Lecture 5
October 4, 2023

Requirements of Integrity Policies

1. Users will not write their own programs, but will use existing production programs and databases.
2. Programmers will develop and test programs on a non-production system; if they need access to actual data, they will be given production data via a special process, but will use it on their development system.
3. A special process must be followed to install a program from the development system onto the production system.
4. The special process in requirement 3 must be controlled and audited.
5. The managers and auditors must have access to both the system state and the system logs that are generated.

Principles of Operation

- *Separation of duty*: if two or more steps are required to perform a critical function, at least two different people should perform the steps
- *Separation of function*: different entities should perform different functions
- *Auditing*: recording enough information to ensure the abilities to both recover and determine accountability

Biba Integrity Model

Basis for all 3 models:

- Set of subjects S, objects O, integrity levels I, relation $\leq \subseteq I \times I$ holding when second dominates first
- min: $I \times I \rightarrow I$ returns lesser of integrity levels
- i: $S \cup O \rightarrow I$ gives integrity level of entity
- $\underline{\text{r}}$: $S \times O$ means $s \in S$ can read $o \in O$
- $\underline{\text{w}}$, $\underline{\text{x}}$ defined similarly

Intuition for Integrity Levels

- The higher the level, the more confidence
  - That a program will execute correctly
  - That data is accurate and/or reliable
- Note relationship between integrity and trustworthiness
- Important point: *integrity levels are **not** security levels*

Information Transfer Path

- An *information transfer path* is a sequence of objects $o_1, ..., o_{n+1}$ and corresponding sequence of subjects $s_1, ..., s_n$ such that s_i $\underline{r}$ o_i and s_i $\underline{w}$ o_{i+1} for all i, $1 \le i \le n$.
- Idea: information can flow from o_1 to o_{n+1} along this path by successive reads and writes

Strict Integrity Policy

- Dual of Bell-LaPadula model
  1. $s \in S$ can read $o \in O$ iff $i(s) \le i(o)$
  2. $s \in S$ can write to $o \in O$ iff $i(o) \le i(s)$
  3. $s_1 \in S$ can execute $s_2 \in S$ iff $i(s_2) \le i(s_1)$
- Add compartments and discretionary controls to get full dual of Bell-LaPadula model
- If there is an information transfer path from $o_1 \in O$ to $o_{n+1} \in O$, the low-water-mark policy requires $i(o_{n+1}) \le i(o_1)$ for all $n > 1$.
- Term "Biba Model" refers to this

LOCUS and Biba

- Goal: prevent untrusted software from altering data or other software
- Approach: make levels of trust explicit
  - *credibility rating* based on estimate of software's trustworthiness (0 untrusted, *n* highly trusted)
  - *trusted file systems* contain software with a single credibility level
  - Process has *risk level* or highest credibility level at which process can execute
  - Must use *run-untrusted* command to run software at lower credibility level

Clark-Wilson Integrity Model

- Integrity defined by a set of constraints
  - Data in a *consistent* or valid state when it satisfies these
- Example: Bank
  - *D* today's deposits, *W* withdrawals, *YB* yesterday's balance, *TB* today's balance
  - Integrity constraint: $D + YB – W$
- *Well-formed transaction* move system from one consistent state to another
- Issue: who examines, certifies transactions done correctly?

Entities

- CDIs: constrained data items
  - Data subject to integrity controls
- UDIs: unconstrained data items
  - Data not subject to integrity controls
- IVPs: integrity verification procedures
  - Procedures that test the CDIs conform to the integrity constraints
- TPs: transaction procedures
  - Procedures that take the system from one valid state to another

Certification Rules 1 and 2

CR1 When any IVP is run, it must ensure all CDIs are in a valid state

CR2 For some associated set of CDIs, a TP must transform those CDIs in a valid state into a (possibly different) valid state

- Defines relation *certified* that associates a set of CDIs with a particular TP
- Example: TP balance, CDIs accounts, in bank example

Enforcement Rules 1 and 2

ER1 The system must maintain the certified relations and must ensure that only TPs certified to run on a CDI manipulate that CDI.

ER2 The system must associate a user with each TP and set of CDIs. The TP may access those CDIs on behalf of the associated user. The TP cannot access that CDI on behalf of a user not associated with that TP and CDI.

- System must maintain, enforce certified relation
- System must also restrict access based on user ID (*allowed* relation)

Users and Rules

CR3 The allowed relations must meet the requirements imposed by the principle of separation of duty.

ER3 The system must authenticate each user attempting to execute a TP

- Type of authentication undefined, and depends on the instantiation
- Authentication *not* required before use of the system, but *is* required before manipulation of CDIs (requires using TPs)

Logging

CR4 All TPs must append enough information to reconstruct the operation to an append-only CDI.

- This CDI is the log
- Auditor needs to be able to determine what happened during reviews of transactions

Handling Untrusted Input

CR5 Any TP that takes as input a UDI may perform only valid transformations, or no transformations, for all possible values of the UDI. The transformation either rejects the UDI or transforms it into a CDI.

- In bank, numbers entered at keyboard are UDIs, so cannot be input to TPs. TPs must validate numbers (to make them a CDI) before using them; if validation fails, TP rejects UDI

Separation of Duty In Model

ER4 Only the certifier of a TP may change the list of entities associated with that TP. No certifier of a TP, or of an entity associated with that TP, may ever have execute permission with respect to that entity.

- Enforces separation of duty with respect to certified and allowed relations

Comparison With Requirements

1. Users can’t certify TPs, so CR5 and ER4 enforce this
2. Procedural, so model doesn’t directly cover it; but special process corresponds to using TP
   - No technical controls can prevent programmer from developing program on production system; usual control is to delete software tools
3. TP does the installation, trusted personnel do certification

Comparison With Requirements

4. CR4 provides logging; ER3 authenticates trusted personnel doing installation; CR5, ER4 control installation procedure
    - New program UDI before certification, CDI (and TP) after
5. Log is CDI, so appropriate TP can provide managers, auditors access
    - Access to state handled similarly

Comparison to Biba

- Biba
  - No notion of certification rules; trusted subjects ensure actions obey rules
  - Untrusted data examined before being made trusted
- Clark-Wilson
  - Explicit requirements that *actions* must meet
  - Trusted entity must certify *method* to upgrade untrusted data (and not certify the data itself)

UNIX Implementation

- Considered "allowed" relation

  (*user*, *TP*, { *CDI set* })
- Each TP is owned by a different user
  - These "users" are actually locked accounts, so no real users can log into them; but this provides each TP a unique UID for controlling access rights
  - TP is setuid to that user
- Each TP's group contains set of users authorized to execute TP
- Each TP is executable by group, not by world

CDI Arrangement

- CDIs owned by *root* or some other unique user
  - Again, no logins to that user's account allowed
- CDI's group contains users of TPs allowed to manipulate CDI
- Now each TP can manipulate CDIs for single user

Examples

- Access to CDI constrained by user
  - In “allowed” triple, *TP* can be any TP
  - Put CDIs in a group containing all users authorized to modify CDI
- Access to CDI constrained by TP
  - In “allowed” triple, *user* can be any user
  - CDIs allow access to the owner, the user owning the TP
  - Make the TP world executable

Problems

- 2 different users cannot use same copy of TP to access 2 different CDIs
  - Need 2 separate copies of TP (one for each user and CDI set)
- TPs are setuid programs
  - As these change privileges, want to minimize their number
- *root* can assume identity of users owning TPs, and so cannot be separated from certifiers
  - No way to overcome this without changing nature of *root*

Cryptosystem

- Quintuple ($\mathcal{E}$, $\mathcal{D}$, $\mathcal{M}$, $\mathcal{K}$, $\mathcal{C}$)
  - $\mathcal{M}$ set of plaintexts
  - $\mathcal{K}$ set of keys
  - $\mathcal{C}$ set of ciphertexts
  - $\mathcal{E}$ set of encryption functions *e*: $\mathcal{M} \times \mathcal{K} \rightarrow \mathcal{C}$
  - $\mathcal{D}$ set of decryption functions *d*: $\mathcal{C} \times \mathcal{K} \rightarrow \mathcal{M}$

Example

- Example: Cæsar cipher
  - $\mathcal{M}$ = { sequences of letters }
  - $\mathcal{K}$ = { i | i is an integer and $0 \leq i \leq 25$ }
  - $\mathcal{E}$ = { E_k | $k \in \mathcal{K}$ and for all letters m, $E_k(m) = (m + k) \bmod 26$ }
  - $\mathcal{D}$ = { D_k | $k \in \mathcal{K}$ and for all letters c, $D_k(c) = (26 + c - k) \bmod 26$ }
  - $\mathcal{C} = \mathcal{M}$

Attacks

- Opponent whose goal is to break cryptosystem is the *adversary*
  - Assume adversary knows algorithm used, but not key
- Three types of attacks:
  - *ciphertext only*: adversary has only ciphertext; goal is to find plaintext, possibly key
  - *known plaintext*: adversary has ciphertext, corresponding plaintext; goal is to find key
  - *chosen plaintext*: adversary may supply plaintexts and obtain corresponding ciphertext; goal is to find key

Basis for Attacks

- Mathematical attacks
  - Based on analysis of underlying mathematics
- Statistical attacks
  - Make assumptions about the distribution of letters, pairs of letters (digrams), triplets of letters (trigrams), *etc.*
    - Called *models of the language*
  - Examine ciphertext, correlate properties with the assumptions.

Symmetric Cryptography

- Sender, receiver share common key
  - Keys may be the same, or trivial to derive from one another
  - Sometimes called *secret key cryptography*
- Two basic types
  - Transposition ciphers
  - Substitution ciphers
  - Combinations are called *product ciphers*

Transposition Cipher

- Rearrange letters in plaintext to produce ciphertext
- Example (Rail-Fence Cipher)
  - Plaintext is `HELLO WORLD`
  - Rearrange as

```
HLOOL
ELWRD
```

  - Ciphertext is `HLOOL ELWRD`

Attacking the Cipher

- Anagramming
  - If 1-gram frequencies match English frequencies, but other *n*-gram frequencies do not, probably transposition
  - Rearrange letters to form *n*-grams with highest frequencies

Example

- Ciphertext: `HLOOLELWRD`
- Frequencies of 2-grams beginning with `H`
  - `HE` 0.0305
  - `HO` 0.0043
  - `HL`, `HW`, `HR`, `HD` < 0.0010
- Frequencies of 2-grams ending in `H`
  - `WH` 0.0026
  - `EH`, `LH`, `OH`, `RH`, `DH` ≤ 0.0002
- Implies `E` follows `H`

Example

- Arrange so the H and E are adjacent

```
HE
LL
OW
OR
LD
```

- Read across, then down, to get original plaintext

Substitution Ciphers

- Change characters in plaintext to produce ciphertext
- Example (Caesar cipher)
  - Plaintext is `HELLO WORLD`
  - Change each letter to the third letter following it (`X` goes to `A`, `Y` to `B`, `Z` to `C`)
    - Key is 3, usually written as letter ‘`D`’
  - Ciphertext is `KHOOR ZRUOG`