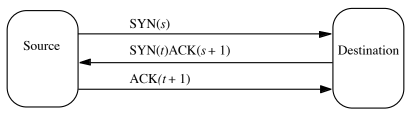
Detect Known Violations of Policy

- Goal: does a specific action and/or state that is known to violate security policy occur?
  - Assume that action *automatically* violates policy
  - Policy may be implicit, not explicit
  - Used to look for known attacks

Example

- Land attack
  - Consider 3-way handshake to initiate TCP connection (next slide)
  - What happens if source, destination ports and addresses the same? Host expects ACK(t+1), but gets ACK(s+1).
  - RFC ambiguous:
    - p. 36 of RFC: send RST to terminate connection
    - p. 69 of RFC: reply with empty packet having current sequence number t+1 and ACK number s+1—but it receives packet and ACK number is incorrect. So it repeats this … system hangs or runs very slowly, depending on whether interrupts are disabled

3-Way Handshake and Land



Normal:
1. srcseq = *s*, expects ACK *s*+1
2. destseq = *t*, expects ACK *t*+1; src gets ACK *s*+1
3. srcseq = *s*+1, destseq = *t*+1; dest gets ACK *t*+1

Land:
1. srcseq = destseq = s, expects ACK s+1
2. srcseq = destseq = t, expects ACK t+1 but gets ACK s+1
3. Never reached; recovery from error in 2 attempted

Detection

- Must spot initial Land packet with source, destination addresses the same
- Logging requirement:
  – source port number, IP address
  – destination port number, IP address
- Auditing requirement:
  – If source port number = destination port number and source IP address = destination IP address, packet is part of a Land attack

Auditing Mechanisms

- Systems use different mechanisms
  - Most common is to log *all* events by default, allow sysadmin to disable logging that is unnecessary
- Two examples
  - One audit system designed for a secure system
  - One audit system designed for non-secure system

Secure Systems

- Auditing mechanisms integrated into system design and implementation
- Security officer can configure reporting and logging:
  - To report specific events
  - To monitor accesses by a subject
  - To monitor accesses to an object
- Controlled at audit subsystem
  - Irrelevant accesses, actions not logged

Example 1: VAX VMM

- Designed to be a secure production system
  - Audit mechanism had to have minimal impact
  - Audit mechanism had to be very reliable
- Kernel is layered
  - Logging done where events of interest occur
  - Each layer audits accesses to objects it controls
- Audit subsystem processes results of logging from mechanisms in kernel
  - Audit subsystem manages system log
  - Invoked by mechanisms in kernel

VAX VMM Audit Subsystem

- Calls provide data to be logged
  - Identification of event, result
  - Auxiliary data depending on event
  - Caller's name
- Subsystem checks criteria for logging
  - If request matches, data is logged
  - Criteria are subject or object named in audit table, and severity level (derived from result)
  - Adds date and time, other information

Other Issues

- Always logged
  - Programmer can request event be logged
  - Any attempt to violate policy
    - Protection violations, login failures logged when they occur repeatedly
    - Use of covert channels also logged
- Log filling up
  - Audit logging process signaled to archive log when log is 75% full
  - If not possible, system stops

Example 2: CMW

- Compartmented Mode Workstation designed to allow processing at different levels of sensitivity
  - Auditing subsystem keeps table of auditable events
  - Entries indicate whether logging is turned on, what type of logging to use
  - User level command *chaud* allows user to control auditing and what is audited
    - If changes affect subjects, objects currently being logged, the logging completes and then the auditable events are changed

CMW Process Control

- System calls allow process to control auditing
  - *audit_on* turns logging on, names log file
  - *audit_write* validates log entry given as parameter, logs entry if logging for that entry is turned on
  - *audit_suspend* suspends logging temporarily
  - *audit_resume* resumes logging after suspension
  - *audit_off* turns logging off for that process

System Calls

- On system call, if auditing on:
  - System call recorded
  - First 3 parameters recorded (but pointers not followed)
- How *audit_write* works
  - If room in log, append new entry
  - Otherwise halt system, discard new entry, or disable event that caused logging
    - Continue to try to log other events

Other Ways to Log

- Problem: some processes want to log higher-level abstractions (application logging)
  - Window manager creates, writes high-level events to log
  - Difficult to map low-level events into high-level ones
  - Disables low-level logging for window manager as unnecessary

CMW Auditing

- Tool (*redux*) to analyze logged events
- Converts binary logs to printable format
- *Redux* allows user to constrain printing based on several criteria
  - Users
  - Objects
  - Security levels
  - Events

Non-Secure Systems

- Have some limited logging capabilities
  - Log accounting data, or data for non-security purposes
  - Possibly limited security data like failed logins
- Auditing subsystems focusing on security usually added after system completed
  - May not be able to log all events, especially if limited kernel modifications to support audit subsystem

Example: Basic Security Module

- BSM enhances SunOS, Solaris security
  - Logs composed of records made up of tokens
    - Token contains information about event: user identity, groups, file system information, network, system call and result, etc. as appropriate

More About Records

- Records refer to auditable events
  - Kernel events: opening a file
  - Application events: failure to authenticate when logging in
- Grouped into audit event classes based on events causing record generation
  - Before log created: tell system what to generate records for
  - After log created: defined classes control which records given to analysis tools

Example Record

- Logs are binary; this is from *praudit*

```
header,35,AUE_EXIT,Wed Sep 18 11:35:28 1991, + 570000 msec,
process,bishop,root,root,daemon,1234,
return,Error 0,5
trailer,35
```

Auditing File Systems

- Network File System (NFS)
  – Industry standard
  – Server exports file system; client imports it
  – Root of tree being exported called *server mount point*; place in client file tree where exported file system imported called *client mount point*
- Logging and Auditing File System (LAFS)
  – Built on NFS

NFS Version 2

- Mounting protocol
  – Client kernel contacts server's mount daemon
  – Daemon checks client is authorized to mount file system
  – Daemon returns *file handle* pointing to server mount point
  – Client creates entry in client file system corresponding to file handle
  – Access restrictions enforced
    - On client side: server not aware of these
    - On server side: client not aware of these

File Access Protocol

- Process tries to open file as if it were local
- Client kernel sends file handle for element of path referring to remote file to server's NFS server using LOOKUP request
- If file handle valid, server replies with appropriate file handle
- Client requests attributes with GETATTR
  - Client then determines if access allowed; if not, denies
- Iterate above three steps until handle obtained for requested file
  - Or access denied by client

Other Important Details

- NFS stateless
  - Server has no idea which files are being accessed and by whom
- NFS access control
  - Most servers require requests to come from privileged programs
    - Check that source port is 1023 or less
  - Underlying messages identify user
    - To some degree of certainty …

Site Policy

1. NFS servers respond only to authorized clients
2. UNIX access controls regulate access to server's exported file system
3. No client host can access a nonexported file system

Resulting Constraints

1. File access granted ⇒ client authorized to import file system, user can search all parent directories, user can access file as requested, file is descendent of server's file system mount point
   - From P1, P2, P3
2. Device file created or file type changed to device ⇒ user's UID is 0
   - From P2; only UID 0 can do these actions

More Constraints

3. Possession of file handle ⇒ file handle issued to user
   - From P1, P2; otherwise unauthorized client could access files in forbidden ways
4. Operation succeeds ⇒ similar local operation would succeed
   - From P2; mount should fail if requester UID not 0

NFS Operations

- Transitions from secure to nonsecure state can occur only when NFS command occurs
- Example commands:
  – MOUNT *filesystem*
    - Mount the named file system on the requesting client, if allowed
  – LOOKUP *dir_handle file_name*
    - Search in directory with handle *dir_handle* for file named *file_name*; return file handle for *file_name*

Logging Requirements

1. When file handle issued, server records handle, UID and GID of user requesting it, client host making request
   - Similar to allocating file descriptor when file opened; allows validation of later requests
2. When file handle used as parameter, server records UID, GID of user
   - Was user using file handle issued that file handle—useful for detecting spoofs

Logging Requirements

3. When file handle issued, server records relevant attributes of containing object
   - On LOOKUP, attributes of containing directory show whether it can be searched
4. Record results of each operation
   - Lets auditor determine result
5. Record file names used as arguments
   - Reconstruct path names, purpose of commands

Audit Criteria: MOUNT

- MOUNT
  - Check that MOUNT server denies all requests by unauthorized clients to import file system that host exports
    - Obtained from constraints 1, 4
    - Log requirements 1 (who requests it), 3 (access attributes—to whom can it be exported), 4 (result)

Audit Criteria: LOOKUP

2. Check file handle comes from client, user to which it was issued
   - Obtained from constraint 3
   - Log requirement 1 (who issued to), 2 (who is using)
3. Check that directory has file system mount point as ancestor and user has search permission on directory
   - Obtained from constraint 1
   - Log requirements 2 (who is using handle), 3 (owner, group, type, permissions of object), 4 (result), 5 (reconstruct path name)

LAFS

- File system that records user level activities
- Uses policy-based language to automate checks for violation of policies
- Implemented as extension to NFS
  - You create directory with *lmkdir* and attach policy with *lattach*:

```
lmkdir /usr/home/xyzzy/project policy
lattach /usr/home/xyzzy/project /lafs/xyzzy/project
```


LAFS Components

- Name server
- File manager
- Configuration assistant
  - Sets up required protection modes; interacts with name server, underlying file protection mechanisms
- Audit logger
  - Logs file accesses; invoked whenever process accesses file
- Policy checker
  - Validates policies, checks logs conform to policy

How It Works

- No changes to applications
- Each file has 3 associated virtual files
  - *file%log*: all accesses to *file*
  - *file%policy*: access control policy for *file*
  - *file%audit*: when accessed, triggers audit in which accesses are compared to policy for file
- Virtual files not shown in listing
  - LAFS knows the extensions and handles them properly

Example Policies

```
prohibit:0900–1700:*:*:wumpus:exec
```

- No-one can execute *wumpus* between 9AM and 5PM

```
allow:*:Makefile:*:make:read
allow:*:Makefile:Owner:makedepend:write
allow:*:*.o,*.out:Owner,Group:gcc,ld:write
allow:-010929:*.c,*.h:Owner:emacs,vi,ed:write
```

- Program *make* can read *Makefile*
- Owner can change Makefile using *makedepend*
- Owner, group member can create .o, .out files using *gcc* and *ld*
- Owner can modify .c, .h files using named editors up to Sep. 29, 2001

Comparison

- Security policy controls access
  - Goal is to detect, report violations
  - Auditing mechanisms built in
- LAFS "stacked" onto NFS
  - If you access files *not* through LAFS, access not recorded
- NFS auditing at lower layer
  - So if you use NFS, accesses recorded

Comparison

- Users can specify policies in LAFS
  - Use *%policy* file
- NFS policy embedded, not easily changed
  - It would be set by site, not users
- Which is better?
  - Depends on goal; LAFS is more flexible but easier to evade. Use both together, perhaps?

Audit Browsing

- Goal of browser: present log information in a form easy to understand and use
- Several reasons to do this:
  - Audit mechanisms may miss problems that auditors will spot
  - Mechanisms may be unsophisticated or make invalid assumptions about log format or meaning
  - Logs usually not integrated; often different formats, syntax, *etc*.

Browsing Techniques

- Text display
  - Does not indicate relationships between events
- Hypertext display
  - Indicates local relationships between events
  - Does not indicate global relationships clearly
- Relational database browsing
  - DBMS performs correlations, so auditor need not know in advance what associations are of interest
  - Preprocessing required, and may limit the associations DBMS can make

More Browsing Techniques

- Replay
  - Shows events occurring in order; if multiple logs, intermingles entries
- Graphing
  - Nodes are entities, edges relationships
  - Often too cluttered to show everything, so graphing selects subsets of events
- Slicing
  - Show minimum set of log events affecting object
  - Focuses on local relationships, not global ones

Example: Visual Audit Browser

- Frame Visualizer
  - Generates graphical representation of logs
- Movie Maker
  - Generates sequence of graphs, each event creating a new graph suitably modified
- Hypertext Generator
  - Produces page per user, page per modified file, summary and index pages
- Focused Audit Browser
  - Enter node name, displays node, incident edges, and nodes at end of edges

Example Use

- File changed
  - Use focused audit browser
    - Changed file is initial focus
    - Edges show which processes have altered file
  - Focus on suspicious process
    - Iterate through nodes until method used to gain access to system determined
- Question: is masquerade occurring?
  - Auditor knows audit UID of attacker

Tracking Attacker

- Use hypertext generator to get all audit records with that UID
  - Now examine them for irregular activity
  - Frame visualizer may help here
  - Once found, work forward to reconstruct activity
- For non-technical people, use movie maker to show what happened
  - Helpful for law enforcement authorities especially!

Example: MieLog

- Computes counts of single words, word pairs
  - Auditor defines "threshold count"
  - MieLog colors data with counts higher than threshold
- Display uses graphics and text together
  - Tag appearance frequency area: colored based on frequency (*e.g.*, red is rare)
  - Time information area: bar graph showing number of log entries in that period of time; click to get entries
  - Outline of message area: outline of log messages, colored to match tag appearance frequency area
  - Message in text area: displays log entry under study

Example Use

- Auditor notices unexpected gap in time information area
  - No log entries during that time!?!?
- Auditor focuses on log entries before, after gap
  - Wants to know why logging turned off, then turned back on
- Color of words in entries helps auditor find similar entries elsewhere and reconstruct patterns

Key Points

- Logging is collection and recording; audit is analysis
- Need to have clear goals when designing an audit system
- Auditing should be designed into system, not patched into system after it is implemented
- Browsing through logs helps auditors determine completeness of audit (and effectiveness of audit mechanisms!)

Intrusion Detection

- Principles
- Basics
- Models of Intrusion Detection
- Architecture of an IDS
- Organization
- Incident Response

Principles of Intrusion Detection

- Characteristics of systems not under attack
  - User, process actions conform to statistically predictable pattern
  - User, process actions do not include sequences of actions that subvert the security policy
  - Process actions correspond to a set of specifications describing what the processes are allowed to do
- Systems under attack do not meet at least one of these

Example

- Goal: insert a back door into a system
  - Intruder will modify system configuration file or program
  - Requires privilege; attacker enters system as an unprivileged user and must acquire privilege
    - Nonprivileged user may not normally acquire privilege (violates #1)
    - Attacker may break in using sequence of commands that violate security policy (violates #2)
    - Attacker may cause program to act in ways that violate program's specification (violates #3)

Basic Intrusion Detection

- *Attack tool* is automated script designed to violate a security policy
- Example: *rootkit*
  - Includes password sniffer
  - Designed to hide itself using Trojaned versions of various programs (*ps*, *ls*, *find*, *netstat*, etc.)
  - Adds back doors (*login*, *telnetd*, etc.)
  - Has tools to clean up log entries (*zapper, etc.)*

Detection

- *Rootkit* configuration files cause *ls*, *du*, etc. to hide information
  - *ls* lists all files in a directory
    - Except those hidden by configuration file
  - *dirdump* (local program to list directory entries) lists them too
    - Run both and compare counts
    - If they differ, *ls* is doctored
- Other approaches possible

Key Point

- *Rootkit* does *not* alter kernel or file structures to conceal files, processes, and network connections
  - It alters the programs or system calls that *interpret* those structures
  - Find some entry point for interpretation that *rootkit* did not alter
  - The inconsistency is an anomaly (violates #1)

Denning's Model

- Hypothesis: exploiting vulnerabilities requires abnormal use of normal commands or instructions
  - Includes deviation from usual actions
  - Includes execution of actions leading to break-ins
  - Includes actions inconsistent with specifications of privileged programs

Goals of IDS

- Detect wide variety of intrusions
  - Previously known and unknown attacks
  - Suggests need to learn/adapt to new attacks or changes in behavior
- Detect intrusions in timely fashion
  - May need to be be real-time, especially when system responds to intrusion
    - Problem: analyzing commands may impact response time of system
  - May suffice to report intrusion occurred a few minutes or hours ago

Goals of IDS

- Present analysis in simple, easy-to-understand format
  - Ideally a binary indicator
  - Usually more complex, allowing analyst to examine suspected attack
  - User interface critical, especially when monitoring many systems
- Be accurate
  - Minimize false positives, false negatives
  - Minimize time spent verifying attacks, looking for them