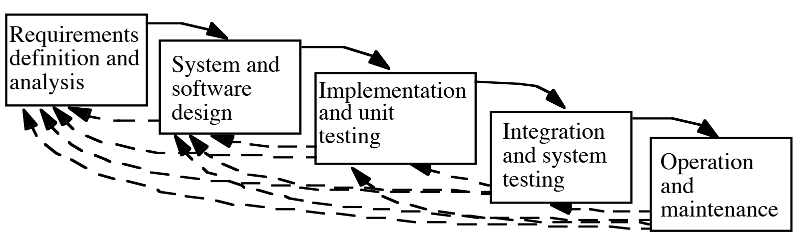
Waterfall Life Cycle Model

- Requirements definition and analysis
  - Functional and non-functional
  - General (for customer), specifications
- System and software design
- Implementation and unit testing
- Integration and system testing
- Operation and maintenance

Relationship of Stages



Models

- Exploratory programming
  - Develop working system quickly
  - Used when detailed requirements specification cannot be formulated in advance, and adequacy is goal
  - No requirements or design specification, so low assurance
- Prototyping
  - Objective is to establish system requirements
  - Future iterations (after first) allow assurance techniques

Models

- Formal transformation
  - Create formal specification
  - Translate it into program using correctness-preserving transformations
  - Very conducive to assurance methods
- System assembly from reusable components
  - Depends on whether components are trusted
  - Must assure connections, composition as well
  - Very complex, difficult to assure

Models

- Extreme programming
  - Rapid prototyping and “best practices”
  - Project driven by business decisions
  - Requirements open until project complete
  - Programmers work in teams
  - Components tested, integrated several times a day
  - Objective is to get system into production as quickly as possible, then enhance it
  - Evidence adduced *after* development needed for assurance

Key Points

- Assurance critical for determining trustworthiness of systems
- Different levels of assurance, from informal evidence to rigorous mathematical evidence
- Assurance needed at all stages of system life cycle

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* ⇒ *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

Remove Tranquility

- New commands to manipulate security level must also record information
  - S reclassify O to $L(O') \Rightarrow L(O) \le L(S)$ and $L(O') \le L(S)$
  - Log $L(O)$, $L(O')$, $L(S)$, action (reclassify), and result (success, failure)
  - Again, need not record O or S to detect violation
    - But needed to follow up …

Example: Chinese Wall

- Subject S has $COI(S)$ and $CD(S)$
  - $CD_H(S)$ is set of company datasets that S has accessed
- Object O has $COI(O)$ and $CD(O)$
  - $san(O)$ iff O contains only sanitized information
- Constraints
  - S reads $O \Rightarrow COI(O) \ne COI(S) \lor \exists Ó(CD(Ó) \in CD_H(S))$
  - S writes $O \Rightarrow (S \text{ canread } O) \land \neg\exists Ó(COI(O) = COI(Ó) \land S \text{ canread } Ó \land \neg san(Ó))$

Recording

- S reads $O \Rightarrow COI(O) \neq COI(S) \vee \exists Ó(CD(Ó) \in CD_H(S))$
  - Record $COI(O)$, $COI(S)$, $CD_H(S)$, $CD(Ó)$ if such an $Ó$ exists, action (read), and result (success, failure)
- S writes $O \Rightarrow (S \text{ canread } O) \wedge \neg\exists Ó(COI(O) = COI(Ó) \wedge S \text{ canread } Ó \wedge \neg san(Ó))$
  - Record $COI(O)$, $COI(S)$, $CD_H(S)$, plus $COI(Ó)$ and $CD(Ó)$ if such an $Ó$ exists, action (write), and result (success, failure)

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

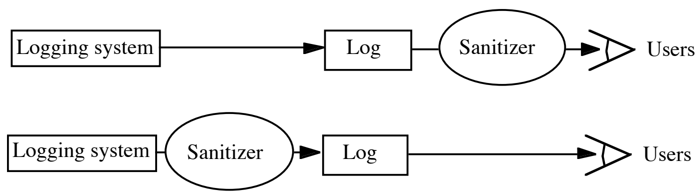
More Syntactic Issues

- 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)