Java Platform, Standard Edition

Java Virtual Machine Guide

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Java Platform, Standard Edition Java Virtual Machine Guide, Release 15

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Contents

Preface

This document provides information about the features supported by Java Virtual Machine technology.

Audience

This document is intended for experienced developers who build applications using the Java HotSpot technology.

Documentation Accessibility

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Related Documents

See JDK 15 Documentation for other JDK 15 guides.

Conventions

The following text conventions are used in this document:

Convention	Meaning
boldface	Boldface type indicates graphical user interface elements associated with an action, or terms defined in text.
italic	Italic type indicates book titles, emphasis, or placeholder variables for which you supply particular values.
`monospace`	Monospace type indicates commands within a paragraph, URLs, code in examples, text that appears on the screen, or text that you enter.

1

Java Virtual Machine Technology Overview

This chapter describes the implementation of the Java Virtual Machine (JVM) and the main features of the Java HotSpot technology:

- **Adaptive compiler**: A standard interpreter is used to launch the applications. When the application runs, the code is analyzed to detect performance bottlenecks, or *hot spots*. The Java HotSpot VM compiles the performance-critical portions of the code for a boost in performance, but does not compile the seldom-used code (most of the application). The Java HotSpot VM uses the adaptive compiler to decide how to optimize compiled code with techniques such as inlining.
- **Rapid memory allocation and garbage collection**: Java HotSpot technology provides rapid memory allocation for objects and fast, efficient, state-of-the-art garbage collectors.
- **Thread synchronization**: Java HotSpot technology provides a thread-handling capability that is designed to scale for use in large, shared-memory multiprocessor servers.

In Oracle Java Runtime Environment (JRE) 8 and earlier, different implementations of the JVM, (the client VM, server VM, and minimal VM) were supported for configurations commonly used as clients, as servers, and for embedded systems. Because most systems can now take advantage of the server VM, only that VM implementation is provided in later versions.

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Compiler Control

Compiler Control provides a way to control Java Virtual Machine (JVM) compilation through compiler directive options. The level of control is runtime-manageable and method specific.

A compiler directive is an instruction that tells the JVM how compilation should occur. A directive provides method-context precision in controlling the compilation process. You can use directives to write small, contained, JVM compiler tests that can run without restarting the entire JVM. You can also use directives to create workarounds for bugs, in the JVM compilers.

You can specify a file that contains compiler directives when you start a program through the command line. You can also add or remove directives from an already running program by using diagnostic commands.

Compiler Control supersedes and is backward compatible with CompileCommand.

Topics:

Writing Directives

This topic examines Compiler Control options and steps for writing directives from those options.

Topics:

- Writing a Directive File
- Writing a Compiler Directive
- Writing a Method Pattern in a Compiler Directive
- Writing an Inline Directive Option
- Preventing Duplication with the Enable Option

Compiler Control Options

Options are instructions for compilation. Options provide method-context precision. Available options vary by compiler and require specific types of values.

Table 2-1 Common Options

Option	Description	Value Type	Default Value
`Enable`	Hides a directive and renders it unmatchable if it is set to `false`. This option is useful for preventing option duplication. See Preventing Duplication with the Enable Option.	`bool`	`true`
`Exclude`	Excludes methods from compilation.	`bool`	`false`
`BreakAtExecute`	Sets a breakpoint to stop execution at the beginning of the specified methods when debugging the JVM.	`bool`	`false`
`BreakAtCompile`	Sets a breakpoint to stop compilation at the beginning of the specified methods when debugging the JVM.	`bool`	`false`
`Log`	Places only the specified methods in a log. You must first set the command-line option `-XX:+LogCompilation`. The default value `false` places all compiled methods in a log.	`bool`	`false`
`PrintAssembly`	Prints assembly code for bytecoded and native methods by using the external `disassembler.so` library.	`bool`	`false`

Table 2-1 (Cont.) Common Options

Option	Description	Value Type	Default Value
`PrintInlining`	Prints which methods are inlined, and where.	`bool`	`false`
`PrintNMethods`	Prints nmethods as they are generated.	`bool`	`false`
`BackgroundCompilation`	Compiles methods as a background task. Methods run in interpreter mode until the background compilation finishes. The value `false` compiles methods as a foreground task.	`bool`	`true`
`ReplayInline`	Enables the same `CIReplay` functionality as the corresponding global option, but on a per-method basis.	`bool`	`false`
`DumpReplay`	Enables the same `CIReplay` functionality as the corresponding global option, but on a per-method basis.	`bool`	`false`
`DumpInline`	Enables the same `CIReplay` functionality as the corresponding global option, but on a per-method basis.	`bool`	`false`
`CompilerDirectivesIgnoreCompileCommands`	Disregards all CompileCommands.	`bool`	`false`
`DisableIntrinsic`	Disables the use of intrinsics based on method-matching criteria.	`ccstr`	No default value.
`inline`	Forces or prevents inlining of a method based on method-matching criteria. See Writing an Inline Directive Option.	`ccstr[]`	No default value.

Table 2-2 C2 Exclusive Options

Option	Description	Value Type	Default Value
`BlockLayoutByFrequency`	Moves infrequent execution branches from the hot path.	`bool`	`true`

Table 2-2 (Cont.) C2 Exclusive Options

Option	Description	Value Type	Default Value
`PrintOptoAssembly`	Prints generated assembly code after compilation by using the external `disassembler.so` library. This requires a debugging build of the JVM.	`bool`	`false`
`PrintIntrinsics`	Prints which intrinsic methods are used, and where.	`bool`	`false`
`TraceOptoPipelining`	Traces pipelining information, similar to the corresponding global option, but on a per-method basis. This is intended for slow and fast debugging builds.	`bool`	`false`
`TraceOptoOutput`	Traces pipelining information, similar to the corresponding global option, but on a per-method basis. This is intended for slow and fast debugging builds.	`bool`	`false`
`TraceSpilling`	Traces variable spilling.	`bool`	`false`
`Vectorize`	Performs calculations in parallel, across vector registers.	`bool`	`false`
`VectorizeDebug`	Performs calculations in parallel, across vector registers. This requires a debugging build of the JVM.	`intx`	`0`
`CloneMapDebug`	Enables you to examine the `CloneMap` generated from vectorization. This requires a debugging build of the JVM.	`bool`	`false`

Table 2-2 (Cont.) C2 Exclusive Options

Option	Description	Value Type	Default Value
`IGVPrintLevel`	Specifies the points where the compiler graph is printed in Oracle's Hotspot Ideal Graphic Visualizer (IGV). A higher value means higher granularity.	`intx`	`0`
`MaxNodeLimit`	Sets the maximum number of nodes to use during a single method's compilation.	`intx`	`80000`

A `ccstr` value type is a method pattern. See Writing a Method Pattern in a Compiler Directive.

The default directive supplies default values for compiler options. See What Is the Default Directive?

Writing a Directive File

Individual compiler directives are written in a directives file. Only directive files, not individual directives, can be added to the stack of active directives.

1. Create a file with a `.json` extension. Directive files are written using a subset of JSON syntax with minor additions and deviations.
2. Add the following syntax as a template you can work from:

```
[  //Array of Directives
    {   //Directive Block
        //Directive 1
    },
    {   //Directive Block
        //Directive 2
    },
]
```

The components of this template are:

Array of Directives

- A directives file stores an array of directive blocks, denoted with a pair of brackets (`[]`).
- The brackets are optional if the file contains only a single directive block.

Directive Block

- A block is denoted with a pair of braces (`{}`).
- A block contains one individual directive.
- A directives file can contain any number of directive blocks.

- Blocks are separated with a comma (,).
- A comma is optional following the final block in the array.

Directive

- Each directive must be within a directive block.
- A directives file can contain multiple directives when it contains multiple directive blocks.

Comments

- Single-line comments are preceded with two slashes (//).
- Multiline comments are not allowed.

3. Add or remove directive blocks from the template to match the number of directives you want in the directives file.
4. In each directive block, write one compiler directive. See Writing a Compiler Directive.
5. Reorder the directive blocks if necessary. The ordering of directives in a file is significant. Directives written closer to the beginning of the array receive higher priority. For more information, see How Directives Are Ordered in the Directives Stack? and How Directives are Applied to Code?

```
[  //Array of directives
    {   //Directive Block
        //Directive 1
        match: ["java*.*", "oracle*.*"],
        c1: {
            Enable: true,
            Exclude: true,
            BreakAtExecute: true,
        },
        c2: {
            Enable: false,
            MaxNodeLimit: 1000,
        },
        BreakAtCompile: true,
        DumpReplay: true,
    },
    {   //Directive Block
        //Directive 2
        match: ["*Concurrent.*"],
        c2: {
            Exclude:true,
        },
    },
]
```

Writing a Compiler Directive

You must write a compiler directive within a directives file. You can repeat the following steps for each individual compiler directive that you want to write in a directives file.

An individual compiler directive is written within a directive block in a directives file. See Writing a Directive File.

1. Insert the following block of code, as a template you can work from, to write an individual compiler directive. This block of code is a directive block.

```
{
    match: [],
    c1: {
        //c1 directive options
    },
    c2: {
        //c2 directive options
    },
    //Directive options applicable to all compilers
},
```

2. Provide the `match` attribute with an array of method patterns. See Writing a Method Pattern in a Compiler Directive.

   For example:

```
match: ["java*.*", "oracle*.*"],
```

3. Provide the `c1` attribute with a block of comma-separated directive options. Ensure that these options are valid for the `c1` compiler.

   For example:

```
c1: {
    Enable: true,
    Exclude: true,
    BreakAtExecute: true,
},
```

4. Provide the `c2` attribute with a block of comma-separated directive options. This block can contain a mix of common and c2-exclusive compiler options.

   For example:

```
c2: {
    Enable: false,
    MaxNodeLimit: 1000,
},
```

5. Provide, at the end of the directive, options you want applicable to all compilers. These options are considered written within the scope of the common block. Options are comma-separated.

For example:

```
        BreakAtCompile: true,
        DumpReplay: true,
```

6. Clean up the file by completing the following steps.
   a. Check for the duplication of directive options. If a conflict occurs, then the last occurrence of an option takes priority. Conflicts typically occur between the common block and the c1 or c2 blocks, not between the c1 and c2 blocks.
   b. Avoid writing c2-exclusive directive options in the common block. Although the common block can accept a mix of common and c2-exclusive options, it's pointless to structure a directive this way because c2-exclusive options in the common block have no effect on the c1 compiler. Write c2-exclusive options within the c2 block instead.
   c. If the `c1` or `c2` attribute has no corresponding directive options, then omit the attribute-value syntax for that compiler.

The following example shows the resulting directive, based on earlier examples, is:

```
{
    match: ["java*.*", "oracle*.*"],
    c1: {
        Enable: true,
        Exclude: true,
        BreakAtExecute: true,
    },
    c2: {
        Enable: false,
        MaxNodeLimit: 1000,
    },
    BreakAtCompile: true,
    DumpReplay: true,
},
```

The JSON format of directive files allows the following deviations in syntax:

- Extra trailing commas are optional in arrays and objects.
- Attributes are strings and are optionally placed within quotation marks.
- If an array contains only one element, then brackets are optional.

Therefore, the following example shows a valid compiler directive:

```
{
   "match": "*Concurrent.*",
    c2: {
        "Exclude": true,
    }
},
```

Writing a Method Pattern in a Compiler Directive

A `ccstr` is a method pattern that you can write precisely or you can generalize with wildcard characters. You can specify what best-matching Java code should have accompanying directive options applied, or what Java code should be inlined.

To write a method pattern:

1. Use the following syntax to write your method pattern: *`package/class.method(parameter_list)`*. To generalize a method pattern with wildcard characters, see Step 2.

   The following example shows a method pattern that uses this syntax:

   ```
   java/lang/String.indexOf()
   ```

   Other formatting styles are available. This ensures backward compatibility with earlier ways of method matching such as CompileCommand. Valid formatting alternatives for the previous example include:

   - `java/lang/String.indexOf()`
   - `java/lang/String,indexOf()`
   - `java/lang/String indexOf()`
   - `java.lang.String::indexOf()`

   The last formatting style matches the HotSpot output.

2. Insert a wildcard character (*) where you want to generalize part of the method pattern.

   The following examples are valid generalizations of the method pattern example in Step 1:

   - `java/lang/String.indexOf*`
   - `*lang/String.indexOf*`
   - `*va/lang*.*dex*`
   - `java/lang/String.*`
   - `*.*`

   Increased generalization leads to decreased precision. More Java code becomes a potential match with the method pattern. Therefore, it's important to use the wildcard character (*) judiciously.

3. Modify the signature portion of the method pattern, according to the Java Specifications. A signature match must be exact, otherwise the signature defaults to a wildcard character (*). Omitted signatures also default to a wildcard character. Signatures cannot contain the wildcard character.

4. Optional: If you write a method pattern to accompany the `inline` directive option, then you must prefix the method pattern with additional characters. See Writing an Inline Directive Option.

Writing an Inline Directive Option

The attribute for an `inline` directive option requires an array of method patterns with special commands prefixed. This indicates which method patterns should or shouldn't inline.

1. Write `inline:` in the common block, c1 block , or c2 block of a directive.
2. Add an array of carefully ordered method patterns. The prefixed command on the first matching method pattern is executed. The remaining method patterns in the array are ignored.
3. Prefix a `+` to force inlining of any matching Java code.
4. Prefix a `-` to prevent inlining of any matching Java code.
5. Optional: If you need inlining behavior applied to multiple method patterns, then repeat Steps 1 to 4 to write multiple `inline` statements. Don't write a single array that contains multiple method patterns.

The following examples show the `inline` directive options:

- `inline: ["+java/lang*.*", "-sun*.*"]`
- `inline: "+java/lang*.*"`

Preventing Duplication with the Enable Option

You can use the `Enable` option to hide aspects of directives and prevent duplication between directives.

In the following example, the `c1`attribute of the compiler directives are identical.:

```
[
    {
        match: ["java*.*"],
        c1: {
            BreakAtExecute: true,
            BreakAtCompile: true,
            DumpReplay: true,
            DumpInline: true,
        },
        c2: {
            MaxNodeLimit: 1000,
        },
    },
    {
        match: ["oracle*.*"],
        c1: {
            BreakAtExecute: true,
            BreakAtCompile: true,
            DumpReplay: true,
            DumpInline: true,
        },
        c2: {
            MaxNodeLimit: 2000,
        },
```

```
    },
]
```

The following example shows how the undesirable code duplication is resolved with the `Enable` option. `Enable` hides the block directives and renders them unmatchable.

```
[
    {
        match: ["java*.*"],
        c1: {
            Enable: false,
        },
        c2: {
            MaxNodeLimit: 1000,
        },
    },
    {
        match: ["oracle*.*"],
        c1: {
            Enable: false,
        },
        c2: {
            MaxNodeLimit: 2000,
        },
    },
    {
        match: ["java*.*", "oracle*.*"],
        c1: {
            BreakAtExecute: true,
            BreakAtCompile: true,
            DumpReplay: true,
            DumpInline: true,
        },
        c2: {
            //Unreachable code
        },
    },
]
```

Typically, the first matching directive is applied to a method's compilation. The `Enable` option provides an exception to this rule. A method that would typically be compiled by `c1` in the first or second directive is now compiled with the `c1` block of the third directive. The `c2` block of the third directive is unreachable because the `c2` blocks in the first and second directive take priority.

Understanding Directives

The following topics examine how directives behave and interact.

Topics:

- What Is the Default Directive?
- How Directives are Applied to Code?

- Compiler Control and Backward Compatibility

What Is the Default Directive?

The default directive is a compiler directive that contains default values for all possible directive options. It is the bottom-most directives in the stack and matches every method submitted for compilation.

When you design a new compiler directive, you specify how the new directive differs from the default directive. The default directive becomes a template to guide your design decisions.

Directive Option Values in the Default Directive

You can print an empty directive stack to reveal the matching criteria and the values for all directive options in the default compiler directive:

```
Directive: (default)
 matching: *.*
 c1 directives:
  inline: -
  Enable:true Exclude:false BreakAtExecute:false BreakAtCompile:false
Log:false PrintAssembly:false PrintInlining:false PrintNMethods:false
BackgroundCompilation:true ReplayInline:false DumpReplay:false
DumpInline:false CompilerDirectivesIgnoreCompileCommands:false
DisableIntrinsic: BlockLayoutByFrequency:true PrintOptoAssembly:false
PrintIntrinsics:false TraceOptoPipelining:false TraceOptoOutput:false
TraceSpilling:false Vectorize:false VectorizeDebug:0
CloneMapDebug:false IGVPrintLevel:0 MaxNodeLimit:80000

 c2 directives:
  inline: -
  Enable:true Exclude:false BreakAtExecute:false BreakAtCompile:false
Log:false PrintAssembly:false PrintInlining:false PrintNMethods:false
BackgroundCompilation:true ReplayInline:false DumpReplay:false
DumpInline:false CompilerDirectivesIgnoreCompileCommands:false
DisableIntrinsic: BlockLayoutByFrequency:true PrintOptoAssembly:false
PrintIntrinsics:false TraceOptoPipelining:false TraceOptoOutput:false
TraceSpilling:false Vectorize:false VectorizeDebug:0
CloneMapDebug:false IGVPrintLevel:0 MaxNodeLimit:80000
```

> **Note:**
>
> Certain options are applicable exclusively to the `c2` compiler. For a complete list, see Table 2-2.

Directive Option Values in New Directives

In a new directives, you must specify how the directive differs from the default directive. If you don't specify a directive option, then that option retains the value from the default directive.

Example:

```
[
    {
        match: ["*Concurrent.*"],
        c2: {
            MaxNodeLimit: 1000,
        },
        Exclude:true,
    },
]
```

When you add a new directive to the directives stack, the default directive becomes the bottom-most directive in the stack. See How Directives Are Ordered in the Directives Stack? for a description of this process. For this example, when you print the directives stack, it shows how the directive options specified in the new directive differ from the values in the default directive:

```
Directive:
 matching: *Concurrent.*
 c1 directives:
  inline: -
  Enable:true Exclude:true BreakAtExecute:false BreakAtCompile:false
Log:false PrintAssembly:false PrintInlining:false PrintNMethods:false
BackgroundCompilation:true ReplayInline:false DumpReplay:false
DumpInline:false CompilerDirectivesIgnoreCompileCommands:false
DisableIntrinsic: BlockLayoutByFrequency:true PrintOptoAssembly:false
PrintIntrinsics:false TraceOptoPipelining:false TraceOptoOutput:false
TraceSpilling:false Vectorize:false VectorizeDebug:0
CloneMapDebug:false IGVPrintLevel:0 MaxNodeLimit:80000

 c2 directives:
  inline: -
  Enable:true Exclude:true BreakAtExecute:false BreakAtCompile:false
Log:false PrintAssembly:false PrintInlining:false PrintNMethods:false
BackgroundCompilation:true ReplayInline:false DumpReplay:false
DumpInline:false CompilerDirectivesIgnoreCompileCommands:false
DisableIntrinsic: BlockLayoutByFrequency:true PrintOptoAssembly:false
PrintIntrinsics:false TraceOptoPipelining:false TraceOptoOutput:false
TraceSpilling:false Vectorize:false VectorizeDebug:0
CloneMapDebug:false IGVPrintLevel:0 MaxNodeLimit:1000


Directive: (default)
 matching: *.*
 c1 directives:
  inline: -
  Enable:true Exclude:false BreakAtExecute:false BreakAtCompile:false
Log:false PrintAssembly:false PrintInlining:false PrintNMethods:false
BackgroundCompilation:true ReplayInline:false DumpReplay:false
DumpInline:false CompilerDirectivesIgnoreCompileCommands:false
DisableIntrinsic: BlockLayoutByFrequency:true PrintOptoAssembly:false
PrintIntrinsics:false TraceOptoPipelining:false TraceOptoOutput:false
TraceSpilling:false Vectorize:false VectorizeDebug:0
```

```
CloneMapDebug:false IGVPrintLevel:0 MaxNodeLimit:80000

 c2 directives:
  inline: -
  Enable:true Exclude:false BreakAtExecute:false BreakAtCompile:false
Log:false PrintAssembly:false PrintInlining:false PrintNMethods:false
BackgroundCompilation:true ReplayInline:false DumpReplay:false
DumpInline:false CompilerDirectivesIgnoreCompileCommands:false
DisableIntrinsic: BlockLayoutByFrequency:true PrintOptoAssembly:false
PrintIntrinsics:false TraceOptoPipelining:false TraceOptoOutput:false
TraceSpilling:false Vectorize:false VectorizeDebug:0
CloneMapDebug:false IGVPrintLevel:0 MaxNodeLimit:80000
```

How Directives are Applied to Code?

A directive is applied to code based on a method matching process. Every method submitted for compilation is matched with a directive in the directives stack.

The process of matching a method with a directive in the directives stack is performed by the CompilerBroker.

The Method Matching Process

When a method is submitted for compilation, the fully qualified name of the method is compared with the matching criteria in the directives stack. The first directive in the stack that matches is applied to the method. The remaining directives in the stack are ignored. If no match is found, then the default directive is applied.

This process is repeated for all methods in a compilation. More than one directive can be applied in a compilation, but only one directive is applied to each method. All directives in the stack are considered active because they are potentially applicable. The key differences between active and applied directives are:

- A directive is active if it's present in the directives stack.
- A directive is applied if it's affecting code.

Example 2-1 When a Match Is Found

The following example shows a method submitted for compilation:

```
public int exampleMethod(int x){
    return x;
}
```

Based on method-matching criteria, `Directive 2` is applied from the following example directive stack:

```
Directive 2:
 matching: *.*example*
Directive 1:
 matching: *.*exampleMethod*
Directive 0: (default)
 matching: *.*
```

Example 2-2 When No Match Is Found

The following example shows a method submitted for compilation:

```
public int otherMethod(int y){
    return y;
}
```

Based on method-matching criteria, `Directive 0` (the default directive) is applied from the following example directive stack:

```
Directive 2:
 matching: *.*example*
Directive 1:
 matching: *.*exampleMethod*
Directive 0: (default)
 matching: *.*
```

Guidelines for Writing a New Directive

- No feedback mechanism is provided to verify which directive is applied to a given method. Instead, a profiler such as Java Management Extensions (JMX) is used to measure the cumulative effects of applied directives.
- The CompilerBroker ignores directive options that create bad code, such as forcing hardware instructions on a platform that doesn't offer support. A warning message is displayed.
- Directive options have the same limitations as typical command-line flags. For example, the instructions to inline code are followed only if the Intermediate Representation (IR) doesn’t become too large.

Compiler Control and Backward Compatibility

CompileCommand and command-line flags can be used alongside Compiler Control directives.

Although Compiler Control can replace CompileCommand, backward compatibility is provided. It’s possible to utilize both at the same time. Compiler Control receives priority. Conflicts are handled based on the following prioritization:

1. Compiler Control
2. CompileCommand
3. Command-line flags
4. Default values

Example 2-3 Mixing Compiler Control and CompileCommand

The following list shows a small number of compilation options and values:

- Compiler Control:
  - `Exclude: true`
  - `BreakAtExecute: false`
- CompileCommand:

  - `BreakAtExecute: true`
  - `BreakAtCompile: true`
- Default values:
  - `Exclude: false`
  - `BreakAtExecute: false`
  - `BreakAtCompile: false`
  - `Log: false`

For the options and values in this example, the resulting compilation is determined by using the rules for handling backward compatibility conflicts:

- `Exclude: true`
- `BreakAtExecute: false`
- `BreakAtCompile: true`
- `Log: false`

Commands for Working with Directive Files

This topic examines commands and the effects of working with completed directive files.

Compiler Directives and the Command Line

You can use the command-line interface to add and print compiler directives while starting a program.

You can specify only one directives file at the command line. All directives within that file are added to the directives stack and are immediately active when the program starts. Adding directives at the command line enables you to test the performance effects of directives during a program's early stages. You can also focus on debugging and developing your program.

Adding Directives Through the Command Line

The following command-line option specifies a directives file:

```
XX:CompilerDirectivesFile=file
```

Include this command-line option when you start a Java program. The following example shows this option, which starts `TestProgram`:

```
java -XX:+UnlockDiagnosticVMOptions -
XX:CompilerDirectivesFile=File_A.json TestProgram
```

In the example:

- `-XX:+UnlockDiagnosticVMOptions` enables diagnostic options. You must enter this before you add directives at the command line.
- `-XX:CompilerDirectivesFile` is a type of diagnostic option. You can use it to specify one directives file to add to the directives stack.
- `File_A.json` is a directives file. The file can contain multiple directives, all of which are added to the stack of active directives when the program starts.
- If `File_A.json` contains syntax errors or malformed directives, then an error message is displayed and `TestProgram` does not start.

Printing Directives Through the Command Line

You can automatically print the directives stack when a program starts or when additional directives are added through diagnostic commands. The following command-line option to enables this behavior:

```
-XX:+CompilerDirectivesPrint
```

The following example shows how to include this diagnostic command at the command line:

```
java -XX:+UnlockDiagnosticVMOptions -XX:+CompilerDirectivesPrint -
XX:CompilerDirectivesFile=File_A.json TestProgram
```

Compiler Directives and Diagnostic Commands

You can use diagnostic commands to manage which directives are active at runtime. You can add or remove directives without restarting a running program.

Crafting a single perfect directives file might take some iteration and experimentation. Diagnostic commands provide powerful mechanisms for testing different configurations of directives in the directives stack. Diagnostic commands let you add or remove directives without restarting a running program's JVM.

Getting Your Java Process Identification Number

To test directives you must find the processor identifier (PID) number of your running program.

1. Open a terminal.
2. Enter the `jcmd` command.

The `jcmd` command returns a list of the Java process that are running, along with their PID numbers. In the following example, the information returned about `TestProgram` :

```
11084 TestProgram
```

Adding Directives Through Diagnostic Commands

You can add all directives in a file to the directives stack through the following diagnostic command.

Syntax:

```
jcmd pid Compiler.directives_add file
```

The following example shows a diagnostic command:

```
jcmd 11084 Compiler.directives_add File_B.json
```

The terminal reports the number of individual directives added. If the directives file contains syntax errors or malformed directives, then an error message is displayed, and no directives from the file are added to the stack, and no changes are made to the running program.

Removing Directives Through Diagnostic Commands

You can remove directives by using diagnostic commands.

To remove the top-most, individual directive from the directive stack, enter:

```
jcmd pid Compiler.directives_remove
```

To clear every directive you added to the directives stack, enter:

```
jcmd pid Compiler.directives_clear
```

It's not possible to specify an entire file of directives to remove, nor is any other way available to remove directives in bulk.

Printing Directives Through Diagnostic Commands

You can use diagnostic commands to print the directives stack of a running program.

To print a detailed description of the full directives stack, enter:

```
jcmd pid Compiler.directives_print
```

Example output is shown in What Is the Default Directive?

How Directives Are Ordered in the Directives Stack?

The order of the directives in a directives file, and in the directives is very important. The top-most, best-matching directive in the stack receives priority and is applied to code compilation.

The following examples illustrate the order of directive files in an example directives stack. The directive files in the examples contain the following directives :

- `File_A` contains `Directive 1` and `Directive 2`.
- `File_B` contains `Directive 3`.
- `File_C` contains `Directive 4` and `Directive 5`.

Starting an Application With or Without Directives

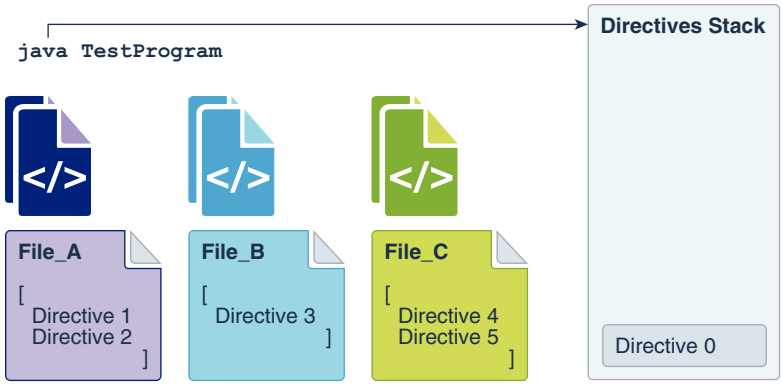
You can start the `TestProgram` without specifying the directive files.

- To start `TestProgram` without adding any directives, at the command line, enter the following command:

  ```
  java TestProgram
  ```

- `TestProgram` starts without any directives file specified.
- The default directive is always the bottom-most directive in the directives stack. Figure 2-1 shows the default directive as `Directive 0`. When you don't specify a directives file, the default directive is also the top-most directive and it receives priority.

Figure 2-1 Starting a Program Without Directives



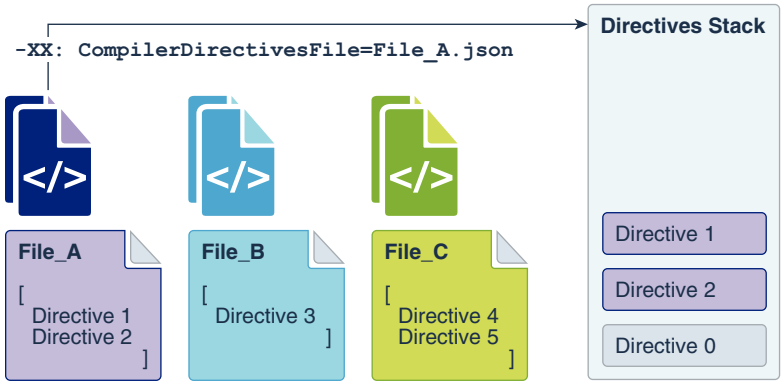
You can start an application and specify directives.

- To start the `TestProgram` application and add the directives from `File_A.json` to the directives stack, at the command line, enter the following command:

  ```
  java -XX:+UnlockDiagnosticVMOptions -
  XX:CompilerDirectivesFile=File_A.json TestProgram
  ```

- `TestProgram` starts and the directives in `File_A` are added to the stack. The top-most directive in the directives file becomes the top-most directive in the directives stack.
- Figure 2-2 shows that the order of directives in the stack, from top to bottom, becomes is [1, 2, 0].

Figure 2-2 Starting a Program with Directives



Adding Directives to a Running Application

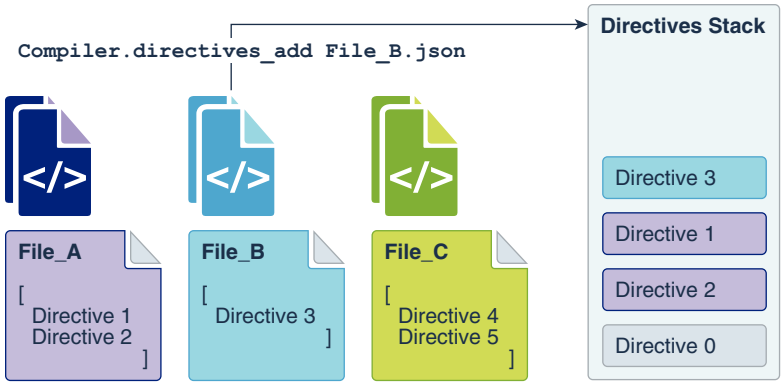
You can add directives to a running application through diagnostic commands.

- To to add all directives from `File_B` to the directives stack, enter the following command:

  ```
  jcmd 11084 Compiler.directives_add File_B.json
  ```

  The directive in `File_B` is added to the top of the stack.
- Figure 2-3 shows that the order of directives in the stack becomes is [3, 1, 2, 0].

Figure 2-3 Adding a Directive to a Running Program



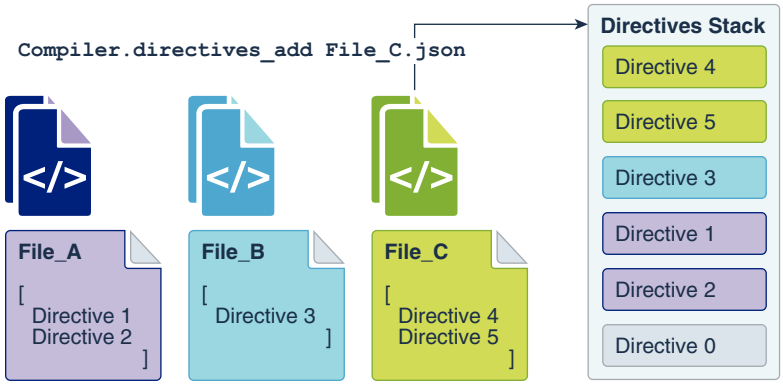
You can add directive files through diagnostic commands to the `TestProgram` while it is running:

- To add all directives from `File_C` to the directives stack, enter the following command.

  ```
  jcmd 11084 Compiler.directives_add File_C.json
  ```

- Figure 2-4 shows that the order of directives in the stack becomes is [4, 5, 3, 1, 2, 0].

Figure 2-4 Adding multiple Directives to a Running Program



Removing Directives from the Directives Stack

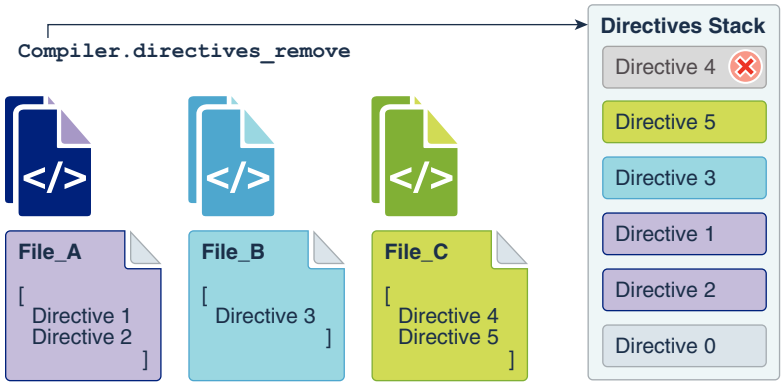
You can remove the top-most directive from the directive stacks through diagnostic commands.

- To remove `Directive 4` from the stack, enter the following command:

  ```
  jcmd 11084 Compiler.directives_remove
  ```

- To remove more, repeat this diagnostic command until only the default directive remains. You can't remove the default directive.
- Figure 2-5 shows that the order of directives in the stack becomes is [5, 3, 1, 2, 0].

Figure 2-5 Removing One Directive from the Stack



You can remove multiple directives from the directives stack.

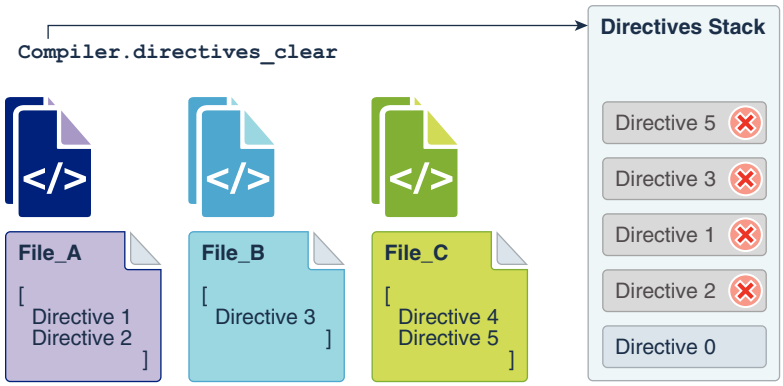
- To clear the directives stack, enter the following command:

  ```
  jcmd 11084 Compiler.directives_clear
  ```

- All directives are removed except the default directive. You can't remove the default directive.

- Figure 2-6 shows that only `Directive 0` remains in the stack.

Figure 2-6 Removing All Directives from the Stack



3
Garbage Collection

Oracle's HotSpot VM includes several garbage collectors that you can use to help optimize the performance of your application. A garbage collector is especially helpful if your application handles large amounts of data (multiple gigabytes), has many threads, and has high transaction rates.

For descriptions on the available garbage collectors, see Garbage Collection Implementation in the *Java Platform, Standard Edition HotSpot Virtual Machine Garbage Collection Tuning Guide*.

4
Class Data Sharing

This chapter describes the class data sharing (CDS) feature that can help reduce the startup time and memory footprints for Java applications.

Topics:

Class Data Sharing

The Class data sharing (CDS) feature helps reduce the startup time and memory footprint between multiple Java Virtual Machines (JVM).

Starting from JDK 12, a default CDS archive is pre-packaged with the Oracle JDK binary. The default CDS archive is created at the JDK build time by running `-Xshare:dump`, using G1 GC and 128M Java heap. It uses a built-time generated default class list that contains the selected core library classes. The default CDS archive resides in the following location:

- On Linux and macOS platforms, the shared archive is stored in `/lib/[arch]/server/classes.jsa`
- On Windows platforms, the shared archive is stored in `/bin/server/classes.jsa`

By default, the default CDS archive is enabled at the runtime. Specify `-Xshare:off` to disable the default shared archive. See Regenerating the Shared Archive to create a customized shared archive. Use the same Java heap size for both dump time and runtime while creating and using a customized shared archive.

When the JVM starts, the shared archive is memory-mapped to allow sharing of read-only JVM metadata for these classes among multiple JVM processes. Because accessing the shared archive is faster than loading the classes, startup time is reduced.

Class data sharing is supported with the ZGC, G1, serial, and parallel garbage collectors. The shared Java heap object feature (part of class data sharing) supports only the G1 garbage collector on 64-bit non-Windows platforms.

The primary motivation for including CDS in Java SE is to decrease in startup time. The smaller the application relative to the number of core classes it uses, the larger the saved fraction of startup time.

The footprint cost of new JVM instances has been reduced in two ways:

1. A portion of the shared archive on the same host is mapped as read-only and shared among multiple JVM processes. Otherwise, this data would need to be

replicated in each JVM instance, which would increase the startup time of your application.

2. The shared archive contains class data in the form that the Java Hotspot VM uses it. The memory that would otherwise be required to access the original class information in the runtime modular image, is not used. These memory savings allow more applications to be run concurrently on the same system. In Windows applications, the memory footprint of a process, as measured by various tools, might appear to increase, because more pages are mapped to the process's address space. This increase is offset by the reduced amount of memory (inside Windows) that is needed to hold portions on the runtime modular image. Reducing footprint remains a high priority.

Application Class-Data Sharing

To further reduce the startup time and the footprint, Application Class-Data Sharing (AppCDS) is introduced that extends the CDS to include selected classes from the application class path.

This feature allows application classes to be placed in a shared drive. The common class metadata is shared across different Java processes. AppCDS allows the built-in system class loader, built-in platform class loader, and custom class loaders to load the archived classes. When multiple JVMs share the same archive file, memory is saved and the overall system response time improves.

See Application Class Data Sharing in *Java Development Kit Tool Specifications*.

Dynamic CDS Archive

Dynamic CDS archive extends application class-data sharing (AppCDS) to allow dynamic archiving of classes when a Java application exits.

It simplifies AppCDS usage by eliminating the trial runs to create a class list for each application. The archived classes include all loaded application classes and library classes that are not present in the default CDS archive.

To create a dynamic CDS archive, run the Java application with the following command:

```
java -XX:ArchiveClassesAtExit=<dynamic archive> -cp <app jar> MyApp
```

See Dynamic CDS Archive in *Java Development Kit Tool Specifications*.

Regenerating the Shared Archive

You can regenerate the shared archive for all supported platforms.

The default class list that is installed with the JDK contains only a small set of core library classes. You might want to include other classes in the shared archive. To create a dynamic CDS archive with the default CDS archive as the base archive, add the following option in the command line:

```
java -XX:ArchiveClassesAtExit=<dynamic archive>
```

A separate dynamically-generated archive is created on top of the default system for each application. You can specify the name of the dynamic archive as an argument to the `-XX:ArchiveClassesAtExit` option.

To regenerate the archive file log in as the administrator. In networked situations, log in to a computer of the same architecture as the Java SE installation. Ensure that you have permissions to write to the installation directory.

To regenerate the shared archive by using a user defined class list, enter the following command:

```
java -XX:SharedClassListFile=<class_list_file> -Xshare:dump
```

Diagnostic information is printed when the archive is generated.

Manually Controlling Class Data Sharing

Class data sharing is enabled by default. You can manually enable and disable this feature.

You can use the following command-line options for diagnostic and debugging purposes.

`-Xshare:off`
To disable class data sharing.

`-Xshare:on`
To enable class data sharing. If class data sharing can't be enabled, print an error message and exit.

> **Note:**
>
> The `-Xshare:on` is for testing purposes only and may cause intermittent failures due to the use of address space layout randomization by the operating system. This option should not be used in production environments.

`-Xshare:auto`
To enable class data sharing by default. Enable class data sharing whenever possible.

5

Java HotSpot Virtual Machine Performance Enhancements

This chapter describes the performance enhancements in the Oracle's HotSpot Virtual Machine technology.

Topics:

Compact Strings

The compact strings feature introduces a space-efficient internal representation for strings.

Data from different applications suggests that strings are a major component of Java heap usage and that most `java.lang.String` objects contain only Latin-1 characters. Such characters require only one byte of storage. As a result, half of the space in the internal character arrays of `java.lang.String` objects are not used. The compact strings feature, introduced in Java SE 9 reduces the memory footprint, and reduces garbage collection activity. This feature can be disabled if you observe performance regression issues in an application.

The compact strings feature does not introduce new public APIs or interfaces. It modifies the internal representation of the `java.lang.String` class from a UTF-16 (two bytes) character array to a byte array with an additional field to identify character encoding. Other string-related classes, such as `AbstractStringBuilder`, `StringBuilder`, and `StringBuffer` are updated to use a similar internal representation.

In Java SE 9, the compact strings feature is enabled by default. Therefore, the `java.lang.String` class stores characters as one byte for each character, encoded as Latin-1. The additional character encoding field indicates the encoding that is used. The HotSpot VM string intrinsics are updated and optimized to support the internal representation.

You can disable the compact strings feature by using the `-XX:-CompactStrings` flag with the `java` command line. When the feature is disabled, the `java.lang.String` class stores characters as two bytes, encoded as UTF-16, and the HotSpot VM string intrinsics to use UTF-16 encoding.

Tiered Compilation

Tiered compilation, introduced in Java SE 7, brings client VM startup speeds to the server VM. Without tired compilation, a server VM uses the interpreter to collect profiling information about methods that is sent to the compiler. With tiered compilation, the server VM also uses the client compiler to generate compiled versions of methods that collect profiling information about themselves. The compiled code is substantially faster than the interpreter, and the program executes with greater performance during the profiling phase. Often, startup is faster than the client VM startup speed because the final code produced by the server compiler might be available during the early stages of application initialization. Tiered compilation can also achieve better peak performance than a regular server VM, because, the faster profiling phase allows a longer period of profiling, which can yield better optimization.

Tiered compilation is enabled by default for the server VM. The 64-bit mode and Compressed Ordinary Object Pointer are supported. You can disable tiered compilation by using the `-XX:-TieredCompilation` flag with the `java` command.

To accommodate the additional profiling code that is generated with tiered compilation, the default size of code cache is multiplied by 5x. To organize and manage the larger space effectively, segmented code cache is used.

Segmented Code Cache

The code cache is the area of memory where the Java Virtual Machine stores generated native code. It is organized as a single heap data structure on top of a contiguous chunk of memory.

Instead of having a single code heap, the code cache is divided into segments, each containing compiled code of a particular type. This segmentation provides better control of the JVM memory footprint, shortens scanning time of compiled methods, significantly decreases the fragmentation of code cache, and improves performance.

The code cache is divided into the following three segments:

Table 5-1 Segmented Code Cache

Code Cache Segments	Description	JVM Command-Line Arguments
Non-method	This code heap contains non-method code such as compiler buffers and bytecode interpreter. This code type stays in the code cache forever. The code heap has a fixed size of 3 MB and remaining code cache is distributed evenly among the profiled and non-profiled code heaps.	`-XX:NonMethodCodeHeapSize`
Profiled	This code heap contains lightly optimized, profiled methods with a short lifetime.	`-XX:ProfiledCodeHeapSize`

Table 5-1 (Cont.) Segmented Code Cache

Code Cache Segments	Description	JVM Command-Line Arguments
Non-profiled	This code heap contains fully optimized, non-profiled methods with a potentially long lifetime.	`-XX:NonProfiledCodeHeapSize`

Graal : a Java-Based JIT Compiler

Graal is a high-performance, optimizing, just-in-time compiler written in Java that integrates with Java HotSpot VM. It's a customizable dynamic compiler that you can invoke from Java.

Some of the features and benefits of Graal include:

- Flexible speculative optimizations
- Better inlining
- Partial escape analysis
- Benefits from Java tooling and IDE support
- Metacircular approach that allows for tighter code generation control

You can use Graal in the static context as well. The static Ahead of Time Compiler is based on the Graal framework.

Graal is part of the JDK build and it is delivered as an internal module, `jdk.internal.vm.compiler`. It communicates with the JVM using the JVM Compiler Interface (JVMCI). The JVMCI is also part of the JDK build and it is contained within the internal module: `jdk.internal.vm.ci`.

To enable Graal as the JIT compiler, use the following option on the `java` command line:

```
-XX:+UnlockExperimentalVMOptions -XX:+UseJVMCICompiler
```

> **Note:**
>
> Graal is an experimental feature and is supported only on Linux-x64.

Ahead-of-Time Compilation

Ahead-of-time (AOT) compilation improves the startup time of small and large Java applications by compiling the Java classes to native code before launching the virtual machine.

Though just-in-time (JIT) compilers are fast, it takes time to compile large Java programs. Also, when certain Java methods that are not compiled are interpreted repeatedly, performance is affected. AOT addresses these issues.

A new tool `jaotc` is used for AOT compilation. The syntax of the `jaotc` tool is as follows:

```
jaotc <options> <list of classes or jar files>
jaotc <options> <--module name>
```

For example:

```
jaotc --output libHelloWorld.so HelloWorld.class
jaotc --output libjava.base.so --module java.base
```

The `jaotc` tool is part of Java installation, similar to `javac`.

Specify the generated AOT library while application execution:

```
java -XX:AOTLibrary=./libHelloWorld.so,./libjava.base.so HelloWorld
```

When JVM startup, the AOT initialization code looks for the libraries specified using the `AOTLibrary` flag. If the libraries are not found, then the AOT is turned off for that JVM instance.

See *Java Development Kit Tool Specifications* for details on `jaotc` tool.

> **Note:**
>
> Ahead-of-Time (AOT) compilation is an experimental feature and is supported only on Linux-x64.

Compressed Ordinary Object Pointer

An ordinary object pointer (oop) in Java Hotspot parlance, is a managed pointer to an object. Typically, an oop is the same size as a native machine pointer, which is 64-bit on an LP64 system. On an ILP32 system, maximum heap size is less than 4 gigabytes, which is insufficient for many applications. On an LP64 system, the heap used by a given program might have to be around 1.5 times larger than when it is run on an ILP32 system. This requirement is due to the expanded size of managed pointers. Memory is inexpensive, but these days bandwidth and cache are in short supply, so significantly increasing the size of the heap and only getting just over the 4 gigabyte limit is undesirable.

Managed pointers in the Java heap point to objects that are aligned on 8-byte address boundaries. Compressed oops represent managed pointers (in many but not all places in the Java Virtual Machine (JVM) software) as 32-bit object offsets from the 64-bit Java heap base address. Because they're object offsets rather than byte offsets, oops can be used to address up to four billion *objects* (not bytes), or a heap size of up to about 32 gigabytes. To use them, they must be scaled by a factor of 8 and added to the Java heap base address to find the object to which they refer. Object sizes using compressed oops are comparable to those in ILP32 mode.

The term *decode* refer to the operation by which a 32-bit compressed oop is converted to a 64-bit native address and added into the managed heap. The term *encode* refers to that inverse operation.

Compressed oops is supported and enabled by default in Java SE 6u23 and later. In Java SE 7, compressed oops is enabled by default for 64-bit JVM processes when `-Xmx` isn't specified and for values of `-Xmx` less than 32 gigabytes. For JDK releases earlier than 6u23 release, use the `-XX:+UseCompressedOops` flag with the `java` command to enable the compressed oops.

Zero-Based Compressed Ordinary Object Pointers

When the JVM uses compressed ordinary object pointers (oops) in a 64-bit JVM process, the JVM software sends a request to the operating system to reserve memory for the Java heap starting at virtual address zero. If the operating system supports such a request and can reserve memory for the Java heap at virtual address zero, then zero-based compressed oops are used.

When zero-based compressed oops are used, a 64-bit pointer can be decoded from a 32-bit object offset without including the Java heap base address. For heap sizes less than 4 gigabytes, the JVM software can use a byte offset instead of an object offset and thus also avoid scaling the offset by 8. Encoding a 64-bit address into a 32-bit offset is correspondingly efficient.

For Java heap sizes up to 26 gigabytes, the Linux and Windows operating systems typically can allocate the Java heap at virtual address zero.

Escape Analysis

Escape analysis is a technique by which the Java HotSpot Server Compiler can analyze the scope of a new object's uses and decide whether to allocate the object on the Java heap.

Escape analysis is supported and enabled by default in Java SE 6u23 and later.

The Java HotSpot Server Compiler implements the flow-insensitive escape analysis algorithm described in:

```
[Choi99] Jong-Deok Choi, Manish Gupta, Mauricio Seffano,
         Vugranam C. Sreedhar, Sam Midkiff,
         "Escape Analysis for Java", Procedings of ACM SIGPLAN
         OOPSLA  Conference, November 1, 1999
```

An object's escape state, based on escape analysis, can be one of the following states:

- `GlobalEscape`: The object escapes the method and thread. For example, an object stored in a static field, stored in a field of an escaped object, or returned as the result of the current method.
- `ArgEscape`: The object is passed as an argument or referenced by an argument but does not globally escape during a call. This state is determined by analyzing the bytecode of the called method.

- `NoEscape`: The object is a scalar replaceable object, which means that its allocation could be removed from generated code.

After escape analysis, the server compiler eliminates the scalar replaceable object allocations and the associated locks from generated code. The server compiler also eliminates locks for objects that do not globally escape. It does *not* replace a heap allocation with a stack allocation for objects that do not globally escape.

The following examples describe some scenarios for escape analysis:

- The server compiler might eliminate certain object allocations. For example, a method makes a defensive copy of an object and returns the copy to the caller.

```
public class Person {
  private String name;
  private int age;
  public Person(String personName, int personAge) {
    name = personName;
                age = personAge;
  }

  public Person(Person p) { this(p.getName(), p.getAge()); }
  public int getName() { return name; }
  public int getAge() { return age; }
}

public class Employee {
  private Person person;

        // makes a defensive copy to protect against modifications
by caller
        public Person getPerson() { return new Person(person) };

        public void printEmployeeDetail(Employee emp) {
          Person person = emp.getPerson();
          // this caller does not modify the object, so defensive
copy was unnecessary
                System.out.println ("Employee's name: " +
person.getName() + "; age: "  + person.getAge());
        }
}
```

The method makes a copy to prevent modification of the original object by the caller. If the compiler determines that the `getPerson` method is being invoked in a loop, then the compiler inlines that method. By using escape analysis, when the compiler determines that the original object is never modified, the compiler can optimize and eliminate the call to make a copy.

- The server compiler might eliminate synchronization blocks (*lock elision*) if it determines that an object is thread local. For example, methods of classes such as `StringBuffer` and `Vector` are synchronized because they can be accessed by different threads. However, in most scenarios, they are used in a thread local manner. In cases where the usage is thread local, the compiler can optimize and remove the synchronization blocks.

6
JVM Constants API

The JVM Constants API is defined in the package `java.lang.constants`, which contains the nominal descriptors of various types of loadable constants. These nominal descriptors are useful for applications that manipulate class files and compile-time or link-time program analysis tools.

A nominal descriptor is not the value of a loadable constant but a description of its value, which can be reconstituted given a class loading context. A loadable constant is a constant pool entry that can be pushed onto the operand stack or can appear in the static argument list of a bootstrap method for the `invokedynamic` instruction. The operand stack is where JVM instructions get their input and store their output. Every Java class file has a constant pool, which contains several kinds of constants, ranging from numeric literals known at compile-time to method and field references that must be resolved at run-time.

The issue with working with non-nominal loadable constants, such as a `Class` objects, whose references are resolved at run-time, is that these references depend on the correctness and consistency of the class loading context. Class loading may have side effects, such as running code that you don't want run and throwing access-related and out-of-memory exceptions, which you can avoid with nominal descriptions. In addition, class loading may not be possible at all.

See the package `java.lang.constant`.

7

Support for Non-Java Languages

This chapter describes the Non-Java Language features in the Java Virtual Machine.

Topics:

Introduction to Non-Java Language Features

The Java Platform, Standard Edition (Java SE) enables the development of applications that have the following features:

- They can be written once and run anywhere
- They can be run securely because of the Java sandbox security model
- They are easy to package and deliver

The Java SE platform provides robust support in the following areas:

- Concurrency
- Garbage collection
- Reflective access to classes and objects
- JVM Tool Interface (JVM TI): A native programming interface for use by tools. It provides both a way to inspect the state and to control the execution of applications running in the JVM.

Oracle's HotSpot JVM provides the following tools and features:

- DTrace: A dynamic tracing utility that monitors the behavior of applications and the operating system.
- Performance optimizations
- PrintAssembly: A Java HotSpot option that prints assembly code for bytecoded and native methods.

The Java SE 7 platform enables non-Java languages to use the infrastructure and potential performance optimizations of the JVM. The key mechanism is the `invokedynamic` instruction, which simplifies the implementation of compilers and runtime systems for dynamically-typed languages on the JVM.

Static and Dynamic Typing

A programming language is statically-typed if it performs type checking at compile time. Type checking is the process of verifying that a program is type safe. A program is type safe if the arguments of all of its operations are the correct type.

Java is a statically-typed language. Type information is available for class and instance variables, method parameters, return values, and other variables when a program is compiled. The compiler for the Java programming language uses this type information to produce strongly typed bytecode, which can then be efficiently executed by the JVM at runtime.

The following example of a Hello World program demonstrates static typing. Types are shown in **bold**.

```
import java.util.Date;

public class HelloWorld {
    public static void main(String[] argv) {
        String hello = "Hello ";
        Date currDate = new Date();
        for (String a : argv) {
            System.out.println(hello + a);
            System.out.println("Today's date is: " + currDate);
        }
    }
}
```

A programming language is dynamically-typed if it performs type checking at runtime. JavaScript and Ruby are examples of dynamically typed languages. These languages verify at runtime, rather than at compile time, that values in an application conform to expected types. Typically, type information for these languages is not available when an application is compiled. The type of an object is determined only at runtime. In the past, it was difficult to efficiently implement dynamically-typed languages on the JVM.

The following is an example of the Hello World program written in the Ruby programming language:

```
#!/usr/bin/env ruby
require 'date'

hello = "Hello "
currDate = DateTime.now
ARGV.each do|a|
  puts hello + a
  puts "Date and time: " + currDate.to_s
end
```

In the example, every name is introduced without a type declaration. The main program is not located inside a holder type (the Java class `HelloWorld`). The Ruby equivalent of the Java `for` loop is inside the dynamic type `ARGV` variable. The body

of the loop is contained in a block called a closure, which is a common feature in dynamic languages.

Statically-Typed Languages Are Not Necessarily Strongly-Typed Languages

Statically-typed programming languages can employ strong typing or weak typing. A programming language that employs strong typing specifies restrictions on the types of values supplied to its operations, and it prevents the execution of an operation if its arguments have the wrong type. A language that employs weak typing would implicitly convert (or cast) arguments of an operation if those arguments have the wrong or incompatible types.

Dynamically-typed languages can employ strong typing or weak typing. For example, the Ruby programming language is dynamically-typed and strongly-typed. When a variable is initialized with a value of some type, the Ruby programming language does not implicitly convert the variable into another data type.

In the following example, the Ruby programming language does not implicitly cast the number 2, which has a `Fixnum` type, to a string.

```
a = "40"
b = a + 2
```

The Challenge of Compiling Dynamically-Typed Languages

Consider the following dynamically-typed method, `addtwo`, which adds any two numbers (which can be of any numeric type) and returns their sum:

```
def addtwo(a, b)
       a + b;
end
```

Suppose your organization is implementing a compiler and runtime system for the programming language in which the method `addtwo` is written. In a strongly-typed language, whether typed statically or dynamically, the behavior of + (the addition operator) depends on the operand types. A compiler for a statically-typed language chooses the appropriate implementation of + based on the static types of `a` and `b`. For example, a Java compiler implements + with the `iadd` JVM instruction if the types of `a` and `b` are `int`. The addition operator is compiled to a method call because the JVM `iadd` instruction requires the operand types to be statically known.

A compiler for a dynamically-typed language must defer the choice until runtime. The statement `a + b` is compiled as the method call `+(a, b)`, where + is the method name. A method named + is permitted in the JVM but not in the Java programming language. If the runtime system for the dynamically-typed language is able to identify that `a` and `b` are variables of integer type, then the runtime system would prefer to call an implementation of + that is specialized for integer types rather than arbitrary object types.

The challenge of compiling dynamically-typed languages is how to implement a runtime system that can choose the most appropriate implementation of a method or function — after the program has been compiled. Treating all variables as objects of `Object` type would not work efficiently; the `Object` class does not contain a method named `+`.

In Java SE 7 and later, the `invokedynamic` instruction enables the runtime system to customize the linkage between a call site and a method implementation. In this example, the `invokedynamic` call site is `+`. An `invokedynamic` call site is linked to a method by means of a *bootstrap method*, which is a method specified by the compiler for the dynamically-typed language that is called once by the JVM to link the site. Assuming the compiler emitted an `invokedynamic` instruction that invokes `+`, and assuming that the runtime system knows about the method `adder(Integer,Integer)`, the runtime can link the `invokedynamic` call site to the `adder` method as follows:

IntegerOps.java

```
class IntegerOps {

  public static Integer adder(Integer x, Integer y) {
    return x + y;
  }
}
```

Example.java

```
import java.util.*;
import java.lang.invoke.*;
import static java.lang.invoke.MethodType.*;
import static java.lang.invoke.MethodHandles.*;

class Example {

  public static CallSite mybsm(
    MethodHandles.Lookup callerClass, String dynMethodName, MethodType
dynMethodType)
    throws Throwable {

    MethodHandle mh =
      callerClass.findStatic(
        Example.class,
        "IntegerOps.adder",
        MethodType.methodType(Integer.class, Integer.class,
Integer.class));

    if (!dynMethodType.equals(mh.type())) {
      mh = mh.asType(dynMethodType);
    }

    return new ConstantCallSite(mh);
  }
}
```

In this example, the `IntegerOps` class belongs to the library that accompanies runtime system for the dynamically-typed language.

The `Example.mybsm` method is a bootstrap method that links the `invokedynamic` call site to the `adder` method.

The `callerClass` object is a `lookup` object, which is a factory for creating method handles.

The `MethodHandles.Lookup.findStatic` method (called from the `callerClass lookup` object) creates a static method handle for the method `adder`.

Note: This bootstrap method links an `invokedynamic` call site to only the code that is defined in the `adder` method. It assumes that the arguments given to the `invokedynamic` call site are `Integer` objects. A bootstrap method requires additional code to properly link `invokedynamic` call sites to the appropriate code to execute if the parameters of the bootstrap method (in this example, `callerClass`, `dynMethodName`, and `dynMethodType`) vary.

The `java.lang.invoke.MethodHandles` class and `java.lang.invoke.MethodHandle` class contain various methods that create method handles based on existing method handles. This example calls the `asType` method if the method type of the `mh` method handle does not match the method type specified by the `dynMethodType` parameter. This enables the bootstrap method to link `invokedynamic` call sites to Java methods whose method types don't exactly match.

The `ConstantCallSite` instance returned by the bootstrap method represents a call site to be associated with a distinct `invokedynamic` instruction. The target for a `ConstantCallSite` instance is permanent and can never be changed. In this case, one Java method, `adder`, is a candidate for executing the call site. This method does not have to be a Java method. Instead, if several such methods are available to the runtime system, each handling different argument types, the `mybsm` bootstrap method could dynamically select the correct method based on the `dynMethodType` argument.

The invokedynamic Instruction

You can use the `invokedynamic` instruction in implementations of compilers and runtime systems for dynamically typed languages on the JVM. The `invokedynamic` instruction enables the language implementer to define custom linkage. This contrasts with other JVM instructions such as `invokevirtual`, in which linkage behavior specific to Java classes and interfaces is hard-wired by the JVM.

Each instance of an `invokedynamic` instruction is called a *dynamic call site*. When an instance of the dynamic call site is created, it is in an unlinked state, with no method specified for the call site to invoke. The dynamic call site is linked to a method by means of a bootstrap method. A dynamic call site's bootstrap method is a method specified by the compiler for the dynamically-typed language. The method is called once by the JVM to link the site. The object returned from the bootstrap method permanently determines the call site's activity.

The `invokedynamic` instruction contains a constant pool index (in the same format as for the other `invoke` instructions). This constant pool index references a `CONSTANT_InvokeDynamic` entry. This entry specifies the bootstrap method (a `CONSTANT_MethodHandle` entry), the name of the dynamically-linked method, and the argument types and return type of the call to the dynamically-linked method.

In the following example, the runtime system links the dynamic call site specified by the `invokedynamic` instruction (which is `+`, the addition operator) to the IntegerOps.adder method by using the Example.mybsm bootstrap method. The `adder` method and `mybsm` method are defined in The Challenge of Compiling Dynamically Typed Languages (line breaks have been added for clarity):

```
invokedynamic   InvokeDynamic
  REF_invokeStatic:
    Example.mybsm:
      "(Ljava/lang/invoke/MethodHandles/Lookup;
        Ljava/lang/String;
        Ljava/lang/invoke/MethodType;)
      Ljava/lang/invoke/CallSite;":
    +:
      "(Ljava/lang/Integer;
        Ljava/lang/Integer;)
      Ljava/lang/Integer;";
```

> **Note:**
>
> The bytecode examples use the syntax of the ASM Java bytecode manipulation and analysis framework.

Invoking a dynamically-linked method with the `invokedynamic` instruction involves the following steps:

1. Defining the Bootstrap Method
2. Specifying Constant Pool Entries
3. Using the `invokedynamic` Instruction

Defining the Bootstrap Method

At runtime, the first time the JVM encounters an `invokedynamic` instruction, it calls the bootstrap method. This method links the name that the `invokedynamic` instruction specifies with the code to execute the target method, which is referenced by a method handle. The next time the JVM executes the same `invokedynamic` instruction, it does not call the bootstrap method; it automatically calls the linked method handle.

The bootstrap method's return type must be `java.lang.invoke.CallSite`. The `CallSite` object represents the linked state of the `invokedynamic` instruction and the method handle to which it is linked.

The bootstrap method takes three or more of the following parameters:

- `MethodHandles.Lookup` object: A factory for creating method handles in the context of the `invokedynamic` instruction.
- `String` object: The method name mentioned in the dynamic call site.
- `MethodType` object: The resolved type signature of the dynamic call site.

- One or more additional static arguments to the `invokedynamic` instruction: Optional arguments, drawn from the constant pool, are intended to help language implementers safely and compactly encode additional metadata useful to the bootstrap method. In principle, the name and extra arguments are redundant because each call site could be given its own unique bootstrap method. However, such a practice is likely to produce large class files and constant pools

See The Challenge of Compiling Dynamically Typed Languages for an example of a bootstrap method.

Specifying Constant Pool Entries

The `invokedynamic` instruction contains a reference to an entry in the constant pool with the `CONSTANT_InvokeDynamic` tag. This entry contains references to other entries in the constant pool and references to attributes. See `java.lang.invoke package documentation` and *The Java Virtual Machine Specification*.

Example Constant Pool

The following example shows an excerpt from the constant pool for the class `Example`, which contains the bootstrap method `Example.mybsm` that links the method `+` with the Java method `adder`:

```
    class #159; // #47
    Utf8 "adder"; // #83
    Utf8 "(Ljava/lang/Integer;Ljava/lang/Integer;)Ljava/lang/
Integer;"; // #84
    Utf8 "mybsm"; // #87
    Utf8 "(Ljava/lang/invoke/MethodHandles/Lookup;Ljava/lang/
String;Ljava/lang/invoke/MethodType;)
      java/lang/invoke/CallSite;"; // #88
    Utf8 "Example"; // #159
    Utf8 "+"; // #166

    // ...

    NameAndType #83 #84; // #228
    Method #47 #228; // #229
    MethodHandle 6b #229; // #230
    NameAndType #87 #88; // #231
    Method #47 #231; // #232
    MethodHandle 6b #232; // #233
    NameAndType #166 #84; // #234
    Utf8 "BootstrapMethods"; // #235
    InvokeDynamic 0s #234; // #236
```

The constant pool entry for the `invokedynamic` instruction in this example contains the following values:

- `CONSTANT_InvokeDynamic` tag
- Unsigned short of value `0`
- Constant pool index `#234`.

The value, `0`, refers to the first bootstrap method specifier in the array of specifiers that are stored in the `BootstrapMethods` attribute. Bootstrap method specifiers are not in the constant pool table. They are contained in this separate array of specifiers. Each bootstrap method specifier contains an index to a `CONSTANT_MethodHandle` constant pool entry, which is the bootstrap method itself.

The following example shows an excerpt from the same constant pool that shows the `BootstrapMethods` attribute, which contains the array of bootstrap method specifiers:

```
  [3] { // Attributes

    // ...

    Attr(#235, 6) { // BootstrapMethods at 0x0F63
      [1] { // bootstrap_methods
        {  //  bootstrap_method
          #233; // bootstrap_method_ref
          [0] { // bootstrap_arguments
          }  //  bootstrap_arguments
        }  //  bootstrap_method
      }
    } // end BootstrapMethods
  } // Attributes
```

The constant pool entry for the bootstrap method `mybsm` method handle contains the following values:

- `CONSTANT_MethodHandle` tag
- Unsigned byte of value `6`
- Constant pool index `#232`.

The value, `6`, is the `REF_invokeStatic` subtag. See, Using the invokedynamic Instruction, for more information about this subtag.

Using the invokedynamic Instruction

The following example shows how the bytecode uses the `invokedynamic` instruction to call the `mybsm` bootstrap method, which links the dynamic call site (`+`, the addition operator) to the `adder` method. This example uses the `+` method to add the numbers `40` and `2` (line breaks have been added for clarity):

```
bipush  40;
invokestatic    Method java/lang/Integer.valueOf:"(I)Ljava/lang/
Integer;";
iconst_2;
invokestatic    Method java/lang/Integer.valueOf:"(I)Ljava/lang/
Integer;";
invokedynamic   InvokeDynamic
  REF_invokeStatic:
    Example.mybsm:
      "(Ljava/lang/invoke/MethodHandles/Lookup;
```

```
        Ljava/lang/String;
        Ljava/lang/invoke/MethodType;)
      Ljava/lang/invoke/CallSite;":
    +:
      "(Ljava/lang/Integer;
        Ljava/lang/Integer;)
      Ljava/lang/Integer;";
```

The first four instructions put the integers `40` and `2` in the stack and boxes them in the `java.lang.Integer` wrapper type. The fifth instruction invokes a dynamic method. This instruction refers to a constant pool entry with a `CONSTANT_InvokeDynamic` tag:

```
REF_invokeStatic:
  Example.mybsm:
    "(Ljava/lang/invoke/MethodHandles/Lookup;
      Ljava/lang/String;
      Ljava/lang/invoke/MethodType;)
    Ljava/lang/invoke/CallSite;":
  +:
    "(Ljava/lang/Integer;
      Ljava/lang/Integer;)
    Ljava/lang/Integer;";
```

Four bytes follow the `CONSTANT_InvokeDynamic` tag in this entry.

- The first two bytes form a reference to a `CONSTANT_MethodHandle` entry that references a bootstrap method specifier:

  ```
  REF_invokeStatic:
    Example.mybsm:
      "(Ljava/lang/invoke/MethodHandles/Lookup;
        Ljava/lang/String;
        Ljava/lang/invoke/MethodType;)
      Ljava/lang/invoke/CallSite;"
  ```

  This reference to a bootstrap method specifier is not in the constant pool table. It is contained in a separate array defined by a class file attribute named `BootstrapMethods`. The bootstrap method specifier contains an index to a `CONSTANT_MethodHandle` constant pool entry, which is the bootstrap method itself.

  Three bytes follow this `CONSTANT_MethodHandle` constant pool entry:

  - The first byte is the `REF_invokeStatic` subtag. This means that this bootstrap method will create a method handle for a static method; note that this bootstrap method is linking the dynamic call site with the static Java `adder` method.
  - The next two bytes form a `CONSTANT_Methodref` entry that represents the method for which the method handle is to be created:

    ```
    Example.mybsm:
    ```

```
  "(Ljava/lang/invoke/MethodHandles/Lookup;
    Ljava/lang/String;
    Ljava/lang/invoke/MethodType;)
   Ljava/lang/invoke/CallSite;"
```

In this example, the fully qualified name of the bootstrap method is `Example.mybsm` . The argument types are `MethodHandles.Lookup`, `String`, and `MethodType`. The return type is `CallSite`.

- The next two bytes form a reference to a `CONSTANT_NameAndType` entry:

```
+:
  "(Ljava/lang/Integer;
    Ljava/lang/Integer;)
   Ljava/lang/Integer;"
```

This constant pool entry specifies the method name (+), the argument types (two `Integer` instances), and return type of the dynamic call site (`Integer`).

In this example, the dynamic call site is presented with boxed integer values, which exactly match the type of the eventual target, the `adder` method. In practice, the argument and return types don't need to exactly match. For example, the `invokedynamic` instruction could pass either or both of its operands on the JVM stack as primitive `int` values. Either or both operands could be untyped `Object` values. The `invokedynamic` instruction could receive its result as a primitive `int` value, or an untyped `Object` value. In any case, the `dynMethodType` argument to `mybsm` accurately describes the method type that is required by the `invokedynamic` instruction.

The `adder` method could be given primitive or untyped arguments or return values. The bootstrap method is responsible for making up any difference between the `dynMethodType` and the type of the `adder` method. As shown in the code, this is easily done with an `asType` call on the target method.

8
Signal Chaining

Signal chaining enables you to write applications that need to install their own signal handlers. This facility is available on Linux and macOS.

The signal chaining facility has the following features:

- Support for preinstalled signal handlers when you create Oracle's HotSpot Virtual Machine.

  When the HotSpot VM is created, the signal handlers for signals that are used by the HotSpot VM are saved. During execution, when any of these signals are raised and are not to be targeted at the HotSpot VM, the preinstalled handlers are invoked. In other words, preinstalled signal handlers are *chained* behind the HotSpot VM handlers for these signals.

- Support for the signal handlers that are installed after you create the HotSpot VM, either inside the Java Native Interface code or from another native thread.

  Your application can link and load the `libjsig.so` shared library before the `libc/libthread/libpthread` library. This library ensures that calls such as `signal()`, `sigset()`, and `sigaction()` are intercepted and don't replace the signal handlers that are used by the HotSpot VM, if the handlers conflict with the signal handlers that are already installed by HotSpot VM. Instead, these calls save the new signal handlers. The new signal handlers are chained behind the HotSpot VM signal handlers for the signals. During execution, when any of these signals are raised and are not targeted at the HotSpot VM, the preinstalled handlers are invoked.

  If support for signal handler installation after the creation of the VM is not required, then the `libjsig.so` shared library is not needed.

  To enable signal chaining, perform one of the following procedures to use the `libjsig.so` shared library:

  – Link the `libjsig.so` shared library with the application that creates or embeds the HotSpot VM:

    ```
    cc -L libjvm.so-directory -ljsig -ljvm java_application.c
    ```

  – Use the `LD_PRELOAD` environment variable:

    * Korn shell (ksh):

      ```
      export LD_PRELOAD=libjvm.so-directory/libjsig.so;
      java_application
      ```

    * C shell (csh):

      ```
      setenv LD_PRELOAD libjvm.so-directory/libjsig.so;
      java_application
      ```

The interposed `signal()`, `sigset()`, and `sigaction()` calls return the saved signal handlers, not the signal handlers installed by the HotSpot VM and are seen by the operating system.

> **Note:**
>
> The `SIGQUIT`, `SIGTERM`, `SIGINT`, and `SIGHUP` signals cannot be chained. If the application must handle these signals, then consider using the `–Xrs` option.

Enable Signal Chaining in macOS

To enable signal chaining in macOS, set the following environment variables:

- `DYLD_INSERT_LIBRARIES`: Preloads the specified libraries instead of the `LD_PRELOAD` environment variable available on Linux.
- `DYLD_FORCE_FLAT_NAMESPACE`: Enables functions in the `libjsig` library and replaces the OS implementations, because of macOS's two-level namespace (a symbol's fully qualified name includes its library). To enable this feature, set this environment variable to any value.

The following command enables signal chaining by preloading the `libjsig` library:

```
$ DYLD_FORCE_FLAT_NAMESPACE=0 DYLD_INSERT_LIBRARIES="JAVA_HOME/lib/
libjsig.dylib" java MySpiffyJavaApp
```

> **Note:**
>
> The library file name on macOS is `libjsig.dylib` not `libjsig.so` as it is on Linux.

9
Native Memory Tracking

This chapter describes the Native Memory Tracking (NMT) feature. NMT is a Java Hotspot VM feature that tracks internal memory usage for a HotSpot VM. You can access NMT data by using the `jcmd` utility. NMT does not track memory allocations for third-party native code and Oracle Java Development Kit (JDK) class libraries. NMT does not include NMT `MBean` in HotSpot for Java Mission Control (JMC).

Topics:

Key Features

When you use Native Memory Tracking with `jcmd`, you can track Java Virtual Machine (JVM) or HotSpot VM memory usage at different levels. NMT tracks only the memory that the JVM or HotSpot VM uses, not the user's native memory. NMT doesn't give complete information for the memory used by the class data sharing (CDS) archive.

NMT for HotSpot VM is turned off by default. You can turn on NMT by using the JVM command-line option. See java in the *Java Development Kit Tool Specifications* for information about advanced runtime options.

You can access NMT using the `jcmd` utility. See Use jcmd to Access NMT Data. You can stop NMT by using the `jcmd` utility, but you can't start or restart NMT by using the `jcmd` utilty.

NMT supports the following features:

- Generate summary and detail reports.
- Establish an early baseline for later comparison.
- Request a memory usage report at JVM exit with the JVM command-line option. See NMT at VM exit.

Using Native Memory Tracking

You must enable NMT and then use the `jcmd` utility to access the NMT data.

Enabling NMT

To enable NMT, use the following command-line options:

```
-XX:NativeMemoryTracking=[off | summary | detail]
```

> **Note:**
>
> Enabling NMT causes a 5% -10% performance overhead.

The following table describes the NMT command-line usage options:

Table 9-1 NMT Usage Options

NMT Options	Description
`off`	NMT is turned `off` by default.
`summary`	Collect only memory usage aggregated by subsystem.
`detail`	Collect the memory usage by individual call sites.

Accessing NMT Data using jcmd

Use `jcmd` to dump the data that is collected and optionally compare the data to the last baseline.

```
jcmd <pid> VM.native_memory [summary | detail | baseline | summary.diff |
detail.diff | shutdown] [scale= KB | MB | GB]
```

Table 9-2 jcmd NMT Options

jcmd NMT Option	Description
`summary`	Print a summary, aggregated by category.
`detail`	• Print memory usage, aggregated by category • Print virtual memory map • Print memory usage, aggregated by call site
`baseline`	Create a new memory usage snapshot for comparison.
`summary.diff`	Print a new summary report against the last baseline.
`detail.diff`	Print a new detail report against the last baseline.
`shutdown`	Stop NMT.

Obtaining NMT Data at VM Exit

To obtain data for the last memory usage at VM exit, when Native Memory Tracking is enabled, use the following VM diagnostic command-line options. The level of detail is based on tracking level.

```
-XX:+UnlockDiagnosticVMOptions -XX:+PrintNMTStatistics
```

See Native Memory Tracking in the *Java Platform, Standard Edition Troubleshooting Guide* for information about how to monitor VM internal memory allocations and diagnose VM memory leaks.

10

DTrace Probes in HotSpot VM

This chapter describes DTrace support in Oracle's HotSpot VM. The *hotspot* and *hotspot_jni* providers let you access probes that you can use to monitor the Java application that is running together with the internal state and activities of the Java Virtual Machine (JVM). All of the probes are USDT probes and you can access them by using the process-id of the JVM process.

Topics:

Using the hotspot Provider

The *hotspot* provider lets you access probes that you can use to track the lifespan of the VM, thread start and stop events, garbage collector (GC) and memory pool statistics, method compilations, and monitor activity. A startup flag can enable additional probes that you can use to monitor the running Java program, such as object allocations and method enter and return probes. The *hotspot* probes originate in the VM library (libjvm.so), so they are provided from programs that embed the VM.

Many of the probes in the provider have arguments for providing further details on the state of the VM. Many of these arguments are opaque IDs which can be used to link probe firings to each other. However, strings and other data are also provided. When string values are provided, they are always present as a pair: a pointer to unterminated modified UTF-8 data (see the JVM Specification) , and a length value which indicates the extent of that data. The string data is not guaranteed to be terminated by a NUL character, and it is necessary to use the length-terminated `copyinstr()` intrinsic to read the string data. This is true even when none of the characters are outside the ASCII range.

VM Lifecycle Probes

The following probes are available for tracking VM lifecycle activities. None have any arguments.

Table 10-1 VM Lifecycle Probes

Probe	Description
`vm-init-begin`	Probe that starts when the VM initialization begins
`vm-init-end`	Probe that starts when the VM initialization finishes, and the VM is ready to start running application code
`vm-shutdown`	Probe that starts as the VM is shuts down due to program termination or an error

Thread Lifecycle Probes

The following probes are available for tracking thread start and stop events.

Probe	Description
`thread-start`	Probe that starts when a thread starts.
`thread-stop`	Probe that starts when the thread has completed.

The following argument are available for the thread lifecycle probes:

Probe Arguments	Description
`args[0]`	A pointer to UTF-8 string data that contains the thread name.
`args[1]`	The length of the thread name data (in bytes).
`args[2]`	The Java thread ID. This value matches other HotSpot VM probes that contain a thread argument.
`args[3]`	The native or OS thread ID. This ID is assigned by the host operating system.
`args[4]`	A boolean value that indicates whether this thread is a daemon or not. A value of 0 indicates a non-daemon thread.

Classloading Probes

The following probes are available for tracking class loading and unloading activity.

Probe	Description
`class-loaded`	Probe that fires when a class is loaded
`class-unloaded`	Probe that fires when a class is unloaded from the system

The following arguments are available for the `classloading` probes:

Probe Arguments	Description
`args[0]`	A pointer to UTF-8 string data that contains the name of the class that is loaded

Probe Arguments	Description
`args[1]`	The length of the class name data (in bytes)
`args[2]`	The class loader ID, which is a unique identifier for a class loader in the VM. (This is the class loader that loaded the class.)
`args[3]`	A boolean value that indicates whether the class is a shared class (if the class was loaded from the shared archive)

Garbage Collection Probes

Probes are available that you can use to measure the duration of a system-wide garbage collection cycle (for those garbage collectors that have a defined begin and end). Each memory pool is tracked independently. The probes for individual pools pass the memory manager's name, the pool name, and pool usage information at both the beginning and ending of pool collection.

The following probes are available for garbage collecting activities:

Probe	Description
`gc-begin`	Probe that starts when a system-wide collection starts. The one argument available for this probe, (`arg[0]`), is a boolean value that indicates whether to perform a Full GC.
`gc-end`	Probe that starts when a system-wide collection is completed. No arguments.
`mem-pool-gc-begin`	Probe that starts when an individual memory pool is collected.
`mem-pool-gc-end`	Probe that starts after an individual memory pool is collected.

The following arguments are available for the memory pool probes:

Probe Arguments	Description
`args[0]`	A pointer to the UTF-8 string data that contains the name of the manager that manages this memory pool.
`args[1]`	The length of the manager name data (in bytes).
`args[2]`	A pointer to the UTF-8 string data that contains the name of the memory pool.
`args[3]`	The length of the memory pool name data (in bytes).
`args[4]`	The initial size of the memory pool (in bytes).
`args[5]`	The amount of memory in use in the memory pool (in bytes).
`args[6]`	The number of committed pages in the memory pool.
`args[7]`	The maximum size of the memory pool.

Method Compilation Probes

Probes are available to indicate which methods are being compiled and by which compiler, and to track when the compiled methods are installed or uninstalled.

The following probes are available to mark the beginning and ending of method compilation:

Probe	Description
`method-compile-begin`	Probe that starts when the method compilation begins.
`method-compile-end`	Probe that starts when method compilation is completed. In addition to the following arguments, the `argv[8]` argument is a boolean value that indicates whether the compilation was successful.

The following arguments are available for the method compilation probes:

Probe Arguments	Description
`args[0]`	A pointer to UTF-8 string data that contains the name of the compiler that is compiling this method.
`args[1]`	The length of the compiler name data (in bytes).
`args[2]`	A pointer to UTF-8 string data that contains the name of the class of the method being compiled.
`args[3]`	The length of the class name data (in bytes).
`args[4]`	A pointer to UTF-8 string data that contains the name of the method being compiled.
`args[5]`	The length of the method name data (in bytes).
`args[6]`	A pointer to UTF-8 string data that contains the signature of the method being compiled.
`args[7]`	The length of the signature data (in bytes).

The following probes are available when compiled methods are installed for execution or uninstalled:

Probe	Description
`compiled-method-load`	Probe that starts when a compiled method is installed. The additional argument, `argv[6]` contains a pointer to the compiled code, and the `argv[7]` is the size of the compiled code.
`compiled-method-unload`	Probe that starts when a compiled method is uninstalled.

The following arguments are available for the compiled method loading probe:

Probe Arguments	Description
`args[0]`	A pointer to UTF-8 string data that contains the name of the class of the method being installed.
`args[1]`	The length of the class name data (in bytes).

Probe Arguments	Description
`args[2]`	A pointer to UTF-8 string data that contains the name of the method being installed.
`args[3]`	The length of the method name data (in bytes).
`args[4]`	A pointer to UTF-8 string data that contains the signature of the method being installed.
`args[5]`	The length of the signature data (in bytes).

Monitor Probes

When your Java application runs, threads enter and exit monitors, wait on monitors, and perform notifications. Probes are available for all wait and notification events, and for contended monitor entry and exit events.

A contended monitor entry occurs when a thread attempts to enter a monitor while another thread is in the monitor. A contended monitor exit event occurs when a thread leaves a monitor while other threads are waiting to enter to the monitor. The contended monitor entry and contended monitor exit events might not match each other in relation to the thread that encounters these events, athough a contended exit from one thread is expected to match up to a contended enter on another thread (the thread waiting to enter the monitor).

Monitor events provide the thread ID, a monitor ID, and the type of the class of the object as arguments. The thread ID and the class type can map back to the Java program, while the monitor ID can provide matching information between probe firings.

The existence of these probes in the VM degrades performance and they start only when the `-XX:+ExtendedDTraceProbes` flag is set on the Java command line. This flag is turned on and off dynamically at runtime by using the `jinfo` utility.

If the flag is off, the monitor probes are present in the probe listing that is obtainable from Dtrace, but the probes remain dormant and don't start. Removal of this restriction is planned for future releases of the VM, and these probes will be enabled with no impact to performance.

The following probes are available for monitoring events:

Probe	Description
`monitor-contended-enter`	Probe that starts when a thread attempts to enter a contended monitor
`monitor-contended-entered`	Probe that starts when a thread successfully enters the contended monitor
`monitor-contended-exit`	Probe that starts when a thread leaves a monitor and other threads are waiting to enter
`monitor-wait`	Probe that starts when a thread begins a wait on a monitor by using the `Object.wait()`. The additional argument, `args[4]` is a long value that indicates the timeout being used.
`monitor-waited`	Probe that starts when a thread completes an `Object.wait()` action.

Probe	Description
`monitor-notify`	Probe that starts when a thread calls `Object.notify()` to notify waiters on a monitor.
`monitor-notifyAll`	Probe that starts when a thread calls `Object.notifyAll()` to notify waiters on a monitor.

The following arguments are available for the monitor:

Probe Arguments	Description
`args[0]`	The Java thread identifier for the thread performing the monitor operation.
`args[1]`	A unique, but opaque identifier for the specific monitor that the action is performed upon.
`args[2]`	A pointer to UTF-8 string data which contains the class name of the object being acted upon.
`args[3]`	The length of the class name data (in bytes).

Application Tracking Probes

You can use probes to allow fine-grained examination of Java thread execution. Application tracking probes start when a method is entered or returned from, or when a Java object has been allocated.

The existence of these probes in the VM degrades performance and they start only when the VM has the `ExtendedDTraceProbes` flag enabled. By default, the probes are present in any listing of the probes in the VM, but are dormant without the appropriate flag. Removal of this restriction is planned in future releases of the VM, and these probes will be enabled no impact to performance.

The following probes are available for the method entry and exit:

Probe	Description
`method-entry`	Probe that starts when a method is being entered.
`method-return`	Probe that starts when a method returns, either normally or due to an exception.

The following arguments are available for the method entry and exit:

Probe Arguments	Description
`args[0]`	The Java thread ID of the thread that is entering or leaving the method.
`args[1]`	A pointer to UTF-8 string data that contains the name of the class of the method.
`args[2]`	The length of the class name data (in bytes).
`args[3]`	A pointer to UTF-8 string data that contains the name of the method.
`args[4]`	The length of the method name data (in bytes).

Probe Arguments	Description
`args[5]`	A pointer to UTF-8 string data that contains the signature of the method.
`args[6]`	The length of the signature data (in bytes).

The following probe is available for the object allocation:

Probe	Description
`object-alloc`	Probe that starts when any object is allocated, provided that the `ExtendedDTraceProbes` flag is enabled.

The following arguments are available for the object allocation probe:

Probe Arguments	Description
`args[0]`	The Java thread ID of the thread that is allocating the object.
`args[1]`	A pointer to UTF-8 string data that contains the class name of the object being allocated.
`args[2]`	The length of the class name data (in bytes).
`args[3]`	The size of the object being allocated.

Using the hotspot_jni Provider

In order to call from native code to Java code, due to embedding of the VM in an application or execution of native code within a Java application, the native code must make a call through the Java Native Interface (JNI). The JNI provides a number of methods for invoking Java code and examining the state of the VM. DTrace probes are provided at the entry point and return point for each of these methods. The probes are provided by the *hotspot_jni* provider. The name of the probe is the name of the JNI method, appended with `-entry` for entry probes, and `-return` for return probes. The arguments available at each entry probe are the arguments that were provided to the function, with the exception of the `Invoke*` methods, which omit the arguments that are passed to the Java method. The return probes have the return value of the method as an argument (if available).

Sample DTrace Probes

```
provider hotspot {
  probe vm-init-begin();
  probe vm-init-end();
  probe vm-shutdown();
  probe class-loaded(
      char* class_name, uintptr_t class_name_len, uintptr_t
class_loader_id, bool is_shared);
  probe class-unloaded(
      char* class_name, uintptr_t class_name_len, uintptr_t
```

```
class_loader_id, bool is_shared);
  probe gc-begin(bool is_full);
  probe gc-end();
  probe mem-pool-gc-begin(
      char* mgr_name, uintptr_t mgr_name_len, char* pool_name,
uintptr_t pool_name_len,
      uintptr_t initial_size, uintptr_t used, uintptr_t committed,
uintptr_t max_size);
  probe mem-pool-gc-end(
      char* mgr_name, uintptr_t mgr_name_len, char* pool_name,
uintptr_t pool_name_len,
      uintptr_t initial_size, uintptr_t used, uintptr_t committed,
uintptr_t max_size);
  probe thread-start(
      char* thread_name, uintptr_t thread_name_length,
      uintptr_t java_thread_id, uintptr_t native_thread_id, bool
is_daemon);
  probe thread-stop(
      char* thread_name, uintptr_t thread_name_length,
      uintptr_t java_thread_id, uintptr_t native_thread_id, bool
is_daemon);
  probe method-compile-begin(
      char* class_name, uintptr_t class_name_len,
      char* method_name, uintptr_t method_name_len,
      char* signature, uintptr_t signature_len);
  probe method-compile-end(
      char* class_name, uintptr_t class_name_len,
      char* method_name, uintptr_t method_name_len,
      char* signature, uintptr_t signature_len,
      bool is_success);
  probe compiled-method-load(
      char* class_name, uintptr_t class_name_len,
      char* method_name, uintptr_t method_name_len,
      char* signature, uintptr_t signature_len,
      void* code, uintptr_t code_size);
  probe compiled-method-unload(
      char* class_name, uintptr_t class_name_len,
      char* method_name, uintptr_t method_name_len,
      char* signature, uintptr_t signature_len);
  probe monitor-contended-enter(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len);
  probe monitor-contended-entered(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len);
  probe monitor-contended-exit(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len);
  probe monitor-wait(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len,
      uintptr_t timeout);
  probe monitor-waited(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len);
```

```
  probe monitor-notify(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len);
  probe monitor-notifyAll(
      uintptr_t java_thread_id, uintptr_t monitor_id,
      char* class_name, uintptr_t class_name_len);
  probe method-entry(
      uintptr_t java_thread_id, char* class_name, uintptr_t
class_name_len,
      char* method_name, uintptr_t method_name_len,
      char* signature, uintptr_t signature_len);
  probe method-return(
      uintptr_t java_thread_id, char* class_name, uintptr_t
class_name_len,
      char* method_name, uintptr_t method_name_len,
      char* signature, uintptr_t signature_len);
  probe object-alloc(
      uintptr_t java_thread_id, char* class_name, uintptr_t
class_name_len,
      uintptr_t size);
};

provider hotspot_jni {
  probe AllocObject-entry(void*, void*);
  probe AllocObject-return(void*);
  probe AttachCurrentThreadAsDaemon-entry(void*, void**, void*);
  probe AttachCurrentThreadAsDaemon-return(uint32_t);
  probe AttachCurrentThread-entry(void*, void**, void*);
  probe AttachCurrentThread-return(uint32_t);
  probe CallBooleanMethodA-entry(void*, void*, uintptr_t);
  probe CallBooleanMethodA-return(uintptr_t);
  probe CallBooleanMethod-entry(void*, void*, uintptr_t);
  probe CallBooleanMethod-return(uintptr_t);
  probe CallBooleanMethodV-entry(void*, void*, uintptr_t);
  probe CallBooleanMethodV-return(uintptr_t);
  probe CallByteMethodA-entry(void*, void*, uintptr_t);
  probe CallByteMethodA-return(char);
  probe CallByteMethod-entry(void*, void*, uintptr_t);
  probe CallByteMethod-return(char);
  probe CallByteMethodV-entry(void*, void*, uintptr_t);

  probe CallByteMethodV-return(char);
  probe CallCharMethodA-entry(void*, void*, uintptr_t);
  probe CallCharMethodA-return(uint16_t);
  probe CallCharMethod-entry(void*, void*, uintptr_t);
  probe CallCharMethod-return(uint16_t);
  probe CallCharMethodV-entry(void*, void*, uintptr_t);
  probe CallCharMethodV-return(uint16_t);
  probe CallDoubleMethodA-entry(void*, void*, uintptr_t);
  probe CallDoubleMethodA-return(double);
  probe CallDoubleMethod-entry(void*, void*, uintptr_t);
  probe CallDoubleMethod-return(double);
  probe CallDoubleMethodV-entry(void*, void*, uintptr_t);
  probe CallDoubleMethodV-return(double);
  probe CallFloatMethodA-entry(void*, void*, uintptr_t);
```

```
  probe CallFloatMethodA-return(float);
  probe CallFloatMethod-entry(void*, void*, uintptr_t);
  probe CallFloatMethod-return(float);
  probe CallFloatMethodV-entry(void*, void*, uintptr_t);
  probe CallFloatMethodV-return(float);
  probe CallIntMethodA-entry(void*, void*, uintptr_t);
  probe CallIntMethodA-return(uint32_t);
  probe CallIntMethod-entry(void*, void*, uintptr_t);
  probe CallIntMethod-return(uint32_t);
  probe CallIntMethodV-entry(void*, void*, uintptr_t);
  probe CallIntMethodV-return(uint32_t);
  probe CallLongMethodA-entry(void*, void*, uintptr_t);
  probe CallLongMethodA-return(uintptr_t);
  probe CallLongMethod-entry(void*, void*, uintptr_t);
  probe CallLongMethod-return(uintptr_t);
  probe CallLongMethodV-entry(void*, void*, uintptr_t);
  probe CallLongMethodV-return(uintptr_t);
  probe CallNonvirtualBooleanMethodA-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualBooleanMethodA-return(uintptr_t);
  probe CallNonvirtualBooleanMethod-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualBooleanMethod-return(uintptr_t);
  probe CallNonvirtualBooleanMethodV-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualBooleanMethodV-return(uintptr_t);
  probe CallNonvirtualByteMethodA-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualByteMethodA-return(char);
  probe CallNonvirtualByteMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualByteMethod-return(char);
  probe CallNonvirtualByteMethodV-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualByteMethodV-return(char);
  probe CallNonvirtualCharMethodA-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualCharMethodA-return(uint16_t);
  probe CallNonvirtualCharMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualCharMethod-return(uint16_t);
  probe CallNonvirtualCharMethodV-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualCharMethodV-return(uint16_t);
  probe CallNonvirtualDoubleMethodA-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualDoubleMethodA-return(double);
  probe CallNonvirtualDoubleMethod-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualDoubleMethod-return(double);
  probe CallNonvirtualDoubleMethodV-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualDoubleMethodV-return(double);
  probe CallNonvirtualFloatMethodA-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualFloatMethodA-return(float);
  probe CallNonvirtualFloatMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualFloatMethod-return(float);
  probe CallNonvirtualFloatMethodV-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualFloatMethodV-return(float);
```

```
  probe CallNonvirtualIntMethodA-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualIntMethodA-return(uint32_t);
  probe CallNonvirtualIntMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualIntMethod-return(uint3t);
  probe CallNonvirtualIntMethodV-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualIntMethodV-return(uint32_t);
  probe CallNonvirtualLongMethodA-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualLongMethodA-return(uintptr_t);
  probe CallNonvirtualLongMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualLongMethod-return(uintptr_t);
  probe CallNonvirtualLongMethodV-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualLongMethodV-return(uintptr_t);
  probe CallNonvirtualObjectMethodA-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualObjectMethodA-return(void*);
  probe CallNonvirtualObjectMethod-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualObjectMethod-return(void*);
  probe CallNonvirtualObjectMethodV-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualObjectMethodV-return(void*);
  probe CallNonvirtualShortMethodA-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualShortMethodA-return(uint16_t);
  probe CallNonvirtualShortMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualShortMethod-return(uint16_t);
  probe CallNonvirtualShortMethodV-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualShortMethodV-return(uint16_t);
  probe CallNonvirtualVoidMethodA-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualVoidMethodA-return();
  probe CallNonvirtualVoidMethod-entry(void*, void*, void*, uintptr_t);
  probe CallNonvirtualVoidMethod-return();
  probe CallNonvirtualVoidMethodV-entry(void*, void*, void*,
uintptr_t);
  probe CallNonvirtualVoidMethodV-return();
  probe CallObjectMethodA-entry(void*, void*, uintptr_t);
  probe CallObjectMethodA-return(void*);
  probe CallObjectMethod-entry(void*, void*, uintptr_t);
  probe CallObjectMethod-return(void*);
  probe CallObjectMethodV-entry(void*, void*, uintptr_t);
  probe CallObjectMethodV-return(void*);
  probe CallShortMethodA-entry(void*, void*, uintptr_t);
  probe CallShortMethodA-return(uint16_t);
  probe CallShortMethod-entry(void*, void*, uintptr_t);
  probe CallShortMethod-return(uint16_t);
  probe CallShortMethodV-entry(void*, void*, uintptr_t);
  probe CallShortMethodV-return(uint16_t);
  probe CallStaticBooleanMethodA-entry(void*, void*, uintptr_t);
  probe CallStaticBooleanMethodA-return(uintptr_t);
  probe CallStaticBooleanMethod-entry(void*, void*, uintptr_t);
  probe CallStaticBooleanMethod-return(uintptr_t);
  probe CallStaticBooleanMethodV-entry(void*, void*, uintptr_t);
  probe CallStaticBooleanMethodV-return(uintptr_t);
  probe CallStaticByteMethodA-entry(void*, void*, uintptr_t);
```

```
probe CallStaticByteMethodA-return(char);
probe CallStaticByteMethod-entry(void*, void*, uintptr_t);
probe CallStaticByteMethod-return(char);
probe CallStaticByteMethodV-entry(void*, void*, uintptr_t);
probe CallStaticByteMethodV-return(char);
probe CallStaticCharMethodA-entry(void*, void*, uintptr_t);
probe CallStaticCharMethodA-return(uint16_t);
probe CallStaticCharMethod-entry(void*, void*, uintptr_t);
probe CallStaticCharMethod-return(uint16_t);
probe CallStaticCharMethodV-entry(void*, void*, uintptr_t);
probe CallStaticCharMethodV-return(uint16_t);
probe CallStaticDoubleMethodA-entry(void*, void*, uintptr_t);
probe CallStaticDoubleMethodA-return(double);
probe CallStaticDoubleMethod-entry(void*, void*, uintptr_t);
probe CallStaticDoubleMethod-return(double);
probe CallStaticDoubleMethodV-entry(void*, void*, uintptr_t);
probe CallStaticDoubleMethodV-return(double);
probe CallStaticFloatMethodA-entry(void*, void*, uintptr_t);
probe CallStaticFloatMethodA-return(float);
probe CallStaticFloatMethod-entry(void*, void*, uintptr_t);
probe CallStaticFloatMethod-return(float);
probe CallStaticFloatMethodV-entry(void*, void*, uintptr_t);
probe CallStaticFloatMethodV-return(float);
probe CallStaticIntMethodA-entry(void*, void*, uintptr_t);
probe CallStaticIntMethodA-return(uint32_t);
probe CallStaticIntMethod-entry(void*, void*, uintptr_t);
probe CallStaticIntMethod-return(uint32_t);
probe CallStaticIntMethodentry(void*, void*, uintptr_t);
probe CallStaticIntMethodV-return(uint32_t);
probe CallStaticLongMethodA-entry(void*, void*, uintptr_t);
probe CallStaticLongMethodA-return(uintptr_t);
probe CallStaticLongMethod-entry(void*, void*, uintptr_t);
probe CallStaticLongMethod-return(uintptr_t);
probe CallStaticLongMethodV-entry(void*, void*, uintptr_t);
probe CallStaticLongMethodV-return(uintptr_t);
probe CallStaticObjectMethodA-entry(void*, void*, uintptr_t);
probe CallStaticObjectMethodA-return(void*);
probe CallStaticObjectMethod-entry(void*, void*, uintptr_t);
probe CallStaticObjectMethod-return(void*);
probe CallStaticObjectMethodV-entry(void*, void*, uintptr_t);
probe CallStaticObjectMethodV-return(void*);
probe CallStaticShortMethodA-entry(void*, void*, uintptr_t);
probe CallStaticShortMethodA-return(uint16_t);
probe CallStaticShortMethod-entry(void*, void*, uintptr_t);
probe CallStaticShortMethod-return(uint16_t);
probe CallStaticShortMethodV-entry(void*, void*, uintptr_t);
probe CallStaticShortMethodV-return(uint16_t);
probe CallStaticVoidMethodA-entry(void*, void*, uintptr_t);
probe CallStaticVoidMethodA-return();
probe CallStaticVoidMethod-entry(void*, void*, uintptr_t);
probe CallStaticVoidMethod-return();
probe CallStaticVoidMethodV-entry(void*, void*, uintptr_t);
probe CallStaticVoidMethodV-return();
probe CallVoidMethodA-entry(void*, void*, uintptr_t);
probe CallVoidMethodA-return();
```

```
  probe CallVoidMethod-entry(void*, void*, uintptr_t);
  probe CallVoidMethod-return();
  probe CallVoidMethodV-entry(void*, void*, uintptr_t);
  probe CallVoidMethodV-return();
  probe CreateJavaVM-entry(void**, void**, void*);
  probe CreateJavaVM-return(uint32_t);
  probe DefineClass-entry(void*, const char*, void*, char, uintptr_t);
  probe DefineClass-return(void*);
  probe DeleteGlobalRef-entry(void*, void*);
  probe DeleteGlobalRef-return();
  probe DeleteLocalRef-entry(void*, void*);
  probe DeleteLocalRef-return();
  probe DeleteWeakGlobalRef-entry(void*, void*);
  probe DeleteWeakGlobalRef-return();
  probe DestroyJavaVM-entry(void*);
  probe DestroyJavaVM-return(uint32_t);
  probe DetachCurrentThread-entry(void*);
  probe DetachCurrentThread-return(uint32_t);
  probe EnsureLocalCapacity-entry(void*, uint32_t);
  probe EnsureLocalCapacity-return(uint32_t);
  probe ExceptionCheck-entry(void*);
  probe ExceptionCheck-return(uintptr_t);
  probe ExceptionClear-entry(void*);
  probe ExceptionClear-return();
  probe ExceptionDescribe-entry(void*);
  probe ExceptionDescribe-return();
  probe ExceptionOccurred-entry(void*);
  probe ExceptionOccurred-return(void*);
  probe FatalError-entry(void* env, const char*);
  probe FindClass-entry(void*, const char*);
  probe FindClass-return(void*);
  probe FromReflectedField-entry(void*, void*);
  probe FromReflectedField-return(uintptr_t);
  probe FromReflectedMethod-entry(void*, void*);
  probe FromReflectedMethod-return(uintptr_t);
  probe GetArrayLength-entry(void*, void*);
  probe GetArrayLength-return(uintptr_t);
  probe GetBooleanArrayElements-entry(void*, void*, uintptr_t*);
  probe GetBooleanArrayElements-return(uintptr_t*);
  probe GetBooleanArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
uintptr_t*);
  probe GetBooleanArrayRegion-return();
  probe GetBooleanField-entry(void*, void*, uintptr_t);
  probe GetBooleanField-return(uintptr_t);
  probe GetByteArrayElements-entry(void*, void*, uintptr_t*);
  probe GetByteArrayElements-return(char*);
  probe GetByteArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
char*);
  probe GetByteArrayRegion-return();
  probe GetByteField-entry(void*, void*, uintptr_t);
  probe GetByteField-return(char);
  probe GetCharArrayElements-entry(void*, void*, uintptr_t*);
  probe GetCharArrayElements-return(uint16_t*);
  probe GetCharArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
uint16_t*);
```

```
  probe GetCharArrayRegion-return();
  probe GetCharField-entry(void*, void*, uintptr_t);
  probe GetCharField-return(uint16_t);
  probe GetCreatedJavaVMs-eintptr_t*);
  probe GetCreatedJavaVMs-return(uintptr_t);
  probe GetCreateJavaVMs-entry(void*, uintptr_t, uintptr_t*);
  probe GetCreateJavaVMs-return(uint32_t);
  probe GetDefaultJavaVMInitArgs-entry(void*);
  probe GetDefaultJavaVMInitArgs-return(uint32_t);
  probe GetDirectBufferAddress-entry(void*, void*);
  probe GetDirectBufferAddress-return(void*);
  probe GetDirectBufferCapacity-entry(void*, void*);
  probe GetDirectBufferCapacity-return(uintptr_t);
  probe GetDoubleArrayElements-entry(void*, void*, uintptr_t*);
  probe GetDoubleArrayElements-return(double*);
  probe GetDoubleArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
double*);
  probe GetDoubleArrayRegion-return();
  probe GetDoubleField-entry(void*, void*, uintptr_t);
  probe GetDoubleField-return(double);
  probe GetEnv-entry(void*, void*, void*);
  probe GetEnv-return(uint32_t);
  probe GetFieldID-entry(void*, void*, const char*, const char*);
  probe GetFieldID-return(uintptr_t);
  probe GetFloatArrayElements-entry(void*, void*, uintptr_t*);
  probe GetFloatArrayElements-return(float*);
  probe GetFloatArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
float*);
  probe GetFloatArrayRegion-return();
  probe GetFloatField-entry(void*, void*, uintptr_t);
  probe GetFloatField-return(float);
  probe GetIntArrayElements-entry(void*, void*, uintptr_t*);
  probe GetIntArrayElements-return(uint32_t*);
  probe GetIntArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
uint32_t*);
  probe GetIntArrayRegion-return();
  probe GetIntField-entry(void*, void*, uintptr_t);
  probe GetIntField-return(uint32_t);
  probe GetJavaVM-entry(void*, void**);
  probe GetJavaVM-return(uint32_t);
  probe GetLongArrayElements-entry(void*, void*, uintptr_t*);
  probe GetLongArrayElements-return(uintptr_t*);
  probe GetLongArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
uintptr_t*);
  probe GetLongArrayRegion-return();
  probe GetLongField-entry(void*, void*, uintptr_t);
  probe GetLongField-return(uintptr_t);
  probe GetMethodID-entry(void*, void*, const char*, const char*);
  probe GetMethodID-return(uintptr_t);
  probe GetObjectArrayElement-entry(void*, void*, uintptr_t);
  probe GetObjectArrayElement-return(void*);
  probe GetObjectClass-entry(void*, void*);
  probe GetObjectClass-return(void*);
  probe GetObjectField-entry(void*, void*, uintptr_t);
  probe GetObjectField-return(void*);
```

```
  probe GetObjectRefType-entry(void*, void*);
  probe GetObjectRefType-return(void*);
  probe GetPrimitiveArrayCritical-entry(void*, void*, uintptr_t*);
  probe GetPrimitiveArrayCritical-return(void*);
  probe GetShortArrayElements-entry(void*, void*, uintptr_t*);
  probe GetShortArrayElements-return(uint16_t*);
  probe GetShortArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
uint16_t*);
  probe GetShortArrayRegion-return();
  probe GetShortField-entry(void*, void*, uintptr_t);
  probe GetShortField-return(uint16_t);
  probe GetStaticBooleanField-entry(void*, void*, uintptr_t);
  probe GetStaticBooleanField-return(uintptr_t);
  probe GetStaticByteField-entry(void*, void*, uintptr_t);
  probe GetStaticByteField-return(char);
  probe GetStaticCharField-entry(void*, void*, uintptr_t);
  probe GetStaticCharField-return(uint16_t);
  probe GetStaticDoubleField-entry(void*, void*, uintptr_t);
  probe GetStaticDoubleField-return(double);
  probe GetStaticFieldID-entry(void*, void*, const char*, const char*);
  probe GetStaticFieldID-return(uintptr_t);
  probe GetStaticFloatField-entry(void*, void*, uintptr_t);
  probe GetStaticFloatField-return(float);
  probe GetStaticIntField-entry(void*, void*, uintptr_t);
  probe GetStaticIntField-return(uint32_t);
  probe GetStaticLongField-entry(void*, void*, uintptr_t);
  probe GetStaticLongField-return(uintptr_t);
  probe GetStaticMethodID-entry(void*, void*, const char*, const char*);
  probe GetStaticMethodID-return(uintptr_t);
  probe GetStaticObjectField-entry(void*, void*, uintptr_t);
  probe GetStaticObjectField-return(void*);
  probe GetStaticShortField-entry(void*, void*, uintptr_t);
  probe GetStaticShortField-return(uint16_t);
  pro GetStringChars-entry(void*, void*, uintptr_t*);
  probe GetStringChars-return(const uint16_t*);
  probe GetStringCritical-entry(void*, void*, uintptr_t*);
  probe GetStringCritical-return(const uint16_t*);
  probe GetStringLength-entry(void*, void*);
  probe GetStringLength-return(uintptr_t);
  probe GetStringRegion-entry(void*, void*, uintptr_t, uintptr_t,
uint16_t*);
  probe GetStringRegion-return();
  probe GetStringUTFChars-entry(void*, void*, uintptr_t*);
  probe GetStringUTFChars-return(const char*);
  probe GetStringUTFLength-entry(void*, void*);
  probe GetStringUTFLength-return(uintptr_t);
  probe GetStringUTFRegion-entry(void*, void*, uintptr_t, uintptr_t,
char*);
  probe GetStringUTFRegion-return();
  probe GetSuperclass-entry(void*, void*);
  probe GetSuperclass-return(void*);
  probe GetVersion-entry(void*);
  probe GetVersion-return(uint32_t);
  probe IsAssignableFrom-entry(void*, void*, void*);
  probe IsAssignableFrom-return(uintptr_t);
```

```
  probe IsInstanceOf-entry(void*, void*, void*);
  probe IsInstanceOf-return(uintptr_t);
  probe IsSameObject-entry(void*, void*, void*);
  probe IsSameObject-return(uintptr_t);
  probe MonitorEnter-entry(void*, void*);
  probe MonitorEnter-return(uint32_t);
  probe MonitorExit-entry(void*, void*);
  probe MonitorExit-return(uint32_t);
  probe NewBooleanArray-entry(void*, uintptr_t);
  probe NewBooleanArray-return(void*);
  probe NewByteArray-entry(void*, uintptr_t);
  probe NewByteArray-return(void*);
  probe NewCharArray-entry(void*, uintptr_t);
  probe NewCharArray-return(void*);
  probe NewDirectByteBuffer-entry(void*, void*, uintptr_t);
  probe NewDirectByteBuffer-return(void*);
  probe NewDoubleArray-entry(void*, uintptr_t);
  probe NewDoubleArray-return(void*);
  probe NewFloatArray-entry(void*, uintptr_t);
  probe NewFloatArray-return(void*);
  probe NewGlobalRef-entry(void*, void*);
  probe NewGlobalRef-return(void*);
  probe NewIntArray-entry(void*, uintptr_t);
  probe NewIntArray-return(void*);
  probe NewLocalRef-entry(void*, void*);
  probe NewLocalRef-return(void*);
  probe NewLongArray-entry(void*, uintptr_t);
  probe NewLongArray-return(void*);
  probe NewObjectA-entry(void*, void*, uintptr_t);
  probe NewObjectA-return(void*);
  probe NewObjectArray-entry(void*, uintptr_t, void*, void*);
  probe NewObjectArray-return(void*);
  probe NewObject-entry(void*, void*, uintptr_t);
  probe NewObject-return(void*);
  probe NewObjectV-entry(void*, void*, uintptr_t);
  probe NewObjectV-return(void*);
  probe NewShortArray-entry(void*, uintptr_t);
  probe NewShortArray-return(void*);
  probe NewString-entry(void*, const uint16_t*, uintptr_t);
  probe NewString-return(void*);
  probe NewStringUTF-entry(void*, const char*);
  probe NewStringUTF-return(void*);
  probe NewWeakGlobalRef-entry(void*, void*);
  probe NewWeakGlobalRef-return(void*);
  probe PopLocalFrame-entry(void*, void*);
  probe PopLocalFrame-return(void*);
  probe PushLocalFrame-entry(void*, uint32_t);
  probe PushLocalFrame-return(uint32_t);
  probe RegisterNatives-entry(void*, void*, const void*, uint32_t);
  probe RegisterNatives-return(uint32_t);
  probe ReleaseBooleanArrayElements-entry(void*, void*, uintptr_t*,
uint32_t);
  probe ReleaseBooleanArrayElements-return();
  probe ReleaseByteArrayElements-entry(void*, void*, char*, uint32_t);
  probe ReleaseByteArrayElements-return();
```

```
  probe ReleaseCharArrayElements-entry(void*, void*, uint16_t*,
uint32_t);
  probe ReleaseCharArrayElements-return();
  probe ReleaseDoubleArrayElements-entry(void*, void*, double*,
uint32_t);
  probe ReleaseDoubleArrayElements-return();
  probe ReleaseFloatArrayElements-entry(void*, void*, float*, uint32_t);
  probe ReleaseFloatArrayElements-return();
  probe ReleaseIntArrayElements-entry(void*, void*, uint32_t*,
uint32_t);
  probe ReleaseIntArrayElements-return();
  probe ReleaseLongArrayElements-entry(void*, void*, uintptr_t*,
uint32_t);
  probe ReleaseLongArrayElements-return();
  probe ReleaseObjectArrayElements-entry(void*, void*, void**,
uint32_t);
  probe ReleaseObjectArrayElements-return();
  probe Releasey(void*, void*, void*, uint32_t);
  probe ReleasePrimitiveArrayCritical-return();
  probe ReleaseShortArrayElements-entry(void*, void*, uint16_t*,
uint32_t);
  probe ReleaseShortArrayElements-return();
  probe ReleaseStringChars-entry(void*, void*, const uint16_t*);
  probe ReleaseStringChars-return();
  probe ReleaseStringCritical-entry(void*, void*, const uint16_t*);
  probe ReleaseStringCritical-return();
  probe ReleaseStringUTFChars-entry(void*, void*, const char*);
  probe ReleaseStringUTFChars-return();
  probe SetBooleanArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const uintptr_t*);
  probe SetBooleanArrayRegion-return();
  probe SetBooleanField-entry(void*, void*, uintptr_t, uintptr_t);
  probe SetBooleanField-return();
  probe SetByteArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const char*);
  probe SetByteArrayRegion-return();
  probe SetByteField-entry(void*, void*, uintptr_t, char);
  probe SetByteField-return();
  probe SetCharArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const uint16_t*);
  probe SetCharArrayRegion-return();
  probe SetCharField-entry(void*, void*, uintptr_t, uint16_t);
  probe SetCharField-return();
  probe SetDoubleArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const double*);
  probe SetDoubleArrayRegion-return();
  probe SetDoubleField-entry(void*, void*, uintptr_t, double);
  probe SetDoubleField-return();
  probe SetFloatArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const float*);
  probe SetFloatArrayRegion-return();
  probe SetFloatField-entry(void*, void*, uintptr_t, float);
  probe SetFloatField-return();
  probe SetIntArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const uint32_t*);
```

```
  probe SetIntArrayRegion-return();
  probe SetIntField-entry(void*, void*, uintptr_t, uint32_t);
  probe SetIntField-return();
  probe SetLongArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const uintptr_t*);
  probe SetLongArrayRegion-return();
  probe SetLongField-entry(void*, void*, uintptr_t, uintptr_t);
  probe SetLongField-return();
  probe SetObjectArrayElement-entry(void*, void*, uintptr_t, void*);
  probe SetObjectArrayElement-return();
  probe SetObjectField-entry(void*, void*, uintptr_t, void*);
  probe SetObjectField-return();
  probe SetShortArrayRegion-entry(void*, void*, uintptr_t, uintptr_t,
const uint16_t*);
  probe SetShortArrayRegion-return();
  probe SetShortField-entry(void*, void*, uintptr_t, uint16_t);
  probe SetShortField-return();
  probe SetStaticBooleanField-entry(void*, void*, uintptr_t, uintptr_t);
  probe SetStaticBooleanField-return();
  probe SetStaticByteField-entry(void*, void*, uintptr_t, char);
  probe SetStaticByteField-return();
  probe SetStaticCharField-entry(void*, void*, uintptr_t, uint16_t);
  probe SetStaticCharField-return();
  probe SetStaticDoubleField-entry(void*, void*, uintptr_t, double);
  probe SetStaticDoubleField-return();
  probe SetStaticFloatField-entry(void*, void*, uintptr_t, float);
  probe SetStaticFloatField-return();
  probe SetStaticIntField-entry(void*, void*, uintptr_t, uint32_t);
  probe SetStaticIntField-return();
  probe SetStaticLongField-entry(void*, void*, uintptr_t, uintptr_t);
  probe SetStaticLongField-return();
  probe SetStaticObjectField-entry(void*, void*, uintptr_t, void*);
  probe SetStaticObjectField-return();
  probe SetStaticShortField-entry(void*, void*, uintptr_t, uint16_t);
  probe SetStaticShortField-return();
  probe Throw-entry(void*, void*);
  probe ThrowNew-entry(void*, void*, const char*);
  probe ThrowNew-return(uint32_t);
  probe Throw-return(uint32_t);
  probe ToReflectedField-entry(void*, void*, uintptr_t, uintptr_t);
  probe ToReflectedField-return(void*);
  probe ToReflectedMethod-entry(void*, void*, uintptr_t, uintptr_t);
  probe ToReflectedMethod-return(void*);
  probe UnregisterNatives-entry(void*, void*);
  probe UnregisterNatives-return(uint32_t);
};
```

11

Fatal Error Reporting

Fatal errors are errors such as native memory exhaustion, memory access errors, or explicit signals directed to the process. Fatal errors can be triggered by native code within the application (for example, developer-written Java Native Interface (JNI) code), by third-party native libraries that the are used by application or the JVM, or by native code in the JVM. If a fatal error causes the process that is hosting the JVM to terminate, the JVM gathers information about the error and writes a crash report.

The JVM tries to identify the nature and location of the error. If possible, the JVM writes detailed information about the state of the JVM and the process, at the time of the crash. The details that are available can depend on the platform and the nature of the crash. The information that is provided by this error-reporting mechanism lets you debug your application more easily and efficiently, and helps you identify issues in third-party code. When an error message indicates a problem in the JVM code, you can submit a more accurate and helpful bug report. In some cases, crash report generation causes secondary errors that prevent full details from being reported.

Error Report Example

The following example shows the start of an error report (file `hs_err_pid18240.log`) for a crash in the native JNI code for an application:

```
#
# A fatal error has been detected by the Java Runtime Environment:
#
#  SIGSEGV (0xb) at pc=0x00007f0f159f857d, pid=18240, tid=18245
#
# JRE version: Java(TM) SE Runtime Environment (9.0+167) (build 9-
ea+167)
# Java VM: Java HotSpot(TM) 64-Bit Server VM (9-ea+167, mixed mode,
tiered, compressed oops, g1 gc, linux-amd64)
# Problematic frame:
# C  [libMyApp.so+0x57d]  Java_MyApp_readData+0x11
#
# Core dump will be written. Default location: /cores/core.18240)
#
# If you would like to submit a bug report, please visit:
#   http://bugreport.java.com/bugreport/crash.jsp
# The crash happened outside the Java Virtual Machine in native code.
# See problematic frame for where to report the bug.
#

---------------  S U M M A R Y ------------

Command Line: MyApp

Host: Intel(R) Xeon(R) CPU           X5675  @ 3.07GHz, 24 cores, 141G,
Ubuntu 12.04 LTS
```

```
Time: Fri Apr 28 02:57:13 2017 EDT elapsed time: 2 seconds (0d 0h 0m 2s)

---------------  T H R E A D  ---------------

Current thread (0x00007f102c013000):
JavaThread "main" [_thread_in_native, id=18245,
stack(0x00007f10345c0000,0x00007f10346c0000)]

Stack: [0x00007f10345c0000,0x00007f10346c0000],
sp=0x00007f10346be930,  free space=1018k
Native frames: (J=compiled Java code, A=aot compiled Java code,
j=interpreted, Vv=VM code, C=native code)
C  [libMyApp.so+0x57d]  Java_MyApp_readData+0x11
j  MyApp.readData()I+0
j  MyApp.main([Ljava/lang/String;)V+15
v  ~StubRoutines::call_stub
V  [libjvm.so+0x839eea]  JavaCalls::call_helper(JavaValue*,
methodHandle const&, JavaCallArguments*, Thread*)+0x47a
V  [libjvm.so+0x896fcf]  jni_invoke_static(JNIEnv_*, JavaValue*,
_jobject*, JNICallType, _jmethodID*, JNI_ArgumentPusher*, Thread*)
[clone .isra.90]+0x21f
V  [libjvm.so+0x8a7f1e]  jni_CallStaticVoidMethod+0x14e
C  [libjli.so+0x4142]  JavaMain+0x812
C  [libpthread.so.0+0x7e9a]  start_thread+0xda

Java frames: (J=compiled Java code, j=interpreted, Vv=VM code)
j  MyApp.readData()I+0
j  MyApp.main([Ljava/lang/String;)V+15
v  ~StubRoutines::call_stub

siginfo: si_signo: 11 (SIGSEGV), si_code: 1 (SEGV_MAPERR), si_addr:
0x0000000000000000
```

12

Java Virtual Machine Related Resources

The following related links are related to the JVM.

- `java.lang.invoke package documentation`
- The Da Vinci Machine Project

Tools

You can control some operating characteristics of the Java HotSpot VM by using command-line flags. For more information about the Java application launcher, see The java Command in the *Java Development Kit Tool Specifications*.