# CS 591: Introduction to Computer Security

# Lecture 5: Integrity Models

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## Objectives

- Integrity models in context
- Introduce integrity models
- Begin hybrid models

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# Plumbing Analogy

- Potable water
  - Cold
  - Hot
- Storm water
- Gray water
- Brown water

- Shower
- Toilet
- Washing machine
- The "CSO" problem

- What comes out of the tap?

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# Simple integrity

- Integrity Levels
  - Potable water
    - Cold
    - Hot
  - Storm water
  - Gray water
  - Brown water

- Multilevel devices:
  - Shower
  - Toilet
  - Washing machine

- What kind(s) of water can people easily obtain (read/execute)?
- What kind(s) of water can people produce (write)?

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# Last Lecture

- Bell LaPadula Confidentiality
- Lattice of security levels
  - No read up
  - No write down
- DG/UX realization of Bell LaPadula

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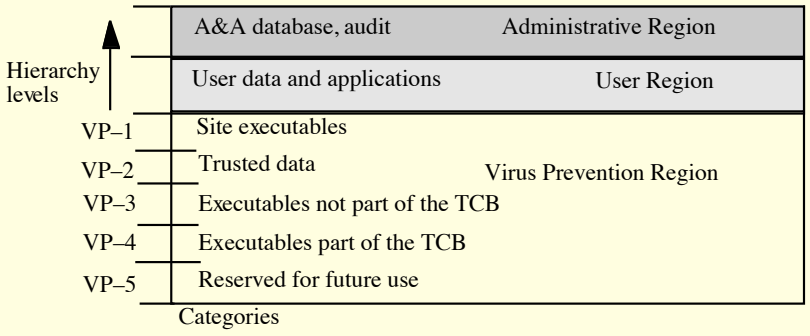
# MAC Regions




IMPL_HI is “maximum” (least upper bound) of all levels
IMPL_LO is “minimum” (greatest lower bound) of all levels

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# Integrity

- Extrinsic:  A system has integrity if it is trusted
- Integrity is not just a property of the information system
- A perfect information system could lose integrity in a corrupt organization



# Integrity Principles

- Separation of Duty:
  - If two or more steps are required to perform a critical function, at least two different people should perform the steps

# Integrity Principles

- Separation of Duty
- Separation of Function
  - Developers do not develop new programs on productions systems

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# Integrity Principles

- Separation of Duty
- Separation of Function
- Auditing
  - Record what actions took place and who performed them
  - Contributes to both recovery and accountability

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# Chapter 6: Integrity Policies

- Overview
- Requirements
- Biba's models
- Clark-Wilson model

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# Overview

- Requirements
  - Very different than confidentiality policies
- Biba's model
- Clark-Wilson model

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# Requirements of 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.



# Biba Integrity Model

- 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
- r: $S \times O$ means $s \in S$ can read $o \in O$
- w, 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*



# Biba's Model

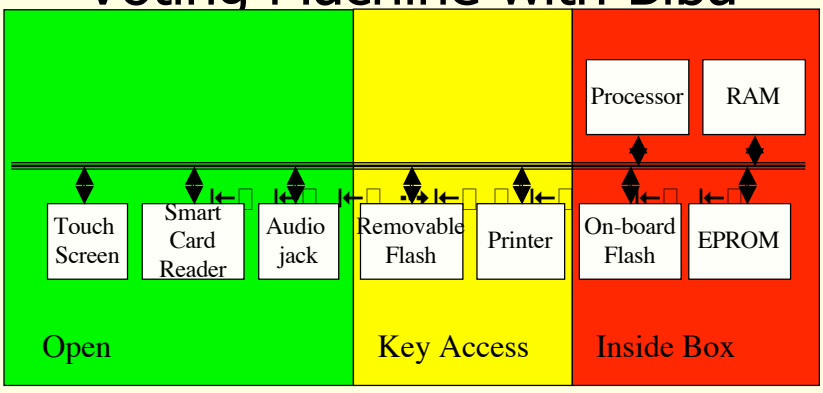
- Similar to Bell-LaPadula model
  1. $s \in S$ can read $o \in O$ iff $i(s) \leq i(o)$
  2. $s \in S$ can write to $o \in O$ iff $i(o) \leq i(s)$
  3. $s_1 \in S$ can execute $s_2 \in S$ iff $i(s_2) \leq i(s_1)$
- Add compartments and discretionary controls to get full dual of Bell-LaPadula model
- Information flow result holds
  - Different proof, though
- Actually the "strict integrity model" of Biba's set of models

# 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



# Voting Machine with Biba




- Subjects? Objects? Integrity Levels?

# Example

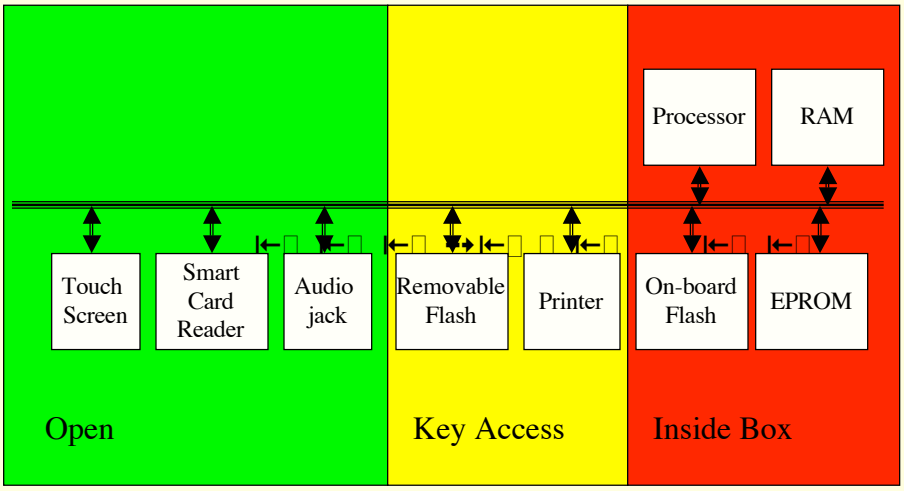
- Elaborate the Biba integrity model for this system by assigning integrity levels to all key files. Specifically assign integrity levels for creating or modifying these files.
- Several known exploits of the system rely on infection via removable media. Propose a mechanism that uses the trusted authentication mechanism and integrity model to prevent these exploits.



# Example (cont)

- Argue that the intended operations can be carried out by appropriate subjects without violating the policy.
- Argue that with these mechanisms and a faithful implementation of the integrity model that Felten's vote stealing and denial of service attacks would not be allowed.

# Voting Machine Architecture

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# Boot Process

- Boot device specified by hardware jumpers (inside box)
  - EPROM
  - on-board flash (default)
  - ext flash
- On Boot:
  - Copy bootloader into RAM; init hardware
  - Scan Removable flash for special files
    - "fboot.nb0" => replace bootloader in on-board flash
    - "nk.bin" => replace OS in on-board flash
    - "EraseFFX.bsq" => erase file system on on-board flash
  - If no special files uncompress OS image
  - Jump to entry point of OS

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# Boot (continued)

- On OS start up:
  - run Filesys.exe
    - unpacks registry
    - runs programs in HKEY_LOCAL_MACHINE\Init
      - shell.exe (debug shell)
      - device.exe (Device manager)
      - gwes.exe (graphics and event)
      - taskman.exe (Task Manager)
  - Device.exe mounts file systems
    - \ (root): RAM only
    - \FFX: mount point for on-board flash
    - \Storage Card: mount point for removable flash



# Boot (continued)

- Customized taskman.exe
  - Check removable flash
    - explorer.glb => launch windows explorer
    - *.ins => run proprietary scripts
      - (script language has buffer overflow vulnerabilities)
      - used to configure election data
    - default => launch "BallotStation"
      - \FFX\Bin\BallotStation.exe

# BallotStation

- Four modes: pre-download, pre-election testing, election, post-election
- Mode recorded in election results file
  - \Storage Card\CurrentElection\election.brs

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# Stealing Votes

- Malicious processes runs in parallel with BallotStation
- Polls election results file every 15 seconds
  - If election mode and new results
    - temporarily suspend Ballot Station
    - steal votes
    - resume Ballot Station

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# Viral propagation

- Malicious bootloader
  - Infects host by replacing existing bootloader in on-board flash
  - subsequent bootloader updates print appropriate messages but do nothing
- fboot.nb0
  - package contains malicious boot loader
  - and vote stealing software

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# Discussion

- Having developed this design, it is now time to critique it!
  - Are you satisfied with the protection against external threats?
  - Are you satisfied with the protection against insider threats?

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# 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)



# Key Points

- Integrity policies deal with trust
  - As trust is hard to quantify, these policies are hard to evaluate completely
  - Look for assumptions and trusted users to find possible weak points in their implementation
- Biba based on multilevel integrity
- Clark-Wilson focuses on separation of duty and transactions

# Presentation

- Bishop Chapter 7 slides

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