Lecture 16
October 27, 2021

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

Violable Prohibition / Limit

- Boundary conditions not handled properly
- Example: OS kept in low memory, user process in high memory
  - Boundary was highest address of OS
  - All memory accesses checked against this
  - Memory accesses not checked beyond end of high memory
    - Such addresses reduced modulo memory size
  - So, process could access (memory size)+1, or word 1, which is part of OS …

Exploitable Logic Error

- Problems not falling into other classes
  - Incorrect error handling, unexpected side effects, incorrect resource allocation, etc.
- Example: unchecked return from monitor
  - Monitor adds 1 to address in user's PC, returns
    - Index bit (indicating indirection) is a bit in word
    - Attack: set address to be –1; adding 1 overflows, changes index bit, so return is to location stored in register 1
  - Arrange for this to point to bootstrap program stored in other registers
    - On return, program executes with system privileges

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

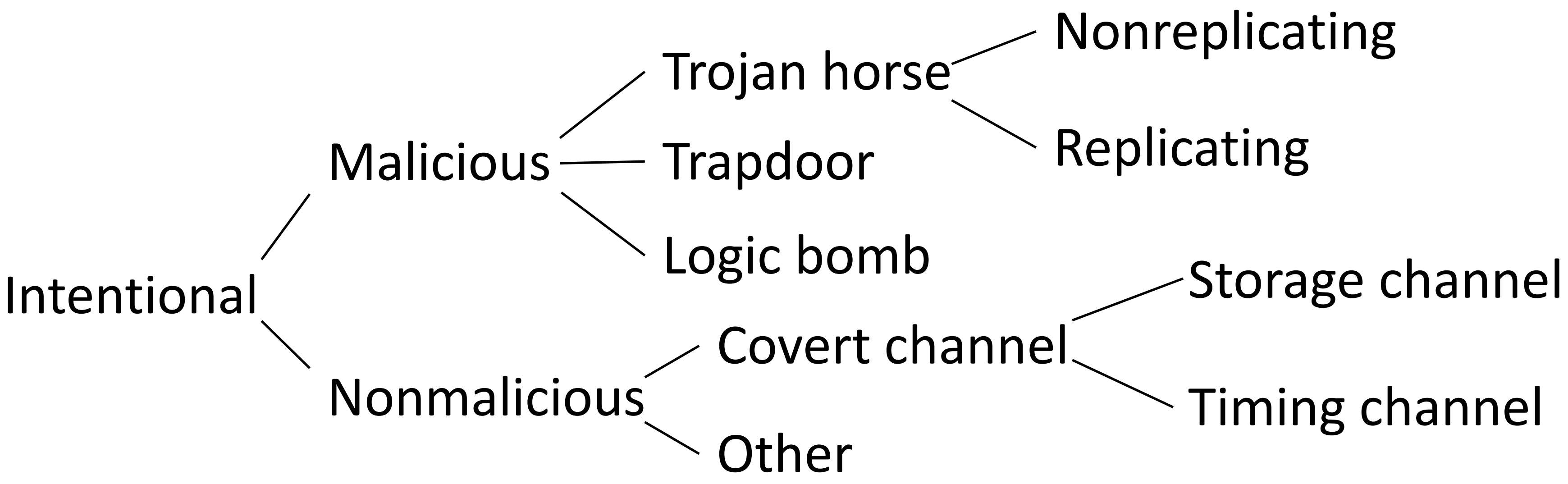
Legacy

- 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

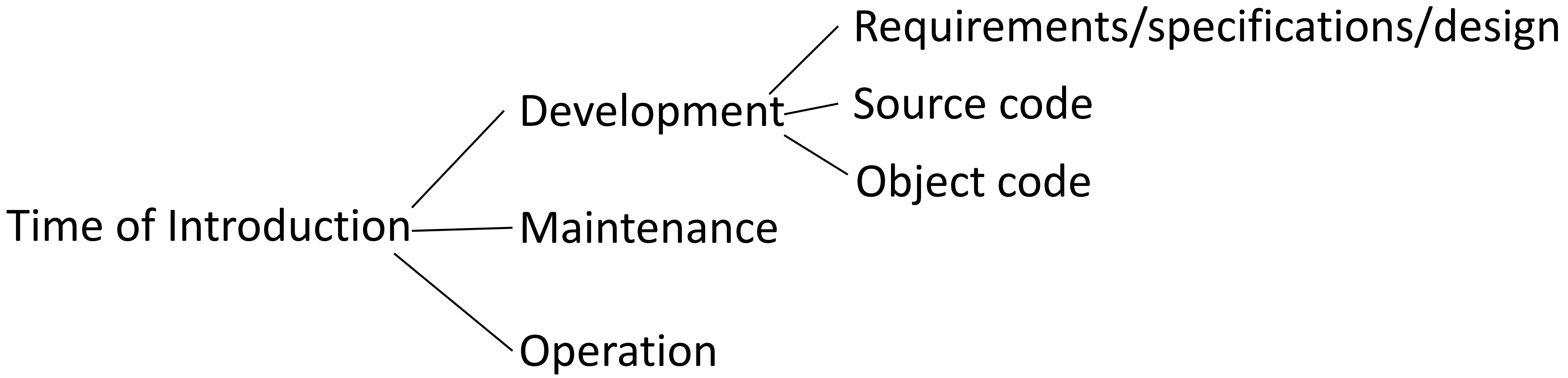
- Goals:
  - Determine how flaws entered system
  - Determine when flaws entered system
  - Determine where flaws are manifested in system
- 3 different schemes used:
  - Genesis of flaws
  - Time of flaws
  - Location of flaws

Genesis of Flaws



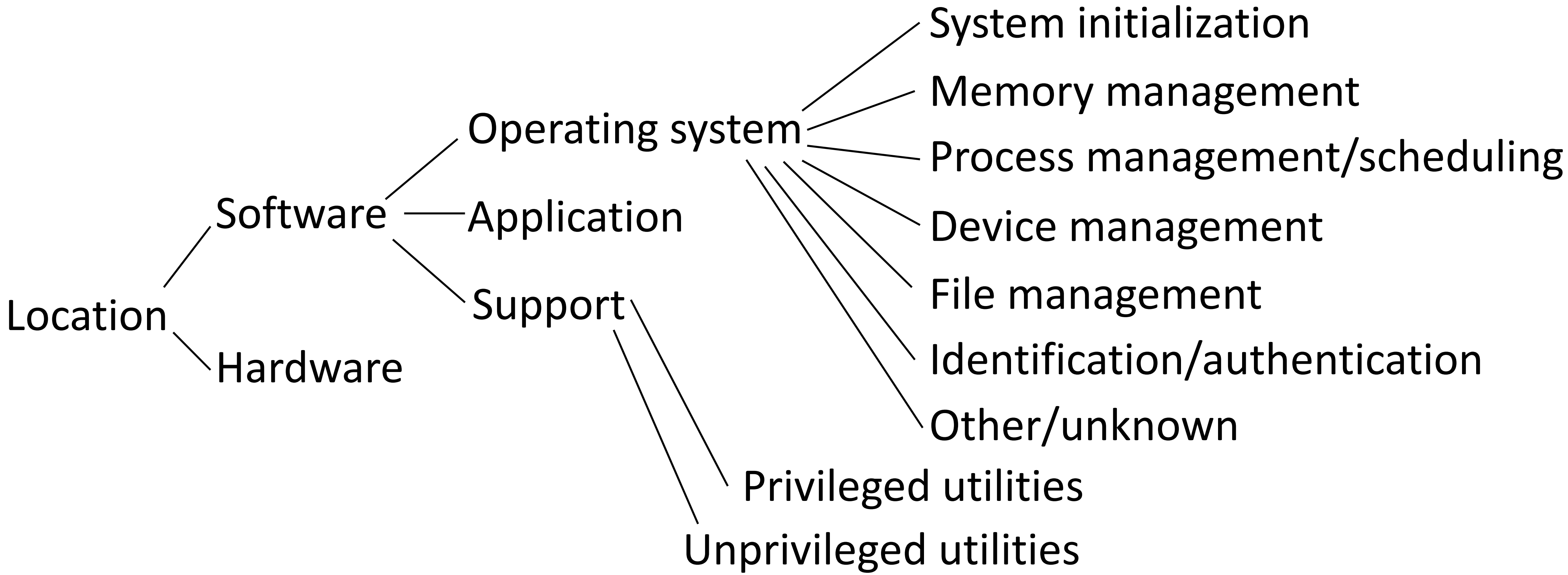
- Inadvertent (unintentional) flaws classified using RISOS categories; not shown above
  - If most inadvertent, better design/coding reviews needed
  - If most intentional, need to hire more trustworthy developers and do more security-related testing

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

xterm and NRL Classification

- Time, location unambiguous
  - Time: during development
  - Location: Support:privileged utilities
- Genesis: ambiguous
  - If intentional:
    - Lowest level: inadvertent flaw of serialization/aliasing
  - If unintentional:
    - Lowest level: nonmalicious: other
  - At higher levels, parallels that of RISOS

xterm and Aslam's Classification

- Implementation level
  - attacker's process: object installed with incorrect permissions
    - attacker's process can delete file
  - *xterm*: access rights validation error
    - *xterm* doesn't properly validate file at time of access
  - operating system: improper or inadequate serialization error
    - deletion, creation should not have been interspersed with access, open
  - Note: in absence of explicit decision procedure, all could go into class race condition

The Point

- The schemes lead to ambiguity
  - Different researchers may classify the same vulnerability differently for the same classification scheme
- Not true for Aslam's, but that misses connections between different classifications
  - *xterm* is race condition as well as others; Aslam does not show this

fingerd and PA Classification

- Implementation level
  - *fingerd*: improper validation
  - attacker’s process: improper choice of operand or operation
  - operating system: improper isolation of implementation detail

fingerd and PA Classification

- Consider higher level of abstraction, where storage space of return address is object
  - operating system: improper change
  - *fingerd*: improper validation
    - Because it doesn't validate the type of instructions to be executed, mistaking data for valid ones
- Consider even higher level of abstraction, where security-related value in memory is changing and data executed that should not be executable
  - operating system: improper choice of initial protection domain

fingerd and RISOS Classification

- Implementation level
  - *fingerd*: incomplete parameter validation
  - attacker’s process: violable prohibition/limit
  - operating system: inadequate identification/authentication/authorization

fingerd and RISOS Classification

- Consider higher level of abstraction, where storage space of return address is object
  - operating system: asynchronous validation/inadequate serialization
  - *fingerd*: inadequate identification/authentication/authorization
- Consider even higher level of abstraction, where security-related value in memory is changing and data executed that should not be executable
  - operating system: inadequate identification/authentication/authorization

fingerd and NRL Classification

- Time, location unambiguous
  - Time: during development
  - Location: support: privileged utilities
- Genesis: ambiguous
  - Known to be inadvertent flaw
  - Parallels that of RISOS

fingerd and Aslam Classification

- Implementation level
  - *fingerd*: boundary condition error
  - attacker's process: boundary condition error
    - operating system: environmental fault
      - If decision procedure not present, could also have been access rights validation errors

Standards

- Descriptive databases used to identify vulnerabilities and weaknesses
- Examples:
  - Common Vulnerabilities and Exposures (CVE)
  - Common Weaknesses and Exposures (CWE)

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, and internationally

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.

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

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