Chapter 21: Auditing

- Overview
- What is auditing?
- What does an audit system look like?
- How do you design an auditing system?
- Auditing mechanisms
- Examples: NFSv2, LAFS

What is Auditing?

- Logging
  - Recording events or statistics to provide information about system use and performance
- Auditing
  - Analysis of log records to present information about the system in a clear, understandable manner

Uses

- Describe security state
  - Determine if system enters unauthorized state
- Evaluate effectiveness of protection mechanisms
  - Determine which mechanisms are appropriate and working
  - Deter attacks because of presence of record

Problems

- What do you log?
  - Hint: looking for violations of a policy, so record *at least* what will show such violations
- What do you audit?
  - Need not audit everything
  - Key: what is the policy involved?

Audit System Structure

- Logger
  - Records information, usually controlled by parameters
- Analyzer
  - Analyzes logged information looking for something
- Notifier
  - Reports results of analysis

Logger

- Type, quantity of information recorded controlled by system or program configuration parameters
- May be human readable or not
  - If not, usually viewing tools supplied
  - Space available, portability influence storage format

Example: RACF

- Security enhancement package for IBM's MVS/VM
- Logs failed access attempts, use of privilege to change security levels, and (if desired) RACF interactions
- View events with LISTUSERS commands

RACF: Sample Entry

```
USER=EW125004   NAME=S.J.TURNER   OWNER=SECADM   CREATED=88.004
  DEFAULT-GROUP=HUMRES    PASSDATE=88.004   PASS-INTERVAL=30
  ATTRIBUTES=ADSP
  REVOKE DATE=NONE    RESUME-DATE=NONE
  LAST-ACCESS=88.020/14:15:10
  CLASS AUTHORIZATIONS=NONE
  NO-INSTALLATION-DATA
  NO-MODEL-NAME
  LOGON ALLOWED     (DAYS)  (TIME)
  ----------------
  ANYDAY                    ANYTIME
    GROUP=HUMRES AUTH=JOIN CONNECT-OWNER=SECADM
                                   CONNECT-DATE=88.004
      CONNECTS= 15  UACC=READ LAST-CONNECT=88.018/16:45:06
      CONNECT ATTRIBUTES=NONE
      REVOKE DATE=NONE RESUME DATE=NONE
    GROUP=PERSNL AUTH=JOIN CONNECT-OWNER=SECADM CONNECT-DATE:88.004
      CONNECTS= 25 UACC=READ LAST-CONNECT=88.020/14:15:10
      CONNECT ATTRIBUTES=NONE
      REVOKE DATE=NONE RESUME DATE=NONE
    SECURITY-LEVEL=NONE SPECIFIED
    CATEGORY AUTHORIZATION
       NONE SPECIFIED
```

Example: Windows NT

- Different logs for different types of events
  - *System event* logs record system crashes, component failures, and other system events
  - *Application event* logs record events that applications request be recorded
  - *Security event* log records security-critical events such as logging in and out, system file accesses, and other events
- Logs are binary; use *event viewer* to see them
- If log full, can have system shut down, logging disabled, or logs overwritten

Windows NT Sample Entry

```
Date: 2/12/2000          Source:      Security
Time:         13:03      Category:    Detailed Tracking
Type:         Success    EventID:     592
User: WINDSOR\Administrator
Computer:     WINDSOR

Description:
A new process has been created:
    New Process ID:         2216594592
    Image File Name:
  \Program Files\Internet Explorer\IEXPLORE.EXE
    Creator Process ID:     2217918496
    User Name:              Administrator
    FDomain:                WINDSOR
    Logon ID:               (0x0,0x14B4c4)
```

[would be in graphical format]

Analyzer

- Analyzes one or more logs
  - Logs may come from multiple systems, or a single system
  - May lead to changes in logging
  - May lead to a report of an event

Examples

- Using *swatch* to find instances of *telnet* from *tcpd* logs:

```
/telnet/&!/localhost/&!/*.site.com/
```

- Query set overlap control in databases
  - If too much overlap between current query and past queries, do not answer
- Intrusion detection analysis engine (director)
  - Takes data from sensors and determines if an intrusion is occurring

Notifier

- Informs analyst, other entities of results of analysis
- May reconfigure logging and/or analysis on basis of results

Examples

- Using *swatch* to notify of *telnet*s

```
/telnet/&!/localhost/&!/*.site.com/      mail staff
```

- Query set overlap control in databases
  - Prevents response from being given if too much overlap occurs
- Three failed logins in a row disable user account
  - Notifier disables account, notifies sysadmin

Designing an Audit System

- Essential component of security mechanisms
- Goals determine what is logged
  - Idea: auditors want to detect violations of policy, which provides a set of constraints that the set of possible actions must satisfy
  - So, audit functions that may violate the constraints
- Constraint p_i : *action* $\Rightarrow$ *condition*

Example: Bell-LaPadula

- Simple security condition and *-property
  - S reads $O \Rightarrow L(S) \geq L(O)$
  - S writes $O \Rightarrow L(S) \leq L(O)$
  - To check for violations, on each read and write, must log $L(S)$, $L(O)$, action (read, write), and result (success, failure)
  - Note: need *not* record S, O!
    - In practice, done to identify the object of the (attempted) violation and the user attempting the violation

Implementation Issues

- Show non-security or find violations?
  - Former requires logging initial state as well as changes
- Defining violations
  - Does “write” include “append” and “create directory”?
- Multiple names for one object
  - Logging goes by *object* and not name
  - Representations can affect this (if you read raw disks, you’re reading files; can your auditing system determine which file?)

Syntactic Issues

- Data that is logged may be ambiguous
  - BSM: two optional text fields followed by two mandatory text fields
  - If three fields, which of the optional fields is omitted?
- Solution: use grammar to ensure well-defined syntax of log files

Example

```
entry     : date host prog [ bad ] user [ “from” host ] “to”
          user “on” tty
date      : daytime
host      : string
prog      : string “:”
bad       : “FAILED”
user      : string
tty       : “/dev/” string
```

- Log file entry format defined unambiguously
- Audit mechanism could scan, interpret entries without confusion

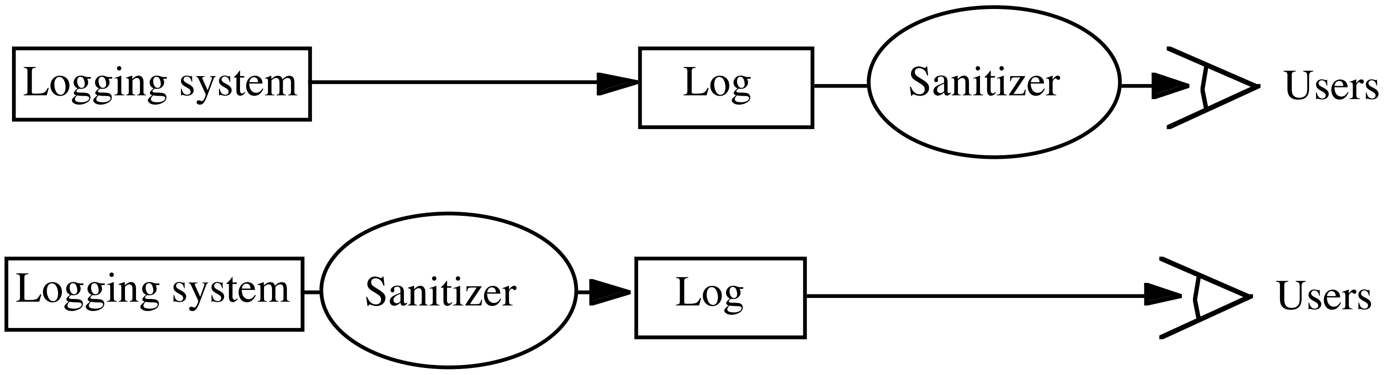
More Syntactic Issues

- Context
  - Unknown user uses anonymous *ftp* to retrieve file “/etc/passwd”
  - Logged as such
  - Problem: *which* /etc/passwd file?
    - One in system /etc directory
    - One in anonymous *ftp* directory /var/ftp/etc, and as *ftp* thinks /var/ftp is the root directory, /etc/passwd refers to /var/ftp/etc/passwd

Log Sanitization

- *U* set of users, *P* policy defining set of information *C*(*U*) that *U* cannot see; log sanitized when all information in *C*(*U*) deleted from log
- Two types of *P*
  - *C*(*U*) can't leave site
    - People inside site are trusted and information not sensitive to them
  - *C*(*U*) can't leave system
    - People inside site not trusted or (more commonly) information sensitive to them
    - Don't log this sensitive information

Logging Organization



- Top prevents information from leaving site
  - Users' privacy not protected from system administrators, other administrative personnel
- Bottom prevents information from leaving system
  - Data simply not recorded, or data scrambled before recording

Reconstruction

- *Anonymizing sanitizer* cannot be undone
  - No way to recover data from this
- *Pseudonymizing sanitizer* can be undone
  - Original log can be reconstructed
- Importance
  - Suppose security analysis requires access to information that was sanitized?

Issue

- Key: sanitization must preserve properties needed for security analysis
- If new properties added (because analysis changes), may have to resanitize information
  - This *requires* pseudonymous sanitization or the original log

Example

- Company wants to keep its IP addresses secret, but wants a consultant to analyze logs for an address scanning attack
  - Connections to port 25 on IP addresses 10.163.5.10, 10.163.5.11, 10.163.5.12, 10.163.5.13, 10.163.5.14, 10.163.5.15
  - Sanitize with random IP addresses
    - Cannot see sweep through consecutive IP addresses
  - Sanitize with sequential IP addresses
    - Can see sweep through consecutive IP addresses

Generation of Pseudonyms

1. Devise set of pseudonyms to replace sensitive information
   - Replace data with pseudonyms
   - Maintain table mapping pseudonyms to data
2. Use random key to encipher sensitive datum and use secret sharing scheme to share key
   - Used when insiders cannot see unsanitized data, but outsiders (law enforcement) need to
   - Requires *t* out of *n* people to read data

Application Logging

- Applications logs made by applications
  - Applications control what is logged
  - Typically use high-level abstractions such as:

    ```
    su: bishop to root on /dev/ttyp0
    ```
  - Does not include detailed, system call level information such as results, parameters, etc.

System Logging

- Log system events such as kernel actions
  - Typically use low-level events

```
3876 ktrace   CALL   execve(0xbfbff0c0,0xbfbff5cc,0xbfbff5d8)
3876 ktrace   NAMI   "/usr/bin/su"
3876 ktrace   NAMI   "/usr/libexec/ld-elf.so.1"
3876 su       RET    xecve 0
3876 su       CALL    __sysctl(0xbfbff47c,0x2,0x2805c928,0xbfbff478,0,0)
3876 su       RET    __sysctl 0
3876 su       CALL   mmap(0,0x8000,0x3,0x1002,0xffffffff,0,0,0)
3876 su       RET    mmap 671473664/0x2805e000
3876 su       CALL   geteuid
3876 su       RET    geteuid 0
```

  - Does not include high-level abstractions such as loading libraries (as above)

Contrast

- Differ in focus
  - Application logging focuses on application events, like failure to supply proper password, and the broad operation (what was the reason for the access attempt?)
  - System logging focuses on system events, like memory mapping or file accesses, and the underlying causes (why did access fail?)
- System logs usually much bigger than application logs
- Can do both, try to correlate them

Design

- *A posteriori* design
  - Need to design auditing mechanism for system not built with security in mind
- Goal of auditing
  - Detect *any* violation of a stated policy
    - Focus is on policy and actions designed to violate policy; specific actions may not be known
  - Detect actions *known* to be part of an attempt to breach security
    - Focus on specific actions that have been determined to indicate attacks

Detect Violations of Known Policy

- Goal: does system enter a disallowed state?
- Two forms
  – State-based auditing
    - Look at current state of system
  – Transition-based auditing
    - Look at actions that transition system from one state to another

State-Based Auditing

- Log information about state and determine if state allowed
  - Assumption: you can get a snapshot of system state
  - Snapshot needs to be consistent
  - Non-distributed system needs to be quiescent
  - Distributed system can use Chandy-Lamport algorithm, or some other algorithm, to obtain this

Example

- File system auditing tools
  - Thought of as analyzing single state (snapshot)
  - In reality, analyze many slices of different state unless file system quiescent
  - Potential problem: if test at end depends on result of test at beginning, relevant parts of system state may have changed between the first test and the last
    - Classic TOCTTOU flaw

Transition-Based Auditing

- Log information about action, and examine current state and proposed transition to determine if new state would be disallowed
  - Note: just analyzing the transition may not be enough; you may need the initial state
  - Tend to use this when specific transitions *always* require analysis (for example, change of privilege)

Example

- TCP access control mechanism intercepts TCP connections and checks against a list of connections to be blocked
  - Obtains IP address of source of connection
  - Logs IP address, port, and result (allowed/blocked) in log file
  - Purely transition-based (current state not analyzed at all)

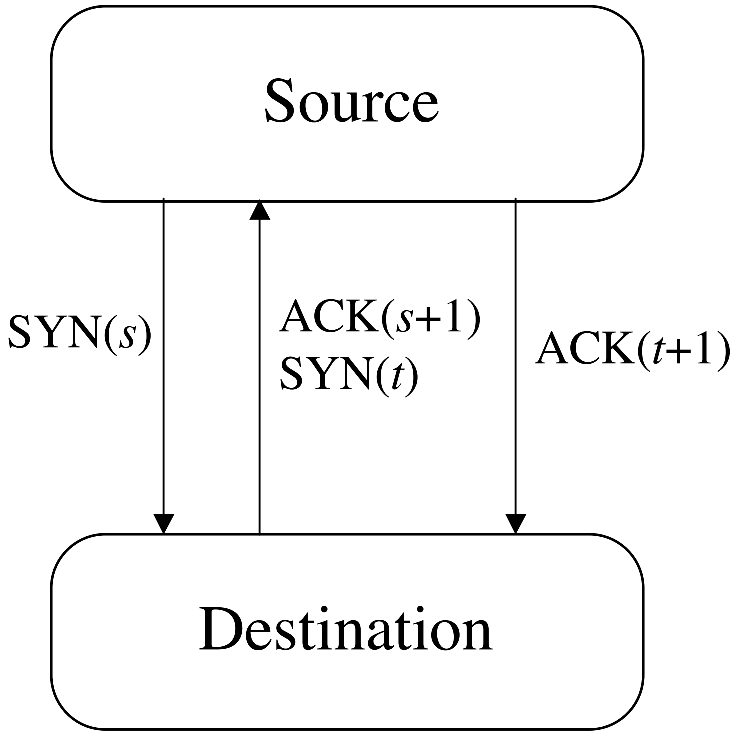
Detect Known Violations of Policy

- 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 system administrator 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 matcher, 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 filke
  - *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 non-exported 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 non-secure 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!)