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# Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

In exceptional circumstances, when the joint technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art”, for example), it may decide to publish a Technical Report. A Technical Report is entirely informative in nature and shall be subject to review every five years in the same manner as an International Standard.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC TR 24772-11, was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 22, *Programming languages, their environments and system software interfaces*.

# Introduction

This Technical Report provides guidance for the programming language Java, so that application developers considering Java or using Java will be better able to avoid the programming constructs that lead to vulnerabilities in software written in the Java language and their attendant consequences. This guidance can also be used by developers to select source code evaluation tools that can discover and eliminate some constructs that could lead to vulnerabilities in their software. This report can also be used in comparison with companion Technical Reports and with the language-independent report, TR 24772–1, to select a programming language that provides the appropriate level of confidence that anticipated problems can be avoided.

This technical report part is intended to be used with TR 24772–1, which discusses programming language vulnerabilities in a language independent fashion.

It should be noted that this Technical Report is inherently incomplete. It is not possible to provide a complete list of programming language vulnerabilities because new weaknesses are discovered continually. Any such report can only describe those that have been found, characterized, and determined to have sufficient probability and consequence.

**Information Technology — Programming Languages — Guidance to avoiding vulnerabilities in programming languages — Vulnerability descriptions for the programming language Java**

# 1. Scope

This Technical Report specifies software programming language vulnerabilities to be avoided in the development of systems where assured behaviour is required for security, safety, mission-critical and business-critical software. In general, this guidance is applicable to the software developed, reviewed, or maintained for any application.

Vulnerabilities described in this Technical Report document the way that the vulnerability described in the language-independent TR 24772–1 are manifested in Java

# 2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

The Java Language Specification, Java SE 10 Edition, 2018-02-20, https://docs.oracle.com/javase/specs/

# 3. Terms and definitions, symbols and conventions

## 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 2382, in TR 24772–1, the Oracle Java Glossary (<https://www.oracle.com/technetwork/java/glossary-135216.html>) and the following apply. Other terms are defined where they appear in *italic* type.

The following terms are in alphabetical order, with general topics referencing the relevant specific terms.

**3.1.1**

**access**

read or modify the value of an object

Note: Modify includes the case where the new value being stored is the same as the previous value. Expressions that are not evaluated do not access objects.

**3.1.2**

**behaviour**
external appearance or action

Note: See: implementation-defined behaviour, undefined behaviour, unspecified behaviour

**3.1.3**

**bit**
unit of data storage in the execution environment large enough to hold an object that may have one of two values

Note: It need not be possible to express the address of each individual bit of an object.

**3.1.4**

**byte**
addressable unit of data storage large enough to hold any member of the basic character set of the execution environment

Note: It is possible to express the address of each individual byte of an object uniquely. A byte is composed of a contiguous sequence of bits, the number of which is implementation-defined. The least significant bit is called the low-order bit; the most significant bit is called the high-order bit.

**3.1.5**

**character**
abstract member of a set of elements used for the organization, control, or representation of data

**3.1.6**

**correctly rounded result**

representation in the result format that is nearest in value, subject to the current rounding mode, to what the result would be given unlimited range and precision.

**3.1.7**

**implementation**

particular set of software, running in a particular translation environment under particular control options, that performs translation of programs for, and supports execution of functions in, a particular execution environment.

**3.1.8**

**implementation-defined behaviour**

behaviour where multiple options are permitted by the standard and where each implementation documents how the choice is made

**3.1.9**

**implementation-defined value**

value not specified in the standard where each implementation documents how the choice for the value is selected

**3.1.10**

**implementation limit**

restriction imposed upon programs by the implementation

**3.1.11**

**memory location**

object of scalar type, or a maximal sequence of adjacent bit-fields all having nonzero width

**3.1.12**

**multibyte character**

sequence of one or more bytes representing a member of the extended character set of either the source or the execution environment, where the extended character set is a superset of the basic character set

**3.1.13**

**undefined behaviour**

use of a non-portable or erroneous program construct or of erroneous data

Note: Undefined behaviour ranges from ignoring the situation completely with unpredictable results, to behaving during translation or program execution in a documented manner characteristic of the environment (with or without the issuance of a diagnostic message), to terminating a translation or execution (with the issuance of a diagnostic message).

**3.1.14**

**unspecified behaviour**

use of an unspecified value, or other behaviour where the language standard provides two or more possibilities and imposes no further requirements on which is chosen in any instance

Note: For example, unspecified behaviour is the order in which the arguments of a function are evaluated.

# 4. Language concepts

Java was originally developed at Sun Microsystems (acquired by Oracle Corporation in 2010) in the early 1990’s. Java was initially defined as a syntactic superset of the C programming language: adding object oriented features such as classes, encapsulation, dynamic dispatch, namespaces and templates. It was designed to be platform independent through the use of platform independent byte code which is then interpreted by the Java Virtual Machine (JVM) on whichever platform it is executed on. Java espoused the Write Once, Run Anywhere (WORA) goal.

While there is a core of Java that is syntactically identical to C, it has always been the case that there are significant differences between the two. Since Java was developed, the two languages have diverged even further, both adding features not present in the other. Notwithstanding that, there is still a significant syntactic and semantic overlap between C and Java.

At its core, Java was designed to address some weaknesses that existed in other languages through the addition of security management features. Some key features of Java are:

* Java uses a Garbage Collector to manage memory automatically.
* Java provides ease of code reuse through inheritance.
* The javac compiler transforms Java code into bytecode instead of into machine executable instructions. The bytecode is then interpreted and run by a Java Virtual Machine (JVM) on a particular platform.
* The keyword static used to indicate that a particular class member belongs to the type itself, rather than to an instance of that type. Therefore, only one instance of the static member is created which is shared across all instances of the class.

Subsequently, in many cases, the additional features of Java provide mechanisms for avoiding vulnerabilities based in memory management and other areas that are very susceptible to language misuse, and these are reflected in the following sections.

# 5. Avoiding programming language vulnerabilities in Java

In addition to the generic programming rules from TR 24772-1 clause 5.4, additional rules from this section apply specifically to the Java programming language. The recommendations of this section are restatements of recommendations from clause 6, but represent ones stated frequently, or that are considered as particularly noteworthy by the authors. Clause 6 of this document contains the full set of recommendations, as well as explanations of the problems that led to the recommendations made.

Every guidance provided in this section, and in the corresponding Part section, is supported by material in Clause 6 of this document, as well as other important recommendations.

***TBD***

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# 6. Specific Guidance for Java Vulnerabilities

## 6.1 General

This clause contains specific advice for Java about the possible presence of vulnerabilities as described in TR 24772-1, and provides specific guidance on how to avoid them in Java code. This section mirrors TR 24772-1 clause 6 in that the vulnerability “Type System [IHN]” is found in 6.2 of TR 24772–1, and Java specific guidance is found in clause 6.2 and subclauses in this TR.

## 6.2 Type System [IHN]

### 6.2.1 Applicability to language

Java is a statically typed language. Java is also a strongly typed language as it requires all variables to be typed and places restrictions on the values that a variable can hold. There are two categories of types in Java: primitive and reference types. Primitive types are boolean, byte, short, int, long, char, float and double. Reference types are the class, interface and array types.

When assigning a smaller type to a larger type such as from a short to an int, there is no need for casting. Going from a larger type to a smaller type such as from a double to a float, where information could be lost, requires explicit casting.

As such, this weakness does not apply to Java as Java contains sufficient protections to mitigate this weakness.

**6.2.2 Guidance to language users**

* None

## 6.3 Bit representations [STR]

### 6.3.1 Applicability to language

Java supports a variety of sizes for integers such as byte, short, int, and long, but Java only supports signed integer types. This simplifies the understanding and use of integer types. Java also supports a variety of bitwise operators that facilitate bit manipulations, such as left and right shifts and bitwise & and |. Some of these bit manipulations can cause unexpected results. For instance, Java differentiates between a signed right shift and an unsigned right shift. The signed right shift is performed using the operator “>>” whereas the unsigned right shift is performed using the operator “>>>”. Although Java has simplified its language by only having signed integers, it has relegated the issue of whether the sign bit is shifted right to the choice of operator. It is very easy to confuse the two operators “>>” and “>>>” and do a signed right shift instead of an unsigned right shift or vice versa. For instance,

int a, b, c, d;

a = 0b00101000; // a = 0010 0100

b = a >> 3; // signed right shift yields b = 0000 0100

 c = 0b11110100; // c = 1111 0100

 d = c >> 3; // signed right shift of a negative number yields d = 1111 1110

int e, f, g, h;

e = 0b00101000; // e = 0010 0100

f = e >>> 3; // unsigned right shift yields f = 0000 0100

g = 0b11110100; // g = 1111 0100

h = g >>> 3; // unsigned right shift of a negative number yields d = 0001 1110

Another issue that may arise is that Java stores data in big-endian format, also known as network byte order. This can cause issues when interfacing with little endian languages such as C.

### 6.3.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.3.5.
* Ensure that the unsigned and signed right shift operators are not confused with each other.

## 6.4 Floating-point arithmetic [PLF]

### 6.4.1 Applicability to language

Java permits the floating-point data types float and double. Due to the approximate nature of floating-point representations, the use of floating-point data types in situations where equality is to be tested or where rounding could accumulate over multiple iterations may lead to unexpected results and potential vulnerabilities.

As with most data types, Java is flexible in how float and double can be used. For instance, Java allows the use of floating-point types to be used as loop counters and in equality statements, even though in some cases these will not have the expected behaviour. For example:

 float x;

 for (x=0f; x!=1f; x+=0.00000001)

may or may not terminate after 10,000,000 iterations. The representations used for x and the accumulated effect of many iterations may cause x to not be identical to 1.0 causing the loop to continue to iterate forever.

Similarly, the Boolean test

 float x=1.336f;

 float y=2.672f;

 if (x == (y/2))

may or may not evaluate to true. Given that x and y are constant values, it is expected that consistent results will be achieved on the same platform. However, it is questionable whether the logic performs as expected when a float that is twice that of another is tested for equality when divided by 2 as above.

Floating point operations are platform dependent. Different platforms can yield different results. To counter this problem, Java introduced the strictfp keyword. The strictfp modifier ensures that all floating point operations yield the same result across different JVMs and platforms. For example:

public class FloatingSum {

 public strictfp float sum() {

 float num1 = 5e+7;

float num2 = 3e+9;

return (num1 + num2);

}

public static strictfp void main(String[] args) {

 FloatingSum t = new FloatingSum();

 System.out.println (t.sum());

 }

}

### 6.4.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.4.5.
* Use thresholds in comparisons such as

final double THRESHOLD = .00001;

double f1,f2;

 // … assignments and operations on f1 and f2

 if (Math.abs(f1 - f2) < THRESHOLD)

* Use the strictfp keyword to ensure consistent floating point results across different JVMs and platforms.
* Use the BigDecimal class to provide better precision such as for monetary or financial calculations

## 6.5 Enumerator issues [CCB]

### 6.5.1 Applicability to language

The enum type in Java comprises a set of named integer constant values as in the example:

 public enum Weekday {SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY, SATURDAY};

Each of the keywords must be unique.

The enum type in Java implicitly extends java.lang.Enum. Java enum types are much more powerful than most other languages.

An enum declaration is implicitly final. The only exception is if it contains at least one enum constant that has a class body.

A more extensive example from the Java Joda.org date and time classes provides an illustration of the associated methods for an enum:

public enum Month implements TemporalAccessor, TemporalAdjuster {

 JANUARY, FEBRUARY, MARCH, APRIL,

 MAY, JUNE, JULY, AUGUST,

 SEPTEMBER, OCTOBER, NOVEMBER, DECEMBER;

 private static final Month[] ENUMS = Month.values();

 public static Month of(int month) {

 if (month < 1 || month > 12) {

 throw new DateTimeException("Invalid value for MonthOfYear: " + month);

 }

 return ENUMS[month - 1];

 }

 // additional methods…

}

However, the flexibility that Java offers with enums can lead to issues as the following illustrates:

public enum Sea {

 BERING (2261060,3937),

 // ...

 MEDITERRANEAN (2509698,5267);

 private int area;

 public int maxDepth; // Public

 Continent(int area, int maxDepth) {

 // ...

 }

 public void setArea(int area) { // Allows modification of private field

 this.area = area;

 }

}

When enum fields are public, it can allow them to be mutable. This can lead to unexpected consequences. Fields in an enum should be private and set in the constructor. In exceptional cases where this is not possible, their visibility should be minimized as much as possible.

### 6.5.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.5.5.

Make fields in an enum private and set in the constructor. If that is not possible, reduce the visibility as much as possible.

* Set all enum fields to be final.
* Ensure that enum values are not mutable.
* Use an enumerated type to select from a limited set of choices to make possible the use of tools to detect omissions of possible values such as in switch statements.

## 6.6 Conversion errors [FLC]

### 6.6.1 Applicability to language

In Java, automatic type conversion can happen if both types are compatible and the target type is larger than the source type so there can be no loss of data. From the smallest to the largest capacity is the order: byte, short, char, int, long, float, and double. For example, a byte can be implicitly cast to any of the others since all of the others have a larger capacity, but a float can only be implicitly cast to a double since there could be a loss of data if a float is cast to something smaller, such as an int.

There are 19 possible instances of widening primitive conversions in Java. These are:

* byte to short, int, long, float, or double
* short to int, long, float, or double
* char to int, long, float, or double
* int to long, float, or double
* long to float or double
* float to double

Though a floating point number can store larger numbers than an integer, precision could still be lost when converting an int to a long or a float, or from a long to a double. Because of the way floating point numbers are stored, the least significant bits could be lost in the conversion. Converting from the smaller integral types such as a short to a floating point type, or a conversion from an int to a double will not result in a loss of precision.

Going in the opposite direction from a larger type to a smaller type requires explicit casting. Though there must be explicit casting, the use of explicit casting does not prevent a loss of precision in the conversion. Data could still be lost when, for instance, a float is explicitly downcast to an int.

There are 22 possible instances of narrowing primitive conversions in Java where a potential loss of precision could occur. These are:

* short to byte or char
* char to byte or short
* int to byte, short, or char
* long to byte, short, char, or int
* float to byte, short, char, int, or long
* double to byte, short, char, int, long, or float

**6.6.2 Guidance to language users**

* Follow the guidance contained in TR 24772-1 clause 6.6.5.
* Check the value of a larger type before converting it to a smaller type to see if the value in the larger type is within the range of the smaller type. Any conversion from a type with larger range to a smaller range could result in a loss of data. In some instances, this loss is desired. Such cases should be explicitly acknowledged in comments.
* Be aware that conversion from certain integral types to floating types can result in a loss of the least significant bits.

## 6.7 String termination [CJM]

### 6.7.1 Applicability to language

This vulnerability does not apply to Java, because Java does not use a string termination character.

## 6.8 Buffer boundary violation (buffer overflow) [HCB]

### 6.8.1 Applicability to language

This vulnerability does not apply to Java, because Java has inherent protections in the language to prevent buffer boundary violations.

## 6.9 Unchecked array indexing [XYZ]

### 6.9.1 Applicability to language

This vulnerability does not apply to Java, because Java has inherent protections in the language to prevent this.

## 6.10 Unchecked array copying [XYW]

### 6.10.1 Applicability to language

This vulnerability does not apply to Java, because Java has inherent protections in the language to prevent this.

## 6.11 Pointer type conversions [HFC]

### 6.11.1 Applicability to language

This vulnerability does not apply to Java, because Java does not allow access to the value of pointers nor does it allow the conversion of pointers.

## 6.12 Pointer arithmetic [RVG]

### 6.12.1 Applicability to language

This vulnerability does not apply to Java, because Java does not permit pointer arithmetic.

## 6.13 Null pointer dereference [XYH]

### 6.13.1 Applicability to language

Prior to making use of a reference to an object, verification needs to be made to ensure that the reference is not null. This can be accomplished through an explicit runtime check or other means of ensuring a reference is not null. Though a null dereference is mitigated in Java by compile-time or run-time checks that ensure that no null-value can be dereferenced, it is better to not rely exclusively on catching the exceptions. Of course, the NullPointerException implicitly raised upon such dereferencing needs to be handled or else the vulnerability of a failing system or components prevails. In addition, Java also performs garbage collection, which limits the time that any reference that does not point to a valid object will be garbage collected. An alternative means introduced in Java 8 called Optional can be used to encapsulate the potential null values safely to avoid generating a null pointer exception.

### 6.13.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.13.5.
* Include checks for null prior to making use of objects that could be null.
* Handle exceptions raised by attempts to dereference null values
* Use the Optional class (java.util.Optional) to handle values as “present” or “absent” instead of checking for null values.

## 6.14 Dangling reference to heap [XYK]

### 6.14.1 Applicability to language

This vulnerability does not apply to Java, because in Java an object’s lifetime is controlled by the references to the object. If the reference still exists, the object will still exist.

## 6.15 Arithmetic wrap-around error [FIF]

### 6.15.1 Applicability to language

Given the fixed size of integer data types, continuously adding a positive value to an integer eventually results in a value that cannot be represented in the space allocated. For Java, this is defined as an overflow. The integer operators do not indicate overflow in any way.

Similarly, repeatedly subtracting from an integer leads to underflow. The integer operators also do not indicate underflow in any way.

For example, consider the following code for an integer operation:

 int foo( int i ) {

 i++;

   return i;

 }

Calling foo with the value of 2147483647 would result in i containing the value of -2147483648 after the i++ statement. Continuing execution using such a value could result in unexpected results such as overflowing a buffer and erroneous operation. The programmer may have been unaware that the value was getting too big to represent in the allocated space. As it is impossible for the compiler or an analysis tool to determine whether overflowing the variable is expected operation, code should be annotated using comments if wrap-around is expected.

### 6.15.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.15.5.
* Check that the result of an operation on an integer value will not cause wrapping, unless it can be shown that wrapping cannot occur. Any of the following operators have the potential to wrap:

a + b a – b a \* b a++ ++a a-- --a

a += b a -= b a \*= b a << b a<<=b -a

* Check that the result of an operation on a signed integer value will not cause an overflow, unless it can be shown that overflow cannot occur. Any of the following operators have the potential to overflow:

a + b a – b a \* b a/b a%b a++ ++a a--

--a a += b a -= b a \*= b a /= b a %= b a << b a <<= b

-a

* Use defensive programming techniques to check whether an operation will overflow or underflow the receiving data type. These techniques can be omitted if it can be shown at compile time that overflow or underflow is not possible.

## 6.16 Using shift operations for multiplication and division [PIK]

### 6.16.1 Applicability to language

Often the use of a shift operator as a substitute for the use of the multiplication and division operators is to increase performance. The Java Virtual Machine (JVM) usually performs such optimizations automatically, and can optimize for the current platform. Therefore, there usually is not any difference in performance in using a shift operator instead of a multiplication or division operator.

Java provides three shift operators: << (left shift), >> (signed right shift), and >>> (unsigned right shift). The signed right shift and the unsigned right shift will produce identical results for positive integers. However, for negative numbers, the two results will be different.

The left operand must be of type int or long. If the type of the left operand is of type byte, short or char, then the left operand is promoted to type int. Since the promotion performs a sign extension, an unsigned right shift could cause the result of the shift to be an unexpected large positive integer.

### 6.16.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.16.5.
* Also see, *[6.15 Arithmetic Wrap-around Error [FIF]](#_6.15_Arithmetic_wrap-around_1).*
* Any testing of calculations involving right shifts should include both positive and negative values to ensure correct operation.

## 6.17 Choice of clear names [NAI]

### 6.17.1 Applicability to language

The possible confusion of names with typographically similar characters is not specific to Java, but Java is as prone to it as any other language. Depending upon the local character set, avoid having names that only differ by characters that may be confused, such as ‘O’ and ‘0’ or ‘I’ and 'l’.

For Java, the maximum significant name length does not have a limit. Very long names can be problematic from the standpoint of readability and maintainability even if Java does not impose a limit.

This issue is related to *6.20 Identifier name reuse [YOW]*, as they are both mechanisms by which the programmer may inadvertently use an object other than the one intended.

### 6.17.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.17.5.
* Use names that are clear and non-confusing.
* Use consistency in choosing names.
* Keep names short and concise in order to make the code easier to understand.
* Choose names that are rich in meaning.
* Do not uses names that only differ by a mixture of case or the presence or absence of an underscore character.
* Avoid differentiating through characters that are commonly confused visually such as ‘O’ and ‘0’, ‘I’ (lower case ‘L’), ‘l’ (capital ‘I’) and ‘1’, ‘S’ and ‘5’, ‘Z’ and ‘2’, and ‘n’ and ‘h’.

## 6.18 Dead store [WXQ]

### 6.18.1 Applicability to language

Because Java is an imperative language, programs in Java can contain dead stores (memory locations that are written but never subsequently read, or overwritten without an intervening read). This can result from an error in the initial design or implementation of a program, or from an incomplete or erroneous modification of an existing program. However, it may also be intended behaviour, for example when initializing a sparse array. It may be more efficient to clear the entire array to zero, then to assign the non-zero values, so the presence of dead stores should be regarded as a warning of a possible error, rather than an actual error.

A store into a volatile variable generally should not be considered a dead store because accessing such a variable may cause additional side effects, such as input/output (memory-mapped I/O) or observability by a debugger or another thread of execution.

### 6.18.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.18.5.
* Use compilers and analysis tools to identify dead stores in the program.
* Mark all variables observable by another thread or hardware agent as volatile, also see *6.61 Concurrent data access [CGX].*

## 6.19 Unused variable [YZS]

### 6.19.1 Applicability to language

Variables may be declared, but never used when writing code or the need for a variable may be eliminated in the code, but the declaration may remain. Most compilers will report this as a warning and the warning can be easily resolved by removing the unused variable.

### 6.19.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.19.5.
* Resolve all compiler warnings for unused variables. Having an unused variable in code indicates that either warnings were turned off during compilation or were ignored by the developer.

## 6.20 Identifier name reuse [YOW]

### 6.20.1 Applicability to language

Java allows scoping so that a variable that is not declared within a method may be resolved to the class. Java allows name reuse within a method and a class. To differentiate between the two identically named variables within the same class, Java uses the keyword “this” as shown in the following example:

public class usernameExample {

private String username;

public void setName(String username) {

 this.username = username;

}

}

The keyword “this” allows the “this.username” to indicate that “username” refers to the class variable “username” instead of the method variable “username”. In the following example:

public class usernameExample {

private String username;

private String newName;

public void setName(String username) {

 this.username = username;

 newName = username;

}

}

“newName” is assigned to the method variable “username”. However, it would have been very easy for the programmer to have accidentally meant to write “newName = this.username;”.

Reuse of any publicly visible identifiers, public utility classes, interfaces, or packages in the Java Standard Library can cause confusion. For instance, naming an identifier, Timer, the same name as the public class java.util.Timer can cause confusion. Future maintainers of the code may not be aware that the identifier Timer refers to a custom class instead of the public class.

### 6.20.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.20.5.
* Ensure that when the identifier that a method uses is identical to an identifier in the class that the correct identifier is used through the use or non-use of “this”.
* Choose unique names for any publicly visible identifiers, public utility classes, interfaces and packages.

## 6.21 Namespace issues [BJL]

### 6.21.1 Applicability to language

Although Java detects conflicting names at compile time, issues could arise in several situations. Packages are one way that namespace issues can be handled when using the same name for two different classes. Should, for example, two classes have the same name, but in different packages as shown here:

com.app1.model (package)

 …

Device (class)

 ...

com.app2.data (package)

…

Device (class)

 ...

would require either a name change of the Device class or the use of the full package and class name when referencing them.

Java allows local variables in a subclass to have the same name as a superclass, as in:

class ExampleClass1 {

public static void main(String[] args) {

int i;

class Local {

{

for (int i = 0; i < 10; i++)

System.out.println(i);

}

}

new Local();

}

}

Java also allows the same variable to be declared multiple times within one method. For instance, the following code that declares int i twice in the same class is legal:

class ExampleClass2 {

public static void main(String[] args) {

for (int i = 0; i < 10; i++)

System.out.print(i + " ");

for (int i = 10; i > 0; i--)

System.out.print(i + " ");

System.out.println();

}

Since the declarations are in two separate blocks, i.e. two different for loops, these are interpreted to be distinct variables.

Although each of these situations likely resulted from decisions in designing Java that balanced alternatives, such as the need to avoid renaming local variables when such variables were in use in a superclass, these situations can cause issues when performing even routine maintenance. Variables that are distinct could become intermingled if careful consideration of the scope of the variables is not considered.

### 6.21.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.21.5.
* Use packages to distinguish variables with the same name.
* Although permitted, do not use the same variable name in different blocks within the same class as this could cause confusion and maintenance issues.

## 6.22 Initialization of variables [LAV]

### 6.22.1 Applicability to language

Java does not contain this vulnerability since Java requires that every variable in a program must have a value before it is used. In addition, Java will assign default values to variables.

## 6.23 Operator precedence and associativity [JCW]

### 6.23.1 Applicability to language

The order of operator precedence for Java is well defined and is listed below in order from highest to lowest precedence.

|  |
| --- |
| **Operator Precedence** |
| **Operators** | **Precedence** |
| postfix | *expr*++ *expr*-- |
| unary | ++*expr* --*expr* +*expr* -*expr* ~ ! |
| multiplicative | \* / % |
| additive | + - |
| shift | << >> >>> |
| relational | < > <= >= instanceof |
| equality | == != |
| bitwise AND | & |
| bitwise exclusive OR | ^ |
| bitwise inclusive OR | | |
| logical AND | && |
| logical OR | || |
| ternary | ? : |
| assignment | = += -= \*= /= %= &= ^= |= <<= >>= >>>= |

As shown in the table above, operator precedence and associativity in Java are clearly defined, and mixing logical and arithmetic operations is allowed without parentheses. However, the language has more than 40 operators with 15 levels of precedence, and experience has shown that even experienced programmers do not always get the interpretation of complex expressions correct.

### 6.23.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.23.5.
* Use parentheses any time arithmetic operators, logical operators, and shift operators are mixed in an expression, or where the expression is complex and may be difficult to parse for review or maintenance.

## 6.24 Side-effects and order of evaluation of operands [SAM]

### 6.24.1 Applicability to language

Java allows methods and expressions to have side effects. If two or more side effects modify the same expression as in:

 int[] array={1,2,3,4,5,6}

 int i=2;

 /\* … \*/

 i = array[i++];

the behaviour is well defined and the assignment of i = array[i] will occur before the i++. Though the rules of Java concerning side effects is fairly straightforward, it can be confusing such as in:

 int i = 2;

 int j = (i=3) \* i;

 System.out.println(j);

The assignment of i=3 will occur first, and then the expression j=i\*i; will be evaluated, leading to the printing out of 9.

In an if statement, such as:

if ( (aVar == 10) && (++i < 25))

 {// do something}

Should aVar not be equal to 10, then the if statement cannot be true, so the second half of the if statement may not be evaluated and thus the (++i < 25) will not be evaluated and i will not be incremented. Testing may give the false impression that the code is working, when it could just be that the values provided cause evaluations to be performed in a particular order that causes side effects to occur as expected.

Assert statements in Javaare used as a diagnostic tool to test assumptions about a program. Assert statements should not contain side effects since although assert statements are enabled by default, the assert statements can be disabled as part of the build process. This could change the program results since the assert statements would not be executed if the assert statements are disabled.

### 6.24.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.24.5.
* Simplify expressions to reduce side effects and potential confusion and improve maintainability.
* Do not have side effects in assert statements.

## 6.25 Likely incorrect expression [KOA]

### 6.25.1 Applicability to language

Java has several instances of operators which are similar in structure, but vastly different in meaning, for example confusing the comparison operator “==” with assignment “=”. Using an expression that is syntactically correct, but which may just be a null statement can lead to unexpected results. Consider:

int x, y;

/\* … \*/

if (x = y){

 /\* … \*/

}

A fair amount of analysis may need to be done to determine whether the programmer intended to do an assignment as part of the if statement (valid in Java) or whether the programmer made the common mistake of using an “=” instead of a “==”. In order to prevent this confusion, it is suggested that any assignments in contexts that are easily misunderstood be moved outside of the Boolean expression. This would change the example code to the semantically equivalent:

int x,y;

/\* … \*/

x = y;

if (x != 0) {

 /\* … \*/

 }

This would clearly state what the programmer meant and that the assignment of y to x was intended.

Confusion of “==” and the equals() method can also cause problems. Consider:

int a=5;

int b=5;

if (a==b)

System.out.println(“a==b is TRUE”);

In this case, “a==b is TRUE” will be printed since the values contained in a and b are the same. However, in the following example:

String obj1 = new String("xyz");

String obj2 = new String("xyz");

if (obj1 == obj2)

System.out.println("obj1==obj2 is TRUE");

else

System.out.println("obj1==obj2 is FALSE");

“obj1==obj2 is FALSE” will be printed since the memory locations where obj1 and obj2 are stored are different. “obj1==obj2 is TRUE” would only be printed if the memory locations of obj1 and obj2 were the same as in the case:

String obj1 = new String("xyz");

String obj2 = obj1;

It is also possible for programmers to insert the “;” statement terminator prematurely. However, inadvertently doing this can drastically alter the meaning of code, even though the code is valid, as in the following example:

 int a,b;

 /\* … \*/

 if (a == b); // the semi-colon will make this a null statement

 {

 /\* … \*/

 }

Because of the misplaced semi-colon, the code block following the if will always be executed. In this case, it is extremely likely that the programmer did not intend to put the semi-colon there.

Java also uses the “>>>” for the unsigned shift operator. This can be easily confused with the “>>” (signed right shift) which will produce identical results for positive values, but very different values for negative values.

### 6.25.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.25.5
* Explain statements with interspersed comments to clarify programming functionality and help future maintainers understand the intent and nuances of the code.
* Avoid assignments embedded within other statements, as these can be problematic. Each of the following would be clearer and have less potential for problems if the embedded assignments were conducted outside of the expressions:

 int a,b,c,d;

 /\* … \*/

 if ((a == b) || (c = (d-1))) // the assignment to c may not

 // occur if a is equal to b

 or:

 int a,b,c;

 /\* … \*/

 foo (a=b, c);

Each is a valid Java statement, but each may have unintended results.

* Give null statements a source line of their own. This, combined with enforcement by static analysis, would make clearer the intention that a statement was meant to be a null statement.
* Consider the adoption of a coding standard that limits the use of the assignment statement within an expression.

## 6.26 Dead and deactivated code [XYQ]

### 6.26.1 Applicability to language

Java allows the usual sources of dead code (described in 6.26 of TR 24772-1) that are common to most conventional programming languages. To avoid dead code, there must be an execution path from the beginning of the constructor, method, instance initializer, or static initializer that contains the statement to the statement itself. If not, the result will in many cases be a compiler error or warning.

Java will not produce a compiler error or warning in what seems to be obvious cases of dead or deactivated code such as in the following example:

{

int num = 10;

while (num > 15) val = 5;

}

Even though the statement “val = 5;” can never be reached, this code will not result in a compiler warning or error. While statements, do statements and for statements are afforded special treatment. Except in the case where the while, do or for expressions have the constant value of true, the values of the expressions are not taken into account in determining reachability.

### 6.26.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.26.5.
* Use “//” comment syntax instead of “/\*…\*/” comment syntax to avoid the inadvertent commenting out of sections of code.
* Use an IDE that adds additional capabilities to detect dead or unreachable code.

## 6.27 Switch statements and static analysis [CLL]

### 6.27.1 Applicability to language

Because of the way in which the switch-case statement in Java is structured, it can be relatively easy to unintentionally omit the break statement between cases causing unintended execution of statements for some cases. Within a Java switch block, all statements after the matching case label are executed in sequence until a break statement or the end of the switch block is reached.

Java contains a switch statement of the form:

public class SwitchWeekday {

 public static void main(String[] args) {

 int weekday = 3;

 String weekdayString;

 switch (weekday) {

 case 1: weekdayString = "Sunday";

 break;

 case 2: weekdayString = "Monday";

 break;

 case 3: weekdayString = "Tuesday";

 break;

 case 4: weekdayString = "Wednesday";

 break;

 case 5: weekdayString = "Thursday";

 break;

 case 6: weekdayString = "Friday";

 break;

 case 7: weekdayString = "Saturday";

 break;

 default: weekdayString = "Invalid weekday";

 break;

 }

 System.out.println(weekdayString);

 }

}

If there is not a default case and the switched expression does not match any of the cases, then control simply shifts to the next statement after the switch statement block. Unintentionally omitting a break statement between two cases will cause subsequent cases to be executed until a break or the end of the switch block is reached. This could cause unexpected results.

### 6.27.2 Guidance to language users

* Apply the guidance contained in TR 24772-1 clause 6.27.5.
* Adopt a coding style that requires every nonempty case statement to be terminated with a break statement as illustrated in the following example:

int i;

/\* … \*/

switch (i) {

 case 1: // fall through from case 1 to 2 is permitted

 case 2: // since there is no intervening code

 i++;

 break;

 case 3:

 j++;

 case 4: // fall through from case 3 to 4 is not permitted

 // as it is not a direct fall through due to the

 // j++ statement

 }

Alternatively, if a direct fall through from one nonempty case to another is required that would violate the coding style, then this should be clearly documented by a comment, preferably one recognized by the analysis tool used.

* Adopt a coding style that permits your language processor and analysis tools to verify that all cases are covered. Where this is not possible, use a default clause that diagnoses the error.
* Adopt a coding style that requires the default clause to be either the first or last clause in the switch statement to assist the maintenance of complex switch statements.
* Adopt a coding style that requires that a break statement be used after the last clause.

## 6.28 Demarcation of control flow [EOJ]

### 6.28.1 Applicability to language

Java lacks a keyword for an explicit terminator. Therefore, it may not be readily apparent which statements are part of a loop construct or an if statement.

Consider the following section of code:

 void foo(int a, int[] b) {

 int i=0, count=0;

 //

 a = 0;

 for (i=0; i<10; i++)

 a += b[i];

 count++;

 System.out.printf(“a=%d count=%d\n”, a, count);

 }

The programmer may have intended both “a += b[i];” and “count++;” to be the body of the loop, but as there are no enclosing brackets, the second statement is only performed once.

If statements in Java are also susceptible to control flow problems since there is not a requirement for there to be an else statement for every if statement. An else statement in Java always belongs to the most recent if statement without an else. However, the situation could occur where it is not readily apparent to which if statement an else belongs due to the way the code is indented or aligned.

### 6.28.2 Guidance to language users

* Follow the guidance provided in TR 24772-1 clause 6.28.5.
* Enclose the bodies of if, else, while, for, and similar constructs in braces. This will reduce confusion and potential problems when modifying the software. For example:

int a,b,i;

//

if (i == 10){

 a = 5; // this is correct

 b = 10;

 }

 else

 a = 10;

 b = 5; // Incorrect since b = 5 will execute after either branch

If the assignments to b were added later and were expected to be part of each if and else clause (they are indented as such), the above code is incorrect: the assignment to b that was intended to be in the else clause is unconditionally executed.

## 6.29 Loop control variables [TEX]

### 6.29.1 Applicability to language

Java allows the modification of loop control variables within the loop, which can cause unexpected behaviour and can make the program more difficult to understand.

Since the modification of a loop control variable within a loop is infrequently encountered and unexpected, reviewers of Java code may not expect it and hence miss noticing the modification or not recognize its significance. Modifying the loop control variable can cause unexpected results, as in:

 int a,i;

 for (i=1; i<10; i++){

 …

 if (a > 7)

 i = 10;

 …

 }

which would cause the for loop to exit once a is greater than 7 regardless of the number of iterations that have occurred.

Java doesn’t require the loop control variable to be an integer type. If, for example, it is a floating point type, the test for completion should not use equality or inequality, as floating point rounding may lead to mathematically inexact results, and hence an unterminated loop. The following may loop ten times or indefinitely:

 for (float x = 0.0f; x != 10.0f; x += 1.0f){

 …

 }

The following is an improvement:

 for (float x = 0.0f; x < 10.0f; x += 1.0f){

 …

 }

Rounding may cause this loop to be performed ten or eleven times. To ensure this loop is performed ten times, x could be initialized to 0.5f.

Enhanced for loops in Java provide for a simplified way of iterating through all elements of an array in order as in the following:

 for (int myIndex : myArray) {

 System.out.println (myIndex);

 }

Unlike the conventional for statement, modifications to the loop variable do not affect the loop’s iteration order over the array. This can cause unexpected results. Thus, it is better to declare the loop control variable as final to prevent this possible confusion as the following illustrates:

for (final int myIndex : myArray) {

 System.out.println (myIndex);

 }

By declaring myIndex as final, the Java compiler will reject any assignments within the loop.

### 6.29.2 Guidance to language users

* Follow the guidance of TR 24772-1 clause 6.29.5.
* Do not modify a loop control variable within a loop.
* Declare all enhanced for statement loop variables final.
* Do not use floating point types as a loop control variable.
* Use enhanced for loops to eliminate the need for a loop control variable

## 6.30 Off-by-one error [XZH]

### 6.30.1 Applicability to language

Arrays are a common place for off by one errors to manifest. In Java, arrays are indexed starting at zero, causing the common mistake of looping from 0 to the size of the array as in:

 public class arrayExample {

 public static void main (String[] args) {

 int intArray = new int[10];

 int i;

 for (i=0, i<=10, i++)

 a[i] = 5;

 …

 return (0);

 }

 }

Java does provide protection in this case as any attempt to access an array with an index less than zero or greater than or equal to the length of the array will result in an ArrayIndexOutOfBoundsException to be thrown.

Programs in Java are susceptible to the usual off by one errors such as looping less than the desired amount. Such errors will usually only be detected by doing good testing of the program.

### 6.30.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.30.5.
* Use careful programming, testing of boundary conditions, and static analysis tools to detect off by one errors in Java.

## 6.31 Structured programming [EWD]

### 6.31.1 Applicability to language

Since Java is an object oriented language, the structure is inherent in the language to lead to well structured programs. The Java language does not contain the goto statement. However, even though Java sets forth this structure and in spite of it, programmers can create unstructured code. Java does have the continue, break, throw, and return statements that can create complicated control flow when used in an undisciplined manner. Unstructured {spaghetti} code can be more difficult for Java static analyzers to analyze and is sometimes used on purpose to obfuscate the functionality of software. Code that has been modified multiple times by an assortment of programmers to add or remove functionality or to fix problems can be prone to become unstructured.

IEC 61508 [3] highly recommends the use of no more than one return statement in a method. At times, this guidance can have the opposite effect, such as in the case of an if check of parameters at the start of a method that requires the remainder of the method to be encased in the if statement in order to reach the single exit point. If, for example, the use of multiple exit points can arguably make a piece of code clearer, then they should be used. However, the code should be able to withstand a critique that a restructuring of the code would have made the need for multiple exit points unnecessary.

### 6.31.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.31.5.
* Write clear and concise structured code to make code as understandable as possible.
* Restrict the use of continue and break to encourage more structured programming.

## 6.32 Passing parameters and return values [CSJ]

### 6.32.1 Applicability to language

Parameters into a method can be any valid Java data type. Method arguments should be validated to ensure that their value falls within the bounds of the method’s anticipated values. Java passes any parameter that is one of the eight primitive types as pass by value. The parameter is evaluated and its value is assigned to the formal parameter of the method or constructor that is being called. Parameters provide information to the method from outside the scope of the method.

public static int minFunction (int n1, int n2) {

int min;

if (n1 > n2)

min = n2;

else

 min = n1;

return min;

}

When the value of an object is passed as a parameter, effectively the reference to the object is passed. This allows the object to be changed in the method.

 public class testObject {

 private int value;

public static void main(String[] args) {

 testObject p = new testObject();

 p.value = 10;

 System.out.println("Before calling: " + p.value);

 increment(p);

 System.out.println("After calling: " + p.value);

 }

 public static void increment(testObject a){

 a.value++;

 }

}

Java also allows expressions such as the post increment expression “i++” to be passed as parameters. This can cause confusion and it is safer to perform the increment in a separate, prior statement to the call. The order of evaluation of parameters proceeds from left to right and care should be taken when side effects modify the same variables such as “testMethod (i++, ++i)”.

### 6.32.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.32.5.
* Use care when using expressions with side effects as parameters to methods
* Avoid the use of expressions with side effects for multiple parameters to functions, since the order in which the parameters are evaluated and hence the side effects occur is unspecified.

## 6.33 Dangling references to stack frames [DCM]

### 6.33.1 Applicability to language

This vulnerability does not apply to Java, because in Java any reference that does not point to a valid object will be garbage collected.

## 6.34 Subprogram signature mismatch [OTR]

### 6.34.1 Applicability to language

There are two concerns identified with this vulnerability. The first is if a subprogram is called with a different number of parameters than it expects. The second is if parameters of different types are passed than are expected.

Java supports variadic functions/methods, termed varargs, as shown in the following example:

public class classSample {

 void demoMethod(String... args) {

 for (String arg: args) {

 System.out.println(arg);

 }

 }

 public static void main(String args[] ){

 new classSample().demoMethod("water", "fire", "earth");

 new classSample().demoMethod("wood", "metal");

 }

}

Prior to the introduction of varargs into JDK 5, variable length arguments could only be handled by putting the arguments into an array and passing the array to the method or by overloading the method. Both methods are error prone and more complicated than varargs. A varargs argument must be the last argument in a multiple argument list and multiple varargs, even if of different primitive types, are not allowed. Though varargs can be very useful, the use of varargs can cause performance issues leading to unexpected results.

Java also supports overloading which allows different methods to have the same name, but different signatures where signatures can differ by the number of input parameters or type of input parameters or both. Should the situation arise that more than one member method is both accessible and applicable to a method invocation, the choice shall be made that the most specific method is chosen. Though the specification is clear, the method that is invoked could be different than what is expected.

### 6.34.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.34.5.
* Do not use the variable argument feature except in rare instances. Instead use arrays to pass parameters.

## 6.35 Recursion [GDL]

### 6.35.1 Applicability to language

Java permits recursion, hence is subject to the problems described in TR 24772-1 clause 6.35.

### 6.35.2 Guidance to language users

* Apply the guidance contained in TR 24772-1 clause 6.35.5.
* If recursion is used, then use java.lang.OutOfMemoryError exception to detect and handle insufficient storage due to recurring execution.

## 6.36 Ignored error status and unhandled exceptions [OYB]

### 6.36.1 Applicability to language

Java offers a set of predefined exceptions for error conditions that may be detected by checks that are compiled into a program. In addition, the programmer may define exceptions that are appropriate for their application. These exceptions are handled using an exception handler. Exceptions may be handled in the environment where the exception occurs or may be propagated out to an enclosing scope.

Java has both checked and unchecked exceptions. If a program can be reasonably expected to recover from an exception, it is a checked exception. For situations where the program cannot do anything to recover, it is an unchecked exception. Lack of handling of checked exceptions, such as FileNotFoundException, can be detected at compile time. There must be a try and catch block to handle the exception as in the following example:

public static void main(String[] args)

{

 try

 {

 FileReader file = new FileReader("datafile.txt");

 }

 catch (FileNotFoundException e)

 {

 // print the stack trace for this Throwable object on the standard error output stream

 e.printStackTrace();

 }

}

Checked exceptions should not simply be suppressed by catching the exceptions with an empty or trivial catch block. The catch block must either recover from the exceptional condition, rethrow the exception by propagating it to an enclosing scope or throw an exception that is appropriate to the context of the catch block.

Unchecked exceptions, such as ArithmeticException, can be ignored in the program and the program will still compile. However, should an exception occur, how the exception should be handled will not be specified. Unchecked errors are mainly due to programming errors that should be fixed to prevent the unchecked exception from occurring again.

Variables defined in a try block are only local, so variables should be defined and initialized outside of the try block.

## 6.36.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.36.5.
* Use try-with-resources which extends the behaviour of the try/catch block to allow access to resources without having to close them afterwards as the resource closures are done automatically.
* Use unchecked exceptions just in case an unanticipated exception occurs.
* Use try-with-resources for automatic resource management.

## 6.37 Type-breaking reinterpretation of data [AMV]

### 6.37.1 Applicability to language

Java intentionally chose not to include union-type constructs due to the security and type-safety issues associated with their use. However, there exists the class sun.misc.Unsafe that provides some low level programming features such as reinterpretation of data, but, as its name implies, is considered unsafe for general use. Documentation is not widely available and its use is usually reliant on miscellaneous web postings which leads to even more unsafe use.

###  6.37.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.37.5.
* Java purposely chose not to include union-type constructs in the language. Though there are ways to circumvent that choice, those ways are for specialized cases and should only be used when absolutely necessary and carefully documented

## 6.38 Deep vs. shallow copying [YAN]

### 6.38.1 Applicability to language

The usual way of performing a copy in Java is through the use of the clone() method. Using the default implementation of the clone method will result in a shallow copy with all of the resulting issues associated with a shallow copy. Unexpected results can occur if the elements of values are changed via some other reference. Using a deep copy that makes the original and cloned object totally disjoint comes at the cost of efficiency and performance. To create a deep copy of an object, the clone method has to be overridden.

Another way of copying objects is to serialize them through the Serializable interface. An object can be serialized and then be deserialized to a new object. Since the constructor is not used for objects copied with clone or serialization which can lead to improperly initialized day and prevents the use of the final member fields.

### 6.38.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.38.5.
* Use reflection to deep copy objects, such as the deep-cloning library.
* Ensure that deep-copied objects are initialized properly.
* Be careful of memory leaks when using deep copying.

## 6.39 Memory leaks and heap fragmentation [XYL]

### 6.39.1 Applicability to language

Java has automatic memory management along with a built-in Garbage Collector (GC). Nevertheless, memory leaks can still occur in Java applications. Although objects are no longer being used by an application, the Garbage Collector cannot remove them from working memory if the objects are still being referenced. Left unchecked, this will likely result in the application consuming more and more resources until a fatal OutOfMemoryError occurs.

Many scenarios may lead to a memory leak:

* Referencing a memory intensive object with a static field ties its lifecycle to the lifecycle of the JVM itself.
* Unclosed resources, such as database connections, input streams, and session objects.
* Non-static inner classes (anonymous classes) always require an instance of the enclosing class and has, by default, an implicit reference to its containing class. If this inner class’ object is used in an application, then even after the containing class’ object goes out of scope, it will not be garbage collected.
* Overriding a class’ finalize() method and then the objects of that class aren’t instantly garbage collected since the garbage collector queues them for finalization, which occurs at a later point in time.
* Reading a large String object, and then calling intern() on that object will result in it being stored in the string pool, which is located in PermGen (permanent memory) where it will stay as long as the application runs.
* Using the ThreadLocal construct to isolate state to a particular thread and thus achieve thread safety, so that each thread will hold an implicit reference to its copy of a ThreadLocal variable and will maintain its own copy, instead of sharing the resource across multiple threads, as long as the thread is alive. This can introduce memory leaks if not used carefully.
* Calling applications written in programming languages that are prone to memory leaks.

### 6.39.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.39.5.
* Use a heap-analyzer tool to assist in detecting memory leaks
* Enable verbose garbage collection to see a detailed trace of the garbage collector actions
* Use Java profiler tools that monitor and diagnose memory leaks
* Use reference objects from the java.lang.ref package instead of directly referencing objects to allow them to be easily garbage collected.

## 6.40 Templates and generics [SYM]

### 6.40.1 Applicability to language

Generics allow programmers to specify with a single method declaration, a set of related methods or with a single class, a set of related types. At the heart of Java generics is type safety, which allows invalid types to be caught at compile time. The emphasis on type safety causes many problems to be averted. This is an improvement over previous techniques to accomplish the same goal.

Java allows the use of upper bounded, lower bounded and unbounded wildcards (“?”) in a generic. The use of a wildcard in generic programming can be useful, but can also introduce uncertainty as to the intention during the maintenance cycle. Generic wildcards also add a level of complexity that may not be fully understood or comprehended by Java programmers who know the basics of generics, but not more sophisticated techniques like wildcards.

### 6.40.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.40.5.
* Use generic wildcards carefully and only when needed.
* Follow the acronym PECS for “Producer Extends, Consumer Super” – use extends when getting values out of a data structure, use super when putting values into a data structure, and use and explicit type when doing both.

## 6.41 Inheritance [RIP]

Java supports inheritance, but does not support multiple inheritance or cyclic inheritance, which allows Java to avoid problems associated with multiple inheritance. Java does allow subclasses to override inherited methods, potentially causing difficulty in determining where in the hierarchy an invoked method is actually defined. An overriding method must specify the same name, parameter list, and return type as the method being overridden. The use of the keyword final in a method header will prevent the method from being overridden. For example, “final String getDate” will prevent getDate from being overridden in a subclass as the compiler will report an error if the method is overridden in a subclass.

### 6.41.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.41.5.
* Use composition and interfaces as an alternative to inheritance
* Keep the inheritance graph as shallow as possible to make following the control flow of the program easier and more straightforward

## 6.42 Violations of the Liskov substitution principle or the contract model [BLP]

### 6.42.1 Applicability to language

Since Java supports inheritance, users should abide by the Liskov substitution principle. As such, Java developers should be wary of having to add a restriction to an overridden method. If that restriction doesn’t exist in the base class, the Liskov Substitution Principle has likely been violated.

### 6.42.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.41.5.

## 6.43 Redispatching [PPH]

### 6.43.1 Applicability to language

Dynamic method dispatch is the mechanism by which a call to an overridden method is resolved at run time, rather than compile time. When an overridden method is called through a superclass reference, Java determines which version (superclass/subclasses) of that method is to be executed based upon the type of the object being referred to at the time the call occurs. Thus, this determination is made dynamically at run time. For methods that are overridden in subclasses in the object being initialized, the overriding methods are used and thus the redispatching problem could manifest.

### 6.43.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.43.5.
* If redispatching is necessary, document the behaviour explicitly.

## 6.44 Polymorphic variables [BKK]

### 6.44.1 Applicability to language

The vulnerabilities related to upcasts in TR 24772-1 clause 6.43 apply to Java.

Downcasts from a superclass to a subclass in the same type hierarchy is legal and will not be flagged by the compiler. In the following example, Subclass extends Superclass, and declares method(). BadDowncast declares a main() method that instantiates Superclass. BadDowncast then downcasts this object to Subclass and assign the result to Subclass. However, if the assignment was allowed, the application would fail when it tried to execute subclass.method(). This occurs due to the JVM attempting to call a nonexistent method, because Superclass doesn't declare method(). The JVM determines that there isn’t a method() in Superclass and would throw a ClassCastException.

class Superclass

{

}

class Subclass extends Superclass

{

void method()

{

}

}

public class BadDowncast

{

public static void main(String[] args)

{

Superclass superclass = new Superclass();

Subclass subclass = (Subclass) superclass;

subclass.method();

}

}

### 6.44.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.44.5.
* Declare all data members as private and provide wrapper members to provide accessibility to the data members.

## 6.45 Extra intrinsics [LRM]

This vulnerability does not apply to Java, because all subprograms belong to the same namespace. Java does allow overloading, but the signatures would be different. If two classes have the same name, only one will be imported. The other one must be referenced with its entire path.

## 6.46 Argument passing to library functions [TRJ]

### 6.46.1 Applicability to language

Parameter validation should always be performed in non-private methods since its caller is out of scope of its implementation. In public methods or other instances where such validation is not performed or it is unsure whether it is performed, the calling routine should perform parameter validation.

There are open source libraries that provide for preconditions to be placed on parameters. For instance, the open source library Guava provides utilities such as checkArgument as illustrated in this example:

public static double sqrt (double value)

{

Preconditions.checkArgument(value >= 0.0, "negative value: %s", value);

 // …perform calculation of the square root

}

## 6.46.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.46.5.
* Do not make assumptions about the values of parameters.
* Use preconditions to validate parameters
* Do not assume that the calling or receiving function will be range checking a parameter. Therefore, establish a strategy for each interface to check parameters in either the calling or receiving routines.

## 6.47 Inter-language calling [DJS]

### 6.47.1 Applicability to language

Interfacing with other languages can be difficult. Though Java attempts to make interfacing with other languages easier, it can still be rather complicated. Foreign Function Interfaces (FFI) are one way to provide a clean API for communicating between the languages. The Java Native Interface (JNI) is a typical FFI designed to make a foreign function interface easier and safer. JNI can be used to interface with C/C++, assembly and other languages. The pitfalls of using JNI or other FFI are generally that of impacted performance and, because of the many issues related to interfacing between languages, correctness potentially causing issues where the code may sometimes work, but not reliably because of the complexities of the interface. FFIs can introduce issues that are difficult to debug because of the complexities and lack of transparency within the interface.

### 6.47.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.47.5.
* Use a foreign function interface such as JNI to provide a clear separation between Java and the other language.
* Use foreign function interfaces carefully as they can be error prone and lack transparency making debugging harder.
* Native code can lack many of the protections afforded by Java such as compile time exception checking not being performed on native methods.
* Minimize the use of those issues known to be error-prone when interfacing between languages, such as:
1. passing character strings
2. dimension, bounds and layout issues of arrays
3. interfacing with other parameter formats such as call by reference or name
4. handling faults/errors, and
5. bit representation.

## 6.48 Dynamically-linked code and self-modifying code [NYY]

### 6.48.1 Applicability to language

The Java vVirtual machine (JVM)does not allow access to random locations in memory, so modifying an already loaded bytecode for self-modifying code would not be possible from a Java program. However, new classes and methods that have not been loaded can be written or modified as a Java program is executing and then loaded.

Class loaders are responsible for loading Java classes during runtime dynamically to the JVM. When the runtime environment needs to load a new class for an application, the class is located and loaded by one of three types of class loaders in the following order: bootstrap class loader; extension class loader; and system class loader. The bootstrap class loader is responsible for loading all core Java classes. The extension class is a child of the bootstrap class loader and load classes from the extension directories. The system class loader is responsible for loading code from the path specified by the CLASSPATH environment variable or alternatively using the –classpath option. The –classpath option will take precedence over the CLASSPATH environment variable. Altering either of these could lead to executing code that is different from what was tested.

The Java platform allows for JAR files to be digitally signed, thus providing a mechanism for verification of the source of the file.

Java classes are not loaded into memory all at once, but when required by an application. Thus, if a class is changed while a program is running, the new version will be used. Java also allows for class reloading. Thus, a program that employs class reloading makes it possible for an attacker to modify a class while a program is running.

### 6.48.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.48.5.
* Do not dynamically modify classes, unless there is a documented rationale and the rationale is carefully reviewed.
* As appropriate, verify through the use of signatures that dynamically linked or shared code being used is the same as that which was tested.
* If possible, retest when dynamically linked or shared code has changed before using the application.

## 6.49 Library signature [NSQ]

### 6.49.1 Applicability to language

Integrating Java and another language into a single executable relies on knowledge of how to interface the method/function calls, argument lists and data structures so that symbols match in the object code during linking.

Arrays and other data structures may be interpreted by another language differently than the way that Java interprets or stores them in memory. This may cause issues with transferring data between Java and the receiving language. For instance, it is common to use one-dimensional arrays to pass array data to and from programs in another language since the way that Java stores multidimensional arrays is significantly different than that of C, C++ and other languages.

Issues can arise when Java interfaces with a language that does not support garbage collection. Java may perform garbage collection and delete objects before the other non-garbage collection language being called is finished with them.

To alleviate some of these issues, wrappers can be used. Though wrappers can make the interfacing easier, wrappers can be error-prone and impact performance through the overhead of the wrapper.

### 6.49.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.49.5.
* Use a tool, if possible, to automatically create interface wrappers.
* Be wary of making assumptions about argument lists and data structures, as other languages are likely to have differences in their data interpretation and storage.

## 6.50 Unanticipated exceptions from library routines [HJW]

### 6.50.1 Applicability to language

Java has two types of exceptions, checked and unchecked. A checked exception requires a response and the existence of a response is checked for at compile time. A method must either handle the exception or it must specify the exception using the throws keyword. This reduces the number of exceptions that are not properly handled. Unchecked exceptions are subclasses of RunTimeException and do not require handling since recovery is likely difficult or impossible, or the addition of an exception would not add significantly to the program’s correctness and could be viewed as simply cluttering up the program needlessly.

Though a response to a checked exception is required, it is unfortunately too common for a programmer to assume that a checked exception could not possibly happen and instead of putting appropriate code in to handle the unexpected event, the programmer does just enough to get a clean compile by inserting an empty catch block as in the following example:

public void whatCouldPossiblyGoWrong() {

 try {

 // do something

 } catch (NumberFormatException e) {

 // this will never happen

 }

}

### 6.50.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.50.5 of TR 24772-1.
* Always have an appropriate response for checked exceptions since even things that should never happen do happen occasionally.
* Do not catch an exception, log it and then rethrow it to the caller to handle as it is likely lacking needed specific information and at best is simply redundant.

## 6.51 Pre-processor directives [NMP]

### 6.51.1 Applicability to language

This vulnerability does not apply to Java, as Java does not have a preprocessor.

## 6.52 Suppression of language-defined run-time checking [MXB]

Does not apply to Java since runtime checks cannot be suppressed.

## 6.53 Provision of inherently unsafe operations [SKL]

### 6.53.1 Applicability to language

The Java compiler generates the “uses unsafe or unchecked operations” warning for code considered to be unsafe. However, it is just a warning and could be ignored.

Although Java is inherently a safe language, it does allow some operations that are inherently unsafe. For example, one undocumented class, sun.misc.Unsafe, contains code that is recognized to be inherently unsafe, but is often required for low-level programming. For instance, it allows the creation of an instance of a class without invoking its constructor code, initialization code and various other JVM security checks. The allocateMemory() method in sun.misc.Unsafe also allows the creation of huge objects, larger than Integer.MAX\_VALUE, that are invisible to the garbage collector and the JVM. Though sun.misc.Unsafe is designed to provide low-level mechanisms for specialized use, the class could be used to evade Java protections. It does throw a security exception, but code that evades the security exception using reflection is readily available.

### 6.53.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.53.5.
* Analyze the Java warnings “uses unsafe or unchecked operations” to determine whether action is needed or whether it is appropriate to leave the code as is.
* The class sun.misc.Unsafe should only be used in specialized instances where the capabilities it provides are essential. It should not be used for everyday use to evade Java protections.

## 6.54 Obscure language features [BRS]

### 6.54.1 Applicability of language

One problem with identifying obscure language features is that an obscure feature to one person is a “must have” commonly used feature to another. That said, Java is a compact language such that most, if not all, of the statements are commonly used. There are ways that a feature of the language can be easily misused and as such restrictions on the feature are commonly expressed in coding standards in software development organizations. For instance, the inclusion of statements other than loop control statements should not be included in a for() statement. For instance:

for (i = 0, total=0; i < 50; i++)

total += value[i];

Though the above code is legal, the inclusion of the non-loop control statement, total=0, reduces the maintainability and readability of the code.

Other features are unique to Java and programmers schooled in other languages may not use these features since they are not as familiar with them as they would be with a feature that was common to both their native language(s) and Java. And finally, some features such as the logical right shift (“>>>”) operator is only applicable under rare circumstances and there are alternative ways of achieving the same result and thus programmers may forget that the feature exists.

Problems can also arise from the use of a combination of features that are rarely used together or fraught with issues if not used correctly. This can cause unexpected results and potential vulnerabilities.

### 6.54.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.54.5.
* Specify a coding standards that restricts or bans the use of features or combinations of features that have been observed to lead to vulnerabilities in the operational environment for which the software is intended.

## 6.55 Unspecified behaviour [BQF]

### 6.55.1 Applicability of language

The Java specification is fairly complete and leaves very little unspecified. Two areas that lack full specification are:

* The garbage-collection algorithm used and any internal optimization that is performed. Since when garbage collection happens can be unpredictable, timing issues can be introduced.
* Optimization of Java virtual machine instructions may cause portions of instructions to be skipped or reordered.

### 6.55.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.55.5.
* Do not rely on unspecified behaviour because the behaviour can change at each instance. Any code that makes assumptions about the behaviour of something that is unspecified should be replaced.
* Reduce the number of temporary objects to minimize the impact and need for garbage collection.
* Increase the Java heap size to reduce the frequency and amount of time spent doing garbage collection.
* Enable verbose garbage collection and profiling to locate and fix memory leaks to reduce need for garbage collection.
* In cases where statements may only be partially evaluated due to optimization, simplify and separate out the side effects in the statement into multiple statements to ensure that the operations will be executed even when optimized.

## 6.56 Undefined behaviour [EWF]

### 6.56.1 Applicability of language

Java is a well-defined language, but has some areas of undefined behaviour. Areas of undefined behaviour are:

* The exact timing and scheduling of multiple threads. This is the primary area where undefined behaviour is experienced in Java.
* Overloading a method with a parameter that is a subclass of the same parameter in the overloaded method. For example:

void doSomething(Object obj);

void doSomething(String str);

There's no way to know which method will be called in doSomething("Hello world!"), since both signatures are valid. Also, this behaviour can change from VM to VM, and even from execution to execution.

* Calling a non-final method of the same class in the constructor. The undefined behaviour occurs if this method is overridden in a subclass. Notice that construction occurs from the superclass to the subclass. The case gets especially nasty if the subclass method uses some local subclass attributes. In case of Oracle VM, the local attributes will be constructed, the superclass constructor will finish its execution then, when the constructor of subclass is reached the attributes will be constructed again, overriding previously defined values.
* Interrupting a byte array using the default encoding, instead of the encoding used to produce the byte array, and lacking a valid character representation for some of the bytes in the default encoding.
* How soon a finalizer will be invoked, which thread will invoke the finalizer for any given object, and the ordering of finalize method calls are all unspecified.
* Details of how and when garbage collection will occur, even when the garbage collection is explicitly invoked.

### 6.56.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.56.5.

## 6.57 Implementation–defined behaviour [FAB]

### 6.57.1 Applicability to language

Java has very little implementation-defined behaviour as Java is a Write Once Run Anywhere (WORA) language. The Java operating model is that the Java source code is compiled and converted into bytecode. The bytecode is designed to be platform independent.

One example of an area that is implementation defined are the two static variables in the java.io.File class which will be used to make file path separation Java code platform independent. File.separator is the String value that an operating system uses to separate file paths. For instance, on Unix based systems, the a “/” is used, whereas on a Windows based system, a “\” is used. In order to make code platform independent, when creating a file path, use String filePath = "temp" + File.separator + "abcd.txt" instead of the platform dependent String filePath = "temp/abcd.txt".

### 6.57.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.57.5.

## 6.58 Deprecated language features [MEM]

### 6.58.1 Applicability to language

As with other languages, it is recommended that deprecated classes, methods, and fields not be used. Java does provide a way to express deprecation because as a class evolves, its API inevitably changes. Methods are renamed for consistency, improved methods are added, and fields change. To facilitate the transition to the new APIs, Java supports two mechanisms for deprecation of a class, method, or field: an annotation and a Javadoc tag. The Javadoc tag is the old method. Java annotations were introduced in Java 5 and are the preferred method. For either mechanism, existing calls to the old API continue to work, but the annotation causes the compiler to issue a warning when it finds references to deprecated program elements. Comments are inserted in the code prior to the @Deprecated annotation to warn users against using the deprecated item and provide information on what should be used instead. However, in some instances where there is not a suitable replacement, users should simply not use the method.

public class ADeprecatedExmp {

 /\*\*

 \* @Deprecated

 \* reason(s) why it was deprecated

 \*/

 @Deprecated

 public void showDeprecatedMessage(){

 System.out.println("This method is marked as deprecated");

 }

 public static void main(String a[]){

 ADeprecatedExmp mde = new ADeprecatedExmp();

 mde.showDeprecatedMessage();

 }

}

### 6.58.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.58.5.
* Use the Java annotation and a Javadoc tag to indicate deprecation of classes, methods, or member fields
* Rewrite code that uses deprecated language features to remove such use, whenever possible.

## 6.59 Concurrency – Activation [CGA]

### 6.59.1 Applicability to language

Java will throw an exception if a thread is not activated. The “java.lang.OutOfMemoryError: Failed to create a thread” message occurs when the system does not have enough resources to create a new thread. There are three possible causes for this message: inadequate user/application resources, lack of native (or system) memory or there are too many threads already running.

### 6.59.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.59.5.
* Check the maximum allowed process per user limit and raise the limit if appropriate. For example, on Linux systems, check the limit using the “ulimit –u” command.
* Increase the amount of native memory available by lowering the size of the Java heap by using the –Xmx option.
* Lower the number of threads if possible.
* Check the amount of free disk space. For example, on Linux systems, check the amount of free disk space by using the “df” command.
* A try/catch can be used to ensure that if an OutOfMemoryError is encountered, then processes can be gracefully shutdown and resources cleanly released. It is generally not recommended that any other recovery be attempted.

## 6.60 Concurrency – Directed termination [CGT]

### 6.60.1 Applicability to language

Killing a thread in Java used to be done by calling the Java.lang.Thread.stop() method. Java.lang.Thread.stop() has been deprecated as it is inherently unsafe leading to an inconsistent state of operation such as monitored objects being corrupted. One recommended way to stop a thread is by using a Boolean flag. The thread periodically checks a Boolean flag that indicates the thread should exit. The flag is initially set to false. If the flag becomes true, the thread can then gracefully exit. To ensure prompt communication of the exit request, the flag must be volatile (or access to the flag must be synchronized).

Another way of directing the termination of a thread is through the use of the Java.lang.Thread.interrupt() method. In a scenario where a thread may be in a sleep state or waiting for a lock for a long period of time, the use of a Boolean flag may not be effective. Instead, the use of Java.lang.Thread.interrupt() can be used to interrupt a thread in a sleeping or waiting state and then the thread can take action to terminate itself gracefully.

Either method of terminating a thread in Java is dependent on the programmer to decide exactly how to respond to the Boolean flag being set to indicate termination or the sent interrupt.

### 6.60.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.58.5.
* Use a protected variable to indicate that a thread should exit.
* Alternatively, use Thread.interrupt() method to interrupt a thread to indicate that the thread should exit.

## 6.61 Concurrent data access [CGX]

### 6.61.1 Applicability to language

Some data elements of Java can be shared between threads, while other data elements cannot. Data elements that can be shared between threads are termed shared memory or heap memory. All instance fields, static fields, and array elements are stored in heap memory and thus can be shared. Other data elements such as local variables, formal method parameters, and exception handler parameters are never shared between threads. The obvious issue is that data elements may be changed by one thread in an unexpected way

Data elements that are shared may have their new values cached delaying the writing of their value to main memory. Other threads reading the current main memory will get the old value until the cache value is written to main memory.

Since concurrent execution of threads are typically interleaved, the order of execution can be very important. Examination of the source code could be misleading since compilers or runtime systems may reorder statements to optimize performance within each thread, but which could affect the resulting execution order leading to different results than expected.

Sixty-four bit operations can be problematic since the operation could be performed as two separate 32 bit operations to a non-volatile long or double. Because other threads may read the value after the first write of 32 bits and before the second write, the value could be incorrect. By declaring the long or double variable as volatile, the writes and reads of the long or double variables are always atomic.

### 6.61.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.61.5.
* Form happens-before relationships through the use of the java.util.concurrent package
* Use the volatile keyword to force a data element to always go to main memory for its reads and writes
* Use the volatile keyword to ensure reads and writes of long and double volatile values are atomic

## 6.62 Concurrency – Premature termination [CGS]

### 6.62.1 Applicability to language

Java provides the java.lang.Thread.isAlive() method to test if a thread is alive. The method will return true if the thread is alive and false otherwise. This allows the thread to be monitored to see if it is still functioning.

### 6.62.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.62.5.
* Use the java.lang.Thread.isAlive() method to check as needed to see if a thread is still active.

## 6.63 Lock protocol errors [CGM]

### 6.63.1 Applicability to language

Each object in Java is associated with a monitor, which a thread can lock or unlock. Every object has an intrinsic lock associated with it. A thread that needs exclusive and consistent access to an object's fields has to acquire the object's intrinsic lock before accessing them, and then release the intrinsic lock when it is done with them

Though Java has intrinsic language features for managing lock protocol errors, per the Java specification, “The Java programming language neither prevents nor requires detection of deadlock conditions.” It is recommended in the Java specification that conventional techniques for deadlock avoidance be used since Java does not inherently have preventions.

### 6.63.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.63.5.
* Use the intrinsic monitor features coupled with conventional techniques to avoid lock protocol errors.

## 6.64 Reliance on external format strings [SHL]

### 6.64.1 Applicability to language

Java provides string classes that use to interpret the data read or format the output. These strings include all of the features described in TR 24772-1 clause 6.64.1. The java.util.Scanner class allows for the parsing of strings using regular expressions. The java.lang.String allows for the creation and manipulation of strings. In Java, strings are immutable. Once a string object is created its data or state cannot be changed, instead a new string object is created. Though Java has classes that can help to avoid external format strings, strings originating outside of the trust boundary always need verification to ensure trust and before use. The standard Java library implementation will throw an exception if a string does not match the corresponding format specification.

Checking strings without normalizing them first can cause validation logic, and in particular, blacklisting comparisons, to be inaccurate. Similarly, if path names and other such strings with more than one possible representation are not canonicalized before comparing, inaccurate results can occur.

### 6.64.2 Guidance to language users

* Follow the guidance contained in TR 24772-1 clause 6.64.5.
* Normalize strings before validating them.
* Canonicalize path names and other strings that have more than one possible representation.
* Use Java classes for importing, exporting, and manipulating strings.

# 7. Language specific vulnerabilities for Java

[Intentionally blank]

# Bibliography

[1] Gosling, James, et al, *The Java Language Specification, Java SE 10 Edition*, 2018-02-20

[2] Long, Fred, et al, The CERT Oracle Secure Coding Standard for Java, Upper Saddle River, NJ, Addison Wesley, 2012.