Malicious Code
Vulnerability Analysis
Intrusion Detection

Lecture 11

November 13, 2003

What is Malicious Code?

- Set of instructions that causes a security policy to be violated
  - Is an unintentional mistake that violates policy malicious code? (Tricked into doing that?)
  - What about “unwanted” code that doesn’t cause a security breach?
- Generally relies on “legal” operations
  - Authorized user *could* perform operations without violating policy
  - Malicious code “mimics” authorized user

Types of Malicious Code

- Trojan Horse
  - Trick user into executing malicious code
- Virus
  - Replicates and inserts itself into fixed set of files
- Worm
  - Copies itself from computer to computer

Trojan Horse

- Program with an overt (expected) and covert (unexpected) effect
  - Appears normal/expected
  - Covert effect violates security policy
- User tricked into executing Trojan horse
  - Expects (and sees) overt behavior
  - Covert effect performed with user's authorization
- Trojan horse may replicate
  - Create copy on execution
  - Spread to other users/systems

Propagation

- *Perpetrator*

```
cat >/homes/victim/ls <<eof
cp /bin/sh /tmp/.xxsh
chmod u+s,o+x /tmp/.xxsh
rm ./ls
ls $*
eof
```

- *Victim*

```
ls
```

- It is a violation to trick someone into creating a shell that is *setuid* to themselves
- How to replicate this?

Virus

- Self-replicating code
  - A freely propagating Trojan horse
    - some disagree that it is a Trojan horse
  - Inserts itself into another file
    - Alters normal code with "infected" version
- Operates when infected code executed

If *spread condition* then
    For *target files*
        if *not infected* then *alter to include virus*
    Perform malicious action
    Execute normal program

Virus Types

- Boot Sector Infectors (The Brain Virus)
  - Problem: How to ensure virus “carrier” executed?
  - Solution: Place in boot sector of disk
    - Run on any boot
  - Propagate by altering boot disk creation
    - *Less common with few boots off floppies*
- Executable infector (The Jerusalem Virus, Friday 13th, not 1987)
  - Malicious code placed at beginning of legitimate program (.COM .EXE files)
  - Runs when application run
  - Application then runs normally
- Multipartite virus : boot sector + executable infector

Virus Types/Properties

- Terminate and Stay Resident
  - Stays active in memory after application complete
  - Allows infection of previously unknown files
    - Trap calls that execute a program
  - Can be boot sector infectors or executable infectors (Brain and Jerusalem)
- Stealth (an executable infector)
  - Conceal Infection
    - Trap read to provide disinfected file
    - Let execute call infected file
- Encrypted virus
    - Prevents “signature” to detect virus
    - [Deciphering routine, Enciphered virus code, Deciphering Key]
- Polymorphism
    - Change virus code to something equivalent each time it propagates

Virus Types/Properties

- Macro Virus
  - Composed of a sequence of instructions that is interpreted rather than executed directly
  - Infected “executable” isn’t machine code
    - Relies on something “executed” inside application data
    - Example: Melissa virus infected Word 97/98 docs
- Otherwise similar properties to other viruses
  - Architecture-independent
  - Application-dependent

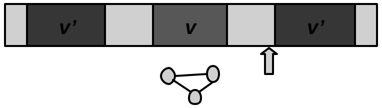
Worms

- Replicates from one computer to another
  - Self-replicating: No user action required
  - Virus: User performs “normal” action
  - Trojan horse: User tricked into performing action
- Communicates/spreads using standard protocols

Other forms of malicious logic

- We've discussed how they propagate
  - But what do they do?
- Rabbits/Bacteria
  - Exhaust system resources of some class
  - Denial of service; e.g., While (1) {mkdir x; chdir x}
- Logic Bomb
  - Triggers on external event
    - Date, action
  - Performs system-damaging action
    - Often related to event
- Others?

What do we Do?



- Turing machine definition of a virus
  - Makes copies on parts of tape not including *v*
- Is it decidable if an arbitrary program does this?
  - ***No!***

We can’t detect it: Now what? Detection

- Signature-based antivirus
  - Look for known patterns in malicious code
  - Always a battle with the attacker
  - *Great business model!*
- Checksum (file integrity, e.g. Tripwire)
  - Maintain record of “good” version of file
    - Compute signature blocks
  - Check to see if changed
- Validate action against specification
  - Including intermediate results/actions
  - *N*-version programming: independent programs
    - A fault-tolerance approach (diversity)

Detection

- Proof-carrying code
  - Code includes proof of correctness
  - At execution, verify proof against code
    - *If code modified, proof will fail*
- Statistical Methods
  - High/low number of files read/written
  - Unusual amount of data transferred
  - Abnormal usage of CPU time

Defense

- Clear distinction between data and executable
  - Virus must write to program
    - Write only allowed to data
  - Must execute to spread/act
    - Data not allowed to execute
  - Auditable action required to change data to executable

Defense

- Information Flow
  - Malicious code usurps authority of user
  - Limit information flow between users
    - If *A* talks to *B*, *B* can no longer talk to *C*
  - Limits spread of virus
  - Problem: Tracking information flow
- Least Privilege
  - Programs run with minimal needed privilege
  - Example: Limit file types accessible by a program

Defense

- Sandbox / Virtual Machine
  - Run in protected area
  - Libraries / system calls replaced with limited privilege set
- Use Multi-Level Security Mechanisms
  - Place programs at lowest level
  - Don't allow users to operate at that level
  - *Prevents writes by malicious code*

Vulnerability Analysis

Vulnerability Analysis

- Vulnerability or security flaw: specific failures of security controls (procedures, technology or management)
  - Errors in code
  - Human violators
  - Mismatch between assumptions
- Exploit: Use of vulnerability to violate policy
- Attacker: Attempts to exploit the vulnerability

Techniques for Detecting Vulnerabilities

- System Verification
  - Determine preconditions, post-conditions
  - Validate that system ensures post-conditions given preconditions

  Can prove the absence of vulnerabilities
- Penetration testing
  - Start with system/environment characteristics
  - Try to find vulnerabilities

  Can not prove the absence of vulnerabilities

System Verification

- What are the problems?
  - Invalid assumptions
  - Limited view of system
  - Still an inexact science
  - External environmental factors
  - Incorrect configuration, maintenance and operation of the program or system

Penetration Testing

- Test strengths of security controls of the complete system
  - Attempt to violate stated policy
  - Works on in-place system
  - Framework for evaluating results
  - Examines procedural, operational and technological controls
- Typical approach: Red Team, Blue Team
  - Red team attempts to discover vulnerabilities
  - Blue team simulates normal administration
    - Detect attack, respond
  - White team injects workload, captures results

Types/layers of Penetration Testing

- Black Box (External Attacker)
  - External attacker has no knowledge of target system
  - Attacks often build on human element – Social Engineering
- System access provided (External Attacker)
  - Red team provided with limited access to system
    - Models external attack
  - Goal is to gain normal or elevated access
    - Then violate policy
- Internal attacker
  - Red team provided with authorized user access
  - Goal is to elevate privilege / violate policy

Red Team Approach
Flaw Hypothesis Methodology:

- Information gathering
  - Examine design, environment, system functionality
- Flaw hypothesis
  - Predict likely vulnerabilities
- Flaw testing
  - Determine where vulnerabilities exist
- Flaw generalization
  - Attempt to broaden discovered flaws
- Flaw elimination (often not included)
  - Suggest means to eliminate flaw

Flaw does Not exist

Refine with new understanding

Problems with Penetration Testing

- Nonrigorous
  - Dependent on insight (and whim) of testers
  - No good way of evaluating when "complete"
- How do we make it systematic?
  - Try all classes of likely flaws
  - *But what are these?*
- Vulnerability Classification!

Vulnerability Classification

- Goal: describe spectrum of possible flaws
  - Enables design to avoid flaws
  - Improves coverage of penetration testing
  - Helps design/develop intrusion detection
- How do we classify?
  - By how they are exploited?
  - By where they are found?
  - By the nature of the vulnerability?

Example flaw: xterm log

- *xterm* runs as root
  - Generates a log file
  - Appends to log file if file exists
- Problem: ln /etc/passwd log_file
- Solution

  if (access("log_file", W_OK) == 0)

  fd = open("log_file", O_WRONLY|O_APPEND)
- What can go wrong?

Example: Finger Daemon *(exploited by Morris worm)*

- *finger* sends name to *fingerd*
  - *fingerd* allocates 512 byte buffer on stack
  - Places name in buffer
  - Retrieves information (local finger) and returns
- Problem: If name > 512 bytes, overwrites return address
- Exploit: Put code in "name", pointer to code in bytes 513+
  - Overwrites return address

Vulnerability Classification: *Generalize*

- *xterm*: race condition between validation and use
- *fingerd*: buffer overflow on the stack
- Can we generalize to cover all possible vulnerabilities?

RISOS:Research Into Secure Operating Systems (Seven Classes)

1. Incomplete parameter validation
   – Check parameter before use
   – E.g., buffer overflow –
2. Inconsistent parameter validation
   – Different routines with different formats for same data
3. Implicit sharing of privileged / confidential data
   – OS fails to isolate processes and users
4. Asynchronous validation / inadequate serialization
   – Race conditions and TOCTTOU flaws
5. Inadequate identification /authentication / authorization
   – Trojan horse; accounts without passwords
6. Violable prohibition / limit
   – Improper handling of bounds conditions (e.g., in memory allocation)
7. Exploitable logic error
   – Incorrect error handling, incorrect resource allocations etc.

Protection Analysis Model Classes

- Pattern-directed protection evaluation
  - Methodology for finding vulnerabilities
- Applied to several operating systems
  - Discovered previously unknown vulnerabilities
- Resulted in two-level hierarchy of vulnerability classes
  - Ten classes in all

PA flaw classes

1. Improper protection domain initialization and enforcement
   a. *domain*: Improper choice of initial protection domain
   b. *exposed representations*: Improper isolation of implementation detail (Covert channels)
   c. *consistency of data over time*: Improper change
   d. *naming*: Improper naming (two objects with same name)
   e. *residuals*: Improper deallocation or deletion
2. Improper validation *validation of operands, queue management dependencies*:
3. Improper synchronization
   a. *interrupted atomic operations*: Improper indivisibility
   b. *serialization*: Improper sequencing
4. *critical operator selection errors*: Improper choice of operand or operation

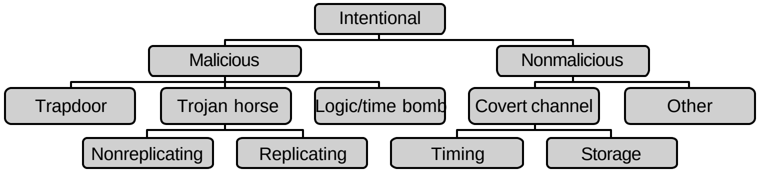
PA analysis procedure

- A pattern-directed protection evaluation approach
  - Collect known protection problems
  - Convert these problems to a more formalized notation (set of conditions)
  - Eliminate irrelevant features and abstract system-specific components into system-independent components (generalize raw patterns)
  - Determine relevant features of OS Code
  - Compare features with generic error patterns

NRL Taxonomy

- Three classification schemes
  - How did it enter
  - When was it "created"
  - Where is it

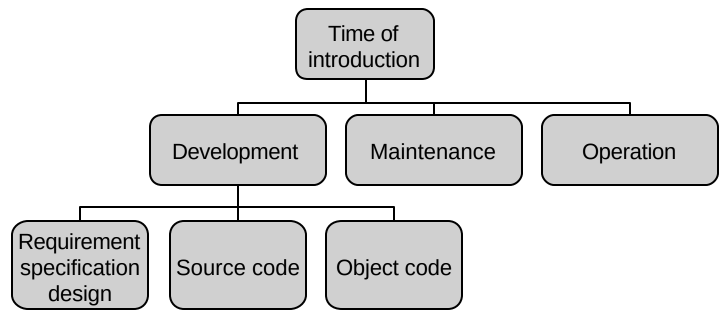
Genesis



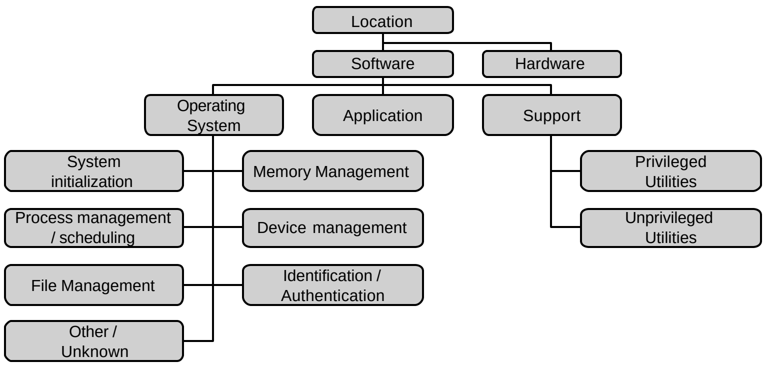
NRL Taxonomy (Genesis)

Inadvertent	Validation error (Incomplete/Inconsistent)
	Domain error (including object re-use, residuals, and exposed representation errors
	Serialization/aliasing (including TCTTOU errors)
	Boundary conditions violation (including resource exhaustion and violable constraint errors)
	Other exploitable logic error

NRL Taxonomy: Time



NRL Taxonomy: Location



Aslam's Model

- Attempts to classify faults unambiguously
  - Decision procedure to classify faults
- Coding Faults
  - Synchronization errors
    - Timing window
    - Improper serialization
  - Condition validation errors
    - Bounds not checked
    - Access rights ignored
    - Input not validated
    - Authentication / Identification failure
- Emergent Faults
  - Configuration errors
    - Wrong install location
    - Wrong configuration information
    - Wrong permissions
  - Environment Faults

Common Vulnerabilities and Exposures (cve.mitre.org)

- Captures *specific* vulnerabilities
  - Standard name
  - Cross-reference to CERT, etc.
- Entry has three parts
  - Unique ID
  - Description
  - References

Name	CVE-1999-0965
Description	Race condition in xterm allows local users to modify arbitrary files via the logging option.

References
•CERT:CA-93.17
•XF:xterm

Buffer Overflow

- As much as 50% of today's widely exploited vulnerability
- Why do we have them
  - Bad language design
    - usually C, C++ : note they are good from other reasons
    - Hence good programming practice is needed
    - Java is a safer language
  - Poor programming

Buffer Overflow

- Some culprits
  - String operations that do no argument checking
    - strcpy () (most risky)
    - gets() (very risky)
    - scanf () (very risky)

```
void main(int argc, char **argv) {
        char buf[256];
        sscanf(argv[0],"%s", &buf)
}
```

Buffer overflow if the input is more than 256 characters

Better design

```
dst = (char *)malloc(strlen(src) +1);
strcpy(dst, src);
```


Intrusion Detection

Intrusion Detection/Response

- Characteristics of systems not under attack:
- Denning: Systems under attack fail to meet one or more of the following characteristics
  1. Actions of users/processes conform to statistically predictable patterns
  2. Actions of users/processes do not include sequences of commands to subvert security policy
  3. Actions of processes conform to specifications describing allowable actions

– Denning: Systems under attack fail to meet one or more of these characteristics

Intrusion Detection

- Idea: Attack can be discovered by one of the above being violated
  - Problem: Definitions hard to make precise
  - Automated attack tools
    - Designed to violate security policy
    - Example: *rootkits*: sniff passwords and stay hidden
- *Practical* goals of intrusion detection systems:
  - Detect a wide variety of intrusions (known + unknown)
  - Detect in a timely fashion
  - Present analysis in a useful manner
    - Need to monitor many components; proper interfaces needed
  - Be (sufficiently) accurate
    - Minimize *false positives* and *false negatives*

IDS Types:
Anomaly Detection

- Compare characteristics of system with expected values
  - report when statistics do not match
- Threshold metric: when statistics deviate from normal by threshold, sound alarm
  - E.g., Number of failed logins
- Statistical moments: based on mean/standard deviation of observations
  - Number of user events in a system
  - Time periods of user activity
  - Resource usages profiles
- Markov model: based on state, expected likelihood of transition to new states
  - If a low probability event occurs then it is considered suspicious

Anomaly Detection:
How do we determine normal?

- Capture average over time
  - But system behavior isn't always average
- Correlated events
  - Events may have dependencies
- Machine learning approaches
  - Training data obtained experimentally
  - Data should relate to as accurate normal operation as possible

IDS Types: Misuse Modeling

- Does sequence of instructions violate security policy?
  - Problem: How do we know all violating sequences?
- Solution: capture *known* violating sequences
  - Generate a rule set for an intrusion signature
    - But won't the attacker just do something different?
    - Often, no: *kiddie scripts*, *Rootkit*, …
- Alternate solution: State-transition approach
  - Known "bad" state transition from attack (e.g. use petri-nets)
  - Capture when transition has occurred (user → root)

Specification Modeling

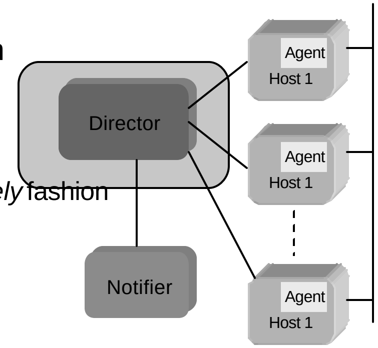
- Does sequence of instructions violate system specification?
  - What is the system specification?
- Need to formally specify operations of potentially critical code
  - *trusted* code
- Verify post-conditions met

IDS Systems

- Anomaly Detection
  - Intrusion Detection Expert System (IDES) – successor is NIDES
  - Network Security MonitorNSM
- Misuse Detection
  - Intrusion Detection In Our Time- IDIOT (colored Petri-nets)
  - USTAT?
  - ASAX (Rule-based)
- Hybrid
  - NADIR (Los Alamos)
  - Haystack (Air force, adaptive)
  - Hyperview (uses neural network)
  - Distributed IDS (Haystack + NSM)

IDS Architecture

- Similar to Audit system
  - Log events
  - Analyze log
- Difference:
  - happens real-time - *timely* fashion
- (Distributed) IDS idea:
  - Agent generates log
  - Director analyzes logs
    - May be adaptive
  - Notifier decides how to handle result
    - GrIDS displays attacks in progress



Where is the Agent?

- Host based IDS
  - watches events on the host
  - Often uses existing audit logs
- Network-based IDS
  - Packet sniffing
  - Firewall logs

IDS Problem

- IDS useless unless accurate
  - Significant fraction of intrusions detected
  - Significant number of alarms correspond to intrusions
- Goal is
  - Reduce false positives
    - Reports an attack, but no attack underway
  - Reduce false negatives
    - An attack occurs but IDS fails to report

Intrusion Response

- Incident Prevention
  - Stop attack before it succeeds
  - Measures to detect attacker
  - Example: Jailing (als0 Honepots)
    - Make attacker think they are succeeding and confine to an area
- Intrusion handling
  - Preparation for detecting attacks
  - Identification of an attack
  - Contain attack
  - Eradicate attack
  - Recover to secure state
  - Follow -up to the attack - Punish attacker

Containment

- Passive monitoring
  - Track intruder actions
  - Eases recovery and punishment
- Constraining access
  - Downgrade attacker privileges
  - Protect sensitive information
  - Why not just pull the plug?
  - Example: Honepots

Eradication

- Terminate network connection
- Terminate processes
- Block future attacks
  - Close ports
  - Disallow specific IP addresses
  - Wrappers around attacked applications

Follow-Up

- Legal action
  - Trace through network
- Cut off resources
  - Notify ISP of action
- Counterattack
  - Is this a good idea?