Java Security

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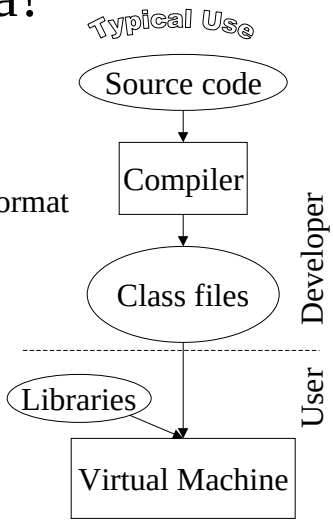
Outline

- Java Basics
  - What's Java, Modes of Use, major components, implications, implementations, politics
- Security-related capabilities (JDK 1.0, 1.1, "1.2")
- Selected upcoming developments
- Miscellaneous
  - Past breaches, malicious applets, advantages & disadvantages, key points

What's Java?

- Java Technologies:
  - Java language
  - Virtual machine (VM)/class file format
  - Libraries
- Can use only VM or language
- Developed by Sun
- Not related to "Javascript"
- Cross-Platform (WORA)



Java Modes of Use

- Applets: Auto-run when view web page
- Applications: Traditional program (performance?)
- Beans: Component (like OLE object)
- Servlets: Server-side applications
- Aglets: Intelligent Agents
- Doclets: Configurable doc generator
- Embedded Systems
- Smart Cards ("JavaCard")

Java Language

- Modern object-oriented (OO) language
  - OO with single inheritance + multiple "interfaces"
  - Classes grouped into hierarchical packages
  - Strong static typing (no arbitrary pointers)
  - Automatic garbage collection
  - Exceptions
  - Multithreaded
- Lacks enumerations and templates (generics)
- Syntax ~C++, semantics ~Ada95/Smalltalk

Java Virtual Machine (VM) and Class File Format

- Class file defines names/types/values of class variables, constants, & methods
- Methods stored as instructions to stack-based VM
  - Very similar to UCSD p-code
- VM executes class files (inc. collections of them)
  - By interpretation, run-time compilation, or combination; performance is a significant issue
- Before execution, VM usually runs "bytecode verifier" to check legality of class file

Java Libraries

- Set of built-in APIs, including:
  - GUIs
  - Networking
  - Computation
- Growth area
- Several classes are security-related
  - This presentation will skim ordinary crypto functions such as ones for encryption/decryption, certificate management, etc., since they are not essentially unique

Class and Method Access Control Modifiers

Access Control Modifier	Class or Interface Accessibility	Member (Field or Method) Accessibility
Public	All	All if class or interface is accessible; interface members always public
Protected	N/A	Same package OR subclass
"default" (Package private)	Same package	Same package
Private	N/A	Only same class (not subclass)

Implications of Java Basics

- No arbitrary pointers: references ~ capabilities
  - Only creator & createe have reference for new object
  - If objectset doesn't pass a reference, you can't manipulate that object
- Can only manipulate objects in limited ways
  - If data private, can only manipulate via methods
  - Methods can be used to protect data
  - Constructor method can limit who can create an object
- Software-enforced protection (small slips break it)

Notes on Java Implementations

- "Java" is the general technology
- Multiple Java Implementations
  - Sun, Microsoft (derived), Kaffe, …
  - This presentation emphasizes Sun's implementations
  - Sun essentially controls the interface and reference implementation

Java: Caught in Political Cross-fire

- Microsoft
  - Intentionally “polluted” with incompatible unmarked extensions to fool developers into unportable code
  - Sun sued & won court injunction partly forbidding this
- Sun
  - Promised to support standardization (they have before)
  - Customers trusted Sun & committed major resources
  - Sun flirted with ISO & ECMA, then halted cooperation
  - Greatly angered users: “Sun lied”
  - Linux port taken without warning or acknowledgement
  - Suddenly charged royalties on enterprise edition, even to those who had partially funded its development

Java: Current Political Situation

- Sun controls spec & primary implementation
  - “Community” license means “Sun controls everything”
  - Java is essentially Sun proprietary language/technology
- Disincentive for other organizations
  - IBM, etc., don’t want to depend on a competitor
  - Sole-source dangerous: surprise fees, nasty changes
- User best interests not in Sun/Microsoft interests
- To avoid total dependence on a capricious vendor:
  - Consider open source, Linux, standardized languages

Security-Related Capabilities (1 of 2)

- JDK 1.0 (Fall 1995)
  - Policy: "Sandbox" for applets; others unlimited
  - Mechanisms: SecurityManager, Bytecode verifier, Classloader
- JDK 1.1 (Spring 1997)
  - Policy: can also grant total trust to signed applets
  - Mechanisms: Java Archive (JAR), crypto-related APIs
- Inflexible: Too little or too much privilege

Security-Related Capabilities (2 of 2)

- Netscape & Microsoft Extensions
  - Enabled more flexible approaches
  - Incompatible with each other and with Sun
- J2SE (Java 2 Platform Standard Edition) (Fall 1998)
  - Includes SDK 1.2 and runtime
  - Policy: can also grant fine-grained privileges to specific applets/classes based on source and/or signatures
  - Mechanisms: AccessController, ProtectionDomain, CodeSource, Permission, GuardedObject, …
  - "Java Plug-in" supports both Microsoft & Netscape

Java 1.0 Security Policy

- Sandbox Policy (for applets)
  - Cannot access local filesystem or devices
  - Network connections only to applet load source
  - Cannot invoke any local program or library
  - "Untrusted" indicator on top-level windows
  - Cannot manipulate basic classes or another ThreadGroup
  - Appletviewer CL can be initialized to vary these
- Applications unlimited in 1.0; can code a policy

SecurityManager

- Class defines check methods called by system
  - E.G. "checkRead(String filename)"
  - Method throws exception if invalid
- To create a security policy from scratch:
  - Create a subclass (code) & instantiate
  - Install using System.setSecurityManager; this cannot be revoked or replaced
  - This is used to create the Sandbox
  - If no SecurityManager installed, all privileges granted

Bytecode Verifier

- Checks a classfile for validity:
  - Code only has valid instructions & register use
  - Code does not overflow/underflow stack
  - Does not convert data types illegally or forge pointers
  - Accesses objects as correct type
  - Method calls use correct number & types of arguments
  - References to other classes use legal names
- Goal is to prevent access to underlying machine
  - via forged pointers, crashes, undefined states

ClassLoader

- Responsible for loading classes
  - given classname, locates/generates its definition
  - always looks at “standard” classes first
  - every class has a reference to the classloader instance that defined it
  - keeps namespaces of different applets separate (different ClassLoader instances)
  - each ClassLoader instance ~ OS process
  - “CLASSPATH” classes trusted in JDK 1.0-1.1, system classes trusted, otherwise invokes bytecode verifier

Java Archive (JAR) Format (1.1)

- Format for collecting & optionally signing sets of files
  - ZIP format + manifest + optional signatures
- Manifest
  - In file META-INF/MANIFEST.MF
  - Lists (some) JAR filenames, digests, digest algorithm(s) (MD5, SHA)
- Signatures
  - Separate manifest-like file, separate signature

Java Cryptography Architecture (Added in 1.1)

- Java cryptography architecture (JCA)
  - Framework (API) for access to services implemented by pluggable “providers”
  - digital signature algorithms (DSA), message digest algorithms (MD5 & SHA-1), key-generation algorithms, simple certificate management (1.1 had no API for specific formats)
  - Simple key management tool (simple “database”)

Problems with 1.0 through 1.1

- Sandbox too limiting
- "Trusted" programs given too much power
- Hard to define new security policy
  - Must write own SecurityManager
  - Must install it on its own JVM
- New privileges difficult to add
  - New method must be added to SecurityManager
  - Creates a backward incompatibility for each addition

Netscape Extensions

- Navigator 4.0 added "Capabilities" API:
  - Call to request privilege enable (string)
  - If not been granted before, UI asks if ok
  - Privilege disabled when method returns, but can be re-enabled without UI
  - Can disable or revert, can select which certificate to use
- May grant privileges to certificates or codebase
- Problems: Incompatible (Netscape only)

Microsoft Extensions

- Used CAB not JAR for signatures (incompatible)
- IE 3.0: Selected signed applets trusted
- IE 4.0: Fine-grained "Trust-Based Security"
  - User defines zones (stnd: Local, intranet, trusted sites, Internet, untrusted sites)
  - Each zone given privileges; standard privilege sets: High, Medium (UI file I/O), Low security
  - CAB file includes privilege request; query if beyond preapproved set (& okay with admin)
- Problem: Incompatible (IE on Win32 only)

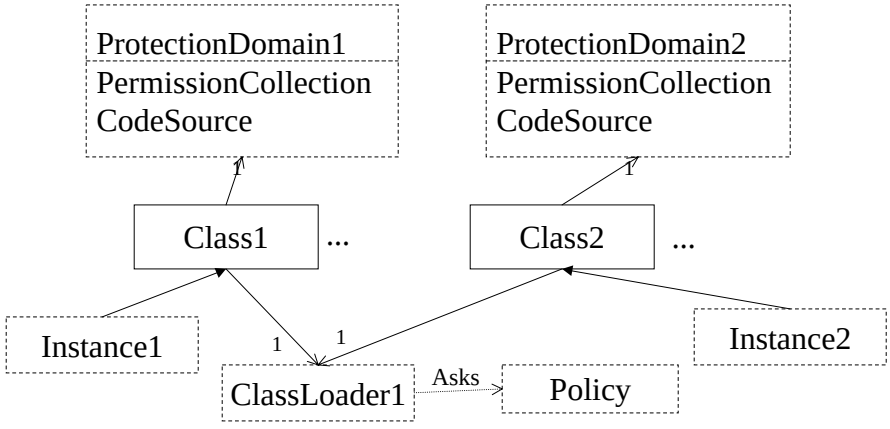
Security-Related Capabilities in Java 2 (SDK 1.2)

- Fine-grained configurable policies
  - Sample Security Policy
  - Runtime State: ProtectionDomain/CodeSource/Policy
  - Java 2 Runtime Security Check Algorithm
  - Permission & Its Subclasses
  - SecurityManager & AccessController
  - GuardedObject & Guard
- Java Cryptography Architecture (JCA) changes
- Java Cryptography Extension (JCE)

Sample Fine-Grained Security Policy for One User

Source of Code (CodeSource)		Permissions
Base URL	Signature	
http://www.schwab.com/classes/stockeditor.jar	Schwab's signature	• Read/write file /home/daw/stocks
http://*.schwab.com/	(not required)	• Connect/accept bankofamerica.com ports 1-1023 • Read file /home/daw/logo.png

Java 2: Each Class Has A ProtectionDomain



ProtectionDomain Class

- ProtectionDomain class
  - Created from a CodeSource and a PermissionCollection
  - Defines the set of permissions granted to classes; change the PermissionCollection to change permissions
  - Each class belongs to ONE ProtectionDomain instance, set at class creation time (and never changed again)
  - Access to these objects restricted; getting its reference requires RuntimePermission getProtectionDomain
- One ClassLoader can have >1 protection domain

CodeSource Class

- Created from:
  - a source (base) URL and
  - array of certificates
- Immutable
- "implies" method implements URL partial matches
  - Permits policies to use URL patterns

Policy Class

- Provides interface to user policy
  - Given a CodeSource, returns a PermissionCollection
  - Used during setup of ProtectionDomain to set a class' permissions

How a Class and ProtectionDomain Are Loaded

1. Loaded class C1 requests an unloaded class C2
2. C1's ClassLoader called, loads C2's class file, calls bytecode verifier
3. C2's CodeSource determined
4. Policy object given CodeSource, returns Permissions
5. If an existing ProtectionDomain has same CodeSource & Permissions, reused, else new ProtectionDomain created; C2 assigned to it

Java 2 Runtime Security Check Algorithm

- If method M requires permission P
  - M's implementation calls current SecurityManager's checkPermission(P)
- By default this calls new "AccessController" class
  - For each call stack entry, unwind from caller:
  - if caller's ProtectionDomain lacks P, exception (fail)
  - if caller called "doPrivileged" without context, return
  - if caller called "doPrivileged" with context, check it: return if context permits P else exception (fail).

Examples of Algorithm At Work

- Multiple ProtectionDomains:
  - Instance1 M1 calls Instance2 M2 calls System1 M3
  - System1 M3 (in System's ProtectionDomain) asks for a permission check
  - Permissions checked against the ProtectionDomains for System1, then Class2, then Class1
- doPrivileged call (without context):
  - Same example, but first System1 M3 calls doPrivileged
  - When permission check requested, ProtectionDomain for System1 checked and *no others* checked

Context

- getContext() takes a snapshot of current execution context ("stack trace")
  - snapshot includes ancestor threads
  - stored in type AccessControlContext
  - results can be stored & can used later to limit privileges (instead of enabling "all" privileges)
- Purpose: support actions "on behalf of another"
  - one thread posts event to another
  - delayed actions ("cron" job)

Algorithm Implications

- Default privileges are the *intersection* (minimum) of all class' permissions in call tree
  - Without doPrivilege, permissions only decrease
- "doPrivilege" enables "all" class' privileges
  - Like Unix "setuid"; enables trusted classes to use their full set of privileges but only when requested
  - Without context enables all privileges
  - With context enables only those privileges *also* in given context; safe because resulting privileges always less than without context

Warning: Don't Mix Protected Variables and Permission Checks

- If a method M1 is not overridden, the ProtectionDomain of its defining superclass used
- Methods running (even indirectly) with privilege shouldn't depend on protected variables
  - Attacker creates subclass with new method M2
  - M2 modifies protected variable used by M1
  - Cause M1 to be invoked; M1 influenced by M2!
- Identified by David A. Wheeler Oct 1999
  - Have not seen this in the literature

Permission Class

- Permission class
  - Encapsulates a permission granted or requested
  - Can be set "readonly" (from then on immutable)
  - Can be grouped using classes PermissionCollection and Permissions
- This briefing's terminology:
  - permissions granted to a ProtectionDomain also called "privileges"
  - no separate "Privilege" class

Permission Subclasses: FilePermission Class

- Gives rights to local files/directories
- Path name/pattern
  - Specific path: *file*, *directory*, *directory/file*
  - All files in directory: *directory/**
  - All files recursively in directory: *directory/-*
  - For current directory, omit "*directory/*"
  - For all files (**dangerous**), "*<<ALL FILES>>*"
- Rights set (1+): read, write, execute, delete

Permission Subclasses: SocketPermission

- Host
  - Local machine: "", "*localhost*"
  - Given machine: *IP address* or *hostname*
  - All hosts in a domain: **.domain*
  - All hosts: *
- Portrange
  - Single port: *portnumber*
  - Port range: *port1-port2*, *port1-*, *-port2*
- Actions (1+): accept, connect, listen, resolve

Permission Subclasses: PropertyPermission

- Gives rights to properties
  - Similar to OS environment variables
- Target
  - Specific property: os.name
  - Pattern: java.*
- Actions (1+): read, write

Permission Subclasses: Other Permission Subclasses

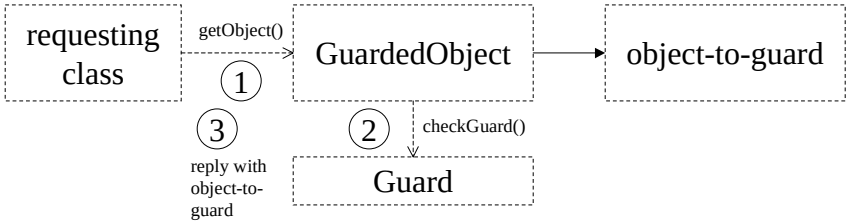
- RunTimePermission: string with permission name
  - createClassLoader
  - getClassLoader
  - setSecurityManager
  - exitVM
  - ...
- Many other specialized Permission subclasses
- AllPermission
  - special class meaning “all permissions”

SecurityManager Changes

- New method checkPermission(P)
  - Throws exception if permission P not held, else returns
  - All previous "check" methods rewritten in terms of checkPermission
  - Permits creation of new Permissions without changing SecurityManager
- By default, calls on AccessController class
  - AccessController implements the new algorithm

GuardedObject (1 of 3)

- To protect *one* method in *all* instances, use SecurityManager directly as shown so far
- To protect a *reference* to an *individual* instance, consider using "GuardedObject":



GuardedObject (2 of 3)

- GuardedObject class encapsulates object-to-guard
  - asks “Guard” interface to determine if access ok
  - Permission implements Guard by calling SecurityManager. checkPermission(self)
  - PermissionCollection doesn’t implement (I’ve reported)
- Provider of object-to-guard does the following:
  - Instantiates new Guard (e.g., a Permission)
  - Instantiates GuardedObject, using object-to-guard and the guard
  - Gives GuardedObject’s reference to requestors

GuardedObject (3 of 3)

- Clients who wish to use object-to-guard call GuardedObject’s getObject()
  - GuardedObject instance calls its Guard’s checkGuard()
  - if ok, object-to-guard’s reference returned
  - if not ok, security exception thrown

Java Cryptography Architecture (JCA) Changes in 1.2

- Adds more APIs that providers can support
  - Keystore creation and management
  - Algorithm parameter management
  - Algorithm parameter generation
  - Conversions between different key representations
  - Certificate factory support to generate certificates and certificate revocation lists (CRLs) from their encodings (Sun implements X.509's)
  - Random-number generation (RNG) algorithm

Java Cryptography Extension (JCE)

- Adds encryption, key exchange, key generation, message authentication code (MAC)
  - Multiple "providers" supported
  - Keys & certificates in "keystore" database
- Separate due to export control

Other Areas In Development: JSSE and JAAS

- Java Secure Socket Extension
  - Implements SSL
- Java Authentication and Authorization Service
  - Based on PAM: pluggable authenticators for passwords, smart cards, biometric devices, etc.
  - Authenticators may be required, requisite (stop on failure), sufficient (but not required), or optional
  - Adds user-centric (vs. code-centric) control: permissions granted to Principal (not just CodeSource), implemented through a modified SecurityManager

Past Java Security Breaches (1 of 2)

- 8 Serious Breaches listed in *Java Security* (1997)
  - "Jumping the Firewall" (DNS interaction)
  - "Slash and Burn" (slash starts classname)
  - "Applets running wild" (evil class loader installed and creates type confusion)
  - "Casting Caution" (failed to test if method private, type casting)
  - "Tag-Team Applets" (create type confusion)

Past Java Security Breaches (2 of 2)

- "You're not my type" (flaw in array implementation - type confusion)
- "Casting Caution #2" (as before, but in a loop test wasn't repeated)
- "Big Attacks Come in Small Packages" (untrusted code could be loaded into sensitive packages, e.g. com.ms, and gain their privileges)

- Others have been announced since
  - See http://java.sun.com/sfaq/chronology.html
  - Many are problems in bytecode verifier or classloader

Malicious Applets (Staying Within the Sandbox)

- Denial of Service
  - Deny platform use (busy threads, loop, exhaust GUI resources)
  - Kill other threads
- Invasion of Privacy
- Annoyance: constant sound
- Flashing display (causes seizures in some users)
- Steal CPU cycles (e.g. crack encryption)

Java Advantages

- Permits controlled execution of less trusted code (vs. ActiveX)
- Permits fine-grained permission control
- Attention paid to security
- Portability
- "Instant installation"
- Sun's source reviewable (*not* open source)

Java Security Disadvantages (1 of 3)

- Hard to prove correct
  - complex from security point-of-view
  - rapidly expanding/changing
  - VM+libraries lacks formal security model
- Many internal interdependencies (vs. reference monitors); often breaks "all the way"
- Complex dependencies on other systems
  - OS, browsers, network (DNS), PKI

Java Security Disadvantages (2 of 3)

- Applets evade many security measures (e.g. most firewalls)
- Breaches demonstrated
- Many areas immature
- No standardized auditing (MS extension)
- Simplifies reverse engineering of code (problem?)
- Poor performance may encourage security-weakening “shortcuts”

Java Security Disadvantages (3 of 3)

- Weak against denial-of-service & nuisances
- Insecure implementation defaults (e.g. null ClassLoader or SecurityManager)
- Security policy management too complex for endusers and weak administrative support
- Flexible policies accepted by users may permit hidden breaching interactions

Key Points

- Progression of Access Control Flexibility
  - JDK 1.0: Sandbox + total trust of local applications
  - JDK 1.1: Above + optional total trust with signature
  - SDK 1.2: Above + Fine-grained access control
- Java 2 ProtectionDomains
  - Checks call tree, by default intersection of permissions
  - doPrivilege permits permissions to be re-enabled
- GuardedObject to protect specific objects

Useful References

- Li Gong, *Inside Java 2 Platform Security*, 1999, Palo Alto, CA: Addison-Wesley.
- G. McGraw & E. Felten, *Java Security: Hostile Applets, Holes, and Antidotes*, 1997, NY: John Wiley & Sons.
- G. McGraw & E. Felten, *Securing Java: Getting Down to Business with Mobile Code*, 1999, NY: John Wiley & Sons, http://www.securingjava.com

Useful Websites

- Sun's Java website: http://java.sun.com
- Existing Java programs/info available at:
  - http://www.gamelan.com
  - http://www.jars.com (Java Applet Rating Service)
- RST's Java Security Hotlist
  - http://www.rstcorp.com/javasecurity/links.html

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Backup Slides

Java Naming and Directory Interface (JNDI)

- Unified interface to multiple naming & directory services
  - E.G.: LDAP (v2 & v3), NIS(YP), NIS+, CORBA's COS Naming, Novell NDS, DNS

Java Card (Smart Cards)

- Limited space:256bytes RAM, 8K EEPROM, 16K ROM
- ISO 7816: command sent, card responds
- Multiple applets/card supported
- Subset JVM
  - Omits dynamic class loading, security manager, threads/synchronization, object cloning, finalization, large primitive data types (float, double, long, char)