Lecture 17
November 3, 2025

ECS 235A, Computer and Information Security

Example Flaws

- Use these to compare classification schemes
- First one: race condition (*xterm*)
- Second one: buffer overflow on stack leading to execution of injected code (*fingerd*)
- Both are very well known, and fixes available!
    - And should be installed everywhere …

Flaw #1: xterm

- *xterm* emulates terminal under X11 window system
  - Must run as *root* user on UNIX systems
    - No longer universally true; reason irrelevant here
- Log feature: user can log all input, output to file
  - User names file
  - If file does not exist, *xterm* creates it, makes owner the user
  - If file exists, *xterm* checks user can write to it, and if so opens file to append log to it

File Exists

- Check that user can write to file requires special system call
    - Because *root* can append to any file, check in *open* will always succeed

Check that user can write to file "/usr/tom/X"

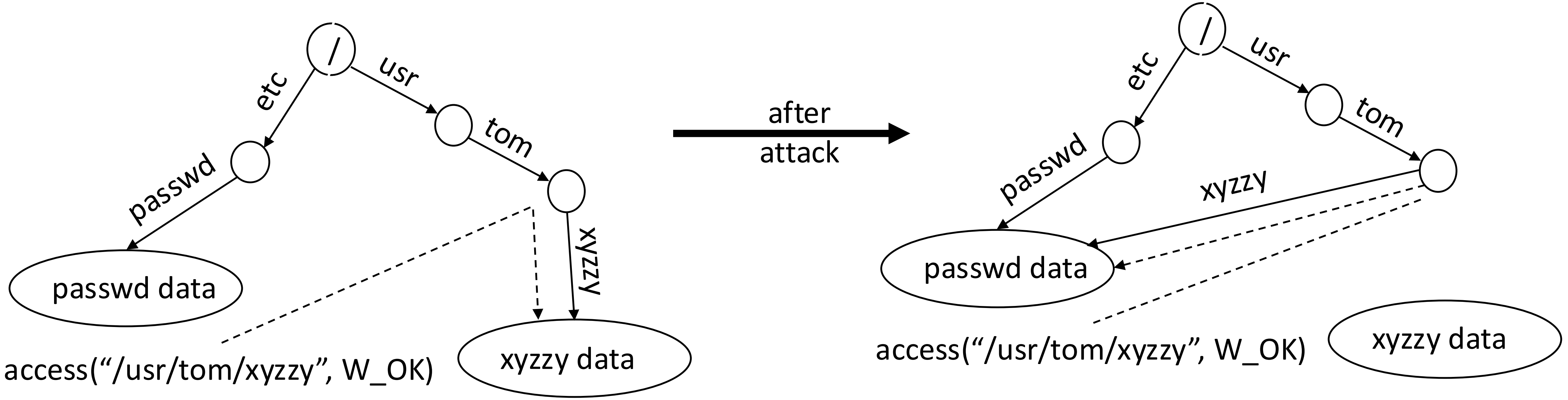
```
if (access("/usr/tom/X", W_OK) == 0){
```

Open "/usr/tom/X" to append log entries

```
  if ((fd = open("/usr/tom/X", O_WRONLY|O_APPEND))< 0){
          /* handle error: cannot open file */
  }
}
```

Problem

- Binding of file name “/usr/tom/X” to file object can change between first and second lines
  - left is at *access*; right is at *open*
  - Note file opened is *not* file checked

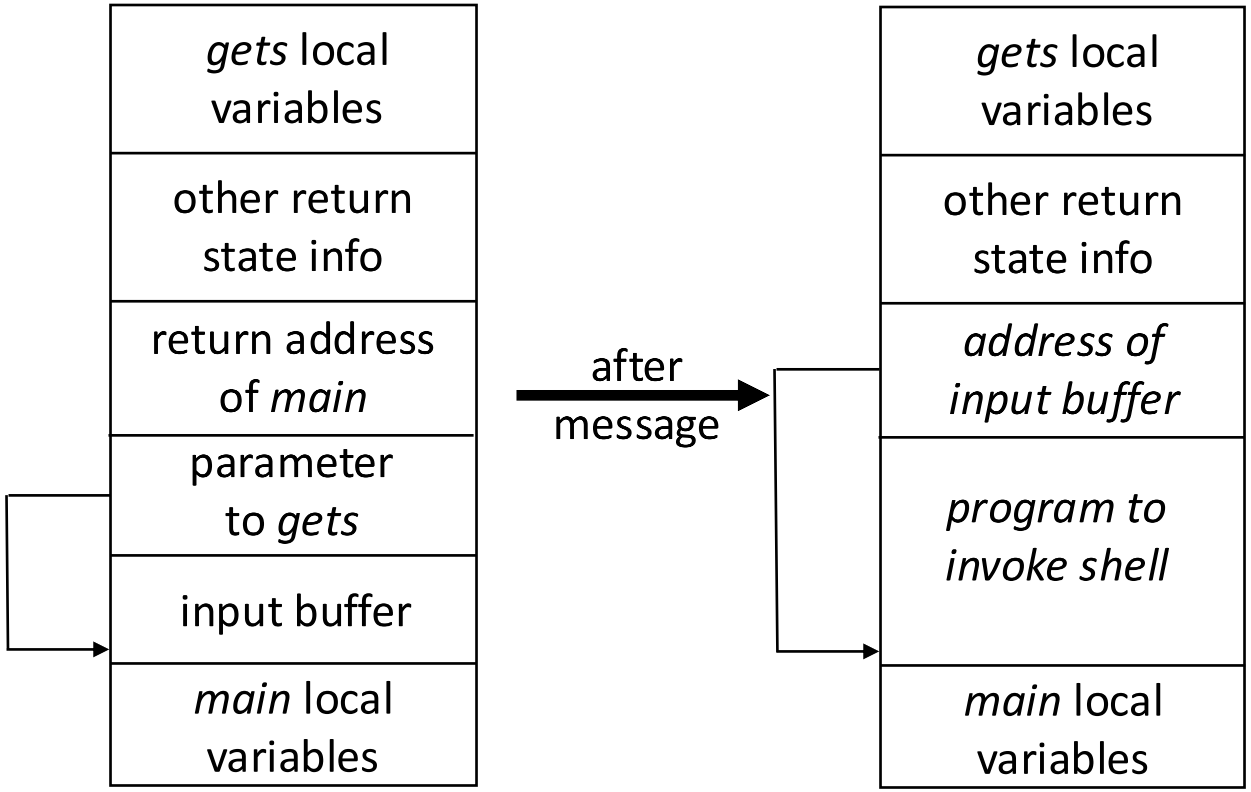


Flaw #2: *fingerd*

- Exploited by Internet Worm of 1988
  - Recurs in many places, even now
- *finger* client send request for information to server *fingerd* (*finger* daemon)
  - Request is name of at most 512 chars
  - What happens if you send more?

Buffer Overflow

- Extra chars overwrite rest of stack, as shown
- Can make those chars change return address to point to beginning of buffer
- If buffer contains small program to spawn shell, attacker gets shell on target system



Frameworks

- Goals dictate structure of classification scheme
  - Guide development of attack tool $\Rightarrow$ focus is on steps needed to exploit vulnerability
  - Aid software development process $\Rightarrow$ focus is on design and programming errors causing vulnerabilities
- Following schemes classify vulnerability as n-tuple, each element of n-tuple being classes into which vulnerability falls
  - Some have 1 axis; others have multiple axes

Research Into Secure Operating Systems (RISOS)

- Goal: aid computer, system managers in understanding security issues in OSes, and help determine how much effort required to enhance system security
- Attempted to develop methodologies and software for detecting some problems, and techniques for avoiding and ameliorating other problems
- Examined Multics, TENEX, TOPS-10, GECOS, OS/MVT, SDS-940, EXEC-8

Classification Scheme

- Incomplete parameter validation
- Inconsistent parameter validation
- Implicit sharing of privileged/confidential data
- Asynchronous validation/inadequate serialization
- Inadequate identification/authentication/authorization
- Violable prohibition/limit
- Exploitable logic error

Incomplete Parameter Validation

- Parameter not checked before use
- Example: emulating integer division in kernel (RISC chip involved)
  - Caller provided addresses for quotient, remainder
  - Quotient address checked to be sure it was in user's protection domain
  - Remainder address *not* checked
    - Set remainder address to address of process' level of privilege
    - Compute 25/5 and you have level 0 (kernel) privileges
- Check for type, format, range of values, access rights, presence (or absence)

Inconsistent Parameter Validation

- Each routine checks parameter is in proper format for that routine but the routines require different formats
- Example: each database record 1 line, colons separating fields
  - One program accepts colons, newlines as pat of data within fields
  - Another program reads them as field and record separators
  - This allows bogus records to be entered

Legacy of RISOS

- First funded project examining vulnerabilities
- Valuable insight into nature of flaws
  - Security is a function of site requirements and threats
  - Small number of fundamental flaws recurring in many contexts
  - OS security not critical factor in design of OSes
- Spurred additional research efforts into detection, repair of vulnerabilities

Program Analysis (PA)

- Goal: develop techniques to find vulnerabilities
- Tried to break problem into smaller, more manageable pieces
- Developed general strategy, applied it to several OSes
  - Found previously unknown vulnerabilities

Classification Scheme

- Improper protection domain initialization and enforcement
  - Improper choice of initial protection domain
  - Improper isolation of implementation detail
  - Improper change
  - Improper naming
  - Improper deallocation or deletion
- Improper validation
- Improper synchronization
  - Improper indivisibility
  - Improper sequencing
- Improper choice of operand or operation

Improper Choice of Initial Protection Domain

- Initial incorrect assignment of privileges, security and integrity classes
- Example: on boot, protection mode of file containing identifiers of all users can be altered by any user
  - Under most policies, should not be allowed

Improper Isolation of Implementation Detail

- Mapping an abstraction into an implementation in such a way that the abstraction can be bypassed
- Example: virtual machines modulate length of time CPU is used by each to send bits to each other
- Example: Having raw disk accessible to system as ordinary file, enabling users to bypass file system abstraction and write directly to raw disk blocks

Improper Change

- Data is inconsistent over a period of time
- Example: *xterm* flaw
  - Meaning of "/usr/tom/X" changes between *access* and *open*
- Example: parameter is validated, then accessed; but parameter is changed between validation and access
  - Burroughs B6700 allowed allowed this

Improper Naming

- Multiple objects with same name
- Example: Trojan horse
  - *loadmodule* attack discussed earlier; “bin” could be a directory or a program
- Example: multiple hosts with same IP address
  - Messages may be erroneously routed

Improper Deallocation or Deletion

- Failing to clear memory or disk blocks (or other storage) after it is freed for use by others
- Example: program that contains passwords that a user typed dumps core
  - Passwords plainly visible in core dump

Improper Validation

- Inadequate checking of bounds, type, or other attributes or values
- Example: *fingerd*’s failure to check input length

Improper Indivisibility

- Interrupting operations that should be uninterruptable
  - Often: “interrupting atomic operations”
- Example: *mkdir* flaw (UNIX Version 7)
  - Created directories by executing privileged operation to create file node of type directory, then changed ownership to user
  - On loaded system, could change binding of name of directory to be that of password file after directory created but before change of ownership
  - Attacker can change administrator’s password

Improper Sequencing

- Required order of operations not enforced
- Example: one-time password scheme
  - System runs multiple copies of its server
  - Two users try to access same account
    - Server 1 reads password from file
    - Server 2 reads password from file
    - Both validate typed password, allow user to log in
    - Server 1 writes new password to file
    - Server 2 writes new password to file
  - Should have every read to file followed by a write, and vice versa; not two reads or two writes to file in a row

Improper Choice of Operand or Operation

- Calling inappropriate or erroneous instructions
- Example: cryptographic key generation software calling pseudorandom number generators that produce predictable sequences of numbers

Legacy

- First to explore automatic detection of security flaws in programs and systems
- Methods developed but not widely used
  - Parts of procedure could not be automated
  - Complexity
  - Procedures for obtaining system-independent patterns describing flaws not complete

NRL Taxonomy

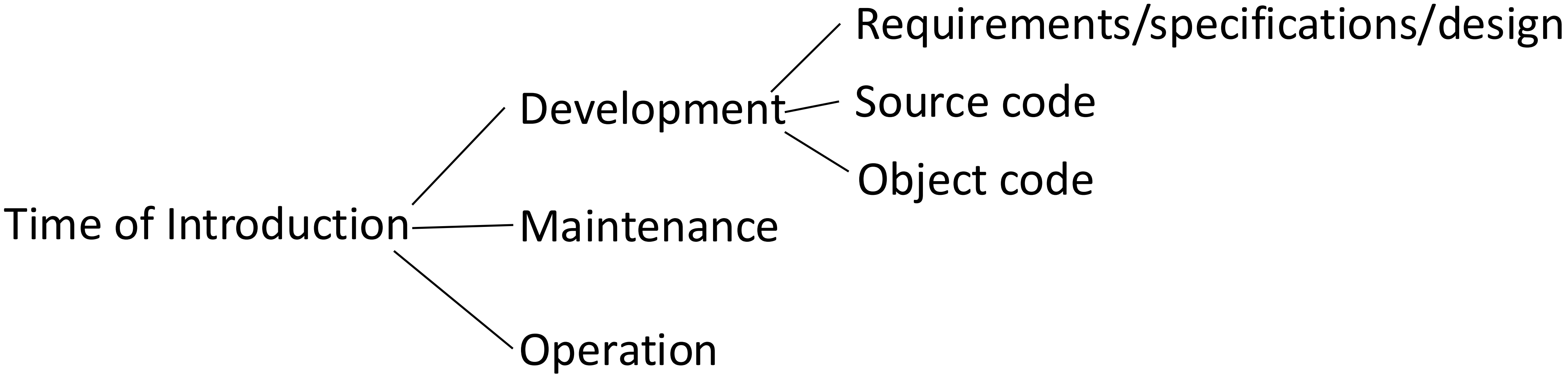
- Goals:
  - Determine how flaws entered system
  - Determine when flaws entered system
  - Determine where flaws are manifested in system
- 3 different schemes used:
  - Genesis of flaws
  - Time of flaws
  - Location of flaws

Genesis of Flaws

- Intentional
  - Malicious
    - Trojan horse
      - Nonreplicating
      - Replicating
    - Trapdoor
    - Logic bomb
  - Nonmalicious
    - Covert channel
      - Storage channel
      - Timing channel
    - Other

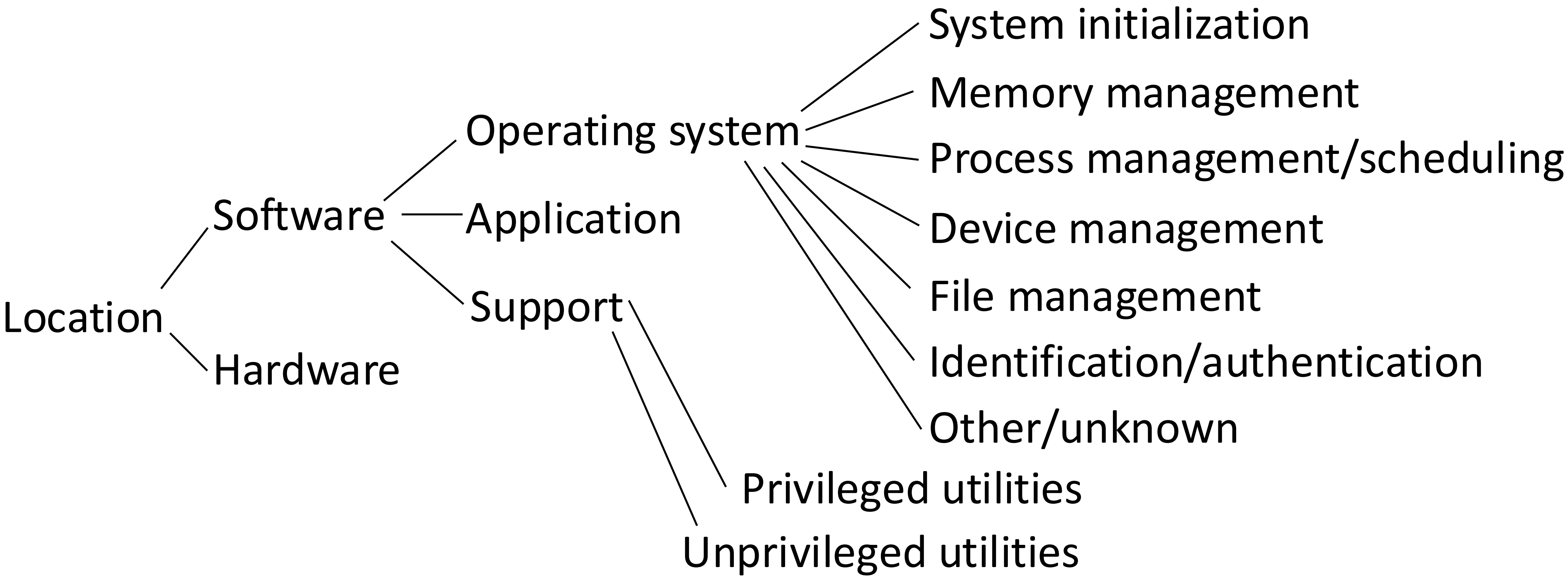
- Inadvertent (unintentional) flaws classified using RISOS categories; not shown above
  - If most inadvertent, better design/coding reviews needed
  - If most intentional, need to hire more trustworthy developers and do more security-related testing

Time of Flaws



- Development phase: all activities up to release of initial version of software
- Maintenance phase: all activities leading to changes in software performed under configuration control
- Operation phase: all activities involving patching and not under configuration control

Location of Flaw



- Focus effort on locations where most flaws occur, or where most serious flaws occur

Legacy

- Analyzed 50 flaws
- Concluded that, with a large enough sample size, an analyst could study relationships between pairs of classes
  - This would help developers focus on most likely places, times, and causes of flaws
- Focused on social processes as well as technical details
  - But much information required for classification not available for the 50 flaws

Aslam’s Model

- Goal: treat vulnerabilities as faults and develop scheme based on fault trees
- Focuses specifically on UNIX flaws
- Classifications unique and unambiguous
  - Organized as a binary tree, with a question at each node. Answer determines branch you take
  - Leaf node gives you classification
- Suited for organizing flaws in a database

Top Level

- Coding faults: introduced during software development
  - Example: *fingerd*’s failure to check length of input string before storing it in buffer
- Emergent faults: result from incorrect initialization, use, or application
  - Example: allowing message transfer agent to forward mail to arbitrary file on system (it performs according to specification, but results create a vulnerability)

Coding Faults

- Synchronization errors: improper serialization of operations, timing window between two operations creates flaw
  - Example: *xterm* flaw
- Condition validation errors: bounds not checked, access rights ignored, input not validated, authentication and identification fails
  - Example: *fingerd* flaw

Emergent Faults

- Configuration errors: program installed incorrectly
  - Example: *tftp* daemon installed so it can access any file; then anyone can copy any file
- Environmental faults: faults introduced by environment
  - Example: on some UNIX systems, any shell with "-" as first char of name is interactive, so find a setuid shell script, create a link to name "-gotcha", run it, and you has a privileged interactive shell

Legacy

- Tied security flaws to software faults
- Introduced a precise classification scheme
  - Each vulnerability belongs to exactly 1 class of security flaws
  - Decision procedure well-defined, unambiguous

Comparison and Analysis

- Point of view
  - If multiple processes involved in exploiting the flaw, how does that affect classification?
    - *xterm*, *fingerd* flaws depend on interaction of two processes (*xterm* and process to switch file objects; *fingerd* and its client)
- Levels of abstraction
  - How does flaw appear at different levels?
    - Levels are abstract, design, implementation, etc.

xterm and PA Classification

- Implementation level
  - *xterm*: improper change
  - attacker's program: improper deallocation or deletion
  - operating system: improper indivisibility

xterm and PA Classification

- Consider higher level of abstraction, where directory is simply an object
  - create, delete files maps to writing; read file status, open file maps to reading
  - operating system: improper sequencing
    - During read, a write occurs, violating Bernstein conditions
- Consider even higher level of abstraction
  - attacker’s process: improper choice of initial protection domain
    - Should not be able to write to directory containing log file
    - Semantics of UNIX users require this at lower levels

xterm and RISOS Classification

- Implementation level
  - *xterm*: asynchronous validation/inadequate serialization
  - attacker’s process: exploitable logic error and violable prohibition/limit
  - operating system: inconsistent parameter validation

xterm and RISOS Classification

- Consider higher level of abstraction, where directory is simply an object (as before)
  - all: asynchronous validation/inadequate serialization
- Consider even higher level of abstraction
  - attacker’s process: inadequate identification/authentication/authorization
    - Directory with log file not protected adequately
    - Semantics of UNIX require this at lower levels

Standards

- Descriptive databases used to identify vulnerabilities and weaknesses
- Examples:
  - Common Vulnerabilities and Exposures (CVE)
  - Common Weaknesses and Exposures (CWE)
  - NIST National Vulnerability Database (NVD)

CVE

- Goal: create a standard identification catalogue for vulnerabilities
  - So different vendors can identify vulnerabilities by one common identifier
  - Created at MITRE Corp.
- Governance
  - CVE Board provides input on nature of specific vulnerabilities, determines whether 2 reported vulnerabilities overlap, and provides general direction and very high-level management
  - Numbering Authorities assign CVE numbers within a distinct scope, such as for a particular vendor
- CVE Numbers: CVE-*year-number*
  - *Number* begins at 1 each year, and is at least 4 digits

Structure of Entry

Main fields:

- CVE-ID: *CVE identifier*
- Description: *what is the vulnerability*
- References: *vendor and CERT security advisories*
- Date Entry Created: *year month day as a string of 8 digits*

Example: Buffer Overflow in GNU C Library

CVE-ID: CVE-2016-3706
Description: Stack-based buffer overflow in the getaddrinfo function in sysdeps/posix/getaddrinfo.c in the GNU C Library (aka glibc or libc6) allows remote attackers to cause a denial of service (crash) via vectors involving hostent conversion. NOTE: this vulnerability exists because of an incomplete fix for CVE-2013-4458
References:

- CONFIRM:https://sourceware.org/bugzilla/show_bug.cgi?id=20010
- CONFIRM:https://sourceware.org/git/gitweb.cgi?p=glibc.git;h=4ab2ab03d4351914ee53248dc5aef4a8c88ff8b9
- CONFIRM:http://www-01.ibm.com/support/docview.wss?uid=swg21995039
- CONFIRM:https://source.android.com/security/bulletin/2017-12-01
- SUSE:openSUSE-SU-2016:1527
- URL:http://lists.opensuse.org/opensuse-updates/2016-06/msg00030.html
- SUSE:openSUSE-SU-2016:1779
- URL:http://lists.opensuse.org/opensuse-updates/2016-07/msg00039.html
- BID:88440
- URL:http://www.securityfocus.com/bid/88440
- BID:102073
- URL:http://www.securityfocus.com/bid/102073

Assigning CNA: N/A
Date Entry Created: 20160330

CVE Use

- CVE database begun in 1999
  - Contains some vulnerabilities from before 1999
- Currently over 82,000 entries
- Used by over 150 organizations
  - Security vendors such as Symantec, Trend Micro, Tripwire
  - Software and system vendors such as Apple, Juniper Networks, Red Hat, IBM
  - Other groups such as CERT/CC, U.S. NIST

CVSS

- Common Vulnerability Scoring System (CVSS)
  - Version 4.0
  - Managed by FIRST (Forum for Internet Response Security Teams)
- Scores
  - CVSS-B: Base metrics — **this measures severity, not risk**
  - CVSS-BE: Base and environmental metrics
  - CVSS-BT: Base and threat metrics
  - CVSS-BTE: Base, threat, and environmental metrics

CVSS-B

- Exploitability metrics
  - Attack Vector (AV):
    - Network (N): vulnerable system is on the network, set of attackers is anywhere on the Internet
    - Adjacent (A): vulnerable system is on the network, set of attackers limited to logically adjacent topology
    - Local (L): vulnerable system is not on the network, attacker's path via r/w/x capabilities
    - Physical (P): attacker must physically manipulate the vulnerable system
  - Attack Complexity (AC):
    - Low (L): attacker must take no measurable action to exploit vulnerability
    - High (H): success depends on evading or circumventing security techniques such as ASLR or gathering target-specific secrets

CVSS-B

- More exploitability metrics
  - Attack Requirements (AT):
    - None (N): attack does not depend on deployment, execution condition conditions
    - Present (P): attack depends on specific deployment, execution condition conditions such as a race condition or being able to inject code into a network connection
  - Privileges Required (PR):
    - None (N): attacker need not authenticate
    - Low (L): attacker needs ordinary user privileges
    - High (H): attacker needs significant privileges (eg., administrative, *root*)
  - User Interaction (UI):
    - None (N): no user interaction other than that of the attacker
    - Passive (P): limited interaction by targeted user with vulnerable system,
    - Active (A): Targeted user must perform specific, conscious interaction with vulnerable system

CVSS-B

- Impact metrics
  - Confidentiality (VC)
    - None (N): no loss of confidentiality within vulnerable system
    - Low (L): access to some confidential information, but attacker does not control what information and it doesn't cause direct, serious loss to vulnerable system
    - High (H): total loss of confidentiality, so attacker can see everything; or, the attacker can only see some information, but that information poses a direct, serious loss
  - Confidentiality impact to the subsequent system (SC)
    - As above, but to a system attacked from the first
  - Integrity (VI): as with VC
  - Integrity impact to the subsequent system (SI): as with SC
  - Availability (VA): as with VC
  - Availability impact to the subsequent system (SA): as with SC

CVSS-B

- Exploit maturity E:
  - Unreported (U): no knowledge of public proof-of-concept exploits, of reported attempts to exploit, of public solutions to ameliorate it
  - Proof-of-concept (P): public proof-of-concept exploits, no knowledge of reported attempts to exploit, of public solutions to ameliorate it
  - Attacked (A): attacks have been reported, or tools to simplify exploiting vulnerability are available
  - Not defined (X): no threat intelligence available; treated as A when calculating score

Environmental Metrics

- Confidentiality Requirements (CR)
    - Low (L): Loss of confidentiality has a limited bad effect on organization, associated people
    - Medium (M): Loss of confidentiality has a serious bad effect on organization, associated people
    - High (H): Loss of confidentiality has a catastrophic bad effect on organization, associated people
- Integrity Requirements (IR): see CR
- Availability Requirements AR): see CR

Other Metrics

- Modified *base metric*: adds Not Defined (X) as default
  - For subsequent systems (SC, SI, SA), lowest value is Negligible (N), not None
  - Also for subsequent systems integrity, highest severity level is Safety (S)
- Supplemental metrics
  - Safety (S)
  - Automatable (AU)
  - Provider Urgency (U)
  - Recovery (R)
  - Value Density (V)
  - Vulnerability Response Effort (RE)

Example: CVSS Vector

`CVSS:4.0/AV:N/AC:L/AT:N/PR:H/UI:N/`

Attackers can attack over the Internet (AV:N), and complexity of attack is low (AC:L); the attack does not depend on conditions on the vulnerable systems (AT:N) but requires administrative/*root* privileges (PR:H); it does not require anyone (except the attacker) to do anything

`VC:L/VI:N/VA:N/`

There is some loss of confidentiality, but not of integrity or availability

`SC:N/SI:N/SA:N`

There is no loss of confidentiality, integrity, or availability to any downstream system

CWE

- Database listing weaknesses underlying CVE vulnerabilities
  - Developed by CVE list developers, with help from NIST, vulnerabilities research community
- Organized as a list
  - Can also be viewed as a graph as some weaknesses are refinements of others
  - Not a tree as some nodes have multiple parents

Types of Entries

- *Category entry*: identifies set of entries with a characteristic of the current entry
- *Chain entry*: sequence of distinct weaknesses that can be linked together within software
  - One weakness can create necessary conditions to enable another weakness to be exploited
- *Compound element composite entry*: multiple weaknesses that must be present to enable an exploit
- *View entry*: view of the CWE database for particular weakness or set of weaknesses.
- *Weakness variant entry*: weakness described in terms of a particular technology or language
- *Weakness base entry*: more abstract description of weakness than a weakness variant entry, but in sufficient detail to lead to specific methods of detection and remediation
- *Weakness class*: describes weakness independently of any specific language or technology.

Abstraction Level of Weaknesses

- Goal is to avoid problem of different classifications depending on the layer of abstraction
- Levels:
  - *Class*: weakness at an abstract level, independent of any programming language or environment
  - *Base*: weakness at an abstract level, with enough detail to enable development of methods of detection, prevention, remediation
  - *Variant*: weakness at a low level, usually tied to specific technology, system, programming language
- Useful demarcation of vulnerabilities related to design, implementation, or both

Examples

- CWE-631, Resource-Specific Weaknesses (a view entry)
  - Child: CWE-632, Weaknesses that Affect Files or Directories
  - Child: CWE-633, Weaknesses that Affect Memory
  - Child: CWE-634, Weaknesses that Affect System Processes
- CWE-680, Integer Overflow to Buffer Overflow (a chain entry)
  - Begins with integer overflow (CWE-190)
  - Leads to failure to restrict some operations to bounds of buffer (CWE-119)
- CWE-61, UNIX Symbolic Link (Symlink) Following (a composite entry)
  - Requires 5 weaknesses to be present before it can be exploited
  - CWE-362, CWE-340, CWE-216, CWE-386, CWE-732