The Java Security Architecture: *How?* and *Why?*

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DM-0001401

Outline

- Introduction
- The Security Manager
- Policy
- Permissions
- Confused Deputy Problem
- doPrivileged()
- Reduced Security Checks
- Summary

Documentation

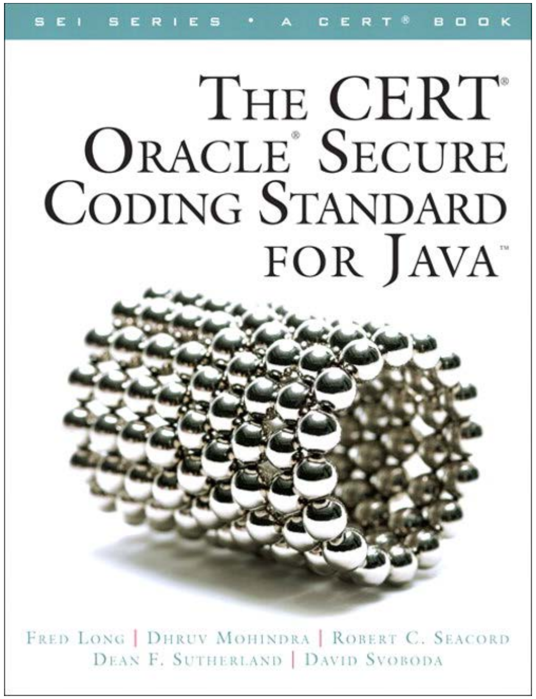
The Java™ Tutorials
http://docs.oracle.com/javase/tutorial
Esp. Trail: **Security Features in Java SE**

The Java™ API Documentation
http://docs.oracle.com/javase/7/docs/api/

Secure Coding Guidelines for the Java Programming Language, Version 4.0

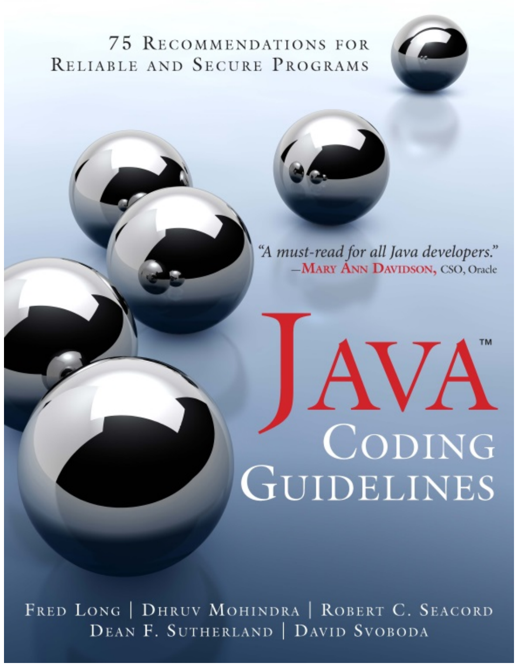
http://www.oracle.com/technetwork/java/seccodeguide-139067.html
Esp. Chapter 9: **Access Control**

CERT Java Documentation



The CERT™ Oracle™ Secure Coding Standard for Java
by Fred Long, Dhruv Mohindra, Robert C. Seacord, Dean F. Sutherland, David Svoboda

Rules available online at
www.securecoding.cert.org



Java Coding Guidelines
by Fred Long, Dhruv Mohindra, Robert C. Seacord, Dean F. Sutherland, David Svoboda

Privilege System

Integrated with a larger system

Delegation of authority

Java privilege system

Grants different privileges to different code segments in the same program

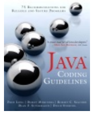
Other examples:

- UNIX privileges and permissions
- Windows NT-based privileges
- Android Permission System

Design: Privilege Separation

Privilege Separation

- Each component possesses the *minimum* privileges required for it to function
- Consequence: component cannot perform *other* privileged operations
  - Limits impact of errors and of successful attacks

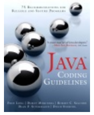


16. Avoid granting excess privileges

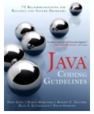
Design: Privilege Minimization

Privilege Minimization

- Privileges are *disabled* most of the time
- Privileges are enabled only when required
- Consequences:
  - Reduces amount of privileged code
    - Easier to get it right
    - Reduces cost of review
  - Temporally limits certain attack opportunities



17. Minimize privileged code



19. Define custom security permissions for fine-grained security

Design: Distrustful Decomposition

Distrustful Decomposition

- Components have limited trust in each other
  - Similar to compartmentalized security
- Consequence: Must manage interactions between differently privileged components with care
  - Canonicalize, sanitize, normalize, and validate inputs
    - Goal: Limit potential attacks
  - Sanitize outputs
    - Goal: Prevent information and capability leaks

A method with certain privileges may be invoked by another method that lacks those privileges. Should the first method proceed?

Usage

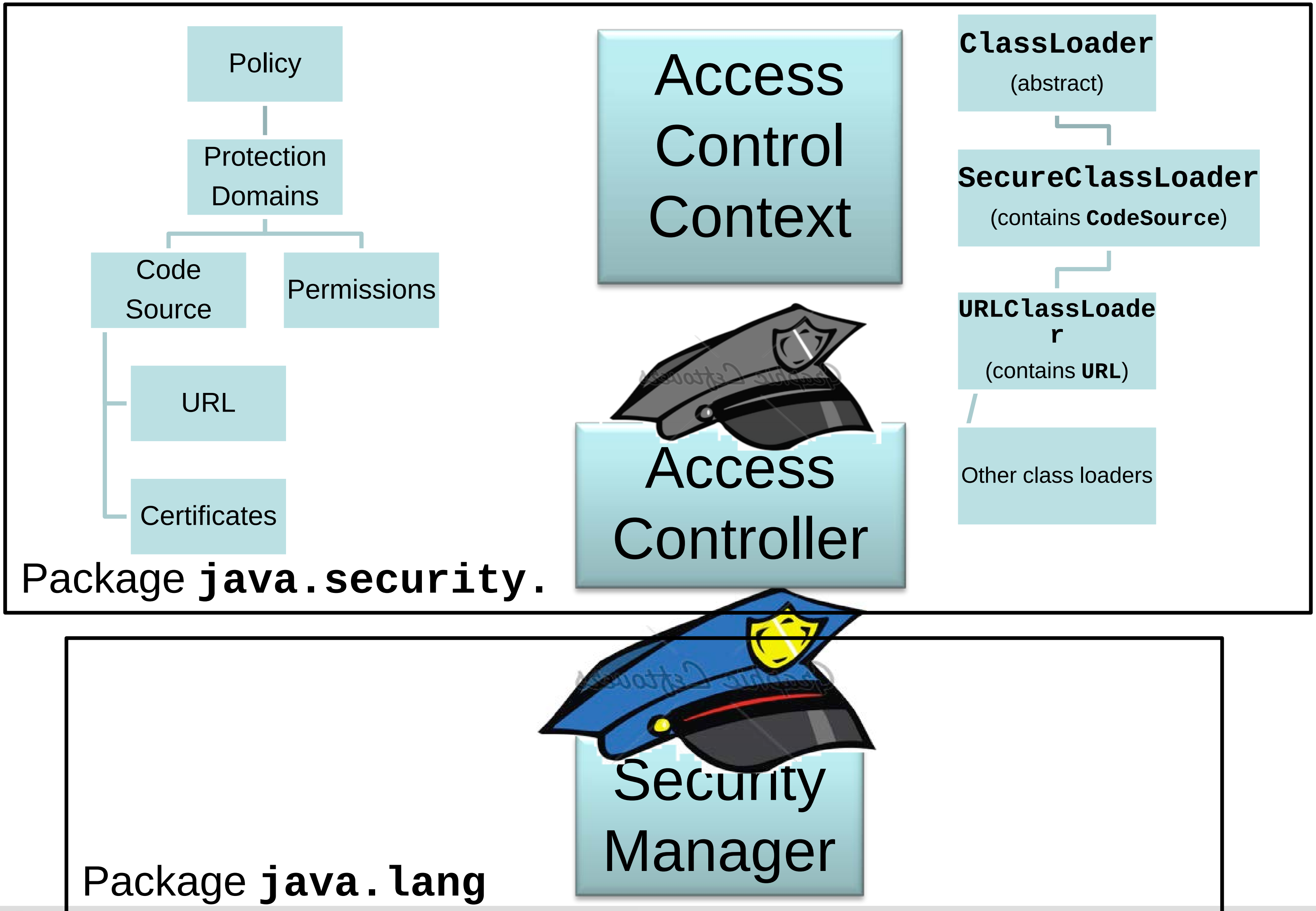
Java’s privilege model is used in

- Applets
- Java Web Start (JWS) applets
- Servlets
  - Tomcat
  - Jetty
- Application servers
  - WebSphere
  - Jboss/WildFly

In Java’s privilege model

- Execution of untrusted code is permitted
- Untrusted code unaware of restrictions
  - Doesn’t need to know Security API

Cast of Characters



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SecurityManager

Class in **java.lang**

- Public interface to Java's security model
- Enforces a security policy
- Provides many **check*()** methods

Each **check*()** method checks to see if the calling program is permitted to perform some action.

- If permitted, **check*()** returns silently
- Otherwise, throws a **SecurityException**

System.SecurityManager 1

Static field in the **`java.lang.System`** class

Indicates the **`SecurityManager`** that is currently in effect (any **`SecurityManager`** object that is not the “system security manager” is ignored)

Can be unset (null)

Managed by static getter/setter methods:

- **`System.getSecurityManager()`**
- **`System.setSecurityManager(SecurityManager s)`**

System.SecurityManager 2

Applets run with the default system security manager

Applications can be run with no security manager

```
java App.java
```

But they can be explicitly run with the default security manager

```
java -Djava.security.manager  App.java
```

or a custom security manager

```
java -Djava.security.manager=MySecMgr \
     App.java
```

System.SecurityManager 3

Any method that performs privileged operations should first make sure its calling program is permitted to execute these operations

```
System.getSecurityManager().check*();
```

Don’t forget to check the system security manager for null first!

Most methods assume that if system security manager is null, all operations are permitted

Example: `FileInputStream`

```
public FileInputStream(File file)
    throws FileNotFoundException {
  String name = (file != null ? file.getPath() : null);
  SecurityManager security =
      System.getSecurityManager();
  if (security != null) {
    security.checkRead(name);
  }
  if (name == null) {
    throw new NullPointerException();
  }
  fd = new FileDescriptor();
  fd.incrementAndGetUseCount();
  open(name);
}
```

Permitted if no system security manager present

Security check before open

Sensitive Operations

- Open a file
- Open a network socket
- Create a new window
- Read a system property
- Write a system property
- Change or remove the system security manager
- Load native libraries
- Load new Java code
- Access classes in certain packages (eg **`sun.*`**)

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Policy 1

Indicates what a program is allowed to do

Enforced by the security manager

Only one policy object in effect; it is returned by

```
java.security.Policy.getPolicy()
```

Policy 2

All applets and applications run with the default policy, which is very restrictive

The policy is ignored, however, if no security manager is installed

An application can be run with a custom policy:

```
java -Djava.security.manager  \
     -Djava.security.policy=my.policy \
     Application.java
```

Default Policy File

```
// Standard extensions get all permissions by default
grant codeBase "file:${{java.ext.dirs}}/*" {
        permission java.security.AllPermission;
};
grant codeBase "file:/usr/lib/jvm/
                                java-7-openjdk-common/jre/lib/ext/*“ {
        permission java.security.AllPermission;
};
…

grant {
…
   // allows anyone to listen on un-privileged ports
   permission java.net                         ost:1024-", "listen";

   // "standard" prope                          nyone
   permission java.uti                          .version", "read";
   permission java.uti                          .vendor", "read";
…
};
```

Grants all permissions to all paths containing core Java libraries and extensions

Some other properties that all code can read:

- **`os.version`**
- **`file.separator`**
- **`path.separator`**
- **`line.separator`**

Default Policy

Permissions that the default policy did NOT grant (except to core libraries):

- Access to the filesystem
- Open a network socket on a privileged port (<1024)
- Access certain system properties
  - **`java.class.path`**
  - **`java.home`**
  - **`user.dir`**
  - **`user.home`**
  - **`user.name`**
- Change or remove the system security manager
- Load new Java code
- Access classes in certain packages (e.g., **`sun.*`**)

Applet Policy

Remote applets can do the following:

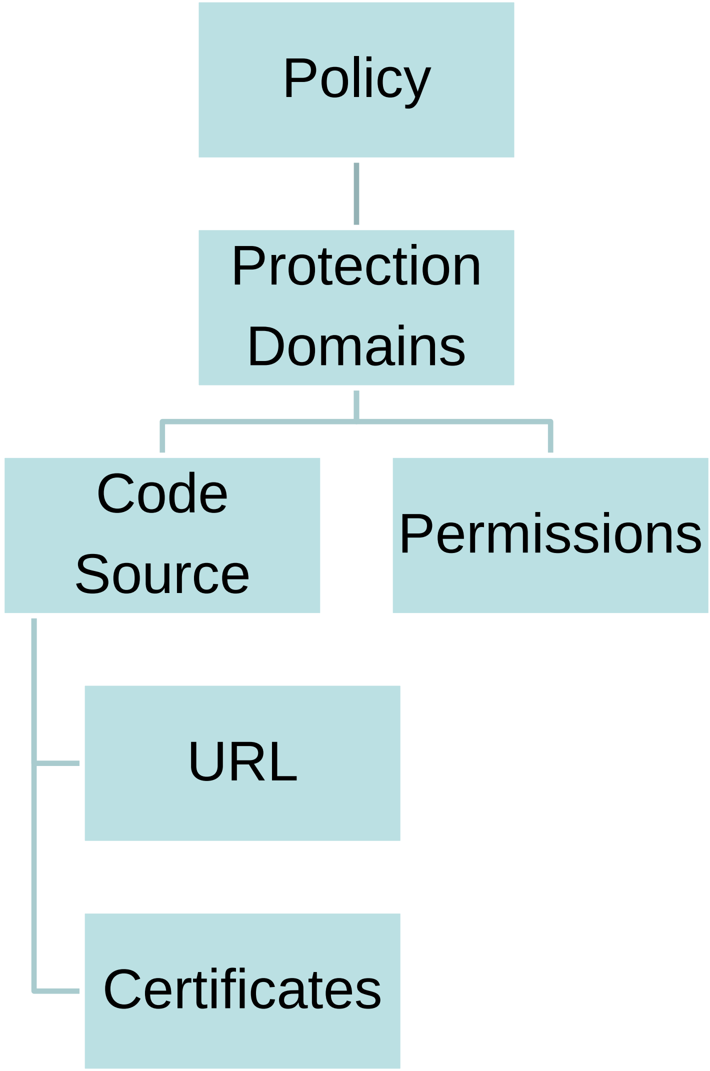
- Open a network socket to their origin host (e.g., *phone home*)
- Access public methods of other active applets

But they can't do the following:

- Access the filesystem
- Open a network socket anywhere besides their origin
- Load native libraries
- Create a **`ClassLoader`**

Local applets and Web Start apps have fewer restrictions

Policy Contents



ProtectionDomain

Used to partition the components of a program into differing levels of security

A policy contains a set of protection domains

Each protection domain contains

- Code source
- Permissions

CodeSource

Used in a protection domain (which is part of a security policy) to indicate where code originates

A code source contains

- URL indicating where the code originated
- List of certificates indicating who vouches for the code
  - Could be empty

Class Loaders

Responsible for loading all classes needed by the program

All class loaders inherit from **`java.lang.ClassLoader`**

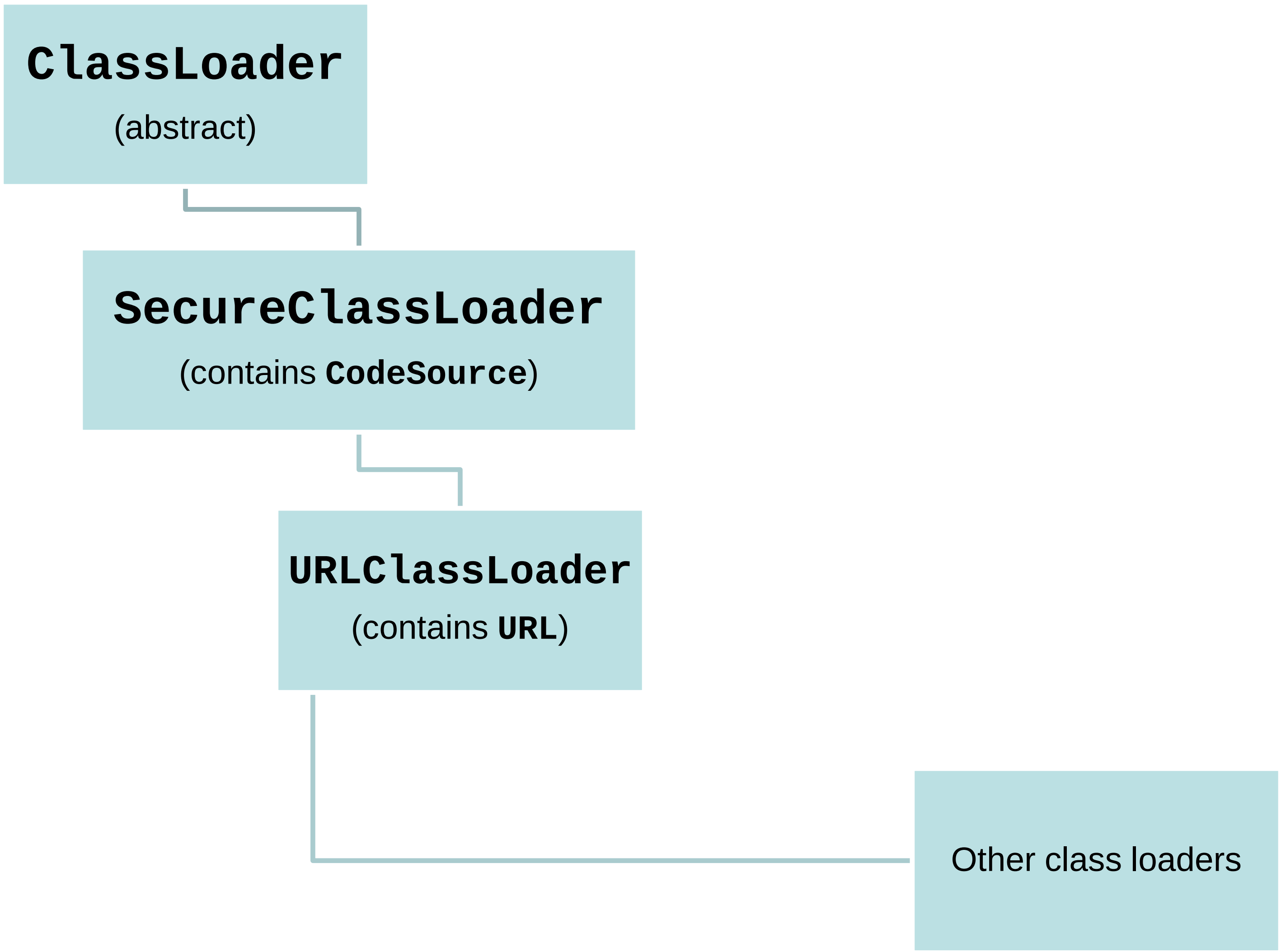
Every object can access its class using
`Object.getClass()`

Every class can access its class loader using
`Class.getClassLoader()`

Since every class loader is itself a class, it has its own class loader, so class loaders have a “loading tree”

Class loaders also have an inheritance tree with **`java.lang.ClassLoader`** at the root

Class Loader Inheritance



Class Loaders

Application and applet class loaders inherit from **`URLClassLoader`**

So each class loader can associate a class with a **`CodeSource`** and consequently with the **`Permissions`** associated with that class by the security policy

Putting the Pieces Together

To check if a method has permission to do something:

1. Get its associated class
2. Get that class's class loader
3. Get the `Permissions` that the class loader associated with the class
4. If the requested permission isn't listed, throw a security exception

OK, but how do we figure this out?

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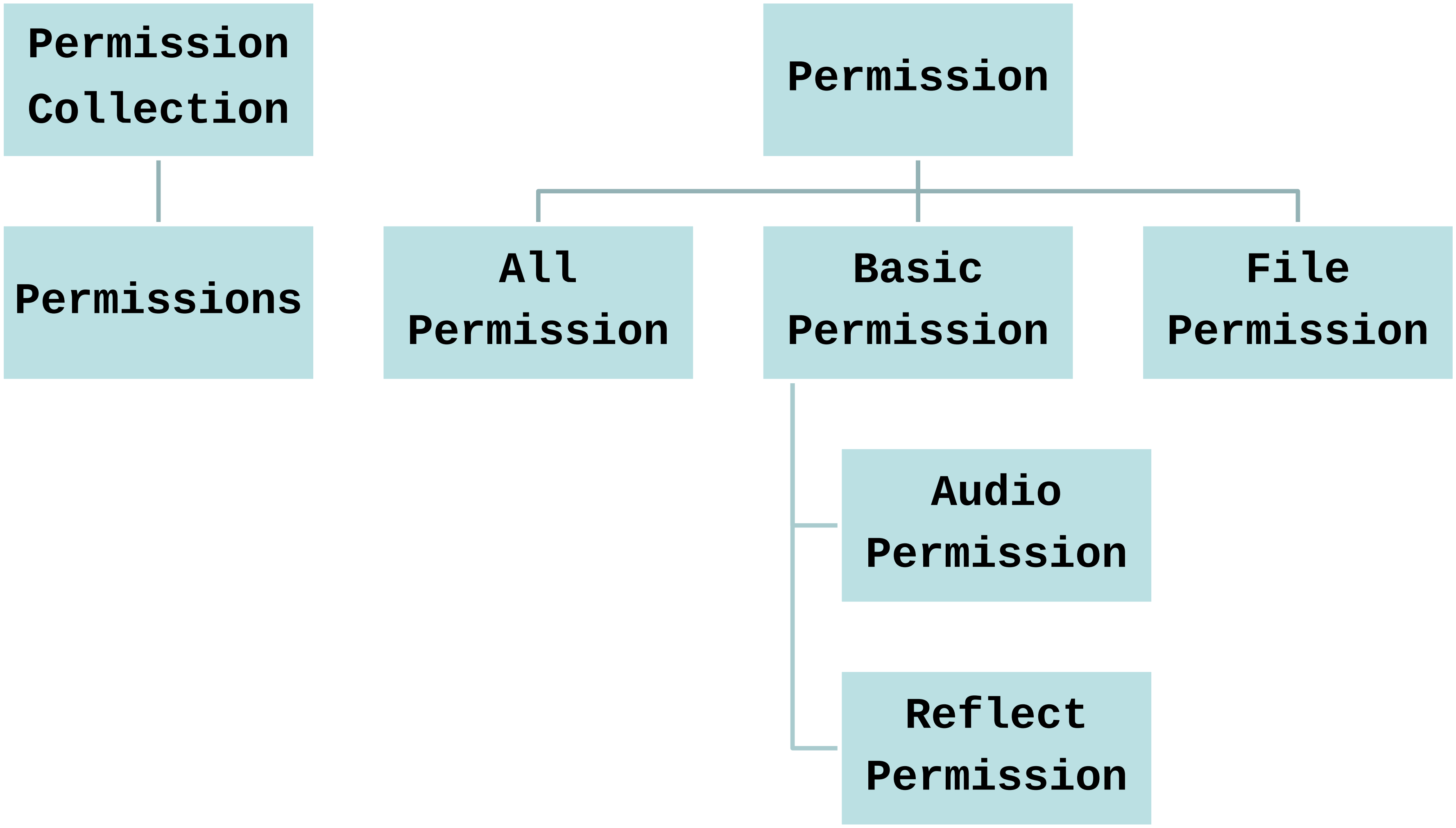
Permissions



FilePermission

Stores an absolute path to file or directory that permissions apply to

Special String	Meaning
`/*`	All files in that directory
`/-`	All files in that directory and all subdirectories
`<<ALL FILES>>`	All files

FilePermission

Also indicates which permissions are granted

Permission	Meaning	Method
`read`	May read path	
`write`	May write to path	
`execute`	May execute program in path	`Runtime.exec()`
`delete`	May delete path	`File.delete()`
`readlink`	May follow symbolic link	`FileSystemProvider .readSymbolicLink()`

Permission Implication

One permission can imply another:

```
boolean Permission.implies(Permission p)
```

For instance,

```
java.security.FilePermission \
  "/home/*", "read,write"
```

implies

```
java.security.FilePermission \
  "/home/.login", "read"
```

Permission Guard

Every permission object supports the **`java.security.Guard`** interface

which provides one method:
`void checkGuard(Object object)`

Determines whether or not to allow access to the guarded **`object`**. Returns silently if access is allowed. Otherwise, throws a **`SecurityException`**

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Privileges Can Vary per Class

If **a** and **b** are objects of the same class, they will always have the same privileges

But if they are different classes, they may have differing privileges

- even if **a** is a subclass of **b**
- even if they are in the same package
- in the same JVM

Object privileges are determined by their classes' **`CodeSource`**

Classes in the Java core library have full privileges

Privilege Security Issues

Privilege escalation vulnerability

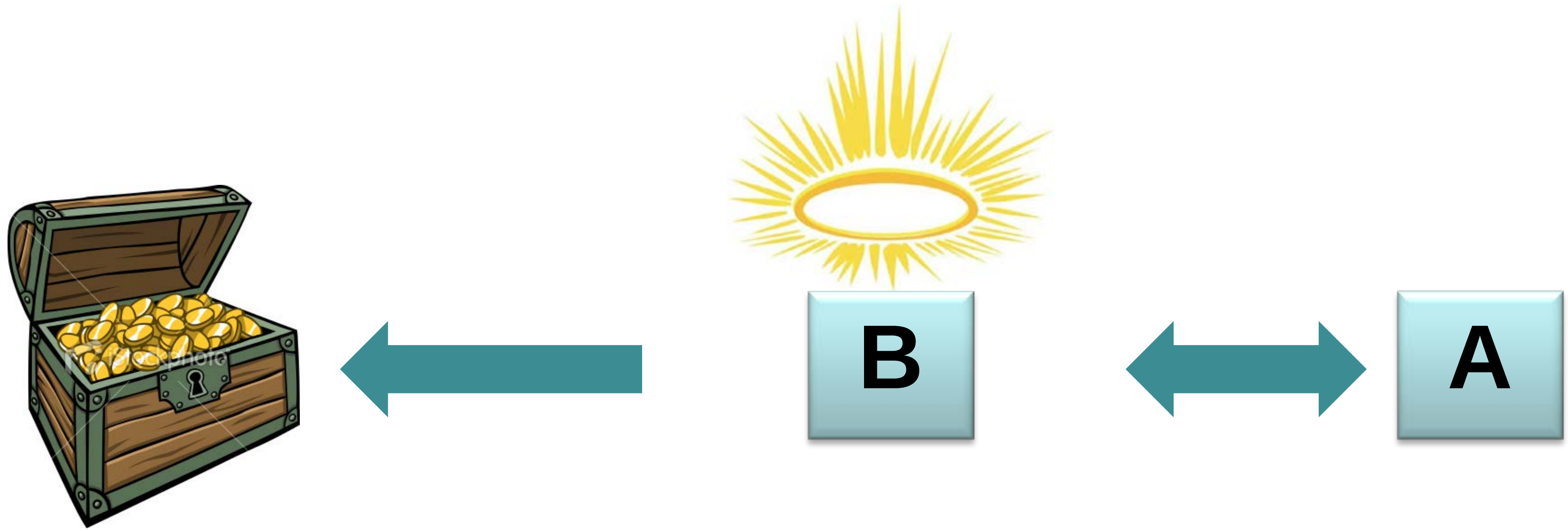
Restricted code manages to execute code in an unrestricted (privileged) context

Less privileged methods can invoke more privileged methods

More privileged methods can invoke less privileged methods unknowingly:

- Unprivileged subclasses
- Interfaces
  - Callbacks
  - Event handlers

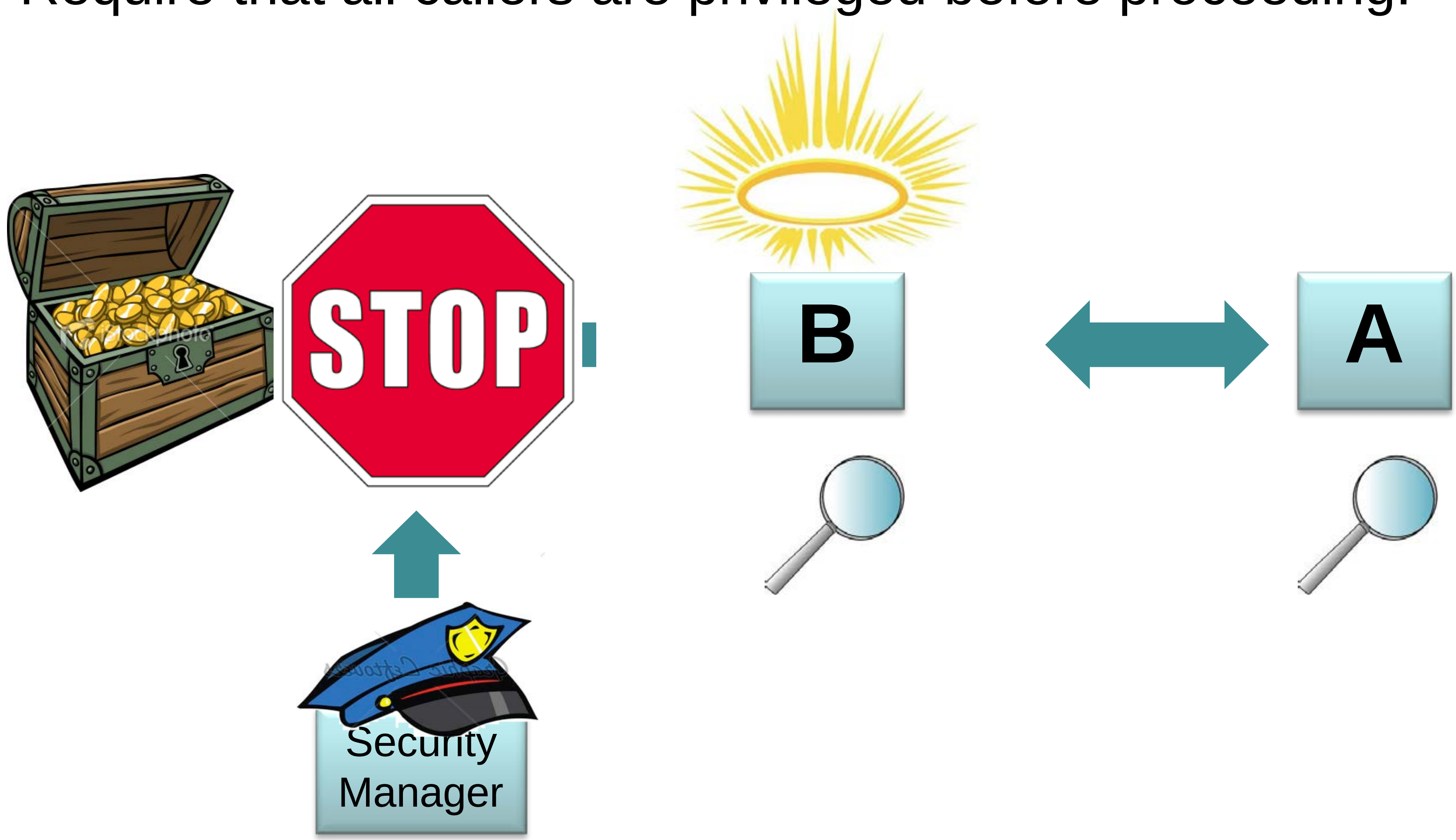
Confused Deputy Problem 1



Q: If class A is unprivileged and class B is privileged, how do we make sure that class A doesn't trick class B into doing something privileged on A's behalf?

Confused Deputy Problem 2

A: Require that all callers are privileged before proceeding.



Mitigating Confused Deputy

For a sensitive operation to proceed, **every** method on the call stack must be allowed to do it

This stops unprivileged classes from “hiding” behind privileged classes when trying to do something malicious

Enables privileged classes to publish sensitive methods, because the security check will prevent unprivileged classes from using them

Sensitive methods can “take care of themselves”

Encourages *Distrustful Decomposition*

OK but is there a way to perform sensitive operations safely?

`AccessControlContext` 1

For a sensitive operation to proceed, **every** method on the call stack must be allowed to do it

This class embodies the permissions th llowed for the current method, as well as every cal

This is the “intersection” of the privileg ss in the

Hey wait! Can’t an attacker start a new thread with a malicious **`Runnable`** object, which would run with full privileges?

`void checkPermission(Permission perm)`

If the access control context contains the given permission, returns silently. If not, throws an **`AccessControlException`**

AccessControlContext 2

For a sensitive operation to proceed, **every** method on the call stack must be allowed to do it

Every **`Thread`** also has a **`private inheritedAccessControlContext`** field, which contains the context it was created in

The **`AccessController`** can access it using this method:

```
static native AccessControlContext
  getInheritedAccessControlContext();
```

So the context is preserved not only across method invocations but also across thread creation

AccessControlContext 3

For a sensitive operation to proceed, **every** method on the call stack must be allowed to do it

```
void checkPermission(Permission perm)
```

If the access control context contains the given permission, returns silently
If not, throws an **`AccessControlException`**

This call creates an **`AccessControlContext`** object from the current stack:

```
AccessControlContext acc =
  AccessController.getContext();
```

AccessController.checkPermission()

```
public static void checkPermission(Permission perm)
                   throws AccessControlException
{
…
  if (perm == null) {
    throw new NullPointerException("permission can't be null");
  }

  AccessControlContext stack = getStackAccessControlContext();
  // if context is null, we had privileged system code on the stack
  if (stack == null) {
    ...lots of debug code
    return;
  }

  AccessControlContext acc = stack.optimize();
  acc.checkPermission(perm);
}
```

This method is **private**, **static**, and **native**

AccessController

java.security.AccessController

Actual enforcer of Java's security model

java.lang.SecurityManager is an "ambassador"

Most **SecurityManager** methods simply delegate their work to **AccessController** methods

SecurityManager Methods

```
public void checkRead(FileDescriptor fd) {
  if (fd == null) {
    throw new NullPointerException(
        "file descriptor can't be null");
  }
  checkPermission(
      new RuntimePermission("readFileDescriptor"));
}

public void checkPermission(Permission perm) {
  j                   ller.checkPermission(perm);
}

public Object getSecurityContext() {
  return AccessController.getContext();
}
```

This actually returns an **`AccessControlContext`**

AccessController methods

Method	Documentation
`getContext()`	Returns the context (e.g., permissions) for the current stack
`checkPermission()`	Validates that the current stack has the given permission
`doPrivileged()`	Executes a privileged action
`doPrivilegedWithCombiner()`	Executes a privileged action

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`AccessController.doPrivileged()`

Executes a block of code with “elevated” privileges

Java’s analogue to UNIX’s setuid feature… sort of

Specifically instructs **`AccessController`** to not check the stack beyond the current method

Does check immediate caller, but no higher

This prevents untrusted code from executing malicious code inside a **`doPrivileged()`** block

AccessController.doPrivileged()

```
Permission perm;

Object f() {
  AccessController.checkPermission(perm);
  return g();
}

Object g() {
  AccessController.checkPermission(perm);
  return AccessController.doPrivileged(
      new PrivilegedAction<Object>() {
        public Object run() {
          return h();
        }});
}

Object h() {
  AccessController.checkPermission(perm);
  ...
}
```

Checks permissions of **f()**

Checks permissions of **g()** and **f()**

Checks permissions of **h()** and **g()** but not **f()**

`doPrivileged()` Features

Always returns an object; the type is a generic parameter of the **`PrivilegedAction`** interface

Use the **`Void`** type for blocks that don't return anything

Privileged code must not throw a checked exception (because **`PrivilegedAction.run()`** has no **`throws`** declaration)

Use a **`PrivilegedExceptionAction`** to run an action that can throw an exception

Can take an extra **`AccessControllerContext`** indicating an arbitrary context to limit items

Analogous to Unix setuid-non-root (sort of)

If no context given, analogous to UNIX setuid-root (sort of)

Other Contexts

```
Permission perm;
AccessControlContext context = …

Object f() {
  AccessController.checkPermission(perm);
  return g();
}

Object g() {
  AccessController.checkPermission(perm);
  return AccessController.doPrivileged(
      new PrivilegedAction<Object>() {
        public Object run() {
          return h();
        }}, context);
}

Object h() {
  AccessController.checkPermission(perm);
  ...
}
```

Checks permissions of **`f()`**

Checks permissions of **`g()`** and **`f()`**

Checks permissions of **`h()`** and **`g()`** and **`context`**

`doPrivileged()` Security

`doPrivileged()` can't be used by unprivileged code to gain privileges

It can be used by privileged code to ignore the restrictions imposed by unprivileged code that called the privileged code

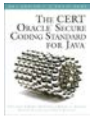
So privileged methods that invoke **`doPrivileged()`** code blocks can be subject to the "confused deputy" problem

doPrivileged() Guidelines

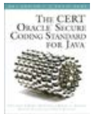
Guideline 9-3: Safely invoke **`java.security.AccessController.doPrivileged`**

Guideline 9-4: Know how to restrict privileges through **`doPrivileged`**

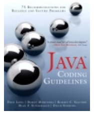
Guideline 9-7: Understand how thread construction transfers context



SEC00-J. Do not allow privileged blocks to leak sensitive information across a trust boundary



SEC01-J. Do not allow tainted variables in privileged blocks



17. Minimize privileged code

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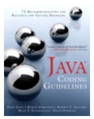
Reduced Security Checks 1

Some core methods use reduced security checks

Instead of checking the permissions for all callers in the call stack, they check the permissions only for the immediate caller

Any method that invokes one of these methods may be vulnerable to “confused deputy”



18. Do not expose methods that use reduced security checks to untrusted code

Reduced Security Checks 2

ORACLE Guideline 9-10: Be aware of standard APIs that perform Java language access checks against the immediate caller

Method
`java.lang.Class.newInstance`
`java.lang.reflect.Constructor.newInstance`
`java.lang.reflect.Field.get*`
`java.lang.reflect.Field.set*`
`java.lang.reflect.Method.invoke`
`java.util.concurrent.atomic.AtomicIntegerFieldUpdater.newUpdater`
`java.util.concurrent.atomic.AtomicLongFieldUpdater.newUpdater`
`java.util.concurrent.atomic.AtomicReferenceFieldUpdater.newUpdater`

Reduced Security Checks 3

ORACLE Guideline 9-9: Safely invoke standard APIs that perform tasks using the immediate caller's class loader instance

Method
`java.lang.Class.forName`
`java.lang.Package.getPackage(s)`
`java.lang.Runtime.load`
`java.lang.Runtime.loadLibrary`
`java.lang.System.load`
`java.lang.System.loadLibrary`
`java.sql.DriverManager.getConnection`
`java.sql.DriverManager.getDriver(s)`
`java.sql.DriverManager.deregisterDriver`
`java.util.ResourceBundle.getBundle`

Reduced Security Checks 4

ORACLE

Guideline 9-8: Safely invoke standard APIs that bypass **`SecurityManager`** checks depending on the immediate caller's class loader

Method
`java.lang.Class.getClassLoader`
`java.lang.Class.getClasses`
`java.lang.Class.getField(s)`
`java.lang.Class.getMethod(s)`
`java.lang.Class.getConstructor(s)`
`java.lang.Class.getDeclaredClasses`
`java.lang.Class.getDeclaredField(s)`
`java.lang.Class.getDeclaredMethod(s)`
`java.lang.Class.getDeclaredConstructor(s)`
`java.lang.ClassLoader.getParent`
`java.lang.ClassLoader.getSystemClassLoader`
`java.lang.Thread.getContextClassLoader`

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Summary 1

Java's security architecture is designed to be

- Extendable
- Modular
- Behind-the-scenes

Encourages the use of these secure design patterns:

- Privilege separation
- Privilege minimization
- Distrustful decomposition

Summary 2

Security architecture is NOT designed to be

- Modifiable
- Familiar
  - Analogies with UNIX privileges or setuid are *very* tenuous

Watch out for

- **`doPrivileged()`**
- Methods that use reduced security checks

For More Information

Visit CERT® websites:
http://www.cert.org/secure-coding
https://www.securecoding.cert.org

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