0` : store long into local variable
- `lstore_1` : store long into local variable
- `lstore_2` : store long into local variable
- `lstore_3` : store long into local variable
- `lsub` : subtract long
- `lushr` : logical shift right long
- `lxor` : boolean XOR long
- `wide lload` : load long from local variable
- `wide lstore` : store long into local variable

## Operations over references

- `aaload` : load reference from array
- `aastore` : store into reference array
- `aconst_null` : push null
- `aload` : load reference from local variable
- `aload_0` : load reference from local variable
- `aload_1` : load reference from local variable
- `aload_2` : load reference from local variable
- `aload_3` : load reference from local variable
- `anewarray` : create new array of references
- `areturn` : return reference from method
- `astore` : store reference into local variable

- `astore_0` : store reference into local variable
- `astore_1` : store reference into local variable
- `astore_2` : store reference into local variable
- `astore_3` : store reference into local variable
- `checkcast` : check whether object is of given type
- `if_acmpeq` : branch if reference comparison succeeds
- `if_acmpne` : branch if reference comparison succeeds
- `ifnonnull` : branch if reference not null
- `ifnull` : branch if reference not null
- `instanceof` : determine if object is of given type
- `monitorenter` : enter monitor for object
- `monitorexit` : exit monitor for object
- `multianewarray` : create new multidimensional array
- `new` : create new object
- `wide aload` : load reference from local variable
- `wide astore` : store reference into local variable

## Operations over shorts

- `i2s` : convert int to short
- `saload` : load short from array
- `sastore` : store into short array
- `sipush` : push short

## Appendix C

# Instructions by opcode

This appendix lists the instructions sorted by opcode.

Hyperlinks allow navigation to the first appendix.

0x00 : <a href="#">nop</a>	0x22 : <a href="#">fload_0</a>	0x44 : <a href="#">fstore_1</a>
0x01 : <a href="#">aconst_null</a>	0x23 : <a href="#">fload_1</a>	0x45 : <a href="#">fstore_2</a>
0x02 : <a href="#">iconst_m1</a>	0x24 : <a href="#">fload_2</a>	0x46 : <a href="#">fstore_3</a>
0x03 : <a href="#">iconst_0</a>	0x25 : <a href="#">fload_3</a>	0x47 : <a href="#">dstore_0</a>
0x04 : <a href="#">iconst_1</a>	0x26 : <a href="#">dload_0</a>	0x48 : <a href="#">dstore_1</a>
0x05 : <a href="#">iconst_2</a>	0x27 : <a href="#">dload_1</a>	0x49 : <a href="#">dstore_2</a>
0x06 : <a href="#">iconst_3</a>	0x28 : <a href="#">dload_2</a>	0x4A : <a href="#">dstore_3</a>
0x07 : <a href="#">iconst_4</a>	0x29 : <a href="#">dload_3</a>	0x4B : <a href="#">astore_0</a>
0x08 : <a href="#">iconst_5</a>	0x2A : <a href="#">aload_0</a>	0x4C : <a href="#">astore_1</a>
0x09 : <a href="#">lconst_0</a>	0x2B : <a href="#">aload_1</a>	0x4D : <a href="#">astore_2</a>
0x0A : <a href="#">lconst_1</a>	0x2C : <a href="#">aload_2</a>	0x4E : <a href="#">astore_3</a>
0x0B : <a href="#">fconst_0</a>	0x2D : <a href="#">aload_3</a>	0x4F : <a href="#">iastore</a>
0x0C : <a href="#">fconst_1</a>	0x2E : <a href="#">iaload</a>	0x50 : <a href="#">lastore</a>
0x0D : <a href="#">fconst_2</a>	0x2F : <a href="#">laload</a>	0x51 : <a href="#">fastore</a>
0x0E : <a href="#">dconst_0</a>	0x30 : <a href="#">faload</a>	0x52 : <a href="#">dastore</a>
0x0F : <a href="#">dconst_1</a>	0x31 : <a href="#">daload</a>	0x53 : <a href="#">aastore</a>
0x10 : <a href="#">bipush</a>	0x32 : <a href="#">aaload</a>	0x54 : <a href="#">bastore</a>
0x11 : <a href="#">sipush</a>	0x33 : <a href="#">baload</a>	0x55 : <a href="#">castore</a>
0x12 : <a href="#">ldc</a>	0x34 : <a href="#">caload</a>	0x56 : <a href="#">sastore</a>
0x13 : <a href="#">ldc_w</a>	0x35 : <a href="#">saload</a>	0x57 : <a href="#">pop</a>
0x14 : <a href="#">ldc2_w</a>	0x36 : <a href="#">istore</a>	0x58 : <a href="#">pop2</a>
0x15 : <a href="#">iload</a>	0x37 : <a href="#">lstore</a>	0x59 : <a href="#">dup</a>
0x16 : <a href="#">lload</a>	0x38 : <a href="#">fstore</a>	0x5A : <a href="#">dup_x1</a>
0x17 : <a href="#">fload</a>	0x39 : <a href="#">dstore</a>	0x5B : <a href="#">dup_x2</a>
0x18 : <a href="#">dload</a>	0x3A : <a href="#">astore</a>	0x5C : <a href="#">dup2</a>
0x19 : <a href="#">aload</a>	0x3B : <a href="#">istore_0</a>	0x5D : <a href="#">dup2_x1</a>
0x1A : <a href="#">iload_0</a>	0x3C : <a href="#">istore_1</a>	0x5E : <a href="#">dup2_x2</a>
0x1B : <a href="#">iload_1</a>	0x3D : <a href="#">istore_2</a>	0x5F : <a href="#">swap</a>
0x1C : <a href="#">iload_2</a>	0x3E : <a href="#">istore_3</a>	0x60 : <a href="#">iadd</a>
0x1D : <a href="#">iload_3</a>	0x3F : <a href="#">lstore_0</a>	0x61 : <a href="#">ladd</a>
0x1E : <a href="#">lload_0</a>	0x40 : <a href="#">lstore_1</a>	0x62 : <a href="#">fadd</a>
0x1F : <a href="#">lload_1</a>	0x41 : <a href="#">lstore_2</a>	0x63 : <a href="#">dadd</a>
0x20 : <a href="#">lload_2</a>	0x42 : <a href="#">lstore_3</a>	0x64 : <a href="#">isub</a>
0x21 : <a href="#">lload_3</a>	0x43 : <a href="#">fstore_0</a>	0x65 : <a href="#">lsub</a>

0x66 : fsub	0x8C : f2l	0xB2 : getstatic
0x67 : dsub	0x8D : f2d	0xB3 : putstatic
0x68 : imul	0x8E : d2i	0xB4 : getfield
0x69 : lmul	0x8F : d2l	0xB5 : putfield
0x6A : fmul	0x90 : d2f	0xB6 : invokevirtual
0x6B : dmul	0x91 : i2b	0xB7 : invokespecial
0x6C : idiv	0x92 : i2c	0xB8 : invokestatic
0x6D : ldiv	0x93 : i2s	0xB9 : invokeinterface
0x6E : fdiv	0x94 : lcmp	0xBA : invokedynamic
0x6F : ddiv	0x95 : fcmpl	0xBB : new
0x70 : irem	0x96 : fcmpg	0xBC : newarray
0x71 : lrem	0x97 : dcmpl	0xBD : anewarray
0x72 : frem	0x98 : dcmpg	0xBE : arraylength
0x73 : drem	0x99 : ifeq	0xBF : athrow
0x74 : ineg	0x9A : ifne	0xC0 : checkcast
0x75 : lneg	0x9B : iflt	0xC1 : instanceof
0x76 : fneg	0x9C : ifge	0xC2 : monitorenter
0x77 : dneg	0x9D : ifgt	0xC3 : monitorexit
0x78 : ishl	0x9E : ifle	0xC5 : multianewarray
0x79 : lshl	0x9F : if_icmpeq	0xC6 : ifnull
0x7A : ishr	0xA0 : if_icmpne	0xC7 : ifnonnull
0x7B : lshr	0xA1 : if_icmplt	0xC8 : goto_w
0x7C : iushr	0xA2 : if_icmpge	0xC9 : jsr_w
0x7D : lushr	0xA3 : if_icmpgt	
0x7E : iand	0xA4 : if_icmple	0xC4 0x15 : wide iload
0x7F : land	0xA5 : if_acmpeq	0xC4 0x16 : wide lload
0x80 : ior	0xA6 : if_acmpne	0xC4 0x17 : wide fload
0x81 : lor	0xA7 : goto	0xC4 0x18 : wide dload
0x82 : ixor	0xA8 : jsr	0xC4 0x19 : wide aload
0x83 : lxor	0xA9 : ret	0xC4 0x36 : wide istore
0x84 : iinc	0xAA : tableswitch	0xC4 0x37 : wide lstore
0x85 : i2l	0xAB : lookupswitch	0xC4 0x38 : wide fstore
0x86 : i2f	0xAC : ireturn	0xC4 0x39 : wide dstore
0x87 : i2d	0xAD : lreturn	0xC4 0x3A : wide astore
0x88 : i2i	0xAE : freturn	0xC4 0x84 : wide iinc
0x89 : i2f	0xAF : dreturn	0xC4 0xA9 : wide ret
0x8A : i2d	0xB0 : areturn	
0x8B : f2i	0xB1 : return	

## Appendix D

# Syntax extension

This appendix presents the syntax extension used throughout the Barista project. The OCaml syntax is extended along two dimensions:

- support for Unicode constants ;
- support for an *exception pattern* (*pattern* being used with the same meaning as by the famous *Gang of Four*).

### D.1 Unicode constants

The syntax extension provides two literal notations that can be used either as expression or pattern :

- `@"str"` for a UTF8 string ;
- `@'c'` for an Unicode character.

The first notation is expanded to `Utils.UTF8.of_string`, while the second is expanded to `Utils.UChar.of_char`. When used as a pattern, the first notation uses `Utils.UTF8.equal` to compare values, while the second one uses `Utils.UChar.equal`.

**Limitation:** the pattern notation can only be used for a simple pattern, but not for a composed pattern (whether in a bare tuple, or inside a constructor). However, the pattern notation can be used in conjunction with a `when` clause.

### D.2 Exception pattern

The *exception pattern* is the factorization of the following code, used to define an exception per module:

```
type error =
  | ...

exception Exception of error

let fail e = raise (Exception e)
```

```

let string_of_error = function
  | ...

let () =
  Printexc.register_printer
    (function
      | Exception e -> Some (string_of_error e)
      | _ -> None)

```

The syntax extension avoid duplication of constructor declarations (marked by ... ellipsis in the code above) through the following notation:

```

BARISTA_ERROR =
| 0 -> "o"
| A of (x : int) -> Printf.sprintf "%d" x
| B of (y : float) * (z : string) * (t : char)-> Printf.sprintf "%f %S %C" y z t

```

that will be expanded to:

```

type error = | 0 | A of int | B of float * string * char

```

```

exception Exception of error

```

```

let fail e = raise (Exception e)

```

```

let string_of_error e =
  match e with
  | 0 -> "o"
  | A x -> Printf.sprintf "%d" x
  | B ((y, z, t)) -> Printf.sprintf "%f %S %C" y z t

```

```

let () =
  Printexc.register_printer
    (function | Exception e -> Some (string_of_error e) | _ -> None)

```

A similar notation is available in module interfaces, without the names of the constructors components:

```

BARISTA_ERROR =
| 0
| A of int
| B of float * string * char

```

will be expanded to:

```

type error = | 0 | A of int | B of float * string * char

```

```

exception Exception of error

```

```

val string_of_error : error -> string

```