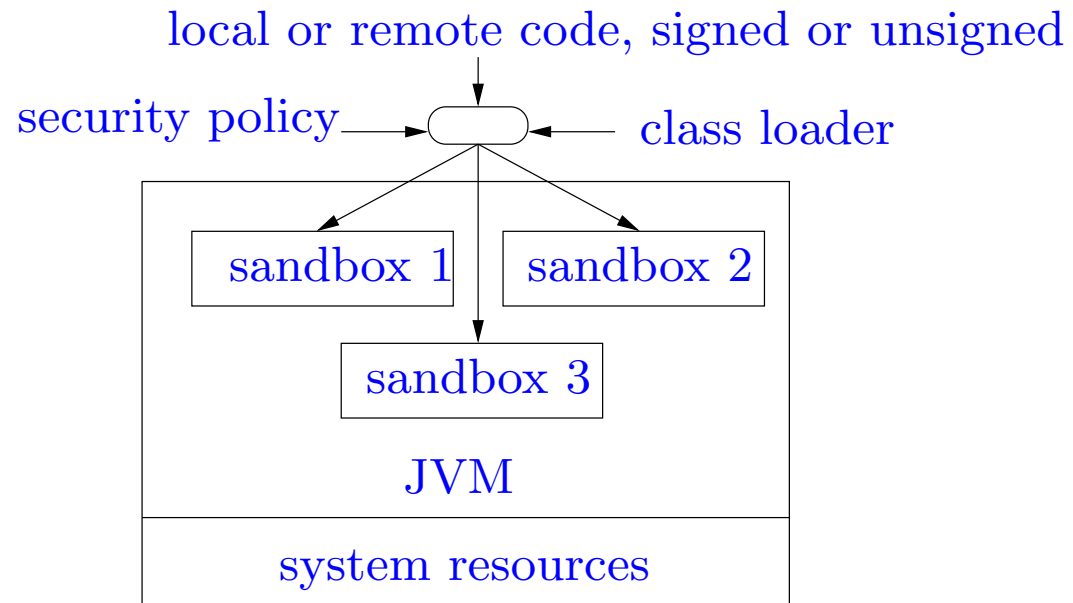
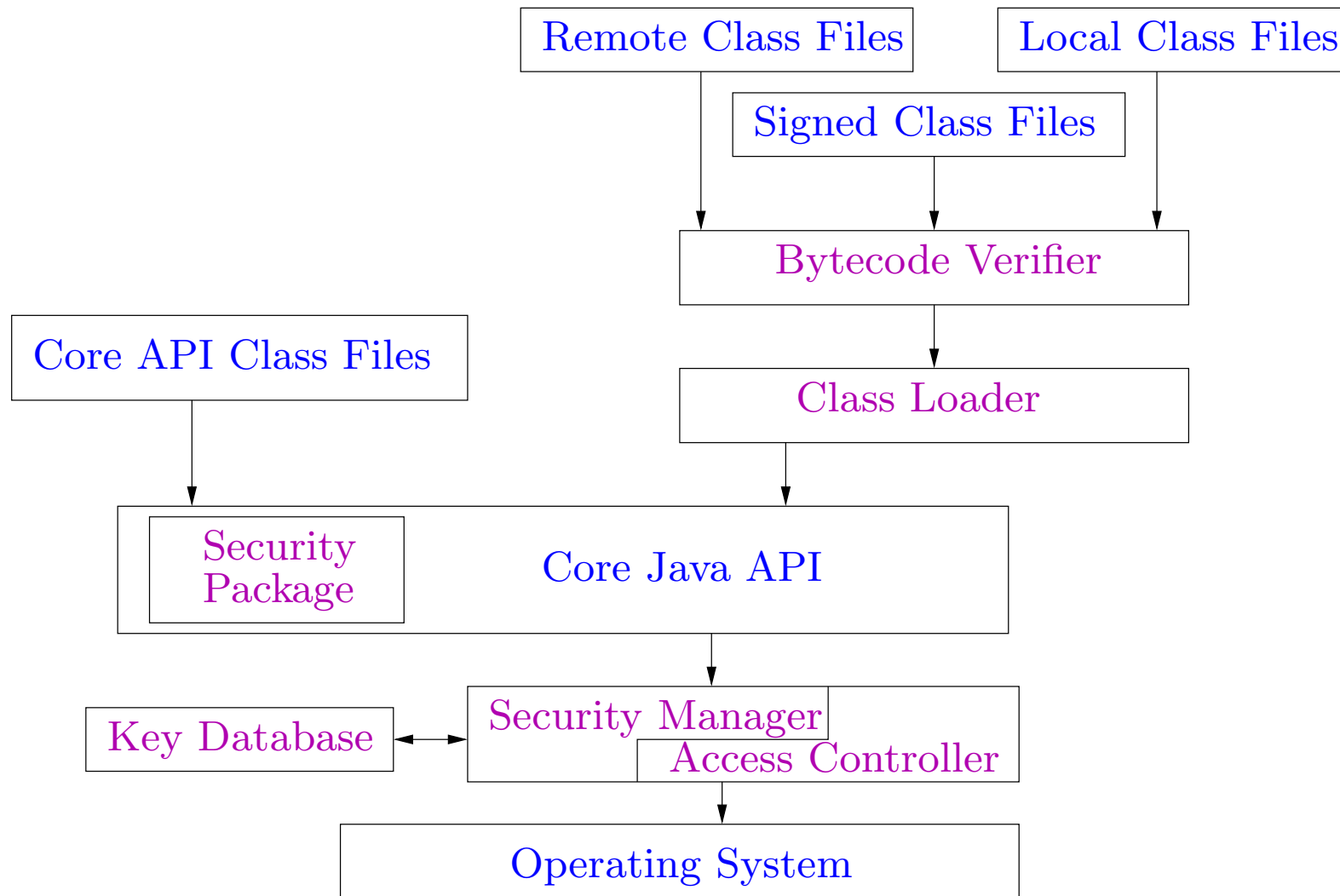


The current sandbox model in Java 2



Elements of the Java sandbox



Java language security constructs

Each entity has an **access level**

Specifier	Class	Package	Subclass	World
private	Yes	No	No	No
(Default)	Yes	Yes	No	No
protected	Yes	Yes	Yes	No
public	Yes	Yes	Yes	Yes

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Not sufficient for memory integrity ...

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- No use of variables before **initialization**.
- **Array bounds** checks.
- No arbitrary **casts** between different classes.

```
public class A {private int x;}  
public class B {public int x;}  
...  
// a is of class A  
B b = (B) a;  
// The above is rejected by the compiler  
Object o = b; B b' = o;  
// The above is allowed by compiler but raises exception at runtime
```


Enforcement of the Java language rules.

- *At compile time:*

check typing rules, enforcement of access qualifiers, prevention of most illegal type casts.

- *At load time:*

verify bytecodes when a class is loaded (prevent malicious bytecodes)

- *At runtime:*

raise exceptions for illegal type casts, out of bound array accesses, ...

Java Class Loading and Bytecode Verification

- Every `object` is a member of some `class`.
- The `Class` class: its members are the (definitions of) various classes that the JVM knows about.
- The classes can be dynamically loaded by the JVM by reading local or remote class files.
- Loading of classes is done by `class loaders` which are objects of the `ClassLoader` class.
- The class loader coordinates with the security manager and the access controller to provide the `sandbox` functions.

```
public class getClassTest {
    public static void main (String args[]) {
        String s = "abc";
        Class c1 = s.getClass();
        System.out.println ("string \" + s + "\" is of class " + c1.getName());
        Class c2 = c1.getClass();
        System.out.println ("class " + c1.getName() + " is of class " + c2.getName());
        Class c3 = c2.getClass();
        System.out.println ("class " + c2.getName() + " is of class " + c3.getName());
    }
}
```

```
public class getClassTest {
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        Class c3 = c2.getClass();
        System.out.println ("class " + c2.getName() + " is of class " + c3.getName());
    }
}
```

string "abc" is of class java.lang.String

class java.lang.String is of class java.lang.Class

class java.lang.Class is of class java.lang.Class

An example involving dynamic class loading

```
import java.lang.reflect.*;
```

```
public class runhello {
```

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

```
        Class c = null;
```

```
        Method m = null;
```

```
        // First we load the required class into the JVM
```

```
        try { c = Class.forName ("hello");
```

```
        } catch (ClassNotFoundException e) {
```

```
            System.out.println ("The class was not found");
```

```
        };
```

```
// Get the main method of the class
Class argtypes[] = new Class[] { String[].class };
try { m = c.getMethod ("main", argtypes);
} catch (NoSuchMethodException e) {
    System.out.println ("The main method was not found");
};

// Invoke the method
Object arglist[] = new Object[1];
try { m.invoke (null, arglist);
} catch (Exception e) {
    System.out.println ("Error upon invocation" + e);
};
} }
```

Hello!

The `forName` function finds, loads and links the class specified by the name.

```
forName(String name, boolean initialize, ClassLoader loader)
```

tries to find the class specified by the name, load it using the specified class loader and link it. The class is initialized if asked for.

```
forName ("hello")
```

above is equivalent to

```
forName ("hello", true, this.getClass().getClassLoader())
```

Security and the class loader

The **security manager** and **access controller** allow or prevent various operations depending upon the context of the request.

This information is provided by the class loader.

The class loader has information about

- **origin**: where the class was loaded from
- whether the class comes from the local filesystem or from the network
- whether the class comes with a **digital signature**

Each class loader defines a **name space**.

All classes loaded by particular class loader belong to its name space.

class loader cl1	class loader cl2	
java.lang.String abc	java.lang.String xyz

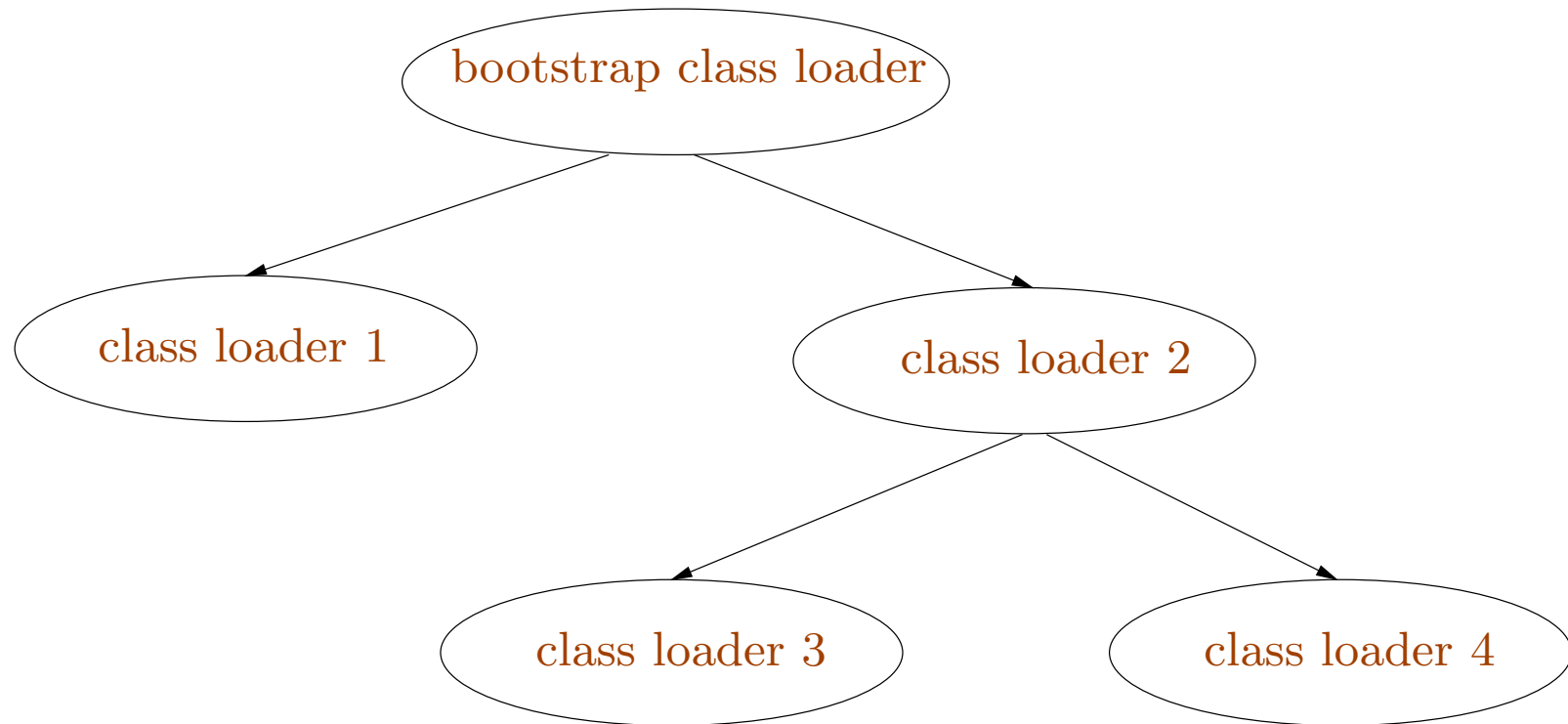
Classes from different sites are always loaded by different class loaders.

Hence the class `java.lang.String` provided by `www.site1.com` is different from the class `java.lang.String` provided by `www.site2.com`.

In particular they belong to different **packages**.

Hierarchy of class loaders

- The **bootstrap class loader** (primordial class loader, internal class loader) is responsible for loading a few initial classes when the JVM is launched.
- All new user defined class loaders have a **parent class loader**.



The class loading mechanism

1. return already **existing class** object, if found
2. ask the security manager for **permission** to **access** this class
3. attempt to load the class using the **parent class loader**
4. ask the security manager for **permission** to **create** this class
5. **read** the class file into an array of bytes
6. perform **bytecode verification**
7. **create** the class object
8. **resolve** the class

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The mechanism can be overridden by class loaders in current versions of Java.

Using a class loader

Class loaders are members of (subclasses of) the `ClassLoader` class.

Classes are loaded using the `loadClass` function of class loaders:

```
protected Class loadClass (String name, boolean resolve)
```

where `name` is the name of the class, and `resolve` tells us whether the class should be resolved or not.

Typically new classes of class loaders are defined by extending standard ones like `SecureClassLoader` or `URLClassLoader`.

Defining a new class of class loader

Either extend `ClassLoader` or one of its subclasses.

```
import java.net.*;
// a trivial extension of URLClassLoader
public class myClassLoader extends URLClassLoader {
    myClassLoader (URL url) { super (new URL[] {url}); }

    protected Class loadClass (String name, boolean resolve) {
        Class c = null;
        try { c = super.loadClass(name, resolve);
        } catch (ClassNotFoundException e) { System.out.println ("Class not found"); }
        return c;
    }
}
```

Using a class loader

```
import java.lang.reflect.*;
import java.net.*;

public class runClass {
    public static void main (String args[]) {

        // Create a class loader
        URL url = null;
        try { url = new URL ("file:/home/userxyz/classes");
        } catch (MalformedURLException e) { }
        myClassLoader cl = new myClassLoader(url);
```

```
Class c = null; Method m = null;
c = cl.loadClass (args[0]); // Load the class

//Compute the argument vector and invoke the main method
Class argtypes[] = new Class[] { String[].class };
try { m = c.getMethod ("main", argtypes); } catch (NoSuchMethodException e) {
    System.out.println ("The main method was not found"); };
Object arglist[] = new Object[1];
arglist[0] = new String[args.length - 1];
for (int i=0; i < args.length - 1; i++) ((String[])arglist[0])[i] = args[i+1];
try { m.invoke (null, arglist); } catch (Exception e) {
    System.out.println ("Error upon invocation" + e); };
}
}
```


Java Bytecode Verification

Static analysis of the bytecodes to ensure security properties like

- operations follow typing rules
- no illegal casts
- no conversion from integers to pointers
- no calling of directly private methods of another class
- no jumping into the middle of a method
- no confusion between data and code

The JVM

- **Stack** based abstract machine: operations pop arguments and push results
- A set of **registers**, typically used for local variables and parameters: accessed by load and store instructions
- Stack and registers are preserved across **method calls**
- For each method, the **number** of stack slots and registers is specified in the bytecode
- unconditional, conditional and multiway (switch) **intra-procedural branches**
- **Exception handlers table** of entries (pc_1, pc_2, C, h) : if exception of class C is raised between locations pc_1 and pc_2 , then handler is at location h .
- Most JVM instructions are **typed**.

Example bytecode

The source code:

```
public class test {  
    public static int factorial (int n) {  
        int res;  
        for (res = 1; n > 0; n--) res = res * n;  
        return res;  
    }  
}
```

and the JVM bytecode (shown by running `javap` on the class file)...

```
...
public static int factorial (int ); 2 stack slots , 2 registers
    0:  iconst_1      // push integer constant 1
    1:  istore_1     // store it in register 1 (res)
    2:  iload_0      // push register 0 (n)
    3:  ifle 16      // if negative or zero, goto 16
    6:  iload_1      // push register 1 (res)
    7:  iload_0      // push register 0 (n)
    8:  imul         // multiply
    9:  istore_1     // store in register 1 (res)
   10:  iinc 0, -1   // increment register 0 (n) by -1
   13:  goto 2       // goto beginning of loop
   16:  iload_1      // load register 1 (res)
   17:  ireturn     // return this value
...
```

Some properties to be verified

- **Type correctness:** the arguments of an instruction are always of the right type.
- **No stack overflow or underflow**
- **Code containment:** the PC points within the code for the method, at the beginning of an instruction
- **Register initialization** before use
- **Object initialization** before use

Minimize runtime checks \implies efficient execution

Verification idea: type level abstract interpretation

Use types as the abstract values.

The partial ordering \sqsubseteq on types is the **subtype** relation.

Hence for example $C \sqsubseteq D \sqsubseteq \text{Object}$ if class C extends class D .

We introduce special types **Null** and \top to abstract null pointers and uninitialized values. Also $T \sqsubseteq \top$ for every T .

An **abstract stack** S is a sequence of types.

The sequence $S = \text{Int} \cdot \text{Int} \cdot \text{Bool}$ abstracts a stack having a Boolean at the bottom of the stack and just two integers above it.

An **abstract register assignment** R maps registers to types.

$$R : \{0, \dots, M_{reg} - 1\} \rightarrow \mathcal{T}$$

where M_{reg} is the maximum number of registers and \mathcal{T} is the set of types.

An **abstract state** is either \perp (unreachable state) or (S, R) where S is an abstract stack and R is an abstract register assignment.

Executing instructions modifies the abstract state.

$$(S, R) \xrightarrow{\text{iconst } n} (\text{Int} \cdot S, R)$$

if $|S| < M_{stack}$ where M_{stack} is the maximum size of the stack

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$$(\text{Int} \cdot S, R) \xrightarrow{\text{istore } n} (S, R\{n \mapsto \text{Int}\})$$

if $0 \leq n < M_{reg}$

$(\text{Int} \cdot S, R) \xrightarrow{\text{ifle } n} (S, R)$
if n is a valid instruction location

$(S, R) \xrightarrow{\text{goto } n} (S, R)$
if n is a valid instruction location

$$(S, R) \xrightarrow{\text{aconst_null}} (\text{Null} \cdot S, R)$$

if $|S| < M_{stack}$

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if $0 \leq n < M_{reg}$ and $R(n) \sqsubseteq \text{Object}$ and $|S| < M_{stack}$

$$(\tau \cdot S, R) \xrightarrow{\text{astore } n} (S, R\{n \mapsto \tau\})$$

if $0 \leq n < M_{reg}$ and $\tau \sqsubseteq \text{Object}$