Operating System Security

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Security Goals

Protecting data and resources has three requirements

- **Secrecy (confidentiality)**
  - Unauthorized disclosure
  - Limits the objects (files/sockets) that a process can read
- **Integrity**
  - Unauthorized modification
  - Limits the objects that a process can write
    (objects may contain information that other processes depend on)
- **Availability**
  - Limits the system resources that processes (or users) may consume
  - Therefore preventing denial of service attacks
  - Achieved by OS resource management techniques like fair scheduling

Confidentiality & Integrity

Achieved by Access Control

- Every access to an object in the system should be controlled
- **All** and **only** authorized accesses can take place

Access ? Specifying an operation on the object like read, write, execute, create, delete

Access Control Systems

- Development of an access control system has three components
  - Security Policy : high level rules that define access control
  - Security Model : a formal representation of the access control security policy and its working.

    (this allows a mathematical representation of a policy; there by aid in proving that the model is secure)
  - Security Mechanism : low level (sw / hw) functional implementations of policy and model

Security Policy

Security Model

Security Mechanisms

Security Policy

- A scheme for specifying and enforcing security policies in a system
- Driven by
  - Understanding of threat and system design
- Often take the form of a set of statements
  - Succinct statements
  - Goals are agreed upon either by
    - The entire community
    - Top management
    - Or is the basis of a formal mathematical analysis

A bad security policy model of a company

Approval of policy should not be part of the policy document itself.

Who enforces this?

Megacorp Inc security policy

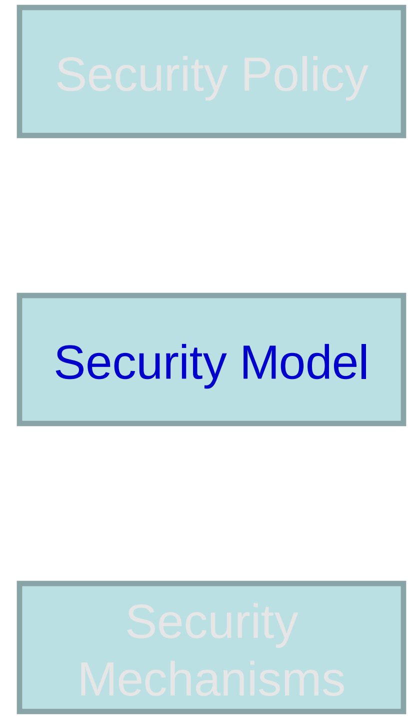
1. This policy is approved by Management.
2. All staff shall obey this security policy.
3. Data shall be available only to those with a 'need-to-know'.
4. All breaches of this policy shall be reported at once to Security.

Who determines need to know?

How are breaches detected?
Who's duty is it to report them

Security Model

- Why have it at all?
  – It is a mathematical representation of the policy.
  – By proving the model is secure and that the mechanism correctly implements the model, we can argue that the system is indeed secure (w.r.t. the security policy)



Security Mechanism

- Implementing a correct mechanism is non trivial
- Could contain bugs in implementation which would break the security
- The implementation of the security policy must work as a ‘trusted base’ (reference monitor)
- Properties of the implementation
  - Tamper proof
  - Non-bypassable (all accesses should be evaluated by the mechanism)
  - Security kernel – must be confined to a limited part of the system (scattering security functions all over the system implies that all code must be verified)
  - Small – so as to achieve rigorous verification

Security Policy

Security Model

Security Mechanisms

Access Control Techniques

- DAC – Discretionary
- MAC – Mandatory
- RBAC -- Role-based

Discretionary Access Control

- Discretionary (DAC)
  - Access based on
    - Identity of requestor
    - Access rules state what requestors are (or are not) allowed to do
  - Privileges granted or revoked by an administrator
  - Users can pass on their privileges to other users
  - Example. Access Matrix Model

Access Matrix Model

- By Butler Lampson, 1971
- Subjects : active elements requesting information
- Objects : passive elements storing information
  - Subjects can also be objects

subjects

objects

rights

	File 1	File 2	File 3	Program 1
Ann	own read write	read write		execute
Bob	read		read write	
Carl		read		execute read

Other actions : ownership (property of objects by a subject),
control (father-children relationships between processes)

Butler Lampson, “Protection”, 1971

A formal representation of Access Matrix Model

- Define an access matrix : $A[X_{s_i}, X_{o_j}]$
- Protection System consists of
  - **Generic rights :** $R = \{r_1, r_2, \cdots, r_k\}$ **thus** $A[X_{s_i}, X_{o_j}] \subseteq R$
  - **Primitive Operations** $O = \{op_1, op_2, \cdots, op_n\}$

enter r into $A[X_{s_i}, X_{o_j}]$
delete r from $A[X_{s_i}, X_{o_j}]$
create subject X_s
create object X_o
destroy subject X_s
destroy object X_o

objects

subjects

Generic rights

	File 1	File 2	File 3	Program 1
Ann	own read write	read write		execute
Bob	read		read write	
Carl		read		execute read

Michael A. Harrison, Walter L. Ruzzo, Jeffrey D. Ullman, Protection in Operating Systems, 1974

A formal representation of Access Matrix Model

- Commands

access matrix $A[X_{s_i}, X_{o_j}]$

Generic rights $R = \{r_1, r_2, \cdots, r_k\}$

Primitive operations $O = \{op_1, op_2, \cdots, op_n\}$

command $\alpha(X_1, X_2, \cdots, X_n)$
  if r_1 in $A[X_{s_1}, X_{o_1}]$ and
    r_2 in $A[X_{s_2}, X_{o_2}]$ and
    r_3 in $A[X_{s_3}, X_{o_3}]$ and
    $\vdots \quad \vdots \quad \vdots$
    r_3 in $A[X_{s_3}, X_{o_3}]$
  then op_1
    op_2
    op_3
    $\vdots \quad \vdots$
  end

enter r into $A[X_{s_i}, X_{o_j}]$
delete r from $A[X_{s_i}, X_{o_j}]$
create subject X_s
create object X_o
destroy subject X_s
destroy object X_o

Example Commands

$$
\begin{array}{l}
\text{command } \alpha(X_1, X_2, \cdots, X_n) \\
\quad \text{if } r_1 \text{ in } A[X_{s_1}, X_{o_1}] \text{ and} \\
\quad\quad r_2 \text{ in } A[X_{s_2}, X_{o_2}] \text{ and} \\
\quad\quad r_3 \text{ in } A[X_{s_3}, X_{o_3}] \text{ and} \\
\quad\quad \vdots \qquad \vdots \qquad \vdots \\
\quad\quad r_3 \text{ in } A[X_{s_3}, X_{o_3}] \\
\quad \text{then} \qquad op_1 \\
\quad\quad op_2 \\
\quad\quad op_3 \\
\quad\quad\; \vdots \; \vdots \\
\quad \text{end}
\end{array}
$$

command *CREATE*(process, file)
  create object file
  enter own into (process, file)
end

Create an object

command *CONFER*$_r$ (owner, friend, file)
  if own in (owner, file)
  then enter *r* **into** (friend, file)
end

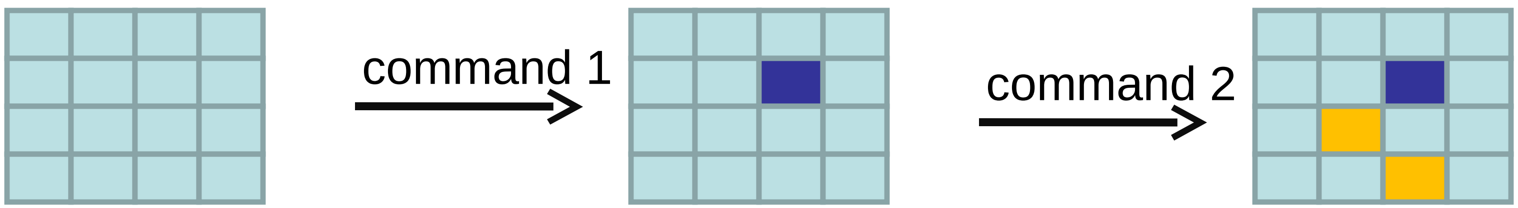
Confer 'r' right to a friend for the object

command *REMOVE*$_r$ (owner, exfriend, file)
  if own in (owner, file) and
    r in (exfriend, file)[1]
  then delete *r* **from** (exfriend, file)
end

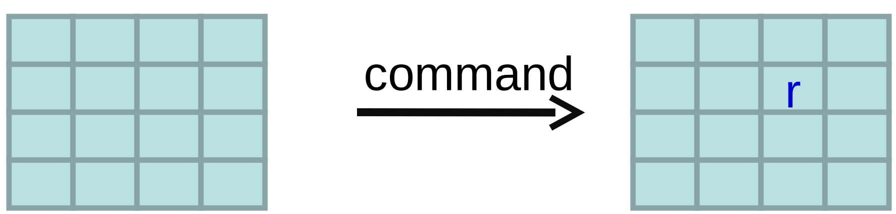
Owner can revoke Right from an 'ex'friend

States of Access Matrix

- A protection system is a **state transition system**



- **Leaky State:**
  - A state (access matrix) is said to leak a right ‘r’ if there exists a command that adds right ‘r’ into an entry in the access matrix that did not previously contain ‘r’



  - Leaks may not be always bad.

Is my system safe?

- **Safety**
  - *Definition 1:* System is safe if access to an object without owner's **concurrence** is impossible
  - *Definition 2:* A user should be able to tell if giving away a right would lead to **further leakage** of that right.

Safety in the formal model

- Suppose a subject **s** plans to give subjects **s'** right **r** to object **o**.
  - with **r** entered into **A[s',o]**, is such that **r** could subsequently be entered somewhere new.
  - If this is possible, then the system is unsafe

Unsafe State (Example)

- Consider a protection system with two commands

command $CONFER_{execute}(S, S', O)$
  if o in $A[S, O]$ then
    enter x in $A[S', 0]$
  end

command $MODIFY\_RIGHT(S, O)$
  if x in $A[S, O]$ then
    enter w in $A[S, O]$
  end

- Scenario: Bob creates an application (object). He wants it to be executed by all others but not modified by them
- The system is unsafe due to the presence of MODIFY_RIGHT in the protection system.
  – Alice could invoke MODIFY_RIGHT to get modification rights for the application

Safety Theorem

- Given an initial state of the matrix (say $\mathbf{A_0}$) and a right '**r**', we say that the state $\mathbf{A_0}$ is unsafe if there exists a state $\mathbf{A_i}$ such that,
  1. $\mathbf{A_i}$ is reachable from $\mathbf{A_0}$
     - There are a sequence of transitions (commands) that would take the state from $\mathbf{A_0}$ to $\mathbf{A_i}$
  2. $\mathbf{A_i}$ leaks 'r'

Determining if a system is safe is undecidable

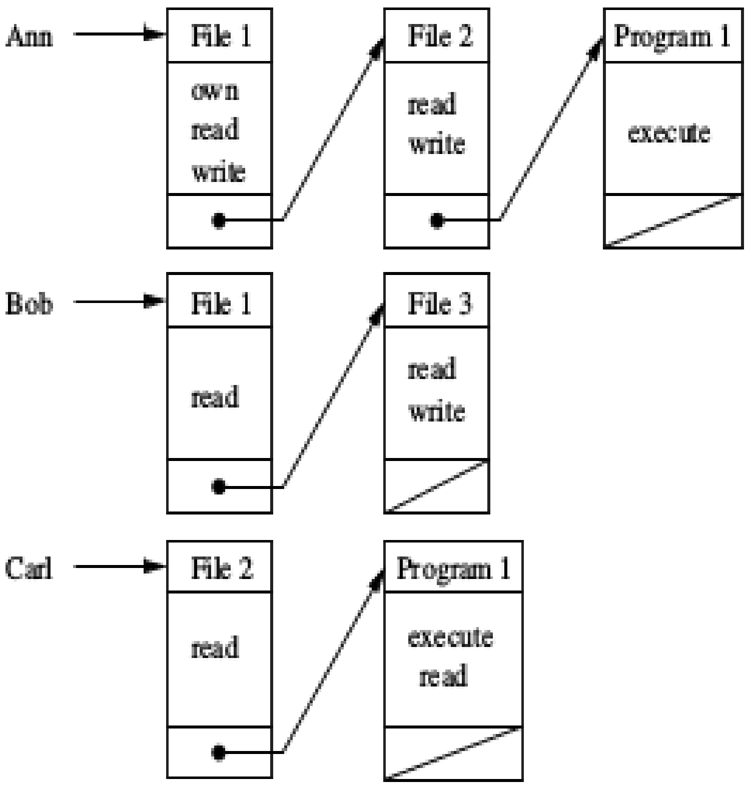
Access Matrix Model Implementation (Authorization Table)

- Matrix not efficient
  - Too large and too sparse
- Authorization Table
  - Used in databases
  - Needs to search entire table in order to identify access permission

User	Access mode	Object
Ann	own	File 1
Ann	read	File 1
Ann	write	File 1
Ann	read	File 2
Ann	write	File 2
Ann	execute	Program 1
Bob	read	File 1
Bob	read	File 3
Bob	write	File 3
Carl	read	File 2
Carl	execute	Program 1
Carl	read	Program 1

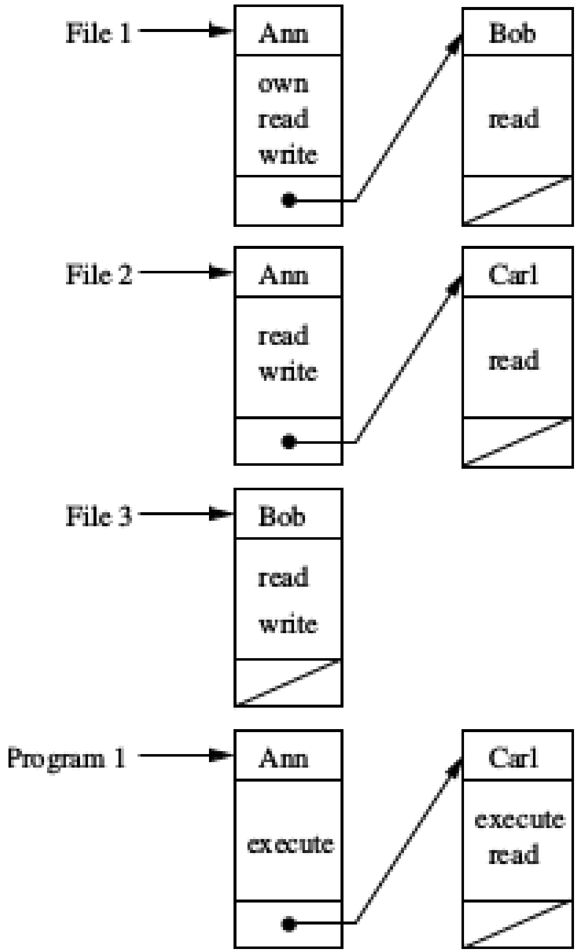
Access Matrix Model Implementation (Capabilities)

- Capabilities
  - Each user associated with a capability list, indicating, for each object the permitted operations
  - Advantage in distributed systems, since it prevents repeated authentication of a subject.
  - Vulnerable to forgery: can be copied and misused by an attacker.



Access Matrix Model Implementation (ACL)

- Access Control Lists
  - Each object is associated with a list indicating the operations that each subject can perform on it
  - Easy to represent by small bit-vectors



ACL Implementation in Unix

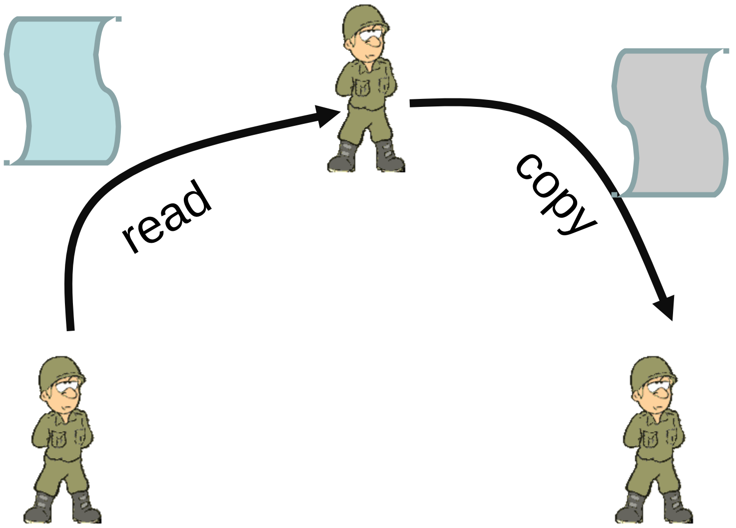
- Users belong to exactly one group
- Each file has an owner
- Authorization for each file can be specified
  - For file's owner (r,w,x → 3 bits)
  - For the group (r,w,x → 3 bits)
  - For the rest of the world (r,w, x →3 bits)

Vulnerabilities in Discretionary Policies

- Subjected to Trojan Horse attacks
  - A Trojan horse can inherit all the user's privileges
  - Why?
    - A trojan horse process started by a user sends requests to OS on the user's behalf

Drawback of Discretionary Policies

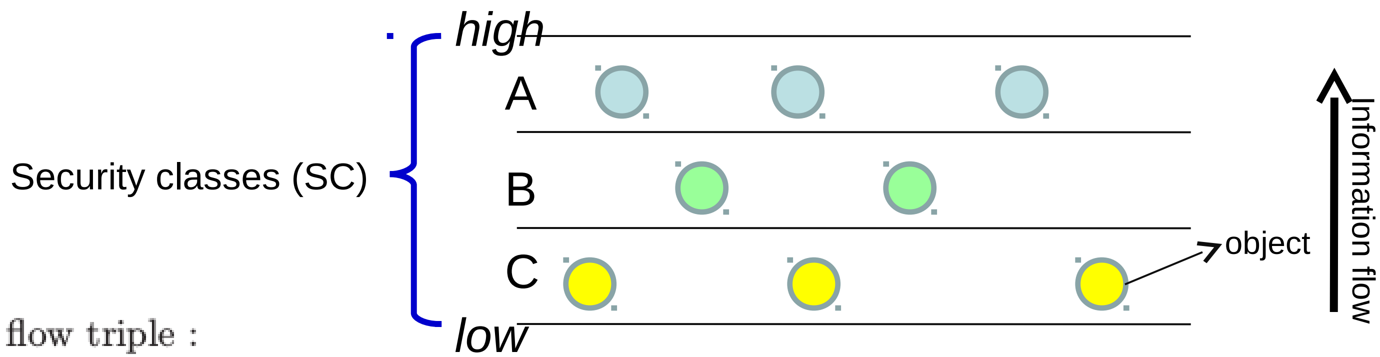
- It is not concerned with information flow
  - Anyone with access can propagate information



- Information flow policies
  - Restrict how information flows between subjects and objects

Information Flow Policies

- Every object in the system assigned to a security class (SC)



- Information flow triple :

  $\langle SC, \rightarrow, \oplus \rangle$

  $\rightarrow$ is the can flow relation
  - $B \rightarrow A$: Information from B can flow to A
  - $C \rightarrow B \rightarrow A$: Information flow
  - $C \leq B \leq A$: Dominance relation

  $\oplus$ is the join relation
  - defines how to label information obtained by combining information from two classes
  - $\oplus : SC \times SC \rightarrow SC$.

  SC, $\rightarrow$, and $\oplus$ are fixed and do not change with time.

  The SC of an object may vary with time

Ravi Sandhu, *Lattice Based Access Control Models*, 1993

Examples

- Trivial case (also the most secure)
  – No information flow between classes

$$- \; SC = \{A_1\,(low), A_2, \cdots, A_n\,(high)\}$$
$$- \; A_i \rightarrow A_i \text{ (for } i = 1 \cdots n)$$
$$- \; A_i \oplus A_i = A_i$$

- High to Low flows only

$$- \; SC = \{A_1\,(low), A_2, \cdots, A_n\,(high)\}$$
$$- \; A_j \rightarrow A_i \text{ only if } j \leq i \text{ (for } i, j = 1 \cdots n)$$
$$- \; A_i \oplus A_j = A_i$$

Examples

- A company has the following security policy
  - A document made by a manager can be read by other managers but no workers
  - A document made by a worker can be read by other workers but no managers
  - Public documents can be read by both Managers and Workers

- What are the security classes?
- What is the flow operator?
- What is the join operator?

Examples

- A company has the following security policy
  - A document made by a manager can be read by other managers but no workers
  - A document made by a worker can be read by other workers but no managers
  - Public documents can be read by both Managers and Workers

- $SC = \{P\,(low), W, M\,(high)\}$
- $P \to M$, $P \to W$, $W \to W$, $M \to M$
- $P \oplus M \to M$, $P \oplus W \to W$, $M \oplus M \to M$, $W \oplus W \to W$

Mandatory Access Control

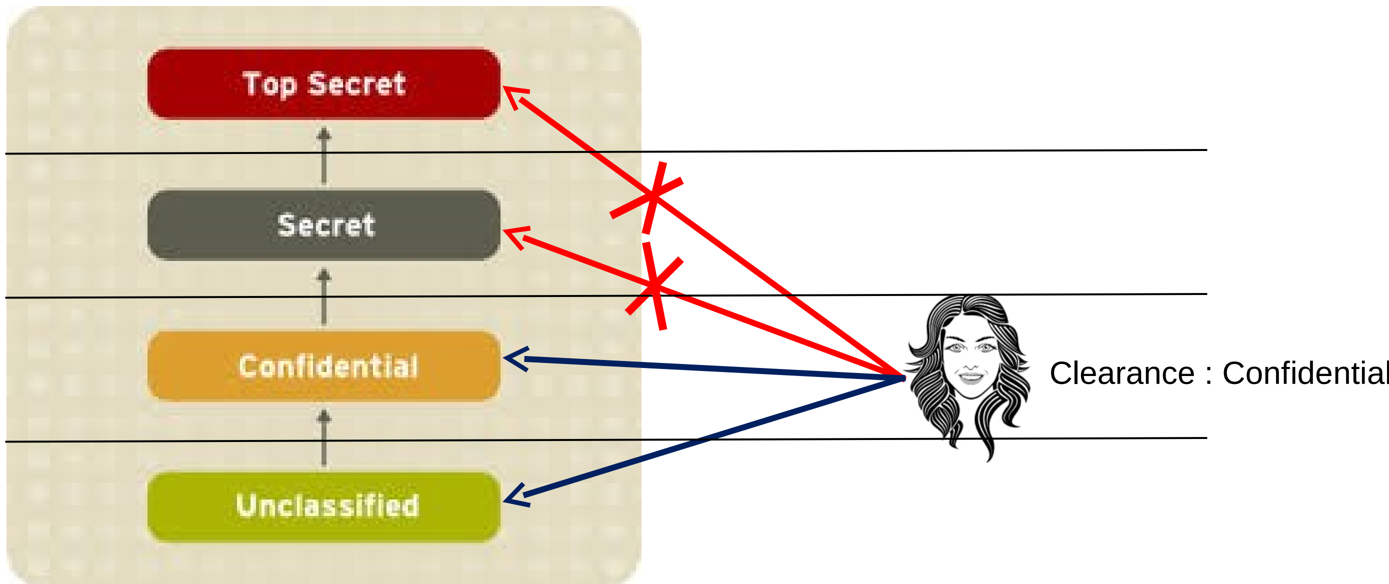
- Access based on regulations set by a central authority
- Most common form is multilevel security (MLS) policy
  - Access Class
    - Objects need a **classification level**
    - Subjects needed a **clearance level**
  - A subject with *X* clearance can access all objects in X and below X but not vice-versa
  - Information only flows upwards and cannot flow downwards

Bell-LaPadula Model

- Developed in 1974
- Formal model for access control
- Four access modes:
  - read, write, append, execute
- Two properties (MAC rules)
  - No read up (simple security property (ss-property))
  - No write down (*-property)

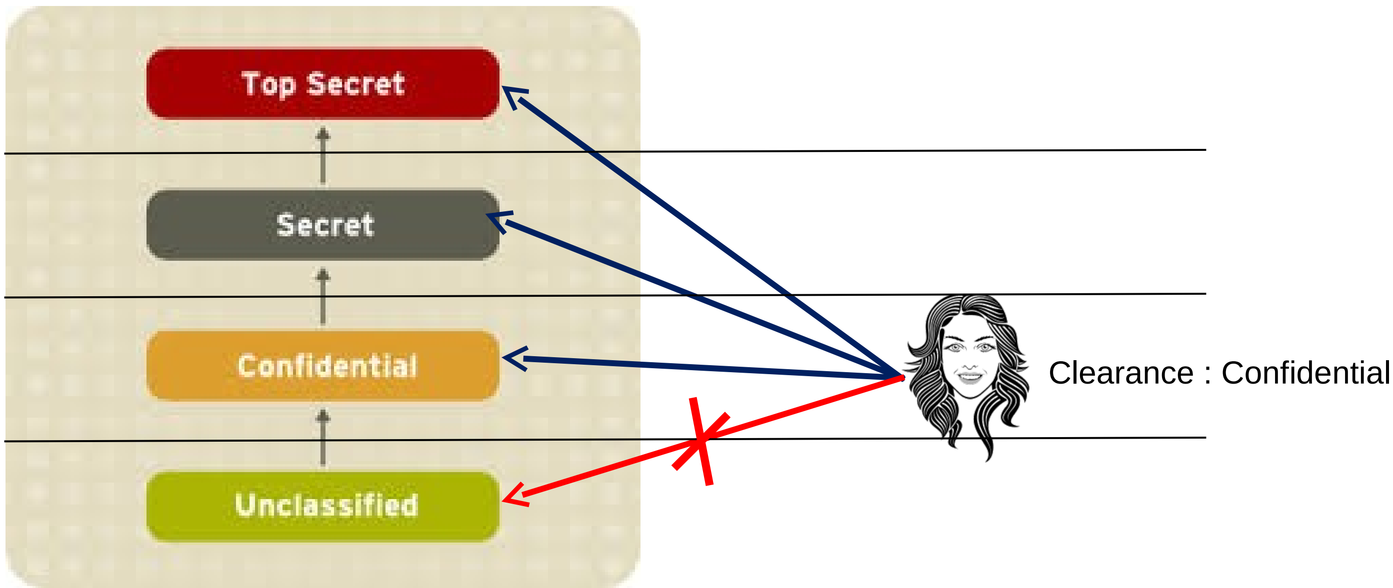
D. E. Bell and L. J. LaPadula, *Secure Computer System: Unified*

No read up



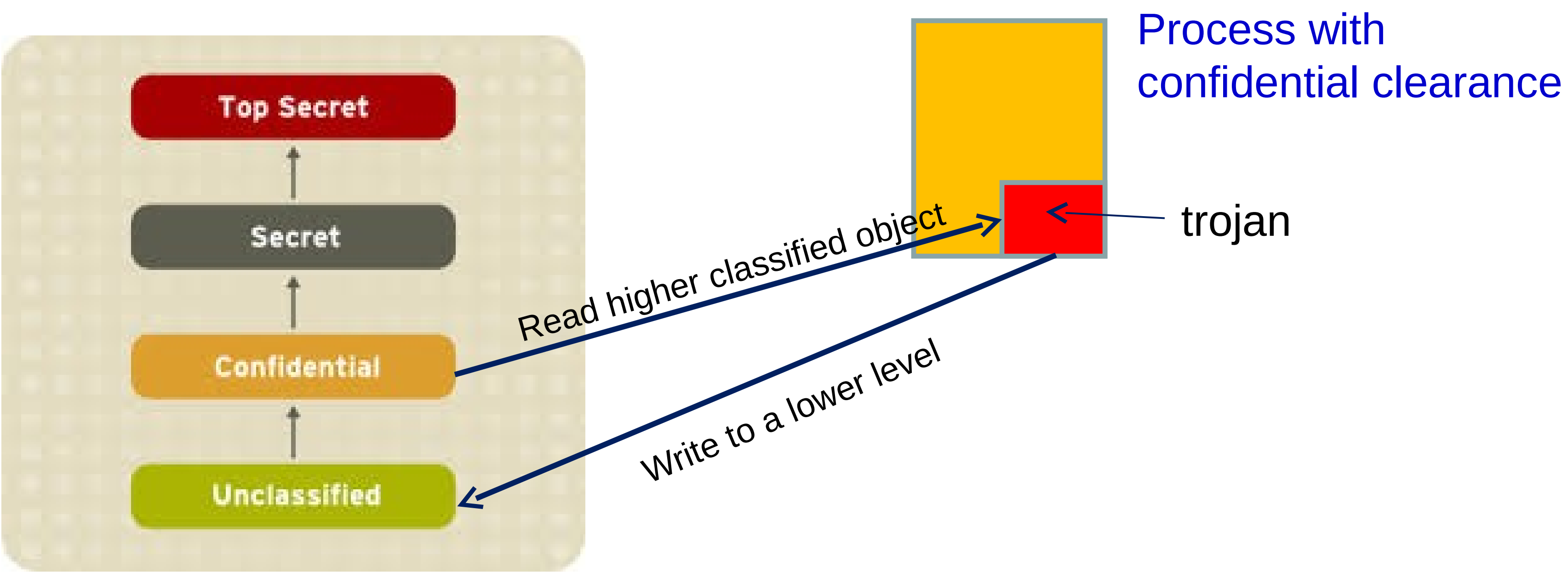
- Can only read confidential and unclassified files

No Write Down



- Cannot write into an unclassfied object

Why No Write Down?



- A process inflected with a trojan, could read confidential data and write it down to unclassified
- We trust users but not subjects (like programs and processes)

ds-property

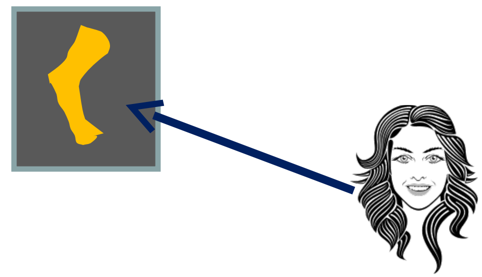
- Discretionary Access Control
  - An individual may grant access to a document he/she owns to another individual.
  - However the MAC rules must be met

MAC rules over rides any discretionary access control. A user cannot give away data to unauthorized persons.

Limitations of BLP

- Write up is possible with BLP
- Does not address Integrity Issues

file with classification *secret*



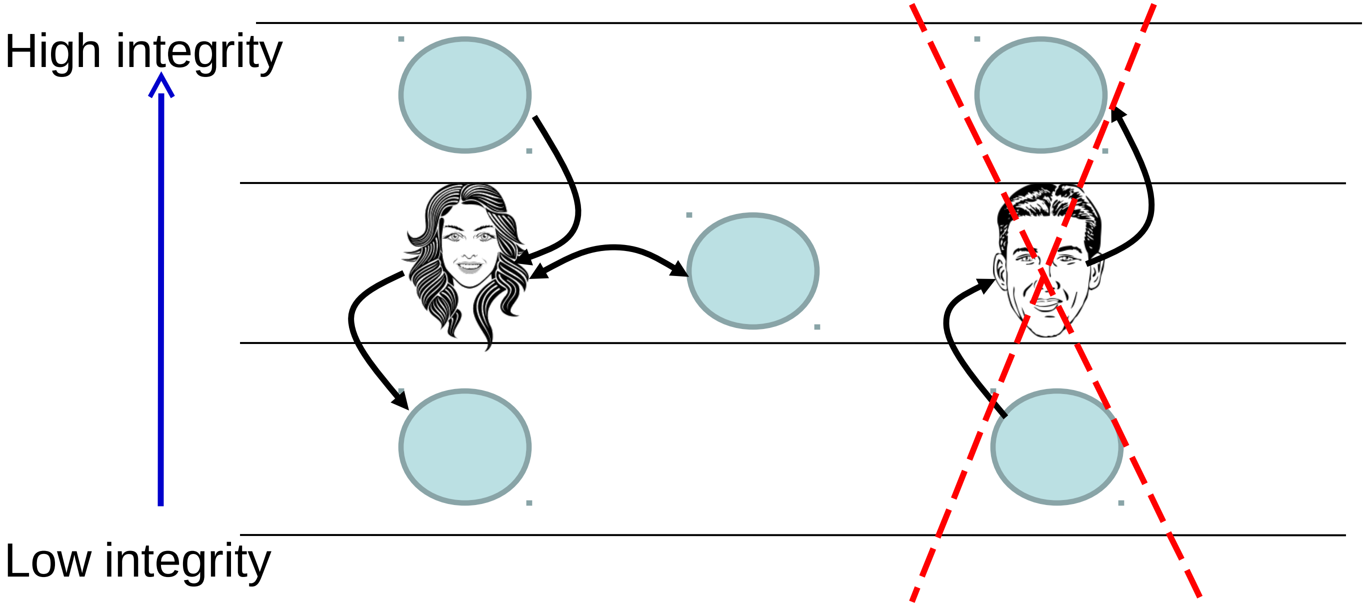
Clearance : Confidential

User with clearance can modify a secret document
BLP only deals with confidentiality. Does not take care of integrity.

Biba Model

- Bell-LaPadula upside down
- **Ignores confidentiality and only deals with integrity**
- Goals of integrity
  - Prevent unauthorized users from making modifications in a document
  - Prevent authorized users from making improper modifications in a document
- Incorporated in Microsoft Windows Vista

BIBA Properties

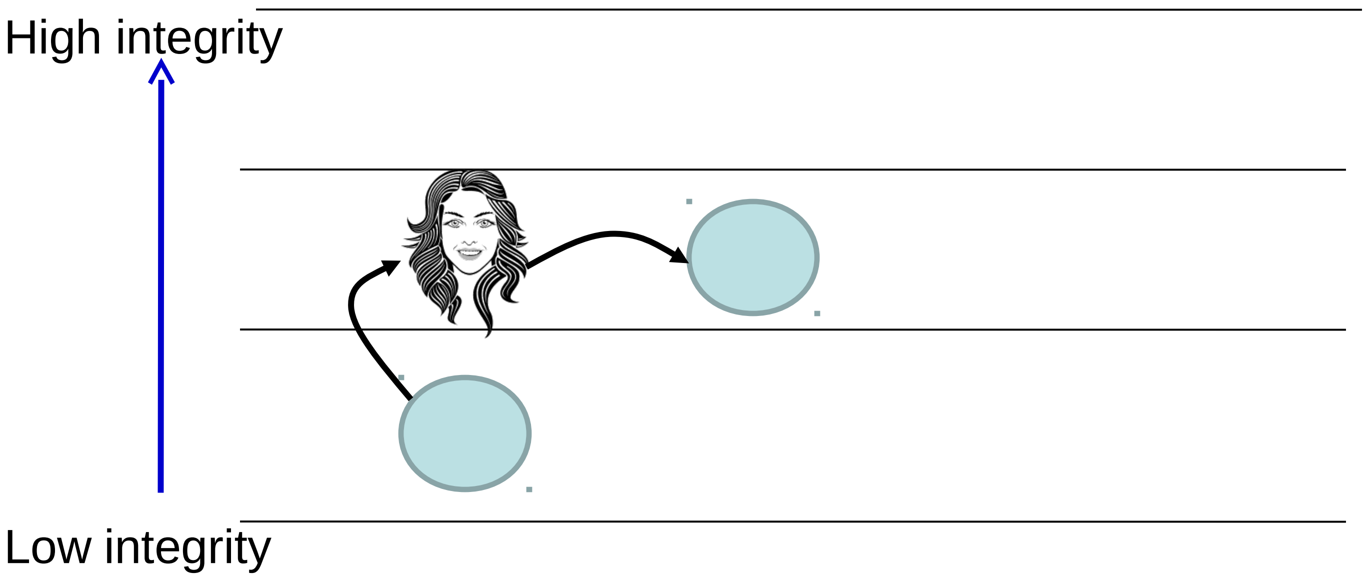


Properties

No read down : Simple Integrity Theorem

No write up : * Integrity Theorem

Why no Read Down?

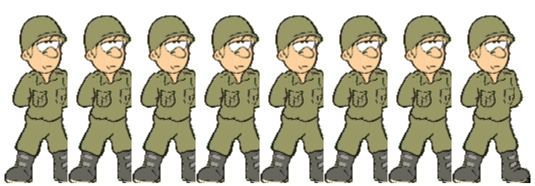


- A higher integrity object may be modified based on a lower integrity document

Example

General

Captains



Privates

Read Up

- A document from the general should be read by all

No Read Down

- A private's document should not affect the General's decisions

Secure Operating Systems

- A secure OS has 3 requirements
  - Complete mediation
    - Access enforcement mechanisms of OS should mediate all security-sensitive operations.
  - Tamperproof
    - Access enforcement mechanisms of OS should not be modifiable by an untrusted process
  - Verifiable
    - The access enforcement mechanisms of OS must be small enough to be completely and thoroughly tested.

How to precisely achieve these requirements!!

Complete Mediation

- Where to mediate is crucial!
- Trivial approach: mediate all system calls as these are entry points
  - Insufficient :
    - example, for the open system call,

      open('/home/user/Desktop/file.txt', 'w')

does the user have write permission for each directory object along the path

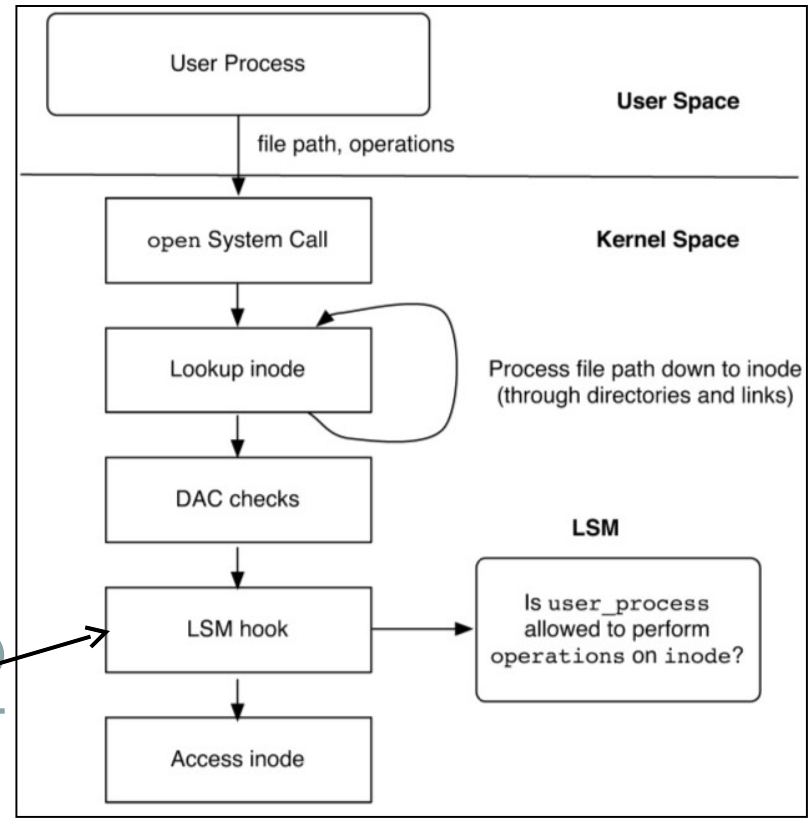
permission to access file.txt may change from the start of the open system call to the actual open operation.

- Reference monitors have to be embedded in the OS. Each system call needs to be considered independently.

Linux Reference Monitor (LSM)

- LSM : Linux Security Module is the reference module for Linux
- Every system call will have a hook that invokes the reference monitor
- LSM does not authorize open system call, but each individual directory, li[illegible] file open after the syst[illegible] object reference has been retrieved.

mainly for authorization of queries



Placement of LSM hook is important?

Tamperproof

- Reference monitor should not be modifiable outside the trusted computing base.
  - This must be verified.
  - Verification tool itself must be tamperproof

Threats

- Control flow hacking
  - Example : Buffer overflows
- Covert Channels

…next