Java Security

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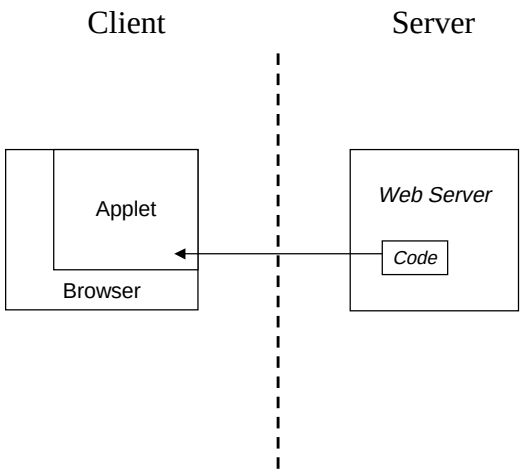
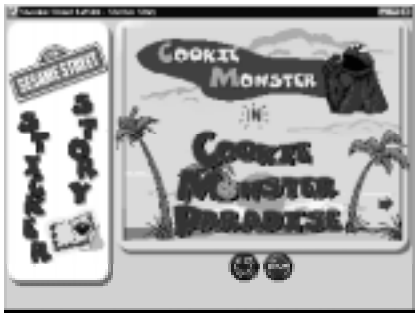
What is Mobile Code?

- Code travels from server machine to your machine



Mobile Code is Your Friend

- Rich data display
- Efficient use of network
- Customize the experience



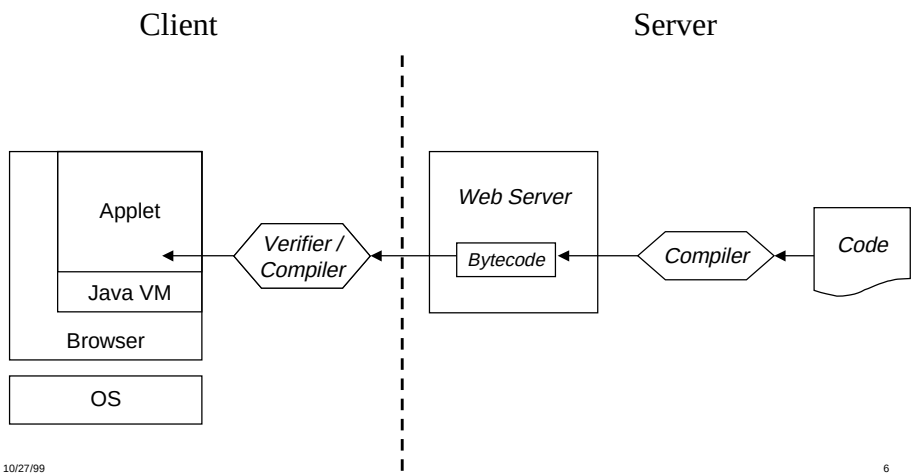
Mobile Code Is Scary

- Untrusted, possibly malicious code on **your** computer!
- Disclose or damage your private data?
- Spend your money?
- Crash your machine?

Mobile Code Can Be Safe

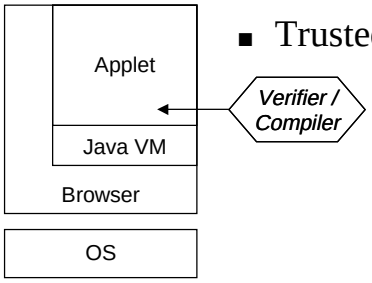
- *Sandbox policy*
  - no file system
  - limited networking
- All code prevented from doing dangerous things

How Mobile Code Works



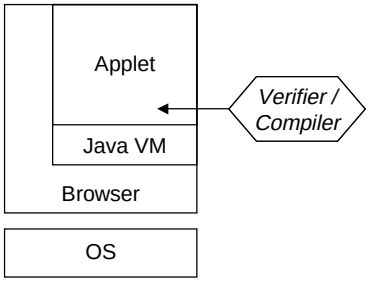
How Mobile Code Fails

- Verifier failures
- Secure service failures
- Name-space confusion
- Denial of service
- Trusted computing base issues



Verifier Failures

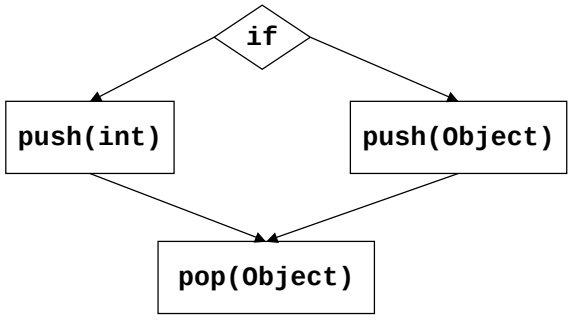
- Verifier failures allow malicious behavior
  - Violate protection rules
  - Forge pointers / make unchecked type casts
  - Read and write any address, execute arbitrary code



☞ Original Microsoft JVM did not enforce access modifiers like *private* and *protected*

Verifier Internals

- Java VM has a stack-based architecture
  - Stack frames, local variables can be reused with new variable types
  - Verifier must validate types



Verifier Internals

- Control / data-flow analysis
  - Track types on stack through all code
- Ugly bytecodes to handle
  - One instruction is equivalent to C `switch` statement
  - Internal subroutines within a method (`jsr` / `ret`)
  - Complex object initialization semantics
    - Memory allocation and initialization are not atomic
  - Exception tables introduce other control flows

Bugs in Sun / Microsoft Verifiers

- Many, many bugs found
- Most recent: Karsten Sohr (September 1999)
  - Microsoft did not properly flow type information through exception blocks
  - Result: Arbitrary type casting, system compromise
- **`check_code.c`** (from Sun's source code):

```
/*-
 *      Verify that the code within a method block doesn't exploit any
 *      security holes.
 *
 *      This code is still a work in progress.  All currently existing code
 *      passes the test, but so does a lot of bad code.
 */
```


Building a Better Verifier?

- Kenny Zadeck (NaturalBridge) proposes:
  - Reduce bytecode to simpler format
    - Exceptions handled explicitly
    - Expand "subroutine" calls
    - ☛ Internal representation used by normal compilers
  - Data / control-flow analysis is now a standard problem
- Paul Martino (Ahpah) proposes:
  - Decompile bytecode to Java source, then recompile
  - Repeat until fixed-point or error

Defining "Correct" Bytecode?

- Simplest definition: bytecode has a corresponding "correct" Java source program
  - *Java Language Spec* is more precise than *JVM Spec*
  - Unnecessarily restrictive?
- Bytecode as its own formal language?
  - JVML – Stata and Abadi
  - Freund and Mitchell (OOPSLA '98)
- Bytecode, version 2?
  - Abstract syntax trees, equivalent to Java source?

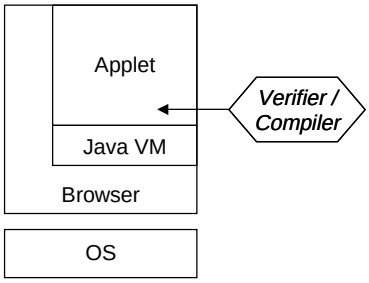
Abstract Syntax Trees vs. Bytecode

- ASTs easier to type check
  - No need for global dataflow analysis
- ASTs have same semantics as language
  - Bytecode has its own semantics
- Comparable compilation speed

- Bytecode was designed for an interpreter
- Modern Java systems use just-in-time compilers

Name Space Confusion

- Java "linking" happens dynamically at runtime
- ClassLoader: two functions
  - Map class name to bytecodes (fetch from network)
  - Map class name to internal representation (name space / linking)
    - Confusion allows for unchecked typecasting



☛ Applets are not allowed to create their own ClassLoaders

Name Space-based Attacks

- Name equality does not imply type equality
  - Attack by David Hopwood, 1996

```
// Applet 1
class BadOutputStream
extends OutputStream {
    public Object obj;
    . . .
}
```

```
// Applet 2
class BadOutputStream
extends OutputStream {
    public int obj;
    . . .
}
```

```
// Shared system class, writable variable
class System {
    public InputStream in;
    public OutputStream out;
}
```

Fixing Name Spaces

- Dean, "The Security of Static Typing with Dynamic Linking", ACM-CCS 1997
- Liang and Bracha, "Dynamic Class Loading in the Java Virtual Machine", OOPSLA 1998

- Rules that a ClassLoader must follow
- Rules for how dynamic type casting works

- Still possible to get in trouble with ClassLoader
  (ClassLoader still restricted)

Name Space Problems Again

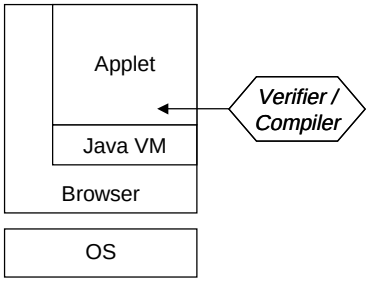
- Balfanz, Dean, Felten, Wallach (August 1999)
- Race condition in Microsoft's ClassLoader
- Two cooperating threads
  - Primary thread asks ClassLoader to map name to class
  - Helper tries to interrupt primary thread
  - **`Thread.stop()`** sends an asynchronous exception
- Results: same name resolves to more than one class
  - Access to "package scoped" variables anywhere

Name Space: Deeper Problems

- Tension between static linking and dynamic loading
  - Goal: running before loading / verification complete
  - Problem: incomplete type information when verifying
  - Solutions: rigid rules, dynamic type constraints
- ClassLoader hacks are dangerous
  - RMI (remote method invocation) will dynamically load classes for objects it has not seen
  - Complex ClassLoaders lead to security failures

Denial of Service

- Consume infinite memory or CPU resources
- Impossible to terminate safely
  - Applet can catch exceptions from **`Thread.stop()`**
  - **`Thread.destroy()`** is dangerous




```
class BadApplet {
    public void start() {
        while(true) {}
    }
}
```

☛ **`Thread.stop()`** is "deprecated" but still supported in Java 2.

Safe Termination

- Threads are not the same as processes
  - Unix process encapsulates all resources in use
  - Unix kernel tracks all resources in use
- Java threads can cross from “user” to “kernel” code
  - Memory is shared
  - Resources in use are not tracked
- Separate JVM per applet (Digitivity, AT&T, others)
- Process-style solutions (U. of Utah)
  - ☛ Restrictions on memory sharing

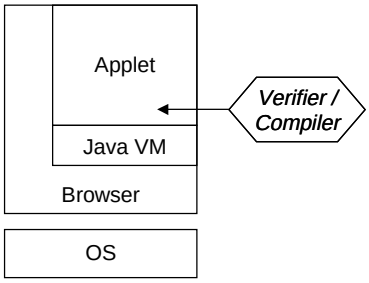
Class vs. Thread Termination

- Our goal: terminate “applets”
  - Applet is a set of classes loaded by one ClassLoader
- Rewrite applet bytecode while loading
  - Add code to check “termination” flag
    - Once per basic block of code
  - Overhead will vary (worst cast: code with tight loops)
    - No overhead on system classes
- Applet threads will now terminate in finite time
- System code will not be disturbed by applet termination

joint work with Algis Rudys

Secure Services

- System classes enforce sandbox policy
  - Bugs in system classes lead to security failures

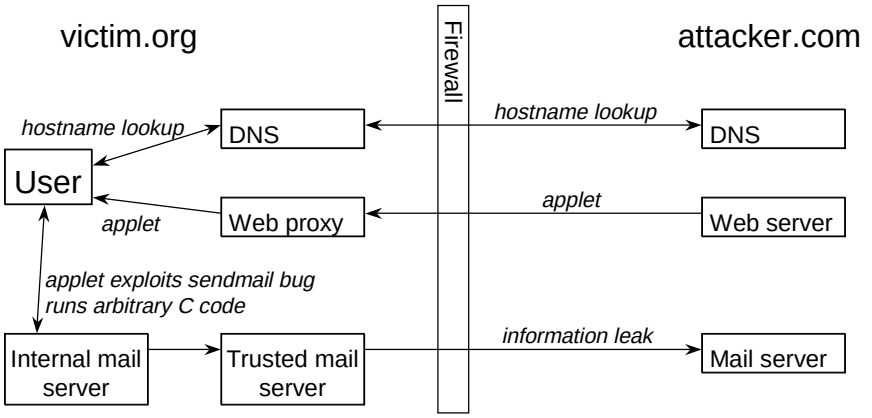


- Name space attack relied on a race condition in a system class
- Sun JVM 1.0 had bugs in network connect logic. Applets could connect anywhere.

Netscape 2.0 Insecurity

- Java trusts DNS
  - Internet hosts can have multiple IP addresses
  - Java host equality test is ***too lenient***
- With a hacked DNS server
  - Two-way channel to any machine on the Internet
  - Applets can connect to machines ***behind*** a firewall
    - Exploit numerous Unix and Windows bugs
    - Talk to internal Web and NetNews servers

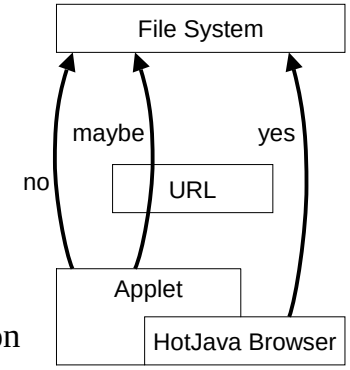
Netscape DNS Attack



The DNS attack allows connections to *any* machine behind the firewall.
Joint work with Dean and Felten (1996)

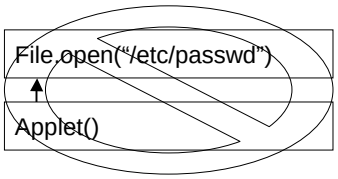
Another Secure Services Problem

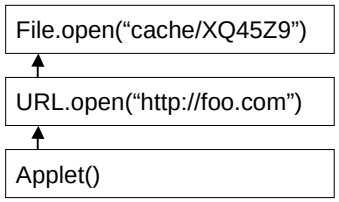
- *Some* parts of Java still need the file system!
  - URL file cache
  - Class dynamic loader
- Secure services
  - Use dangerous primitives
  - Export safe interfaces
  - How to decide if an operation should be allowed?

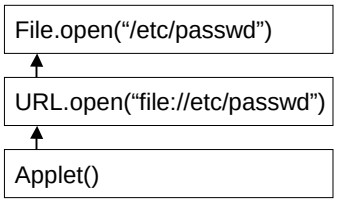


Handling the "Maybe" Cases

- Dangerous actions should be forbidden unless explicitly allowed
  - principle of least privilege
  - fail-safe

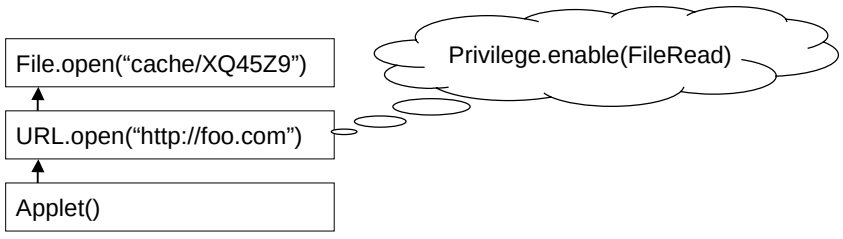






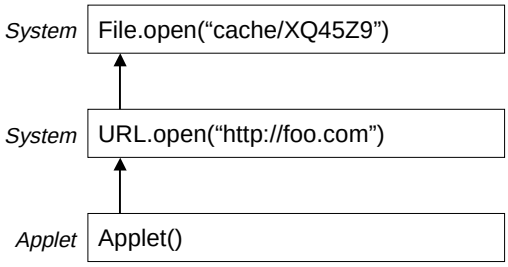
Solution: Stack Inspection

- Code *must* explicitly authorize a dangerous action
  - A method *enables its privileges*
    - Privileges revert when the method returns
- Used in Netscape 4, Microsoft IE 4, Sun JDK 1.2
  - Invented at Netscape



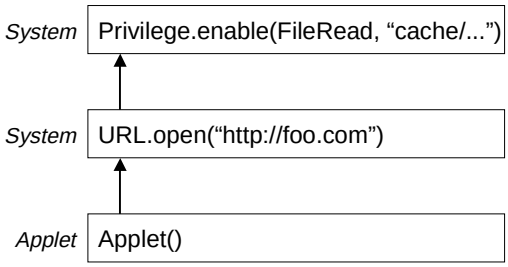
How Stack Inspection Works

What if the URL code wants to use a file cache?



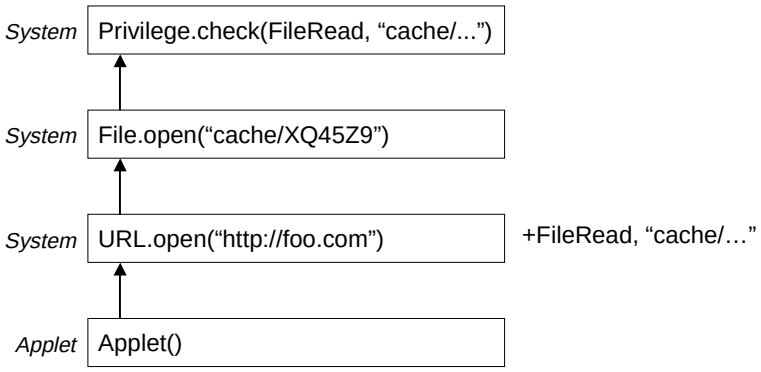
How Stack Inspection Works

First, enable the file reading privilege...



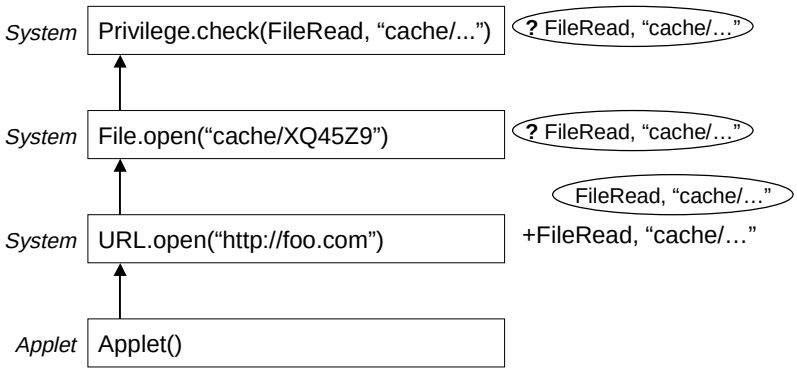
How Stack Inspection Works

… which places an annotation on the stack



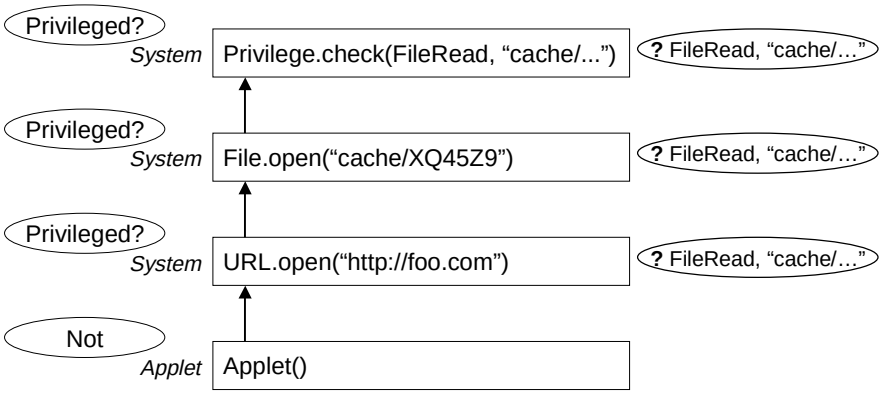
How Stack Inspection Works

… then search for the enabled privilege



How Stack Inspection Works

What if the privilege was never enabled?



Netscape 4.0 Privileges

- File system, network
  - UniversalFileRead, UniversalFileDelete, UniversalAccept, UniversalConnect
- Browser features
  - UniversalPrintJobAccess, UniversalSendMail
- Parameterized variants of universal privileges
  - FileRead, FileWrite
- Macros
  - TerminalEmulatorAccess, GamesAccess

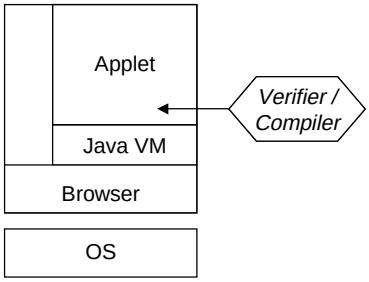
Why Stack Inspection is Cool

- Software engineering experience
  - Security audits
  - Porting code
- Formal basis
  - Modeled with a belief logic
- Fast implementation
  - Based on the formal model
  - Portable, compiler-friendly
- Extends naturally to remote procedure calls

My Contributions

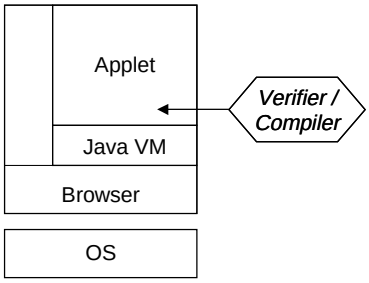
Trusted Computing Base

- TCB – the subset that must be correct for the system to be secure
  - TCB minimization = secure software engineering
  - ☛ Stack inspection helps reduce the TCB



Browser / External Interaction

- Some “safe” modules are dangerous
  - ActiveX problems: Richard Smith, Phar Lap
- Trap users with infinite popup windows



Conclusions

- Java has had serious problems
  - Security issues at all levels of the design
- Great research problems come from security holes
  - Dean’s PhD research: understanding class loading
  - My PhD research: understanding stack inspection
  - My current research: how to build a “secure” Java OS
- Java is a great source of research problems

☛ Combine hacking, theorem proving, software engineering and press releases