Java Platform, Standard Edition
Oracle JDK Migration Guide

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Preface

The purpose of this guide is to help you identify potential issues and give you suggestions on how to proceed as you migrate your existing Java application to JDK 16.

Audience

This guide is intended for experienced users of the Java language, such as systems administrators and software developers, for whom the performance of the Java platform and their applications is of vital importance.

Documentation Accessibility

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Related Documents

See JDK 16 Documentation for other JDK 16 guides.

Conventions

The following text conventions are used in this document:

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

1
Getting Started

The guide highlights the significant changes and enhancements done in JDK 16.

This guide contains the following sections:

- Significant Changes in the JDK
- Security Updates
- Removed APIs
- Removed Tools and Components
- Preparing For Migration
- Migrating From JDK 8 to Later JDK Releases
- Next Steps

> ✎ **Note:**
>
> - Check the Oracle JDK Certified System Configurations for the latest supported platforms and operating system versions.
> - See Removed APIs, Tools, and Components before you start the migration process.

2

Significant Changes in the JDK

Before migrating your application to the latest JDK release, you must understand what the updates and changes are between it and the previous JDK release. If you are migrating from JDK 8, you should also be familiar with the differences between JDK 8 and later releases that are described in Migrating From JDK 8 to Later JDK Releases.

See the following sections to learn about some of the significant changes in latest JDK releases.

Significant Changes in JDK 16 Release

See JDK 16 Release Notes for additional descriptions of the new features and enhancements, and API specification in JDK 16.

The following are some of the updates in Java SE 16 and JDK 16:

- The Java programming language is enhanced with pattern matching for the `instanceof` operator. This feature allows common logic in a program, namely the conditional extraction of components from objects, to be expressed more concisely and safely. See JEP 394: Pattern Matching for instanceof and Pattern Matching for instanceof in *Java Platform, Standard Edition Java Language Updates* guide.

- Records, first previewed in Java SE 14, is a permanent feature in this release. The earlier restrictions have been relaxed whereby the inner classes can declare members that are either explicitly or implicitly static. This includes record class members, which are implicitly static. See JEP 395: Records and Record Classes in *Java Platform, Standard Edition Java Language Updates* guide.

- By default, all internal elements of the JDK are strongly encapsulated, except for critical internal APIs such as `sun.misc.Unsafe`. You can choose the relaxed strong encapsulation that has been the default since JDK 9. See JEP 396: Strongly Encapsulate JDK Internals by Default and Illegal Reflective Access.

- UNIX domain socket channels have been integrated into JDK 16. See JEP 380: Unix-Domain Socket Channels and Internet Protocol and UNIX Domain Sockets NIO Example in *Java Platform, Standard Edition Core Libraries*.

- The Z Garbage Collector processes the thread stacks concurrently. This allows all roots in the JVM to be processed by ZGC in a concurrent phase. See JEP 376: ZGC: Concurrent Thread-Stack Processing and The Z Garbage Collector in *Java Platform, Standard Edition HotSpot Virtual Machine Garbage Collection Tuning Guide*.

- The `jpackage` tool, which was incubated in JDK 14, is now a permanent feature. The tool packages a Java application into a platform-specific package that includes the necessary dependencies. See JEP 392: Packaging Tool and *Java Platform, Standard Edition Packaging Tool User's Guide*.

- Elastic metaspace overhauls the VM-internal metaspace- and class-space-implementation. The unused HotSpot class-metadata (that is *metaspace*) memory is returned to the operating system. It reduces the metaspace footprint and

simplify the metaspace code in order to reduce maintenance costs. See JEP 387: Elastic Metaspace.

Preview Features and Incubator Modules

See Java Language Preview Feature for more information about preview features.

- Sealed classes, a preview feature from JDK 15, is re-previewed in this release. Sealed classes and interfaces restrict which other classes or interfaces may extend or implement them. There has been several refinements in this release, including the introduction of character sequences `sealed`, `non-sealed`, and `permits` as contextual keywords. See JEP 397: Sealed Classes (Second Preview) and Sealed Classes in *Java Platform, Standard Edition Java Language Updates* guide.

- Initial iteration of an incubator module, `jdk.incubator.vector`, is provided to express vector computations. It reliably compiles at runtime to optimal vector hardware instructions on supported CPU architectures and thus achieve superior performance to equivalent scalar computations. See JEP 338: Vector API (Incubator).

- Foreign Linker API is introduced that offers statically-typed, pure-Java access to native code. This API, along with the Foreign-Memory Access API (JEP 393), will simplify the otherwise error-prone process of binding to a native library. See JEP 389: Foreign Linker API (Incubator).

- Foreign-Memory Access API allows Java programs to safely and efficiently access foreign memory outside of the Java heap. See JEP 393: Foreign-Memory Access API (Third Incubator).

Removed APIs, Tools, and Components

See:

- API Removed in Java SE 16

- Tools and Components Removed in JDK 16

In addition, there are security related updates that you need to be aware of. See: Security Updates in JDK 16.

Significant Changes in JDK 15 Release

See JDK 15 Release Notes for the complete list of new features and enhancements in JDK 15.

The following are some of the updates in Java SE 15 and JDK 15:

- Text Blocks, first previewed in Java SE 13, is a permanent feature in this release and can be used without enabling preview features.
  Text blocks are multiline string literals that avoid the need for most escape sequences, automatically format the string in a predictable way, and give the developer control over the format when desired. See JEP 378: Text Blocks and Programmer's Guide to Text Blocks.

- The Z Garbage Collector (ZGC) is ready to use in production and no longer an experimental feature. Enable ZGC by using the command-line option `-XX:+UseZGC`. See JEP 377: ZGC: A Scalable Low-Latency Garbage Collector (Production).

- Hidden classes are classes that cannot be used directly by the bytecode of other classes. Hidden classes are intended for use by frameworks that generate classes at run time and use them indirectly through reflection. See JEP 371: Hidden Classes.

Preview and Incubator Features

See Java Language Preview Feature for more information about preview features.

- Sealed Classes is a Java language preview feature. Sealed classes and interfaces restrict which other classes or interfaces may extend or implement them. See JEP 360: Sealed Classes (Preview) and Sealed Classes in *Java Platform, Standard Edition Java Language Updates* guide.

- Pattern Matching for `instanceof`, a preview feature from Java SE 14, is re-previewed for this release. This feature allows common logic in a program, namely the conditional extraction of components from objects, to be expressed more concisely and safely. See JEP 375: Pattern Matching for instanceof (Second Preview) and Pattern Matching for the instanceof in *Java Platform, Standard Edition Java Language Updates* guide.

- Records, a preview feature from Java SE 14, is re-previewed for this release. Records are classes that act as transparent carriers for immutable data. See JEP 384: Records (Second Preview) and Record Classes in *Java Platform, Standard Edition Java Language Updates* guide.

- The Foreign Memory Access API allows Java programs to efficiently and safely access foreign memory outside of the Java heap. See JEP 383: Foreign-Memory Access API (Second Incubator).

Removed APIs, Tools, and Components

See:

- APIs Removed in Java SE 15
- Tools and Components Removed and Deprecated in JDK 15

In addition, there are security related updates that you need to be aware of. See: Security Updates in JDK 15.

Significant Changes in JDK 14 Release

The following are some of the changes in Java SE 14 and JDK 14:

- Switch is extended so it can be used as either a statement or an expression, so that both forms can use either traditional `case ... :` labels (with fall through) or new `case ... ->` labels (with no fall through), with a further new statement for yielding a value from a switch expression. See JEP 361: Switch Expressions (Standard) and Java Language Changes.

- G1 is enhanced to improve allocation performance on non-uniform memory access (NUMA) memory systems. See JEP 345: NUMA-Aware Memory Allocation for G1.

- JDK Flight Recorder data is now available as a data stream allowing for continuous monitoring. See JEP 349: JFR Event Streaming.

- New JDK-specific file mapping modes have been added so that the `FileChannel` API can be used to create `MappedByteBuffer` instances that refer to non-volatile (NVM) memory. See JEP 352: Non-Volatile Mapped Byte Buffers.

- Allows currencies to be formatted with locale-specific accounting formats, for example, ($3.27) instead of -$3.27. See Accounting Currency Format Support.

- Enhanced `com.sun.management.OperatingSystemMXBean` to ensure that it reports values based on the current operating environment, such as a container environment. The MXBean for tools to get information on the operating system has been improved for container environments. See OperatingSystemMXBean made container aware.

Experimental, Preview, and Incubator Features

- `Records` is a Java language preview feature, which provides a compact syntax for declaring classes that are transparent holders for shallowly immutable data. See JEP 359: Records (Preview).

- Pattern Matching for `instanceof` is a Java language preview feature that simplifies the `instanceof-and-cast` idiom. See JEP 305: Pattern Matching for instanceof (Preview).

- Text blocks are multi-line string literals that avoids the need for most escape sequences, automatically formats the string in a predictable way, and gives the developer control over the format when desired. Text Blocks were introduced in JDK 13 as a Preview Feature. Text Blocks is being previewed again in JDK 14 with the addition of two new escape sequences. See JEP 368: Text Blocks (Second Preview).

- `jpackage`, a simple tool for packaging self-contained Java applications. See JEP 343: Packaging Tool (Incubator).

- An API that allows Java programs to efficiently access foreign memory outside of the Java heap is introduced. See JEP 370: Foreign-Memory Access API (Incubator).

- The Z Garbage Collector (ZGC), previously available only for Linux, is introduced as an experimental feature on Windows and macOS. See JEP 364: ZGC on macOS and JEP 365: ZGC on Windows.

Removed APIs, Tools, and Components

See:

- APIs Removed in Java SE 14

- Features and Components Removed in JDK 14

In addition, there are security related updates that you need to be aware of. See: Security Updates in JDK 14.

Significant Changes in JDK 13 Release

The following were some of the important enhancements in Java SE 13 and JDK 13:

- Dynamic CDS Archiving extends application class-data sharing (ApsCDS), which allows dynamic archiving of classes when the Java application exits. See JEP 350: Dynamic CDS Archives.

- Text blocks were added to Java language, which provide developers with control over the format when desired. This is a preview language feature. See JEP 355 Text Blocks (Preview) and JEP 12: Preview Language and VM Features.

- The `switch` expression, a preview language feature, was extended to be used as either a statement or an expression, so that both forms can use either traditional labels (with fall through) or new labels (with no fall through). It is used with a further new statement for yielding a value from a `switch` expression. See JEP 354: Switch Expressions (Preview) and JEP 12: Preview Language and VM Features.

- The implementation used by `java.net.Socket` and `java.net.ServerSocket` APIs was replaced with a simpler and more modern implementation that is easy to maintain and debug. See JEP 353: Reimplement the Legacy Socket API.

- Support for Unicode 12.1. See Unicode 12.1.

- ZGC was enhanced to return unused heap memory to the operating system, which enhances the memory footprint of the applications. See JEP 351 ZGC Uncommit Unused Memory.

Significant Changes in JDK 12 Release

The following were some of the important additions and updates in Java SE 12 and JDK 12:

- JVM Constants API was introduced to model nominal descriptions of key class-file and run-time artifacts, in particular constants that were loadable from the constant pool. See JVM Constant API.

- The `switch` statement was extended so that it can be used either as a statement or an expression. This is a preview language feature. See JEP 325: Switch Expressions (Preview) and JEP 12: Preview Language and VM Features.

- Support for Unicode 11.0. See Unicode 11.0.

- Square character support was provided for the Japanese Reiwa Era, which began on May, 2019. See Square character support.

- The `NumberFormat` added support for formatting a number in its compact form. See Compact Number Formatting Support .

Significant Changes in JDK 11 Release

JDK 11 had some significant changes too. As JDK 11 is a long term support (LTS) release, you should be familiar with the following important changes in JDK 11 release:

- Oracle no longer offers JRE and Server JRE downloads; consequently, Auto-Update is not available anymore.

- Java Web Start, Java Plugin, and Java Control Panel are not available in JDK. See Removal of the Deployment Stack.

- JavaFX is no longer included in the JDK. It is now available as a separate download from https://openjfx.io/.

- JAXB and JAX-WS are no longer bundled with JDK. See Removal of Java EE and CORBA Modules.

3
Security Updates

This section provides details on the security updates in JDK releases.

Security Updates in JDK 16

The following are the notable security updates in JDK 16:

- Signed JAR support for RSASSA-PSS and EdDSA
- SUN, SunRsaSign, and SunEC providers support SHA-3-based signature algorithms
- The SunPKCS11 provider now supports SHA-3-related algorithms
- TLS support for the EdDSA signature algorithm

See Release Notes for additional information on security-related changes.

Security Updates in JDK 15

The following are the noteable security updates in JDK 15:

- A new signature scheme Edwards-Curve Digital Signature Algorithm (EdDSA) is implemented, which is a modern elliptic curve signature scheme that has several advantages over the existing signature schemes in the JDK. This new signature scheme does not replace ECDSA. See JEP 339: Edwards-Curve Digital Signature Algorithm (EdDSA).
- SunJCE provider now supports SHA-3 based Hmac algorithms
- New System Properties to Configure the TLS Signature Schemes
- Support the certificate_authorities extension

See Release Notes for additional information on security related changes.

Security Updates in JDK 14

The following are the noteable security updates in JDK 14:

- Exact Match Required for Trusted TLS Server Certificate
- New Checks on Trust Anchor Certificates

See Release Notes for additional information on security related changes.

Security Updates in JDK 13

The following were removed from JDK 13:

- Experimental FIPS 140 compliant mode from SunJSSE provider

- Duplicated RSA services no longer supported by SunJSSE provider

Removal of Security Certificates

The following root certificates were removed from the keystore in JDK 13:

- T-Systems Deutsche Telekom Root CA 2 certificate
- Two DocuSign Root CA certificates
- Two Comodo Root CA certificates

Security Updates in JDK 11 and JDK 12

The following security updates were made in JDK 11 and JDK 12:

The JDK 11 release included an implementation of the Transport Layer Security (TLS) 1.3 specification (RFC 8446).

TLS 1.3 is the latest iteration (August 2018) of the Transport Layer Security (TLS) protocol and is enabled by default in JDK 11. This version focuses not only on speed improvements, but also updates the overall security of the protocol by emphasizing modern cryptography practices, and disallows outdated or weak crypto algorithms. (For example, RSA key exchange and plain DSA signatures are no longer allowed.)

Several features were added to the TLS 1.3 protocol to improve backwards compatibility, but there are several issues of which you need to be aware of. For details, see JEP 332.

Removal of Security Certificates

The following root certificate was removed from the keystore in JDK 12:

- Removal of GTE CyberTrust Global Root

The following root certificates were removed from the truststore in JDK 11:

- Several Symantec Root CAs
- Baltimore Cybertrust Code Signing CA
- SECOM Root Certificate
- AOL and Swisscom root certificates

Products that use certificates that have been removed may no longer work. If these certificates are required, then you must configure and populate the cacerts with the missing certs. To add certs to the truststore, see keytool in *Java Development Kit Tool Specifications* guide.

Security Updates in JDK 9 and JDK 10

Some security-related defaults have changed, starting from JDK 9.

JCE Jurisdiction Policy File Default is Unlimited

If your application previously required the Java Cryptography Extension (JCE) Unlimited Strength Jurisdiction Policy Files, then you no longer need to download or install them. They are included in the JDK and are activated by default.

If your country or usage requires a more restrictive policy, the limited Java cryptographic policy files are still available.

If you have requirements that are not met by either of the policy files provided by default, then you can customize these policy files to meet your needs.

See the `crypto.policy` Security property in the `<java-home>/conf/security/java.security` file, or Cryptographic Strength Configuration in the *Java Platform, Standard Edition Security Developer's Guide*.

You are advised to consult your export/import control counsel or attorney to determine the exact requirements.

Create PKCS12 Keystores

We recommend that you use the PKCS12 format for your keystores. This format, which is the default keystore type, is based on the RSA PKCS12 Personal Information Exchange Syntax Standard.

See Creating a Keystore to Use with JSSE in *Java Platform, Standard Edition Security Developer's Guide* and keytool in *Java Development Kit Tool Specifications*.

4

Removed APIs

This section provides details about Java SE APIs that were removed in JDK 16, JDK 15, JDK 14, JDK 13, JDK 12, and JDK 11 releases.

Run `jdeprscan --release 16 -l --for-removal` to get the list of APIs that are marked for removal in JDK 16.

> **Note:**
>
> The jdeprscan tool is available since JDK 9. If you want to print the list of APIs for a different JDK version, then replace the release number with 9 or later.

API Removed in Java SE 16

Constructor

```
javax.tools.ToolProvider.<init>()
```

APIs Removed in Java SE 15

The following APIs have been removed in Java SE 15.

Fields

```
java.management.rmi.RMIConnectorServer.CREDENTIAL_TYPES
```

Constructors

```
java.lang.invoke.ConstantBootstraps.<init>
    java.lang.reflect.Modifier.<init>
```

APIs Removed in Java SE 14

The following APIs have been removed in Java SE 14.

Packages

```
java.security.acl
```

Interfaces

```
java.security.acl.Acl
java.security.acl.AclEntry
java.security.acl.Group
java.security.acl.Owner
java.security.acl.Permission
java.util.jar.Pack200.Packer
java.util.jar.Pack200.Unpacker
```

Classes

```
java.util.jar.Pack200
```

APIs Removed in Java SE 13

The following APIs were removed in Java SE 13. Both of these APIs were deprecated and marked for removal with JDK 9. Both have been superseded by JVM-specific tracing mechanisms. See JVMTM Tool Interface specification.

```
java.lang.Runtime.traceInstructions(boolean)
java.lang.Runtime.traceMethodCalls(boolean)
```

APIs Removed in Java SE 12

The following APIs were removed in Java SE 12.

```
java.io.FileInputStream.finalize()
java.io.FileOutputStream.finalize()
java.util.zip.Deflater.finalize()
java.util.zip.Inflater.finalize()
java.util.zip.ZipFile.finalize()
```

APIs Removed in JDK 11

The following APIs were removed in JDK 11. Many of these APIs were deprecated in previous releases and have been replaced by newer APIs.

```
javax.security.auth.Policy
java.lang.Runtime.runFinalizersOnExit(boolean)
java.lang.SecurityManager.checkAwtEventQueueAccess()
java.lang.SecurityManager.checkMemberAccess(java.lang.Class,int)
java.lang.SecurityManager.checkSystemClipboardAccess()
java.lang.SecurityManager.checkTopLevelWindow(java.lang.Object)
java.lang.System.runFinalizersOnExit(boolean)
```

```
java.lang.Thread.destroy()
java.lang.Thread.stop(java.lang.Throwable)
```

APIs Removed in JDK 10

The following common DOM APIs were removed in JDK 10.

```
com.sun.java.browser.plugin2.DOM
```

```
sun.plugin.dom.DOMObject
```

APIs Removed JDK 9

The following are some important APIs that have been removed from JDK 10 and JDK 9 releases.

Removed java.* APIs

The Java team is committed to backward compatibility. If an application runs in JDK 8, then it will run on JDK 9 and later releases as long as it uses APIs that are supported and intended for external use.

These include:

- JCP standard, `java.*`, `javax.*`
- JDK-specific APIs, some `com.sun.*`, some `jdk.*`

Supported APIs can be removed from the JDK, but only with notice. Find out if your code is using deprecated APIs by running the static analysis tool jdeprscan.

`java.*` APIs that were removed in JDK 9 include the previously deprecated methods from the `java.util.logging.LogManager` and `java.util.jar.Pack200` packages:

```
java.util.logging.LogManager.addPropertyChangeListener
java.util.logging.LogManager.removePropertyChangeListener
java.util.jar.Pack200.Packer.addPropertyChangeListener
java.util.jar.Pack200.Packer.removePropertyChangeListener
java.util.jar.Pack200.Unpacker.addPropertyChangeListener
java.util.jar.Pack200.Unpacker.removePropertyChangeListener
```

Removal and Future Removal of sun.misc and sun.reflect APIs

Unlike the `java.*` APIs, almost all of the `sun.*` APIs are unsupported, JDK-internal APIs, and may go away at any time.

A few `sun.*` APIs were removed in JDK 9. Notably, `sun.misc.BASE64Encoder` and `sun.misc.BASE64Decoder` were removed. Instead, use the supported `java.util.Base64` class, which was added in JDK 8.

If you use these APIs, you may wish to migrate to their supported replacements:

- `sun.misc.Unsafe`
  The functionality of many of the methods in this class is available by using variable handles, see JEP 193: Variable Handles.
- `sun.reflect.Reflection::getCallerClass(int)`
  Instead, use the stack-walking API, see JEP 259: Stack-Walking API.

See JEP 260: Encapsulate Most Internal APIs.

java.awt.peer Not Accessible

The `java.awt.peer` and `java.awt.dnd.peer` packages aren't accessible, starting in JDK 9. The packages were never part of the Java SE API, despite being in the `java.*` namespace.

All methods in the Java SE API that refer to types defined in these packages were removed from JDK 9. Code that calls a method that previously accepted or returned a type defined in these packages no longer compiles or runs.

There are two common uses of the `java.awt.peer` classes. You should replace them as follows:

- To see if a peer has been set yet:

  ```
  if (component.getPeer() != null) { .. }
  ```

  Replace this with `Component.isDisplayable()` from the JDK 1.1 API:

  ```
  public boolean isDisplayable() {
      return getPeer() != null;
  ```

- To test if a component is lightweight:

  ```
  if (component.getPeer() instanceof LightweightPeer) ..
  ```

  Replace this with `Component.isLightweight()` from the JDK 1.2 API:

  ```
  public boolean isLightweight() {
      return getPeer() instanceof LightweightPeer;
  ```

Removed com.sun.image.codec.jpeg Package

The nonstandard package `com.sun.image.codec.jpeg` has been removed. Use the Java Image I/O API instead.

The `com.sun.image.codec.jpeg` package was added in JDK 1.2 as a nonstandard way of controlling the loading and saving of JPEG format image files. It has never been part of the platform specification.

In JDK 1.4, the Java Image I/O API was added as a standard API, residing in the `javax.imageio` package. It provides a standard mechanism for controlling the loading and saving of sampled image formats and requires all compliant Java SE implementations to support JPEG based on the Java Image I/O specification.

Removed Tools Support for Compact Profiles

Starting in JDK 9, you can choose to build and run your application against any subset of the modules in the Java runtime image, without needing to rely on predefined profiles.

Profiles, introduced in Java SE 8, define subsets of the Java SE Platform API that can reduce the static size of the Java runtime on devices that have limited storage capacity. The tools in JDK 8 support three profiles, `compact1`, `compact2`, and `compact3`. For the API composition of each profile, see Detailed Profile Composition and API Reference in the JDK 8 documentation.

In JDK 8, you use the `-profile` option to specify the profile when running the `javac` and `java` commands. Starting in JDK 9, the `-profile` option is supported by `javac` only in conjunction with the `--release 8` option, and isn't supported by `java`.

JDK 9 and later releases let you choose the modules that are used at compile and run time. By specifying modules with the new `--limit-modules` option, you can obtain the same APIs that are in the compact profiles. This option is supported by both the `javac` and `java` commands, as shown in the following examples:

```
javac --limit-modules java.base,java.logging MyApp.java
```

```
java --limit-modules java.base,java.logging MyApp
```

The packages specified for each profile in Java SE 8 are exported, collectively, by the following sets of modules:

- For the `compact1` profile: `java.base, java.logging, java.scripting`
- For the `compact2` profile: `java.base, java.logging, java.scripting, java.rmi, java.sql, java.xml`
- For the `compact3` profile: `java.base, java.logging, java.scripting, java.rmi, java.sql, java.xml, java.compiler, java.instrument, java.management, java.naming, java.prefs, java.security.jgss, java.security.sasl, java.sql.rowset, java.xml.crypto`

You can use the `jdeps` tool to do a static analysis of the Java packages that are being used in your source code. This gives you the set of modules that you need to execute your application. If you had been using the `compact3` profile, for example, then you may see that you don't need to include that entire set of modules when you build your application. See `jdeps` in *Java Development Kit Tool Specifications*.

See JEP 200: The Modular JDK.

Use CLDR Locale Data by Default

Starting in JDK 9, the Unicode Consortium's Common Locale Data Repository (CLDR) data is enabled as the default locale data, so that you can use standard locale data without any further action.

In JDK 8, although CLDR locale data is bundled with the JRE, it isn't enabled by default.

Code that uses locale-sensitive services such as date, time, and number formatting may produce different results with the CLDR locale data. Remember that even `System.out.printf()` is locale-aware.

To enable behavior compatible with JDK 8, set the system property `java.locale.providers` to a value with `COMPAT` ahead of `CLDR`, for example, `java.locale.providers=COMPAT,CLDR`.

See CLDR Locale Data Enabled by Default in the *Java Platform, Standard Edition Internationalization Guide* and JEP 252: Use CLDR Locale Data by Default.

5
Removed Tools and Components

The following section lists tools and components that are experimental, obsolete, or no longer used and have been removed from the JDK.

Tools and Components Removed in JDK 16

Removal of Experimental Features AOT and Graal JIT

The Java Ahead-of-Time compilation experimental tool `jaotc` and Java-based Graal JIT compiler have been removed. See Removal of experimental features AOT and Graal JIT.

Removed Root Certificates with 1024-bit Keys

The root certificates with weak 1024-bit RSA public keys have been removed from the `cacerts` keystore. For details, see Remove root certificates with 1024-bit keys.

Removal of Legacy Elliptic Curves

The SunEC provider no longer supports the following elliptic curves that were deprecated in JDK 14.

```
secp112r1, secp112r2, secp128r1, secp128r2, secp160k1, secp160r1,
secp160r2,
secp192k1, secp192r1, secp224k1, secp224r1, secp256k1, sect1
```

To continue using any of these curves, find third-party alternatives. See Remove the legacy elliptic curves.

Deprecated Tracing Flags Are Obsolete and Must Be Replaced With Unified Logging Equivalents

When Unified Logging was added in Java 9, several tracing flags were deprecated and mapped to their unified logging equivalent. These flags are now obsolete and you must explicitly replace the use of these flags with their unified logging equivalent.

Obsolete Tracing Flag	Unified Logging Replacement
`-XX:+TraceClassLoading`	`-Xlog:class+load=info`
`-XX:+TraceClassUnloading`	`-Xlog:class+unload=info`
`-XX:+TraceExceptions`	`-Xlog:exceptions=info`

See Obsolete the long term deprecated and aliased Trace flags.

Tools and Components Removed and Deprecated in JDK 15

Removal of Nashorn JavaScript Engine

Nashorn JavaScript script engine and APIs, and the `jjs` tool have been removed in JDK 15. The engine, APIs, and tool were deprecated for removal in Java 11. See JEP 372: Remove the Nashorn JavaScript Engine.

Removal of RMI Static Stub Compiler (rmic) Tool

The RMI static stub compiler (rmic) tool has been removed. The rmic tool was deprecated for removal in JDK 13. See Remove rmic from the set of supported tools.

Disable and Deprecate Biased Locking

The biased locking is disabled by default and all related command-line options have been deprecated. See JEP 374: Disable and Deprecate Biased Locking.

Deprecate RMI Activation for Removal

The RMI Activation mechanism has been deprecated and may be removed in a future version of the platform. See JEP 385: Deprecate RMI Activation for Removal.

Features and Components Removed in JDK 14

Remove the Concurrent Mark Sweep (CMS) Garbage Collector

The CMS garbage collector has been removed. See JEP 363: Remove the Concurrent Mark Sweep (CMS) Garbage Collector.

Removal of Pack200 Tools and API

The Pack200 tools and API were deprecated in JDK 11 and have been removed in JDK 14.

The `pack200` and `unpack200` tools, and `Pack200` in `java.util.jar.Pack200` package have been removed .

See JEP 367: Remove the Pack200 Tools and API.

Tools and Components Removed in JDK 13

Removal of Old Features from `javadoc` Tool

The following four features have been removed from the *javadoc* tool:

- Support for generating API documentation using HTML 4
- Support for the old *javadoc* API
- Support for generating documentation using HTML frames
- Support for the `--no-module-directories` options

For details about removed `javadoc` features, see JDK-8215608 : Remove old javadoc features.

See Removed Features and Options of JDK 13 Release Notes for list of removed tools and components.

Tools and Components Removed in JDK 12

To know more about the tools and components that are removed in JDK 12, see Removed Features and Options in JDK 12.

Tools and Components Removed in JDK 11

Removal of the Deployment Stack

Java deployment technologies were deprecated in JDK 9 and removed in JDK 11.

Java applet and Web Start functionality, including the Java plug-in, the Java Applet Viewer, Java Control Panel, and Java Web Start, along with `javaws` tool, have been removed in JDK 11.

See Remove Java Deployment Technologies.

Removal of Java EE and CORBA Modules

In JDK 11, the Java EE and CORBA modules were removed. These modules were deprecated for removal in JDK 9.

The removed modules were:

- `java.xml.ws`: Java API for XML Web Services (JAX-WS), Web Services Metadata for the Java Platform, and SOAP with Attachments for Java (SAAJ)

- `java.xml.bind`: Java Architecture for XML Binding (JAXB)

- `java.xml.ws.annotation`: The subset of the JSR-250 Common Annotations defined by Java SE to support web services

- `java.corba`: CORBA

- `java.transaction`: The subset of the Java Transaction API defined by Java SE to support CORBA Object Transaction Services

- `java.activation`: JavaBeans Activation Framework

- `java.se.ee`: Aggregator module for the six modules above

- `jdk.xml.ws`: Tools for JAX-WS

- `jdk.xml.bind`: Tools for JAXB

Existing code with references to classes in these APIs will not compile without changes to the build. Similarly, code on the class path with references to classes in these APIs will fail with `NoDefClassFoundError` or `ClassNotFoundException` unless changes are made in how the application is deployed.

See JEP 320: Remove the Java EE and CORBA Modules to get more information about possible replacements for the modules.

> **✎ Note:**
>
> You can download JAXB and JAX-WS from Maven.

Removal of Tools and Components

Main Tools

- `appletviewer`
  See JDK-8200146 : Remove the appletviewer launcher.

CORBA Tools

- `idlj`

- `orbd`

- `servertool`

- `tnamesrv`

In addition, the `rmic` (the RMI compiler) no longer supports the `-idl` or `-iiop` options. See JDK 11 Release Notes.

Java Web Services Tools

- `schemagen`

- `wsgen`

- `wsimport`

- `xjc`

Java Deployment Tools

- `javapackager`

- `javaws`
  See Removal of JavaFX from JDK.

Monitoring Tools

- `jmc`: In JDK 11, JMC is available as a standalone package and not bundled in the JDK.

See Removal of JMC from JDK and Java Mission Control.

JVM-MANAGEMENT-MIB.mib

The specification for JVM monitoring and management through SNMP `JVM-MANAGEMENT-MIB.mib` has been removed. See Removal of JVM-MANAGEMENT-MIB.mib.

SNMP Agent

The `jdk.snmp` module has been removed. See Removal of SNMP Agent.

Oracle Desktop Specific Removals

- Oracle JDK T2K font rasterizer has been removed.

- Lucida Fonts: Oracle JDK no longer ships any fonts and relies entirely on fonts installed on the operating system. See Removal of Lucida Fonts from Oracle JDK.

Tools and Components Removed in JDK 9 and JDK 10

This list includes tools and components that are no longer bundled with the JDK.

Removed Native-Header Generation Tool (javah)

The `javah` tool has been superseded by superior functionality in `javac`. It was removed in JDK 10.

Since JDK 8, `javac` provides the ability to write native header files at the time that Java source code is compiled, thereby eliminating the need for a separate tool.

Instead of `javah`, use

```
javac -h
```

Removed JavaDB

JavaDB, which was a rebranding of Apache Derby, is no longer included in the JDK.

JavaDB was bundled with JDK 7 and JDK 8. It was found in the `db` directory of the JDK installation directory.

You can download and install Apache Derby from Apache Derby Downloads.

Removed the JVM TI hprof Agent

The `hprof` agent library has been removed.

The `hprof` agent was written as demonstration code for the JVM Tool Interface and wasn't intended to be a production tool. The useful features of the `hprof` agent have been superseded by better alternatives, including some that are included in the JDK.

For creating heap dumps in the `hprof` format, use a diagnostic command (`jcmd`) or the `jmap` tool:

- Diagnostic command: `jcmd <pid> GC.heap_dump`. See jcmd.

- jmap: `jmap -dump`. See jmap.

For CPU profiler capabilities, use the Java Flight Recorder, which is bundled with the JDK.

See JEP 240: Remove the JVM TI hprof Agent.

Removed the jhat Tool

The `jhat` tool was an experimental, unsupported heap visualization tool added in JDK 6. Superior heap visualizers and analyzers have been available for many years.

Removed java-rmi.exe and java-rmi.cgi Launchers

The launchers `java-rmi.exe` from Windows and `java-rmi.cgi` from Linux and Solaris have been removed.

`java-rmi.cgi` was in `$JAVA_HOME/bin` on Linux.

`java-rmi.exe` was in `$JAVA_HOME/bin` on Windows.

These launchers were added to the JDK to facilitate use of the RMI CGI proxy mechanism, which was deprecated in JDK 8.

The alternative of using a servlet to proxy RMI over HTTP has been available, and even preferred, for several years. See Java RMI and Object Serialization.

Removed Support for the IIOP Transport from the JMX RMIConnector

The IIOP transport support from the JMX RMI Connector along with its supporting classes have been removed from the JDK.

In JDK 8, support for the IIOP transport was downgraded from required to optional. This was the first step in a multirelease effort to remove support for the IIOP transport from the JMX Remote API. In JDK 9, support for IIOP was removed completely.

Public API changes include:

- The `javax.management.remote.rmi.RMIIIOPServerImpl` class has been deprecated. Upon invocation, all its methods and constructors throw `java.lang.UnsupportedOperationException` with an explanatory message.

- Two classes, `org.omg.stub.javax.management.rmi._RMIConnection_Stub`, and `org.omg.stub.javax.management.rmi._RMIConnection_Tie`, aren't generated.

Dropped Windows 32–bit Client VM

The Windows 32–bit client VM is no longer available. Only a server VM is offered.

JDK 8 and earlier releases offered both a client JVM and a server JVM for Windows 32-bit systems. JDK 9 and later releases offer only a server JVM, which is tuned to maximize peak operating speed.

Removed Java VisualVM

Java VisualVM is a tool that provides information about code running on a Java Virtual Machine. The `jvisualvm` tool was provided with JDK 6, JDK 7, and JDK 8.

Java VisualVM is no longer bundled with the JDK, but you can get it from the VisualVM open source project site.

Removed native2ascii Tool

The `native2ascii` tool has been removed from the JDK. Because JDK 9 and later releases support UTF-8 based properties resource bundles, the conversion tool for UTF-8 based properties resource bundles to ISO-8859-1 is no longer needed.

See UTF-8 Properties Files in *Java Platform, Standard Edition Internationalization Guide*.

6
Preparing For Migration

The following sections will help you successfully migrate your application:

- Download the Latest JDK
- Run Your Program Before Recompiling
- Update Third-Party Libraries
- Compile Your Application if Needed
- Run jdeps on Your Code

Download the Latest JDK

Download and install the latest JDK release from Java SE Downloads.

Run Your Program Before Recompiling

Try running your application on the latest JDK release (JDK 16). Most code and libraries should work on JDK 16 without any changes, but there may be some libraries that need to be upgraded.

> ✎ **Note:**
>
> Migrating is an iterative process. You'll probably find it best to try running your program (this task) first, then complete these three tasks in parallel:
>
> - Update Third-Party Libraries
> - Compile Your Application if Needed
> - Run jdeps on Your Code

When you run your application, look for warnings from the JVM about obsolete VM options. If the VM fails to start, then look for Removed GC Options.

If your application starts successfully, look carefully at your tests and ensure that the behavior is the same as on the JDK version you have been using. For example, a few early adopters have noticed that their dates and currencies are formatted differently. See Use CLDR Locale Data by Default.

To make your code work on the latest JDK release, understand the new features and changes in each of the JDK release.

- For detailed information about the new features and changes in JDK 16, see What's New in JDK 16 - New Features and Enhancements.
- For detailed information about the new features and changes in JDK 15, see What's New in JDK 15 - New Features and Enhancements.

- For detailed information about the new features and changes in JDK 14, see What's New in JDK 14 - New Features and Enhancements.

- For detailed information about the new features and changes in JDK 13, see What's New in JDK 13 - New Features and Enhancements.

- For detailed information about the new features and changes in JDK 12, see What's New in JDK 12 - New Features and Enhancements.

- For detailed information about the new features and changes in JDK 11, see What's New in JDK 11 - New Features and Enhancements.

- For detailed information about the new features and changes in JDK 10, see What's New in JDK 10.

- For a comprehensive list of all of the new features of JDK 9, see What's New in JDK 9.

  For detailed information about the changes in JDK 9, see JDK 9 Release Notes.

Even if your program appears to run successfully, you should complete the rest of the steps in this guide and review the list of issues.

Update Third-Party Libraries

For every tool and third-party library that you use, you may need to have an updated version that supports the latest JDK release.

Check the websites for your third-party libraries and your tool vendors for a version of each library or tool that's designed to work on the latest JDK. If one exists, then download and install the new version.

If you use Maven or Gradle to build your application, then make sure to upgrade to a recent version that supports the latest JDK version.

If you use an IDE to develop your applications, then it might help in migrating the existing code. The NetBeans, Eclipse, and IntelliJ IDEs all have versions available that include support for the latest JDK.

You can see the status of the testing of many Free Open Source Software (FOSS) projects with OpenJDK builds at Quality Outreach on the OpenJDK wiki.

Compile Your Application if Needed

Compiling your code with the latest JDK compiler will ease migration to future releases since the code may depend on APIs and features, which have been identified as problematic. However, it is not strictly necessary.

If you need to compile your code with JDK 11 and later compilers, then take note of the following:

- If you use the underscore character (`"_"`) as a one-character identifier in source code, then your code won't compile in JDK 11 and later releases. It generates a warning in JDK 8, and an error, starting from JDK 9.

  As an example:

  ```
  static Object _ = new Object();
  ```

This code generates the following error message from the compiler:

```
MyClass.java:2: error: as of release 9, '_' is a keyword, and may
not be used as a legal identifier.
```

- If you use the `-source` and `-target` options with `javac`, then check the values that you use.

  The supported `-source/-target` values are 16 (the default), 15, 14, 13, 12, 11, 10, 9, 8, 7, and 6 (6 is deprecated, and a warning is displayed when this value is used).

  In JDK 8, `-source` and `-target` values of 1.5/5 and earlier were deprecated, and caused a warning. In JDK 9 and above, those values cause an error.

  ```
  >javac -source 5 -target 5 Sample.java
  warning: [options] bootstrap class path not set in conjunction with
  -source 5
  error: Source option 5 is no longer supported. Use 6 or later.
  error: Target option 1.5 is no longer supported. Use 1.6 or later.
  ```

  If possible, use the new `--release` flag instead of the `-source` and `-target` options. See javac in *Java Development Kit Tool Specifications*.

  The valid arguments for the `--release` flag follow the same policy as for `-source` and `-target`, one plus three back.

  The `javac` can recognize and process class files of all previous JDKs, going all the way back to JDK 1.0.2 class files.

  See JEP 182: Policy for Retiring javac -source and -target Options.

- Critical internal JDK APIs such as `sun.misc.Unsafe` are still accessible in JDK 11 and later, but most of the JDK's internal APIs are not accessible at compile time. You may get compilation errors that indicate that your application or its libraries are dependent on internal APIs.

  To identify the dependencies, run the Java Dependency Analysis tool. See Run jdeps on Your Code. If possible, update your code to use the supported replacement APIs.

  You may use the `--add-exports` option as a temporary workaround to compile source code with references to JDK internal classes.

- You may see more deprecation warnings than previously.

Run jdeps on Your Code

Run the `jdeps` tool on your application to see what packages and classes your applications and libraries depend on. If you use internal APIs, then `jdeps` may suggest replacements to help you to update your code.

To look for dependencies on internal JDK APIs, run `jdeps` with the `-jdkinternals` option. For example, if you run `jdeps` on a class that calls `sun.misc.BASE64Encoder`, you'll see:

```
>jdeps -jdkinternals Sample.class
Sample.class -> JDK removed internal API
```

```
    Sample  -> sun.misc.BASE64Encoder  JDK internal API (JDK removed
internal API)


Warning: JDK internal APIs are unsupported and private to JDK
implementation that are
subject to be removed or changed incompatibly and could break your
application.
Please modify your code to eliminate dependency on any JDK internal
APIs.
For the most recent update on JDK internal API replacements, please
check:
https://wiki.openjdk.java.net/display/JDK8/Java+Dependency+Analysis+Tool


JDK Internal API                       Suggested Replacement
----------------                       --------------------
sun.misc.BASE64Encoder                 Use java.util.Base64 @since 1.8
```

If you use Maven, there's a `jdeps` plugin available.

For `jdeps` syntax, see jdeps in the *Java Development Kit Tool Specifications*.

Keep in mind that `jdeps` is a static analysis tool, and static analysis of code might not provide a complete list of dependencies. If the code uses reflection to call an internal API, then `jdeps` doesn't warn you.

7

Migrating From JDK 8 to Later JDK Releases

There were significant changes made between the JDK 8 and later JDK releases.

Every new Java SE release introduces some binary, source, and behavioral incompatibilities with previous releases. The modularization of the Java SE Platform that happened in JDK 9 and later brought many benefits, but also many changes. Code that uses only official Java SE Platform APIs and supported JDK-specific APIs should continue to work without change. Code that uses JDK-internal APIs should continue to run but should be migrated to use the supported APIs.

Some APIs that have been made inaccessible, removed, or altered in their default behavior. You might encounter issues when compiling or running your application. See Removed Tools and Components and Security Updates.

The following sections describe the changes in the JDK package that you should be aware of when migrating your JDK 8 applications to later JDK releases.

Look at the list of changes that you may encounter as you run your application.

- Illegal Reflective Access
- New Version-String Scheme
- Changes to the Installed JDK/JRE Image
- Deployment
- Changes to Garbage Collection

When your application is running successfully on the latest version of JDK, review Next Steps, which will help you avoid problems with future releases.

Illegal Reflective Access

Some tools and libraries use reflection to access parts of the JDK that are meant for internal use only. This is called illegal reflective access and by default is not permitted in JDK 16 and later.

The following examples demonstrate the potential impact of the change:

- Code successfully compiled with earlier releases that directly accesses internal APIs of the JDK will no longer work by default. For example:

  ```
  System.out.println(sun.security.util.SecurityConstants.ALL_PERMISSIO
  N);
  ```

  The compiler will generate an `IllegalAccessError`, and the code will throw an `InaccessibileObjectException`.

- Code that uses reflection to access `private` fields of exported `java.*` APIs will no longer work by default. For example:

```
var ks = java.security.KeyStore.getInstance("jceks");
var f = ks.getClass().getDeclaredField("keyStoreSpi");
f.setAccessible(true);
```

  The code will throw an `InaccessibileObjectException`.

- Code that uses reflection to access `protected` methods of exported `java.*` APIs will no longer work by default. For example:

```
var dc = ClassLoader.class.getDeclaredMethod("defineClass",
                                             String.class,
                                             byte[].class,
                                             int.class,
                                             int.class);
dc.setAccessible(true);
```

  The code will throw an `InaccessibileObjectException`.

The `java` launcher option `--illegal-access` controls relaxed strong encapsulation. The default value of this option is `--illegal-access=deny`, which disables illegal access operations.

As a temporary solution, specify either the `--illegal-access=permit` or `--illegal-access=warn` option to continue to perform illegal access operations. To obtain detailed information about illegal reflective-access operations, including stack traces, specify the `--illegal-access=debug` option.

There are two options that enable you to break encapsulation (most internal APIs are encapsulated) in specific ways. You could use these in combination with the `--illegal-access` command-line option.

- If you need to use an internal API that has been made inaccessible, then use the `--add-exports` runtime option. You can also use `--add-exports` at compile time to access internal APIs.

- If you have to allow code on the class path to do *deep reflection* to access nonpublic members, then use the `--add-opens` option.

If you want to suppress all reflective access warnings, then use the `--add-exports` and `--add-opens` options where needed.

--add-exports

If you must use an internal API that has been made inaccessible by default, then you can break encapsulation using the `--add-exports` command-line option.

The syntax of the `--add-exports` option is:

```
--add-exports <source-module>/<package>=<target-module>(,<target-
module>)*
```

where `<source-module>` and `<target-module>` are module names and `<package>` is the name of a package.

The `--add-exports` option allows code in the target module to access types in the named package of the source module if the target module reads the source module.

As a special case, if the `<target-module>` is `ALL-UNNAMED`, then the source package is exported to all unnamed modules, whether they exist initially or are created later on. For example:

```
--add-exports java.management/sun.management=ALL-UNNAMED
```

This example allows code in all unnamed modules (code on the class path) to access the public members of public types in `java.management/sun.management`. If the code on the class path attempts to do *deep reflection* to access nonpublic members, then the code fails.

If an application `oldApp` that runs on the classpath must use the unexported `com.sun.jmx.remote.internal` package of the `java.management` module, then the access that it requires can be granted in this way:

```
--add-exports java.management/com.sun.jmx.remote.internal=ALL-UNNAMED
```

You can also break encapsulation with the JAR file manifest:

```
Add-Exports:java.management/sun.management
```

Use the `--add-exports` option carefully. You can use it to gain access to an internal API of a library module, or even of the JDK itself, but you do so at your own risk. If that internal API changes or is removed, then your library or application fails.

See also JEP 261.

--add-opens

If you have to allow code on the class path to do *deep reflection* to access nonpublic members, then use the `--add-opens` runtime option.

Some libraries do deep reflection, meaning `setAccessible(true)`, so they can access all members, including private ones. You can grant this access using the `--add-opens` option on the `java` command line. No warning messages are generated as a result of using this option.

If `--illegal-access=`**deny**, and you see `IllegalAccessException` or `InaccessibleObjectException` messages at runtime, you could use the `--add-opens` runtime option, basing the arguments upon the information shown in the exception message.

The syntax for `--add-opens` is:

```
--add-opens module/package=target-module(,target-module)*
```

This option allows `<module>` to open `<package>` to `<target-module>`, regardless of the module declaration.

ORACLE

As a special case, if the `<target-module>` is `ALL-UNNAMED`, then the source package is exported to all unnamed modules, whether they exist initially or are created later on. For example:

```
--add-opens java.management/sun.management=ALL-UNNAMED
```

This example allows all of the code on the class path to access nonpublic members of public types in the `java.management/sun.management` package.

> **✎ Note:**
>
> If you are using the JNI Invocation API, including, for example, a Java Web Start JNLP file, you must include an equals sign between `--add-opens` and its value.
>
> ```
> <j2se version="10" java-vm-args="--add-opens=module/
> package=ALL-UNNAMED"  />
> ```
>
> The equals sign between `--add-opens` and its value is optional on the command line.

New Version-String Scheme

JDK 10 introduced some minor changes, to better accommodate the time-based release model, to the version-string scheme introduced in JDK 9. JDK 11 and later retains the version string format that was introduced in JDK 10.

If your code relies on the version-string format to distinguish major, minor, security, and patch update releases, then you may need to update it.

The format of the new version-string is:

`$FEATURE.$INTERIM.$UPDATE.$PATCH`

A simple Java API to parse, validate, and compare version strings has been added. See `java.lang.Runtime.Version`.

See Version String Format in *Java Platform, Standard Edition Installation Guide* .

For the changes to the version string introduced in JDK 9, see JEP 223: New Version-String Scheme .

For the version string changes introduced in JDK 10, see JEP 322: Time-Based Release Versioning.

Changes to the Installed JDK/JRE Image

Significant changes have been made to the JDK and JRE.

Changed JDK and JRE Layout

After you install the JDK, if you look at the file system, you'll notice that the directory layout is different from that of releases before JDK 9.

JDK 11 and Later

JDK 11 and later does not have the JRE image. See Installed Directory Structure of JDK in *Java Platform, Standard Edition Installation Guide*.

JDK 9 and JDK 10

Prior releases had two types of runtime images: the JRE, which was a complete implementation of the Java SE Platform, and the JDK, which included the entire JRE in a `jre/` directory, plus development tools and libraries.

In JDK 9 and and JDK 10, the JDK and JRE are two types of modular runtime images containing the following directories:

- **`bin`**: contains binary executables.
- **`conf`**: contains `.properties`, `.policy`, and other kinds of files intended to be edited by developers, deployers, and end users. These files were formerly found in the `lib` directory or its subdirectories.
- **`lib`**: contains dynamically linked libraries and the complete internal implementation of the JDK.

In JDK 9 and JDK 10, there are still separate JDK and JRE downloads, but each has the same directory structure. The JDK image contains the extra tools and libraries that have historically been found in the JDK. There are no `jdk/` versus `jre/` wrapper directories, and binaries (such as the `java` command) aren't duplicated.

See JEP 220: Modular Run-Time Images.

New Class Loader Implementations

JDK 9 and later releases maintain the hierarchy of class loaders that existed since the 1.2 release. However, the following changes have been made to implement the module system:

- The application class loader is no longer an instance of `URLClassLoader` but, rather, of an internal class. It is the default loader for classes in modules that are neither Java SE nor JDK modules.

- The extension class loader has been renamed; it is now the platform class loader. All classes in the Java SE Platform are guaranteed to be visible through the platform class loader.

  Just because a class is visible through the platform class loader does not mean the class is actually defined by the platform class loader. Some classes in the Java SE Platform are defined by the platform class loader while others are defined by the bootstrap class loader. Applications should not depend on which class loader defines which platform class.

  The changes that were implemented in JDK 9 may impact code that creates class loaders with `null` (that is, the bootstrap class loader) as the parent class loader and assumes that all platform classes are visible to the parent. Such code

may need to be changed to use the platform class loader as the parent (see `ClassLoader.getPlatformClassLoader`).

The platform class loader is not an instance of `URLClassLoader`, but, rather, of an internal class.

- The bootstrap class loader is still built-in to the Java Virtual Machine and represented by `null` in the `ClassLoader` API. It defines the classes in a handful of critical modules, such as `java.base`. As a result, it defines far fewer classes than in JDK 8, so applications that are deployed with `-Xbootclasspath/a` or that create class loaders with `null` as the parent may need to change as described previously.

Removed rt.jar and tools.jar

Class and resource files previously stored in `lib/rt.jar`, `lib/tools.jar`, `lib/dt.jar` and various other internal JAR files are stored in a more efficient format in implementation-specific files in the `lib` directory.

The removal of `rt.jar` and similar files leads to issues in these areas:

- Starting from JDK 9, `ClassLoader.getSystemResource` doesn't return a URL pointing to a JAR file (because there are no JAR files). Instead, it returns a `jrt` URL, which names the modules, classes, and resources stored in a runtime image without revealing the internal structure or format of the image.

  For example:

  ```
  ClassLoader.getSystemResource("java/lang/Class.class");
  ```

  When run on JDK 8, this method returns a JAR URL of the form:

  ```
  jar:file:/usr/local/jdk8/jre/lib/rt.jar!/java/lang/Class.class
  ```

  which embeds a file URL to name the actual JAR file within the runtime image.

  A modular image doesn't contain any JAR files, so URLs of this form make no sense. On JDK 9 and later releases, this method returns:

  ```
  jrt:/java.base/java/lang/Class.class
  ```

- The `java.security.CodeSource` API and security policy files use URLs to name the locations of code bases that are to be granted specific permissions. See Policy File Syntax in *Java Platform, Standard Edition Security Developer's Guide*. Components of the runtime system that require specific permissions are currently identified in the `conf/security/java.policy` file by using file URLs.

- Older versions of IDEs and other development tools require the ability to enumerate the class and resource files stored in a runtime image, and to read their contents directly by opening and reading `rt.jar` and similar files. This isn't possible with a modular image.

Removed Extension Mechanism

In JDK 8 and earlier, the extension mechanism made it possible for the runtime environment to find and load extension classes without specifically naming them on the class path. Starting from JDK 9, if you need to use the extension classes, ensure that the JAR files are on the class path.

In JDK 9 and JDK 10, the `javac` compiler and `java` launcher will exit if the `java.ext.dirs` system property is set, or if the `lib/ext` directory exists. To additionally check the platform-specific systemwide directory, specify the `-XX:+CheckEndorsedAndExtDirs` command-line option. This causes the same exit behavior to occur if the directory exists and isn't empty. The extension class loader is retained in JDK 9 (and later releases) and is specified as the platform class loader (see `getPlatformClassLoader`.) However, in JDK 11, this option is obsolete and a warning is issued when it is used.

The following error means that your system is configured to use the extension mechanism:

```
<JAVA_HOME>/lib/ext exists, extensions mechanism no longer supported;
Use -classpath instead.
.Error: Could not create the Java Virtual Machine.
Error: A fatal exception has occurred. Program will exit.
```

You'll see a similar error if the `java.ext.dirs` system property is set.

To fix this error, remove the `ext/` directory or the `java.ext.dirs` system property.

See JEP 220: Modular Run-Time Images.

Removed Endorsed Standards Override Mechanism

The `java.endorsed.dirs` system property and the `lib/endorsed` directory are no longer present. The `javac` compiler and `java` launcher will exit if either one is detected.

Starting from JDK 9, you can use upgradeable modules or put the JAR files on the class path.

This mechanism was intended for application servers to override components used in the JDK. Packages to be updated would be placed into JAR files, and the system property `java.endorsed.dirs` would tell the Java runtime environment where to find them. If a value for this property wasn't specified, then the default of `$JAVA_HOME/lib/endorsed` was used.

In JDK 8, you can use the `-XX:+CheckEndorsedAndExtDirs` command-line argument to check for such directories anywhere on the system.

In JDK 9 and later releases, the `javac` compiler and `java` launcher will exit if the `java.endorsed.dirs` system property is set, or if the `lib/endorsed` directory exists.

The following error means that your system is configured to use the endorsed standards override mechanism:

```
<JAVA_HOME>/lib/endorsed is not supported. Endorsed standards and
standalone APIs
```

```
in modular form will be supported via the concept of upgradeable
modules.
Error: Could not create the Java Virtual Machine.
Error: A fatal exception has occurred. Program will exit.
```

You'll see a similar error if the `java.endorsed.dirs` system property is set.

To fix this error, remove the `lib/endorsed` directory, or unset the `java.endorsed.dirs` system property.

See JEP 220: Modular Run-Time Images.

Removed macOS-Specific Features

This section includes macOS-specific features that have been removed, starting in JDK 9.

Platform-Specific Desktop Features

The `java.awt.Desktop` class contains replacements for the APIs in the Apple–specific `com.apple.eawt` and `com.apple.eio` packages. The new APIs supersede the macOS APIs and are platform-independent.

The APIs in the `com.apple.eawt` and `com.apple.eio` packages are encapsulated, so you won't be able to compile against them in JDK 9 or later releases. However, they remain accessible at runtime, so existing code that is compiled to old versions continues to run. Eventually, libraries or applications that use the internal classes in the `apple` and `com.apple` packages and their subpackages will need to migrate to the new API.

The `com.apple.concurrent` and `apple.applescript` packages are removed without any replacement.

See JEP 272: Platform-Specific Desktop Features.

Removed AppleScript Engine

The AppleScript engine, a platform-specific `javax.script` implementation, has been removed without any replacement in the JDK.

The AppleScript engine has been mostly unusable in recent releases. The functionality worked only in JDK 7 or JDK 8 on systems that already had Apple's version of the `AppleScriptEngine.jar` file on the system.

Windows Registry Key Changes

The Java 11 and later installer creates Windows registry keys when installing the JDK. For JDK 16, the installer creates the following Windows registry keys:

- `"HKEY_LOCAL_MACHINE\SOFTWARE\JavaSoft\JDK"`

- `"HKEY_LOCAL_MACHINE\SOFTWARE\JavaSoft\JDK\16"`

If two versions of the JDK are installed, then two different Windows registry keys are created. For example, if JDK 15.0.1 is installed with JDK 16, then the installer creates the another Windows registry key as shown:

- `"HKEY_LOCAL_MACHINE\SOFTWARE\JavaSoft\JDK"`

- `"HKEY_LOCAL_MACHINE\SOFTWARE\JavaSoft\JDK\16"`

- `"HKEY_LOCAL_MACHINE\SOFTWARE\JavaSoft\JDK\15.0.1"`

Deployment

Java deployment technologies were deprecated in JDK 9 and removed in JDK 11.

Use the `jlink` tool introduced with JDK 9 to package and deploy dedicated runtimes rather than relying on a pre-installed system JRE.

Removed Launch-Time JRE Version Selection

The ability to request a version of the JRE that isn't the JRE being launched at launch time is removed, starting in JDK 9.

Modern applications are typically deployed using Java Web Start (JNLP), native OS packaging systems, or active installers. These technologies have their own methods to manage the JREs needed, by finding or downloading and updating the required JRE, as needed. This makes the launcher's launch-time JRE version selection obsolete.

In the previous releases, you could specify what JRE version (or range of versions) to use when starting an application. Version selection was possible through both a command-line option and manifest entry in the application's JAR file.

Starting in JDK 9, the `java` launcher is modified as follows:

- Emits an error message and exits if the `-version:` option is given on the command line.

- Emits a warning message and continues if the `JRE-Version` manifest entry is found in a JAR file.

See JEP 231: Remove Launch-Time JRE Version Selection.

Removed Support for Serialized Applets

Starting in JDK 9, the ability to deploy an applet as a serialized object isn't supported. With modern compression and JVM performance, there's no benefit to deploying an applet in this way.

The `object` attribute of the `applet` tag and the `object` and `java object` applet parameter tags are ignored when starting applet.

Instead of serializing applets, use standard deployment strategies.

JNLP Specification Update

JNLP (Java Network Launch Protocol) has been updated to remove inconsistencies, make code maintenance easier, and enhance security.

JNLP has been updated as follows:

1. `&` instead of `&` in JNLP files.
   The JNLP file syntax conforms to the XML specification and all JNLP files should
   be able to be parsed by standard XML parsers.

   JNLP files let you specify complex comparisons. Previously, this was done by
   using the ampersand (`&`), but this isn't supported in standard XML. If you're using `&`
   to create complex comparisons, then replace it with `&` in your JNLP file. `&`
   is compatible with all versions of JNLP.

2. Comparing numeric version element types against nonnumeric version element
   types.

   Previously, when an `int` version element was compared with another version
   element that couldn't be parsed as an `int`, the version elements were compared
   lexicographically by ASCII value.

   Starting in JDK 9, if the element that can be parsed as an `int` is a shorter string
   than the other element, it will be padded with leading zeros before being compared
   lexicographically by ASCII value. This ensures there can be no circularity.

   In the case where both version comparisons and a JNLP servlet are used, you
   should use only numeric values to represent versions.

3. Component extensions with nested resources in `java` (or `j2se`) elements.
   This is permitted in the specification. It was previously supported, but this support
   wasn't reflected in the specification.

4. FX XML extension.
   The JNLP specification has been enhanced to add a `type` attribute to
   `application-desc` element, and add the subelement `param` in `application-desc`
   (as it already is in `applet-desc`).

   This doesn't cause problems with existing applications because the previous way
   of specifying a JavaFX application is still supported.

   See the JNLP specification updates at JSR-056.

Changes to Garbage Collection

This section describes changes to garbage collection starting in JDK 9.

Make G1 the Default Garbage Collector

The Garbage-First Garbage Collector (G1 GC) is the default garbage collector in JDK
9 and later releases.

A low-pause collector such as G1 GC should provide a better overall experience, for
most users, than a throughput-oriented collector such as the Parallel GC, which is the
JDK 8 default.

See Ergonomic Defaults for G1 GC and Tunable Defaults in *Java Platform, Standard
Edition HotSpot Virtual Machine Garbage Collection Tuning Guide* for more information
about tuning G1 GC.

Removed GC Options

The following GC combinations will cause your application to fail to start in JDK 9 and
later releases:

- `DefNew + CMS`

- `ParNew + SerialOld`

- `Incremental CMS`

The foreground mode for CMS has also been removed. The command-line flags that were removed are `-Xincgc`, `-XX:+CMSIncrementalMode`, `-XX:+UseCMSCompactAtFullCollection`, `-XX:+CMSFullGCsBeforeCompaction`, and `-XX:+UseCMSCollectionPassing`.

The command-line flag `-XX:+UseParNewGC` no longer has an effect. The `ParNew` flag can be used only with CMS and CMS requires `ParNew`. Thus, the `-XX:+UseParNewGC` flag has been deprecated and is eligible for removal in a future release.

See JEP 214: Remove GC Combinations Deprecated in JDK 8.

Removed Permanent Generation

The permanent generation was removed in JDK 8, and the related VM options cause a warning to be printed. You should remove these options from your scripts:

- `-XX:MaxPermSize=`*size*

- `-XX:PermSize=`*size*

In JDK 9 and later releases, the JVM displays a warning like this:

```
Java HotSpot(TM) 64-Bit Server VM warning: Ignoring option MaxPermSize;
support was removed in 8.0
```

Tools that are aware of the permanent generation may have to be updated.

See JEP 122: Remove the Permanent Generation and JDK 9 Release Notes - Removed APIs, Features, and Options .

Changes to GC Log Output

Garbage collection (GC) logging uses the JVM unified logging framework, and there are some differences between the new and the old logs. Any GC log parsers that you're working with will probably need to change.

You may also need to update your JVM logging options. All GC-related logging should use the `gc` tag (for example, `−Xlog:gc`), usually in combination with other tags. The `−XX:+PrintGCDetails` and `-XX:+PrintGC` options have been deprecated.

See Enable Logging with the JVM Unified Logging Framework in the *Java Development Kit Tool Specifications* and JEP 271: Unified GC Logging.

8
Next Steps

After you have your application working on JDK 16, here are some suggestions that can help you get the most from the Java SE Platform:

- Cross-compile to an older release of the platform using the new `--release` flag in the `javac` tool, if required.

- Take advantage of your IDE's suggestions for updating your code with the latest features.

- Find out if your code is using deprecated APIs by running the static analysis tool `jdeprscan`. As already mentioned in this guide, APIs can be removed from the JDK, but only with advance notice.

- Get familiar with new features like multi-release JAR files (see `jar`).