2550 Intro to cybersecurity

L~~6~~7: Authorization

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Thanks Christo for slides!

Authentication:

Authorization

After Authenticating a subject, what next?

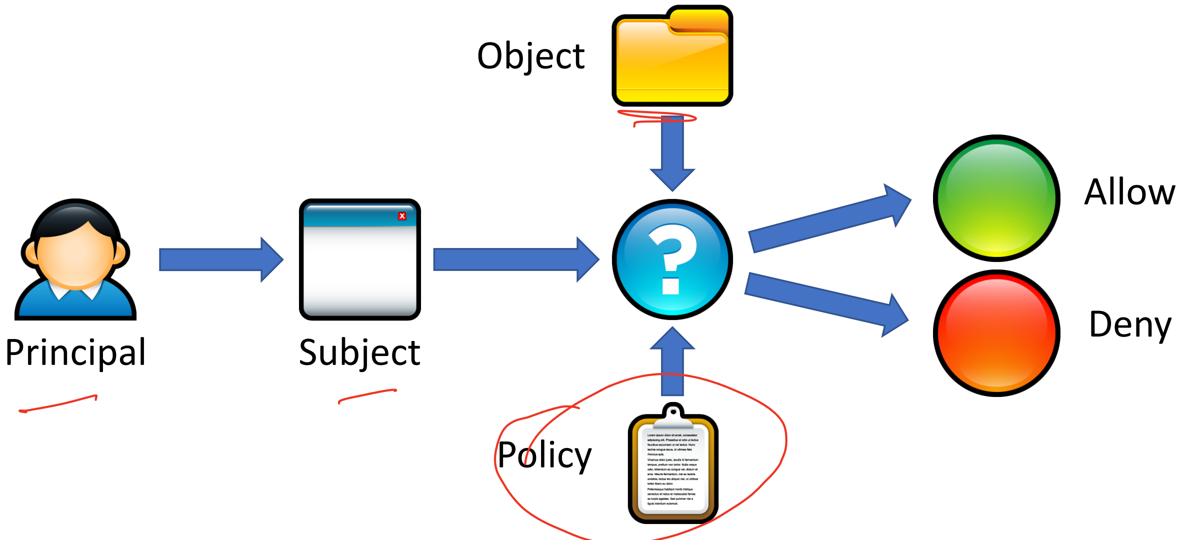
Access Control

- Policy specifying how entities can interact with resources
  - i.e., Who can access what?
  - Requires authentication and authorization
- Access control primitives

Principal	User of a system	
Subject	Entity that acts on behalf of principals	Software program
Object	Resource acted upon by subjects	Files Sockets Devices OS APIs

Access Control Check

- Given an access request from a subject, on behalf of a principal, for an object, return an access control decision based on the policy



Access Control Models

- Discretionary Access Control (DAC)
  - The kind of access control you are familiar with
  - Access rights propagate and may be changed at subject’s discretion

Access Control Models

- Discretionary Access Control (DAC)
  - The kind of access control you are familiar with
  - Access rights propagate and may be changed at subject’s discretion

- Mandatory Access Control (MAC)
  - Access of subjects to objects is based on a system-wide policy
  - Denies users full control over resources they create

Discretionary Access Control

Access Control Matrices

Access Control Lists

Unix Access Control

Discretionary Access Control

- According to Trusted Computer System Evaluation Criteria (TCSEC)

"A means of restricting access to objects based on the identity and need-to-know of users and/or groups to which they belong.

Controls are discretionary in the sense that a subject with a certain access permission is capable of passing that permission (directly or indirectly) to any other subject."

Access Control Matrices

Given subjects $s_i \in S$, objects $o_j \in O$, rights {**R**ead, **W**rite, e**X**ecute},

- Introduced by Lampson in 1971
- Static description of protection state
- Abstract model of concrete systems

	o_1	o_2	o_3
s_1	RW	RX	
s_2	R	RWX	RW
s_3		RWX	

Access Control List (ACL)

- Each object has an associated list of subject→operation pairs
- Authorization verified for each request by checking list of tuples
- Used pervasively in filesystems and networks
  - "Users a, b, and c and read file x."
  - "Hosts a and b can listen on port x."

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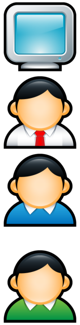
ACL for o_2

	o_1	o_2	o_3
s_1	RW	RX	
s_2	R	RWX	RW
s_3		RWX	

Windows ACLs



	D:\Music	D:\Images	D:\Documents
System	RWX	RWX	RWX
Administrators	RW	RW	RW
Users:Bob	RWX	RW	
Users:Alice		RW	R

Windows ACLs

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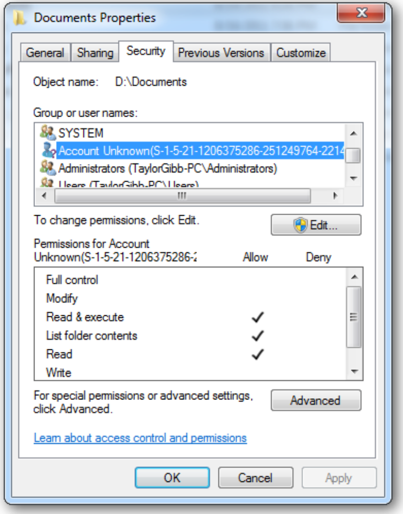

ACL Review

The Good

- Very flexible
  - Can express any possible access control matrix
  - Any principal can be configured to have any rights on any object

The Bad

ACL Review

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- Very flexible
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  - Any principal can be configured to have any rights on any object

The Bad

- Complicated to manage
  - Every object can have wildly different policies
  - Infinite permutations of subjects, objects, and rights

Unix-style Permissions

- Based around the concept of owners and groups
  - All objects have an owner and a group
  - Permissions assigned to owner, group, and everyone else
- Authorization verified for each request by mapping the subject to owner, group, or other and checking the associated permissions

Unix Permissions

```
cbw@DESKTOP:~$ ls -l
drwxrwxrwx 0 cbw  cbw      512 Jan 29 22:46 my_dir
-rw-rw-rw- 1 cbw  cbw       17 Jan 29 22:46 my_file
-rwxrwxrwx 1 cbw  faculty  313 Jan 29 22:47 my_program.py
-rw------- 1 root root     896 Jan 29 22:47 sensitive_data.csv
```

d → **Directory** **r →** **Read** **w →** **Write** **x →** **eXecute**

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Owner Group

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Unix Permissions

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Owner Group Other

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Unix Permissions

Directory

Permission to list the contents of a directory

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drwxrwxrwx 0 cbw  cbw      512 Jan 29 22:46 my_dir
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Owner Group Other

Owner Group

d → Directory

r → Read w → Write x → eXecute

Setting Permissions

+ → add permissions
- → remove permissions

chmod [who]<+/-><permissions> <file1> [file2] …

(omitted) → user, group, and other
a → user, group, and other
u → user
g → group
o → other

r → Read
w → Write
x → eXecute

```
cbw@DESKTOP:~$ ls -l
drwxrwxrwx 0 cbw  cbw      512 Jan 29 22:46 my_dir
-rw-rw-rw- 1 cbw  cbw       17 Jan 29 22:46 my_file
-rwxrwxrwx 1 cbw  faculty 313 Jan 29 22:47 my_program.py
cbw@DESKTOP:~$ chmod ugo-rwx my_dir
cbw@DESKTOP:~$ chmod go-rwx my_program.py
cbw@DESKTOP:~$ chmod u-rw my_program.py
cbw@DESKTOP:~$ chmod +x my_file
cbw@DESKTOP:~$ ls -l
d--------- 0 cbw  cbw      512 Jan 29 22:46 my_dir
-rwxrwxrwx 1 cbw  cbw       17 Jan 29 22:46 my_file
---x------ 1 cbw  faculty 313 Jan 29 22:47 my_program.py
```

Alternate Form of Setting Permissions

chmod ### <file1> [file2] …

- #s correspond to owner, group, and other
- Each value encodes read, write, and execute permissions
  - 1 → execute
  - 2 → write
  - 4 → read

Alternate Form of Setting Permissions

chmod ### <file1> [file2] …

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- What if you want to set something as read, write, and execute?

Alternate Form of Setting Permissions

chmod ### <file1> [file2] …

- #s correspond to owner, group, and other
- Each value encodes read, write, and execute permissions
  - 1 → execute
  - 2 → write
  - 4 → read
- What if you want to set something as read, write, and execute?
  - 1 + 2 + 4 = 7

```
cbw@DESKTOP:~$ ls -l
drwxrwxrwx 0 cbw  cbw     512 Jan 29 22:46 my_dir
-rw-rw-rw- 1 cbw  cbw      17 Jan 29 22:46 my_file
-rwxrwxrwx 1 cbw  faculty 313 Jan 29 22:47 my_program.py
cbw@DESKTOP:~$ chmod 000 my_dir
cbw@DESKTOP:~$ chmod 100 my_program.py
cbw@DESKTOP:~$ chmod 777 my_file
cbw@DESKTOP:~$ ls -l
d--------- 0 cbw  cbw     512 Jan 29 22:46 my_dir
-rwxrwxrwx 1 cbw  cbw      17 Jan 29 22:46 my_file
---x------ 1 cbw  faculty 313 Jan 29 22:47 my_program.py
```

Who May Change Permissions?

```
cbw@DESKTOP:~$ groups
cbw faculty
cbw@DESKTOP:~$ ls -l
-rw-rw-rw- 1 cbw  cbw      17 Jan 29 22:46 my_file
-rw-rw-rw- 1 cbw  faculty  17 Jan 29 22:46 my_other_file
-rw------- 1 root root    896 Jan 29 22:47 sensitive_data.csv
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- Which files is user *cbw* permitted to *chmod*?

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-rw------- 1 root root    896 Jan 29 22:47 sensitive_data.csv
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```

- Which files is user *cbw* permitted to *chmod*?
  - Only owners can *chmod* files
  - *cbw* can *chmod my_file* and *my_other_file*
  - Group membership doesn't grant *chmod* ability (cannot *chmod program.py*)

Setting Ownership

- Unix uses discretionary access control
  - New objects are owned by the subject that created them
- How can you modify the owner or group of an object?

```
chown <owner>:<group> <file1> [file2] …
```

Who May Change Ownership?

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cbw faculty
cbw@DESKTOP:~$ ls -l
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-rwxrwx--- 1 root faculty 313 Jan 29 22:47 program.py
```

- Which operations are permitted?

chown cbw:faculty my_file

chown root:root my_other_file

chown cbw:cbw sensitive_date.csv

chown cbw:faculty program.py

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cbw@DESKTOP:~$ groups
cbw faculty
cbw@DESKTOP:~$ ls -l
-rw-rw-rw- 1 cbw  cbw      17 Jan 29 22:46 my_file
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```

- Which operations are permitted?

chown cbw:faculty my_file	Yes, cbw belongs to the faculty group
chown root:root my_other_file	No, only root many change file owners!
chown cbw:cbw sensitive_date.csv	No, only root many change file owners!
chown cbw:faculty program.py	No, only root many change file owners!

Unix Access Control Exercise (1)

- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file1	file2
user1	r--	rwx
user2	r--	rw-
user3	r--	rw-
user4	rwx	rw-

Unix Access Control Exercise (1)

- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file1	file2
user1	r--	rwx
user2	r--	rw-
user3	r--	rw-
user4	rwx	rw-

User	Groups
user1	user1
user2	user2
user3	user3
user4	user4

```
~$ ls -l
-rwxr--r-- 1 user4  user4  0 file1
-rwxrw-rw- 1 user1  user1  0 file2
```

Unix Access Control Exercise (2)

- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file1	file2
user1	r--	--x
user2	r-x	rwx
user3	r-x	r--
user4	rwx	r--

Unix Access Control Exercise (2)

- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file1	file2
user1	r--	--x
user2	r-x	rwx
user3	r-x	r--
user4	rwx	r--

User	Groups
user1	user1
user2	user2, group1
user3	user3, group1, group2
user4	user4, group2

```
~$ ls -l
-rwxr-xr-- 1 user4  group1  0 file1
-rwxr----x 1 user2  group2  0 file2
```

Unix Access Control Exercise (3)

- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file 1	file 2
user 1	---	rw-
user 2	r--	r--
user 3	rwx	rwx
user 4	rwx	---

Unix Access Control Exercise (3)

- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file 1	file 2
user 1	---	rw-
user 2	r--	r--
user 3	rwx	rwx
user 4	rwx	---

- Trick question! This matrix **cannot** be represented

Unix Access Control Exercise (3)

- What Unix group and permission assignments satisfy this access control matrix?

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	file 1	file 2
user 1	---	rw-
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- Trick question! This matrix **cannot** be represented
- *file2*: four distinct privilege levels
  - Maximum of three levels (user, group, other)

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- What Unix group and permission assignments satisfy this access control matrix?

Desired Permissions

	file 1	file 2
user 1	---	rw-
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user 4	rwx	---

- Trick question! This matrix **cannot** be represented
- *file2*: four distinct privilege levels
  - Maximum of three levels (user, group, other)
- *file1*: two users have high privileges
  - If *user3* and *user4* are in a group, how to give *user2* read and *user1* nothing?
  - If *user1* or *user2* are owner, they can grant themselves write and execute permissions :(

Unix Access Control Review

The Good

- Very simple model
  - Owners, groups, and other
  - Read, write, execute
- Relatively simple to manage and understand

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- Not all policies can be encoded!
  - Contrast to ACL

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- Very simple model
  - Owners, groups, and other
  - Read, write, execute
- Relatively simple to manage and understand

The Bad

- Not all policies can be encoded!
  - Contrast to ACL
- Not quite as simple as it seems
  - setuid

Problems with Principals

setuid

The Confused Deputy Problem

Capability-based Access Control

From Principals to Subjects

- Thus far, we have focused on principals
  - What user created/owns an object?
  - What groups does a user belong to?
- What about subjects?
  - When you run a program, what permissions does it have?
  - Who is the “owner” of a running program?

Process Owners

```
cbw@DESKTOP:~$ ls -l
-rwxr-xr-x 1 cbw cbw 313 Jan 29 22:47 my_program.py
cbw@DESKTOP:~$ ./my_program.py
…
```

Process Owners

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```

Who is the owner of this process?

```
cbw@DESKTOP:~$ ps aux | grep my_program.py
cbw          tty1     S     01:06    0:00 python ./my_program.py
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cbw is the owner. Why?

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Process Owners

```
cbw@DESKTOP:~$ ls -l /bin/ls*
-rwxr-xr-x 1 root root 110080 Mar 10  2016 /bin/ls
-rwxr-xr-x 1 root root  44688 Nov 23  2016 /bin/lsblk
cbw@DESKTOP:~$ ls
…
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Subject Ownership

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- Under normal circumstances, subjects are owned by the principal that executes them
  - **File ownership is irrelevant**
- Why is this important for security?
  - A principal that is able to execute a file owned by root should not be granted root privileges

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Corner Cases

```
cbw@DESKTOP:~$ passwd
Changing password for cbw.
(current) UNIX password:
```

Corner Cases

```
cbw@DESKTOP:~$ passwd
Changing password for cbw.
(current) UNIX password:
```

- Consider the *passwd* program
  - All users must be able to execute it (to set and change their passwords)
  - Must have write access to */etc/shadow* (file where password hashes are stored)
- Problem: */etc/shadow* is only writable by root user

```
cbw@DESKTOP:~$ ls -l /etc/shadow
-rw-r----- 1 root shadow 922 Jan  8 14:56 /etc/shadow
```

setuid

```
cbw@DESKTOP:~$ ls -l /usr/bin/passwd
-rwsr-xr-x 1 root root 47032 May 16  2017 /usr/bin/passwd
cbw@DESKTOP:~$ passwd
Changing password for cbw.
(current) UNIX password:
```

setuid

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cbw@DESKTOP:~$ ls -l /usr/bin/passwd
-rwsr-xr-x 1 root root 47032 May 16  2017 /usr/bin/passwd
cbw@DESKTOP:~$ passwd
Changing password for cbw.
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setuid

- Objects may have the *setuid* permission
  - Program may execute as the **file owner**, rather than **executing principal**

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chmod Revisited

- How to add *setuid* to an object?

chmod u+s <file1> [file2] …

chmod 2### <file1> [file2] …

chmod Revisited

- How to add *setuid* to an object?

chmod u+s <file1> [file2] …

chmod 2### <file1> [file2] …

- **WARNING: NEVER SET A SCRIPT AS SETUID**
  - Only set *setuid* on compiled binary programs
  - Scripts with *setuid* lead to Time of Check Time of Use (TOCTOU) vulnerabilities

Another setuid Example

- Consider an example *turnin* program

/cs2550/turnin <project #> <in_file> <out_file>

1. Copies *<in_file>* to *<out_file>*
2. Grades the assignment
3. Writes the grade to */cs2550/<project#>/grades*

Another setuid Example

- Consider an example *turnin* program

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  1. Copies *<in_file>* to *<out_file>*
  2. Grades the assignment
  3. Writes the grade to */cs2550/<project#>/grades*

- Challenge: students cannot have write access to project directories or grade files
  - *turnin* program must be *setuid*

```
alice@login:~$ /cs2550/turnin project1 pwcrack.py /cs2550/project1/pwcrack.py
Thank you for turning in project 1.
```

```
alice@login:~$ /cs2550/turnin project1 pwcrack.py /cs2550/project1/
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Thank you for turning in project 1.
alice@login:~$ ls –l /cs2550/
drwx--x--x 0 cbw  faculty     512 Jan 29 22:46 project1
-rwsr-xr-x 1 cbw  faculty      17 Jan 29 22:46 turnin
```

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```

Ambient Authority

Ambient Authority

- Ambient authority
  - A subject's permissions are automatically exercised
  - No need to select specific permissions
- Systems that use ACLs or Unix-style permissions grant ambient authority
  - A subject automatically gains all permissions of the principal
  - A setuid subject also gains permissions of the file owner
- Ambient authority is a security vulnerability

The Confused Deputy Problem

```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /cs2550/project1/grades
Thank you for turning in project 1.
alice@login:~$ ls –l /cs2550/project1/
```

The Confused Deputy Problem

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mallory@login:~$ /cs2550/turnin project1 best_grade.txt /cs2550/project1/grades
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Thank you for turning in project 1.
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```

- The *turnin* program is a confused deputy
  - It is the deputy of two principals: *mallory* and *cbw*
  - *mallory* cannot directly access */cs2550/project1/grades*
  - However, *cbw* can access */cs2550/project1/grades*

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-rw------- 1 cbw  faculty      17 Jan 29 22:46 grades
```

- The *turnin* program is a confused deputy
  - It is the deputy of two principals: *mallory* and *cbw*
  - *mallory* cannot directly access */cs2550/project1/grades*
  - However, *cbw* can access */cs2550/project1/grades*
- Key problem: the subject cannot tell which principal it is serving when it performs a write

Preventing Confused Deputies

- ACL and Unix-style systems are fundamentally vulnerable to confused deputies
  - Cannot prevent misuse of ambient authority
- Solution: move to capability-based access control system

Capabilities

ACLs

- Encode columns of an access control matrix

ACL for o_2

	o_1	o_2	o_3
s_1	RW	RX	
s_2	R	RWX	RW
s_3		RWX	

Capabilities

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- Encode columns of an access control matrix

ACL for o_2

	o_1	o_2	o_3
s_1	RW	RX	
s_2	R	RWX	RW
s_3		RWX	

Capabilities

- Encode rows of an access control matrix

	o_1	o_2	o_3
s_1	RW	RX	
s_2	R	RWX	RW
s_3		RWX	

Capabilities for s_1

Capability-based Access Control

- Principals and subjects have capabilities which:
  - Give them access to objects
    - Files, keys, devices, etc.
  - Are transferable and unforgeable tokens of authority
    - Can be passed from principal to subject, and subject to subject
    - Similar to file descriptors
- Why do capabilities solve the confused deputy problem?
  - When attempting to access an object, a capability must be selected
  - Selecting a capability inherently also selects a master

Confused Deputy Revisited

```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
cs2550/project1/grades
```

Confused Deputy Revisited

Principal	…	/home/mallory/*	/cs2550/project1/grades	…
mallory	…	RWX	---	…

```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
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Confused Deputy Revisited

Principal	…	/home/mallory/*	/cs2550/project1/grades	…
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```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
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Allow

Deny

Confused Deputy Revisited

Principal	…	/home/mallory/*	/cs2550/project1/grades	…
mallory	…	RWX	---	…

Allow

```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
cs2550/project1/grades

ERROR: Permission denied to /cs2550/project1/grades
```

Deny

Confused Deputy Revisited

Principal	…	/home/mallory/*	/cs2550/project1/grades	…
mallory	…	RWX	---	…

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mallory@login:~$ /cs2550/turnin project1 best_grade.txt /cs2550/project1/grades
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Allow

Deny

- Principal must pass capabilities to objects at invocation time
  - *mallory* has permission to access best_grade.txt
  - *mallory* does not have permission to access */cs2550/project1/grades*

Confused Deputy Revisited

Principal	…	/home/mallory/*	/cs2550/project1/grades	…
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Allow

```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
cs2550/project1/grades
ERROR: Permission denied to /cs2550/project1/grades
```

Deny

- Principal must pass capabilities to objects at invocation time
  - *mallory* has permission to access best_grade.txt
  - *mallory* does not have permission to access */cs2550/project1/grades*
- No ambient authority in a capability-based access control system
  - Principal cannot pass a capability it doesn't have

Capabilities vs. ACLs

- Consider two security mechanisms for bank accounts

1. Identity-based
   - Each account has multiple authorized owners
   - To authenticate, show a valid ID at the bank
   - Once authenticated, you may access all authorized accounts

2. Token-based
   - When opening an account, you are given a unique hardware key
   - To access an account, you must possess the corresponding key
   - Keys may be passed from person to person

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    - Keys may be passed from person to person

> - Capability system
> - No ambient authority

Capabilities IRL

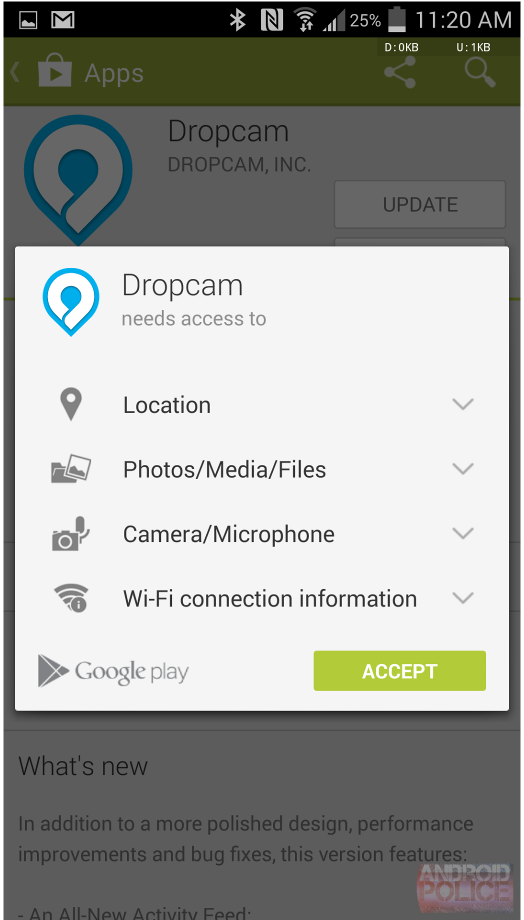
- From a security perspective, capability systems are more secure than ACL and Unix-style systems
- … and yet, most major operating systems use the latter
- Why?
  - Easier for users
    - ACLs are good for user-level sharing, intuitive
    - Capabilities are good for process-level sharing, not untuitive
  - Easier for developers
    - Processes are tightly coupled in capability systems
    - Must carefully manage passing capabilities around
    - In contrast, ambient authority makes programming easy, but insecure

Small Steps Towards Capabilities

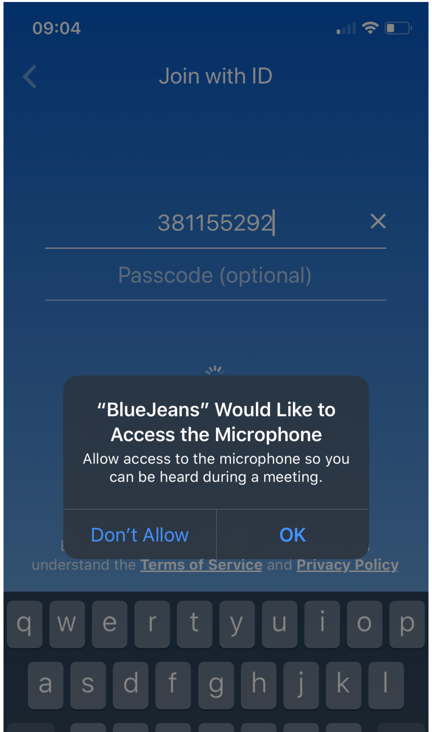
- Some limited examples of capability systems exist
  - Android/iOS app permissions
  - POSIX capabilities
  - SELinux

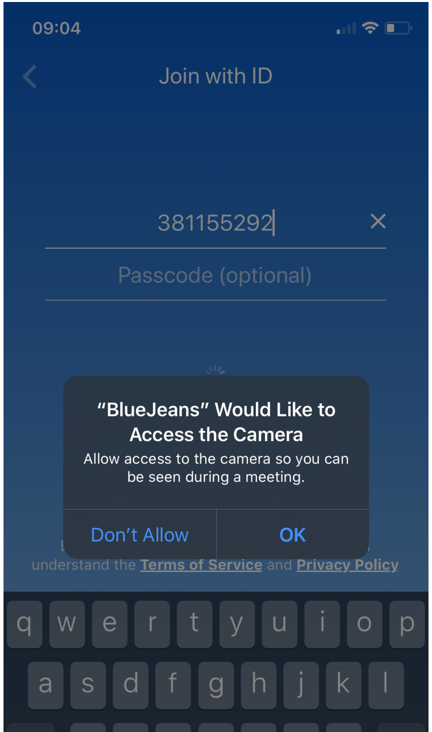
Android/iOS Capabilities

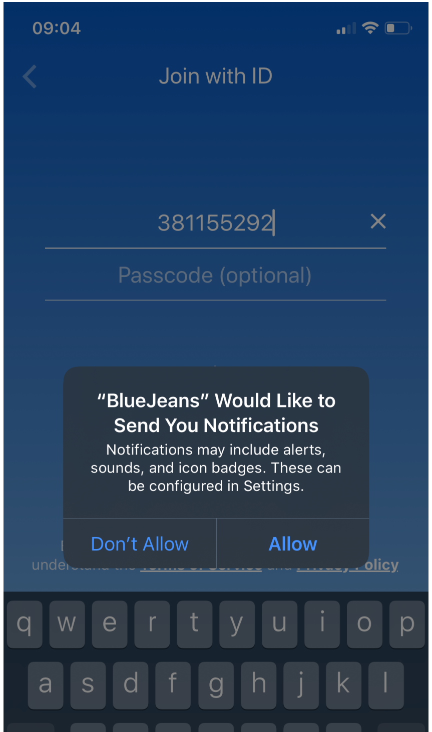
- Android and iOS support (relatively) fine grained capabilities for apps
  - User must grant permissions to apps at install time
  - May only access sensitive APIs with user consent
- Apps can "borrow" capabilities from each other by exporting *intents*
  - Example: an app without camera access can ask the camera app to return a photo



Android/IOS just-in-time capability







Per-event capability

POSIX Capabilities

- Traditional Unix systems had two types of processes
  - Privileged, i.e. root processes
    - Bypass all security and access control checks
  - Unprivileged, i.e. everything else
    - Subject to access controls
- Modern Unix/Linux systems offer some finer grained capabilities
  - Specified processes may be granted a subset of root privileges
  - CAP_CHOWN: make arbitrary changes to file owners and groups
  - CAP_KILL: kill arbitrary processes
  - CAP_SYS_TIME: change the system clock

Keeping Secrets?

- Suppose we have secret data that only certain users should access
- Is DAC enough to prevent leaks?

```
charlie@DESKTOP:~$ groups
charlie topsecret
```

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drwxr-xr-x 0 root root      512 Jan  8 14:55 .
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Failure of DAC

- DAC cannot prevent the leaking of secrets

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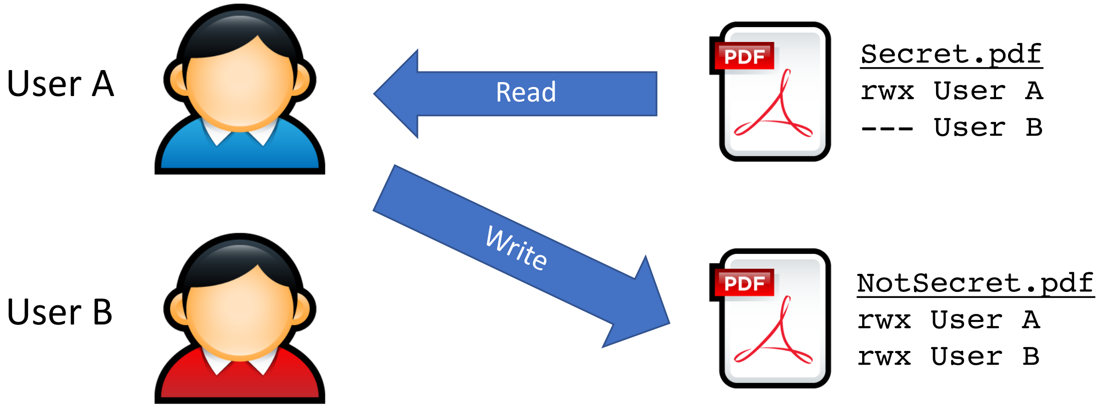

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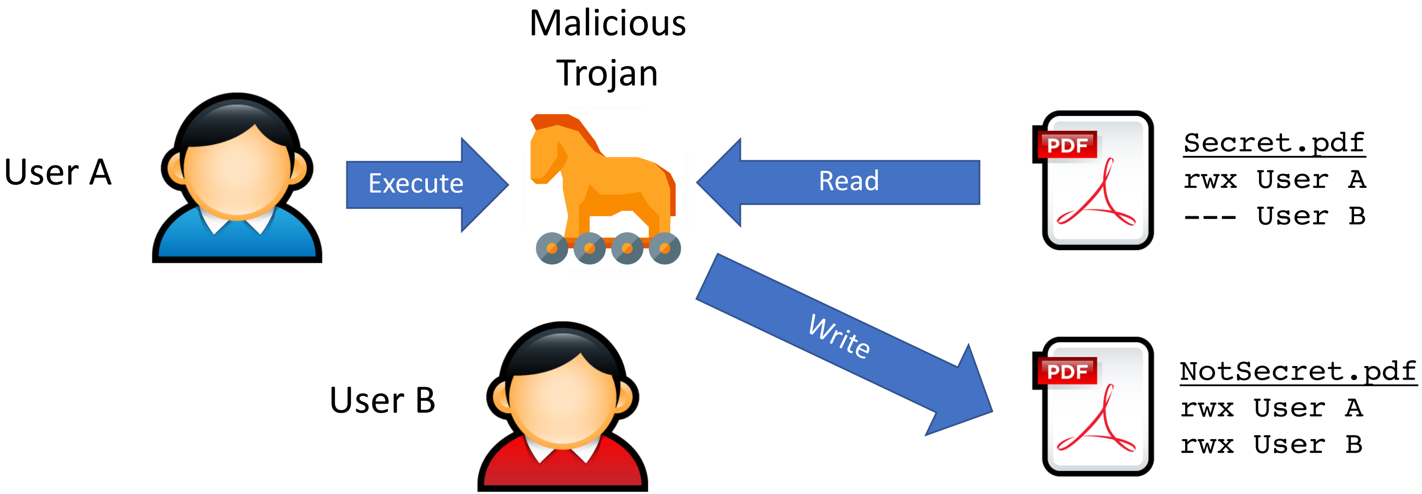


Mandatory Access Control

Mandatory Access Control Goals

- Restrict the access of subjects to objects based on a system-wide policy

- BLP - confidentiality
- Apparmor
- Biba - integrity

Bell-Lapadula (1973)

"No read , no write "

System Model: MACHINE (abstract)

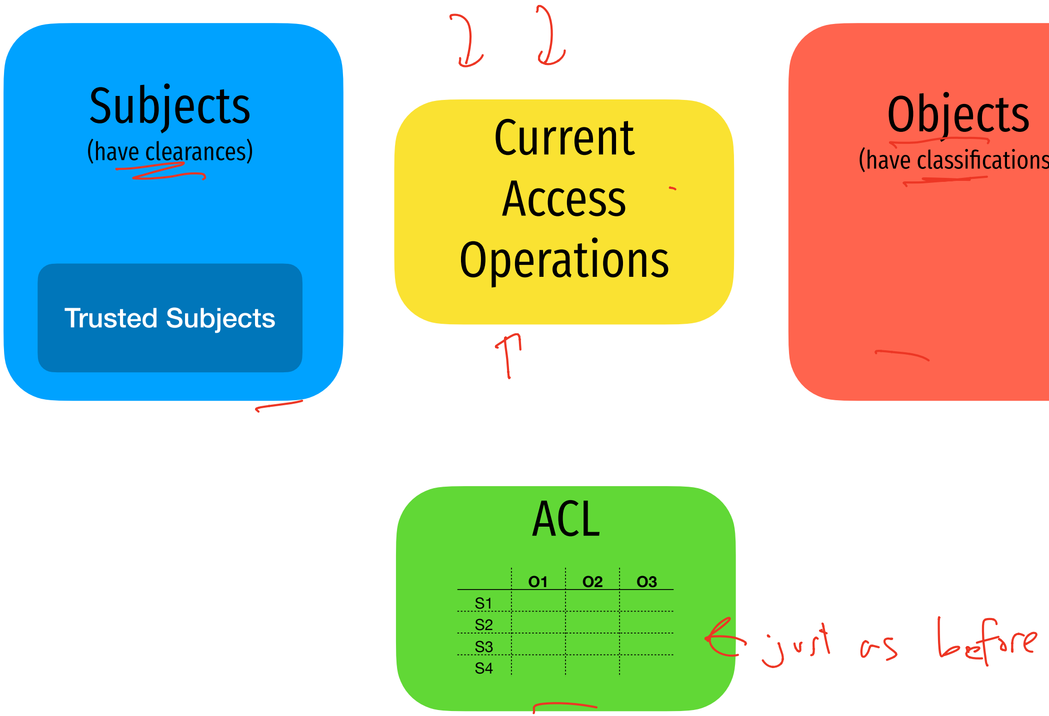
Security Policy: → which states of the machine are valid.

BLP System Model

Clearances: label like "Top Secret" "secret" "confidential" "unclass"
applied to subjects

Classifications: objects have classifications.

BLP System State



Elements of the Bell-LaPadula Model

Subjects

$L_m(s)$: maximum level

$L_c(s)$: current level

Top Secret

Secret

Confidential

Discretionary Access Control Matrix

Defined by the administrator

	o_1	o_2	o_3
s_1	RW	RX	
s_2	R	RWX	RW
s_3		RWX	

Objects

$L(o)$: level

Top Secret

Secret

Confidential

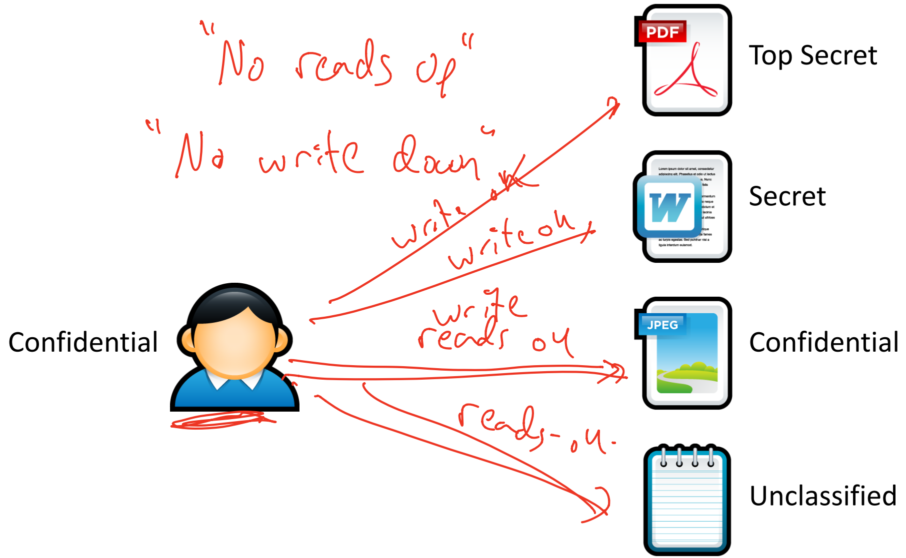
Unclassified

Simplified Bell-LaPadula Example

- Assume $L_m(s) = L_c(s)$ is always true

"No reads up"

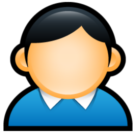
"No write down"

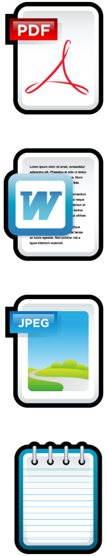


Simplified Bell-LaPadula Example

- Assume $L_m(s) = L_c(s)$ is always true
- ★-property
  - s can read o iff $L(s) >= L(o)$ (**no read up**)
  - s can write o iff $L(s) <= L(o)$ (**no write down**)

Confidential





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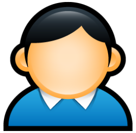

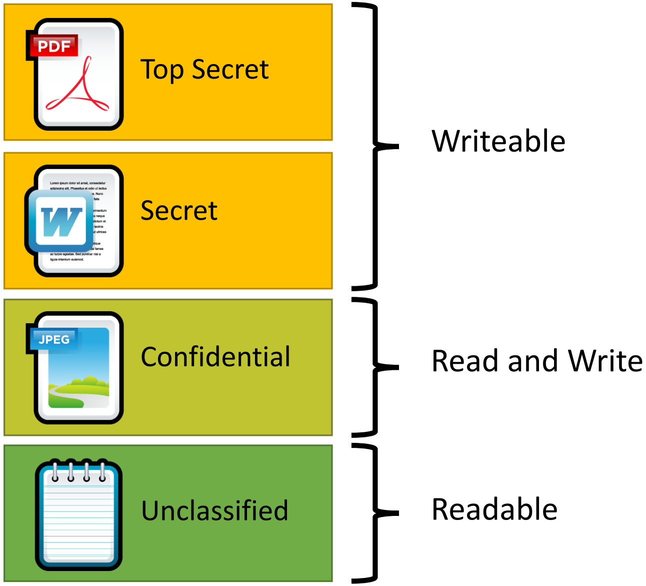

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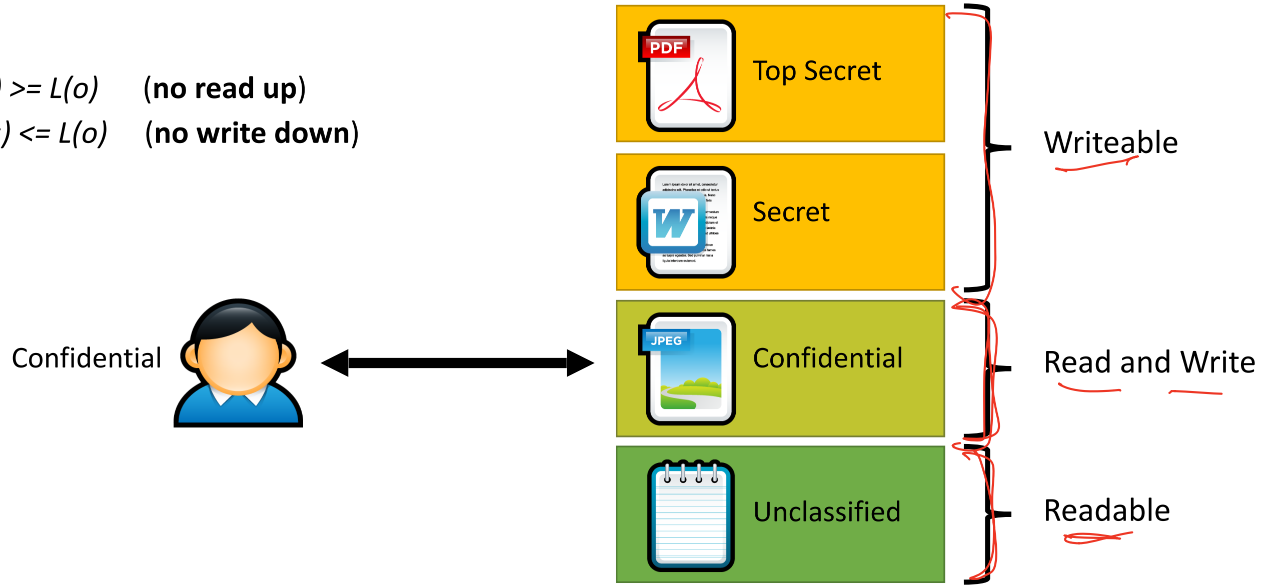

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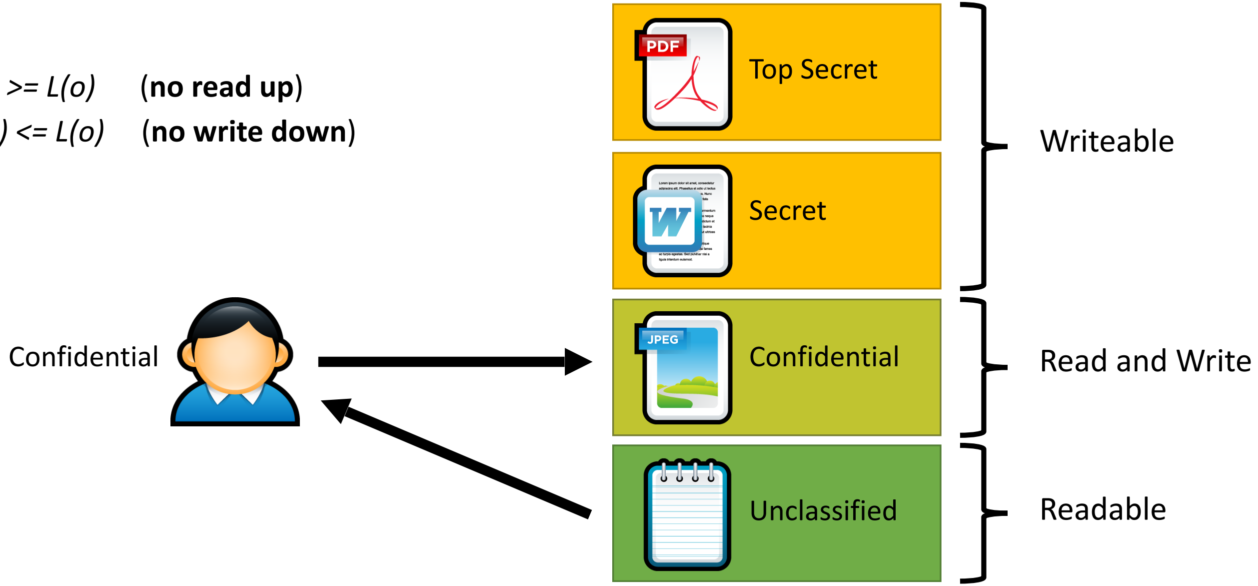

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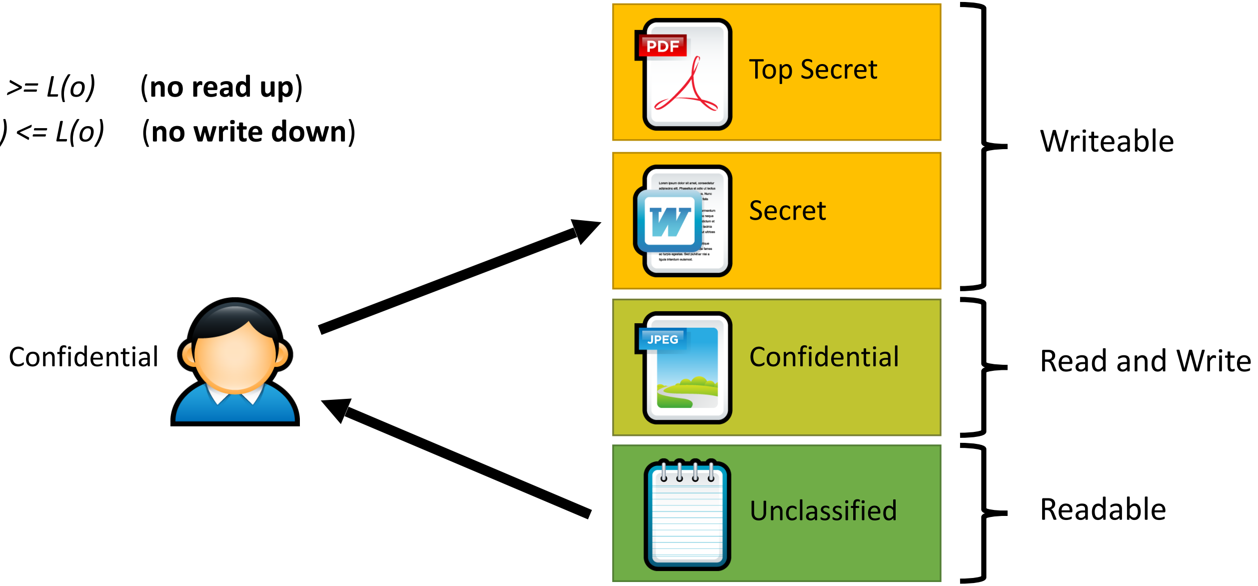


BLP Idea

A computer system is in a state, and undergoes state transitions whenever an operation occurs..

System is secure if all transitions satisfy 3 properties:

Simple:

Star:

Discretionary:

TRANQUILITY: Subjects never reduce their clearance.

BLP Idea

A computer system is in a state, and undergoes state transitions whenever an operation occurs..

System is secure if all transitions satisfy 3 properties:

Simple: S can read O if S has higher clearance

Star: S can write O if S has lower clearance.

Discretionary: Every access allowed by ACL.

Users are trusted

Subjects are not trusted. (Malware)

App armor

MAC

- Whenever a protected program runs regardless of UID, AppArmor controls:
  - The POSIX capabilities it can have (even if it is running as root)
  - The directories/files it can read/write/execute

Example security profile for **ntpd**

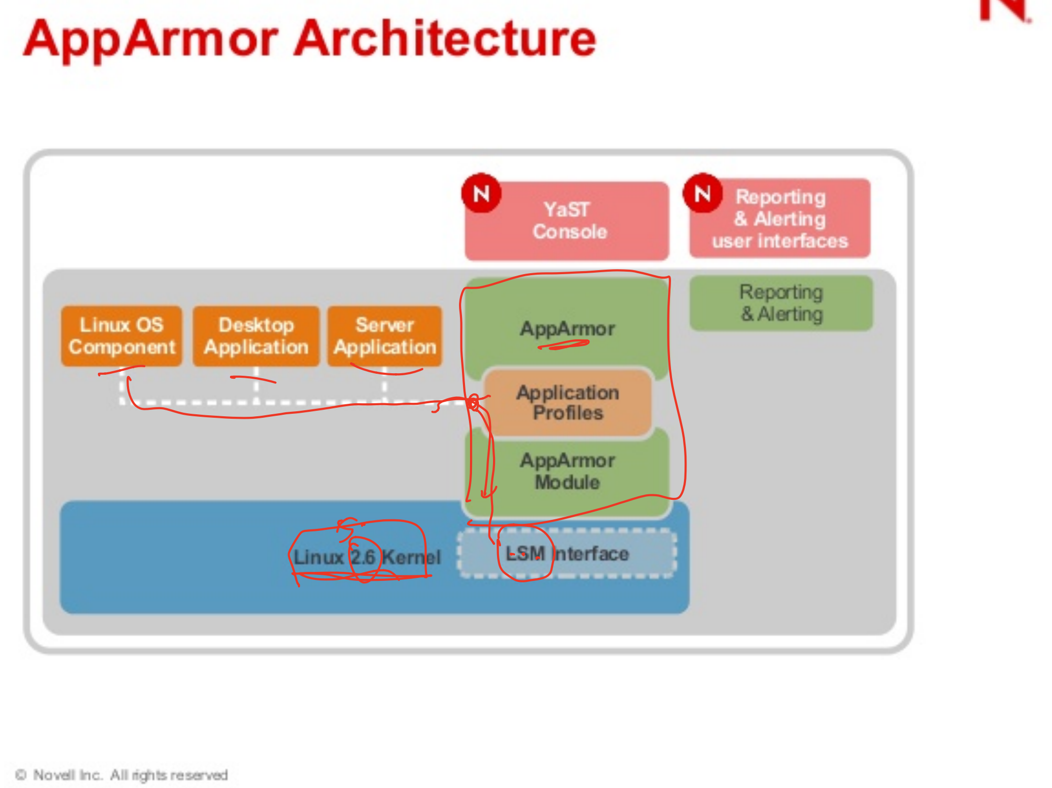
```
/usr/sbin/ntpd {
  #include <abstractions/base>
  #include <abstractions/nameservice>

  capability ipc_lock,
  capability net_bind_service,
  capability sys_time,
  capability sys_chroot,
  capability setuid,

  /etc/ntp.conf                          r,
  /etc/ntp/drift*                        rwl,
  /etc/ntp/keys                          r,
  /etc/ntp/step-tickers                  r,
  /tmp/ntp*                              rwl,
  /usr/sbin/ntpd                         rix,
  /var/log/ntp                           w,
  /var/log/ntp.log                       w,
  /var/run/ntpd.pid                      w,
  /var/lib/ntp/drift                     rwl,
  /var/lib/ntp/drift.TEMP                rwl,
  /var/lib/ntp/var/run/ntp/ntpd.pid      w,
  /var/lib/ntp/drift/ntp.drift           r,
  /drift/ntp.drift.TEMP                  rwl,
  /drift/ntp.drift                       rwl,
}
```

Yes

file

Slide from Novell/defcon 2015

Apparmor



AppArmor Architecture
YaST Console
Reporting & Alerting user interfaces
Reporting & Alerting
Linux OS Component
Desktop Application
Server Application
AppArmor
Application Profiles
AppArmor Module
Linux 2.6 Kernel
LSM Interface
14
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abhi@abhi-VirtualBox: ~

```
abhi@abhi-VirtualBox:~$ aa-
aa-audit        aa-complain     aa-enabled      aa-genprof      aa-remove-unknown  aa-unconfined
aa-autodep      aa-decode       aa-enforce      aa-logprof      aa-status          aa-update-browser
aa-cleanprof    aa-disable      aa-exec         aa-mergeprof    aa-teardown
abhi@abhi-VirtualBox:~$ aa-
```

apparmor_parser -r ______

Apparmor

abhi@abhi-VirtualBox: ~

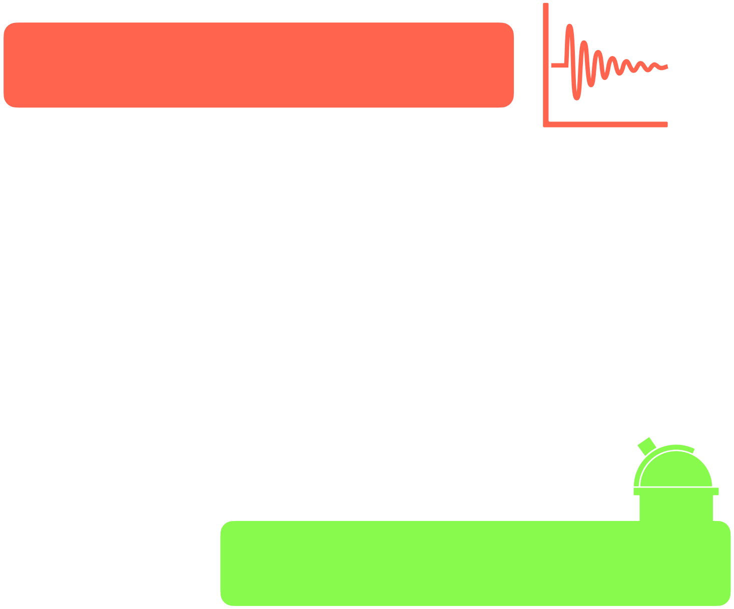
```
# vim:syntax=apparmor
#include <tunables/global>

/usr/sbin/tcpdump {
  #include <abstractions/base>
  #include <abstractions/nameservice>
  #include <abstractions/user-tmp>

  capability net_raw,
  capability setuid,
  capability setgid,
  capability dac_override,
  capability chown,
  network raw,
  network packet,

  # for -D
  @{PROC}/bus/usb/ r,
  @{PROC}/bus/usb/** r,

  # for finding an interface
  /dev/ r,
  @{PROC}/[0-9]*/net/dev r,
  /sys/bus/usb/devices/ r,
  /sys/class/net/ r,
  /sys/devices/**/net/** r,

  # for -j
  capability net_admin,

  # for tracing USB bus, which libpcap supports
  /dev/usbmon* r,
  /dev/bus/usb/ r,
  /dev/bus/usb/** r,

  # for init_etherarray(), with -e
  /etc/ethers r,

  # for USB probing (see libpcap-1.1.x/pcap-usb-linux.c:probe_devices())
  /dev/bus/usb/**/[0-9]* w,

  # for -z
  /{usr/,}bin/gzip ixr,
  /{usr/,}bin/bzip2 ixr,

  # for -F and -w
  audit deny @{HOME}/.* mrwkl,
  audit deny @{HOME}/.*/ rw,
/etc/apparmor.d/usr.sbin.tcpdump
```

Not Enough

```
TopSecret.pdf
rwx User A
--- User B
```

```
NotSecret.pdf
rwx User A
rwx User B
```

Not Enough: Covert channels

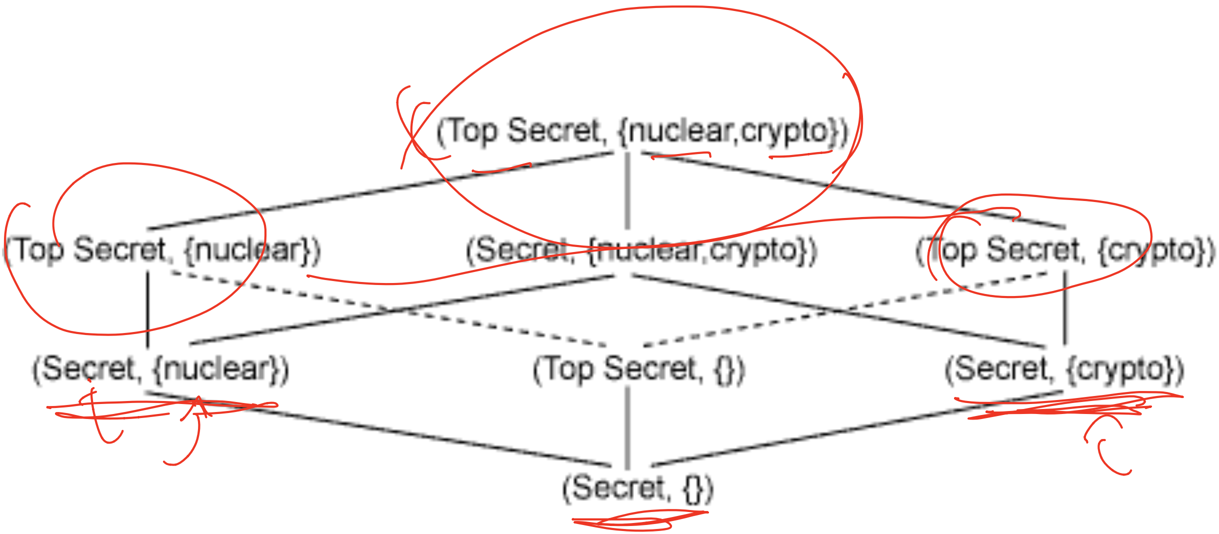


Security Lattice

Compartments:

Ordering between (Level, Compartment)

Lattice



(Top Secret, {nuclear,crypto})
(Top Secret, {nuclear})
(Secret, {nuclear,crypto})
(Top Secret, {crypto})
(Secret, {nuclear})
(Top Secret, {})
(Secret, {crypto})
(Secret, {})

Need-to-Know policy

Integrity Protection in Practice

- Mandatory Integrity Control in Windows
  - Since Vista
  - Four integrity levels: Low, Medium, High, System
  - Each process assigned a level
    - Processes started by normal users are Medium
    - Elevated processes have High
  - Some processes intentionally run as Low
    - Internet Explorer in protected mode
  - Ring policy
    - Reading and writing do not change integrity level

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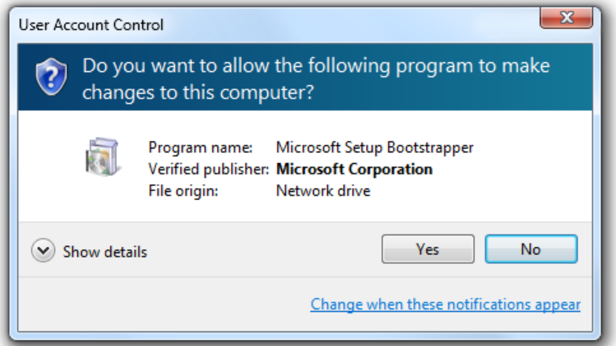

Confidentiality? What else?

Authorization

(what a subject can see)

Integrity

(what a subject can write)

Biba Integrity Policy

Biba Integrity Model

- Proposed in 1975
- Like Bell-LaPadula, security model with provable properties based on a state transition model
  - Each subject has an integrity level
  - Each object has an integrity level
  - Integrity levels are totally ordered (high → low)
- Integrity levels in Biba are not the same as security levels in Bell-LaPadula
  - Some high integrity data does not need confidentiality
  - Examples: stock prices, official statements from the president

Possible Mandatory Policies in Biba

1. Strict integrity
   - *s* can read *o* iif *i(s)* <= *i(o)* **(no read down)**
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   - *s* can always read *o*; afterward *i(s) = min(i(s), i(o))* (**subject tainting**)
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5. Ring
   - *s* can read any object *o*
   - *s* can write *o* iff *i(s) >= i(o)* **(no write up)**

Biba Strict Integrity Example

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Medium Integrity

High Integrity

Medium Integrity

Low Integrity

Unverified

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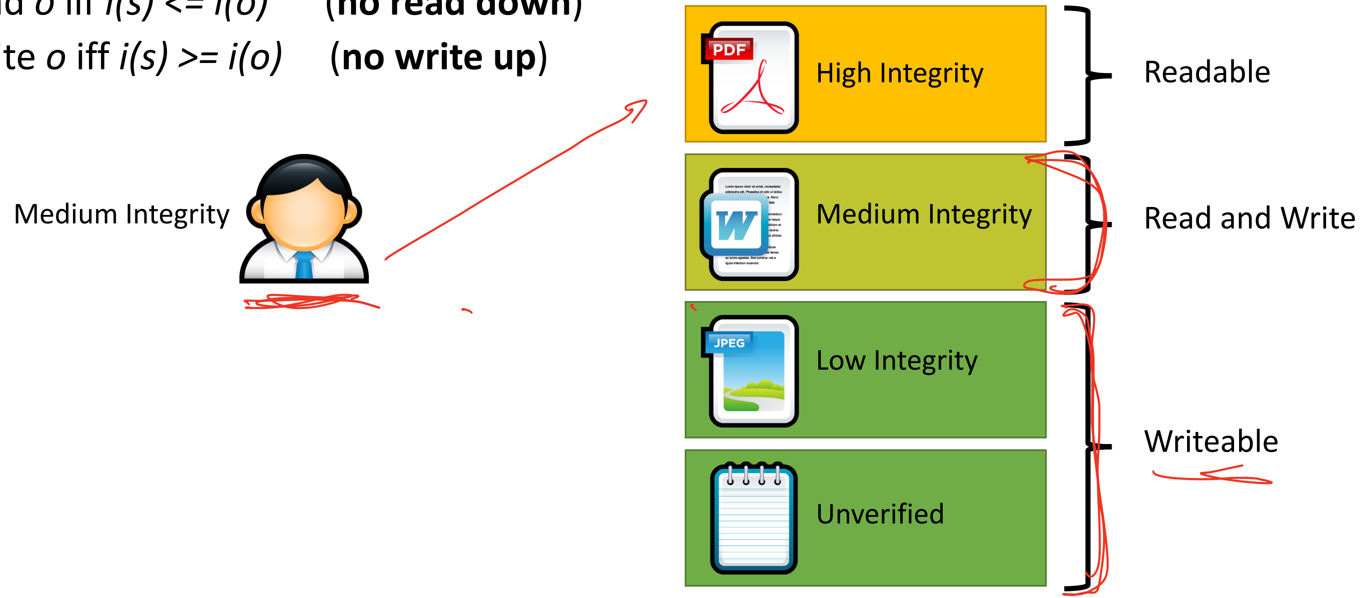

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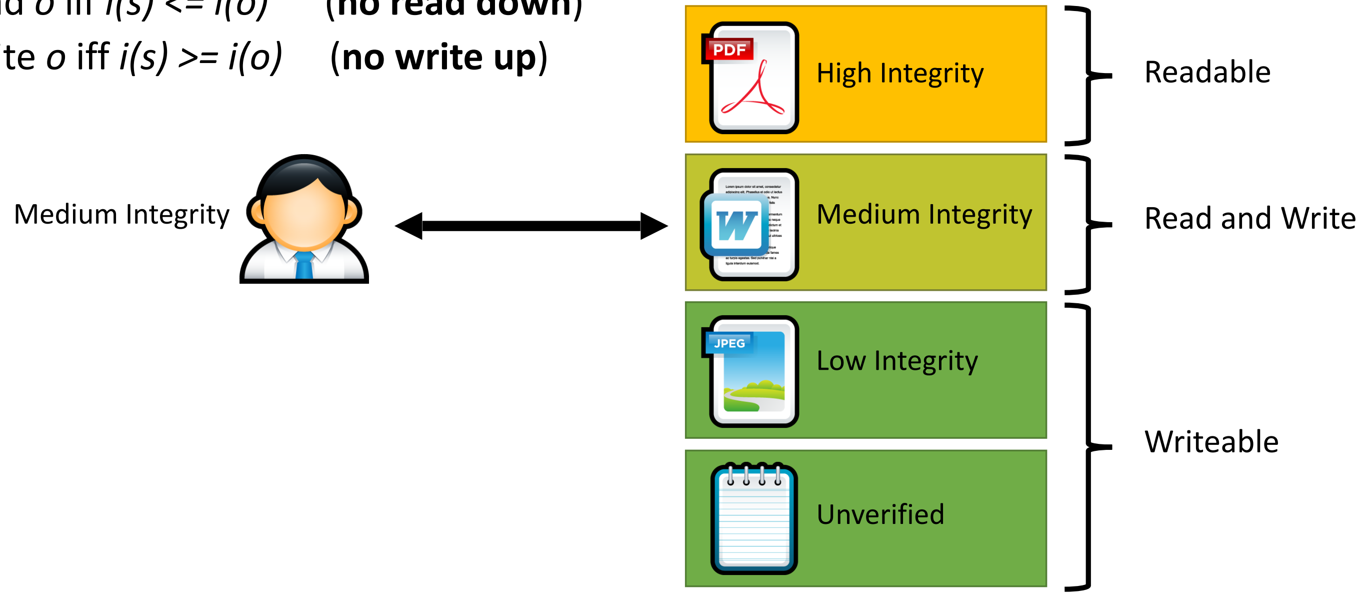

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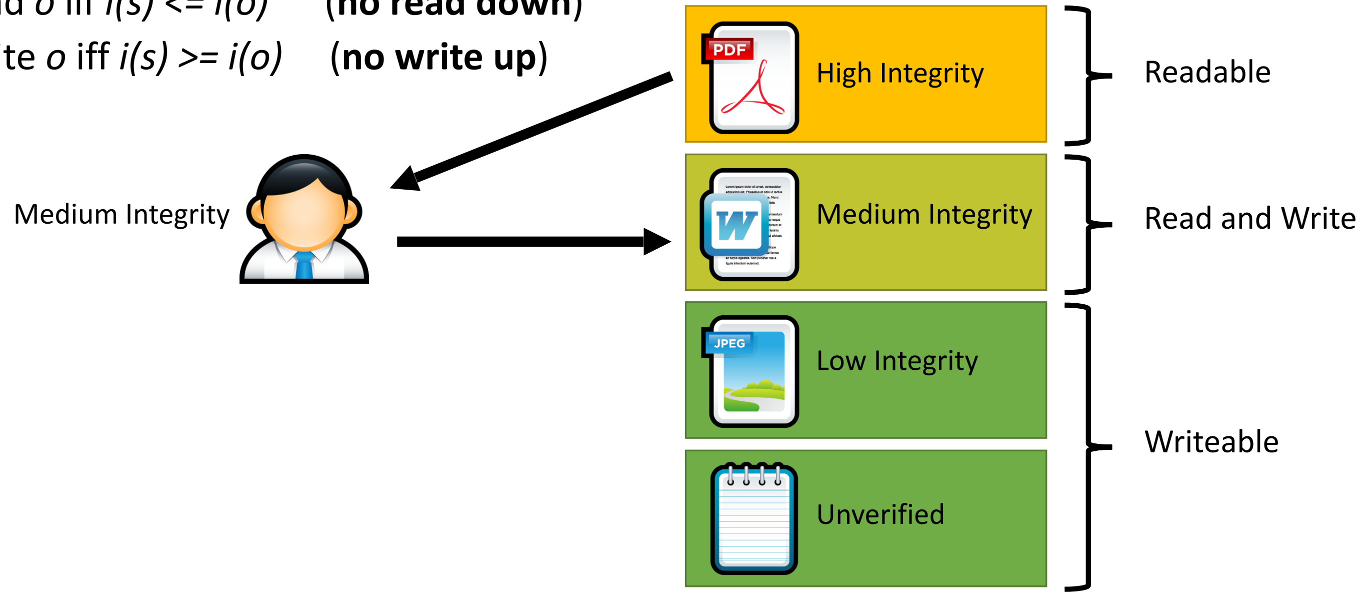

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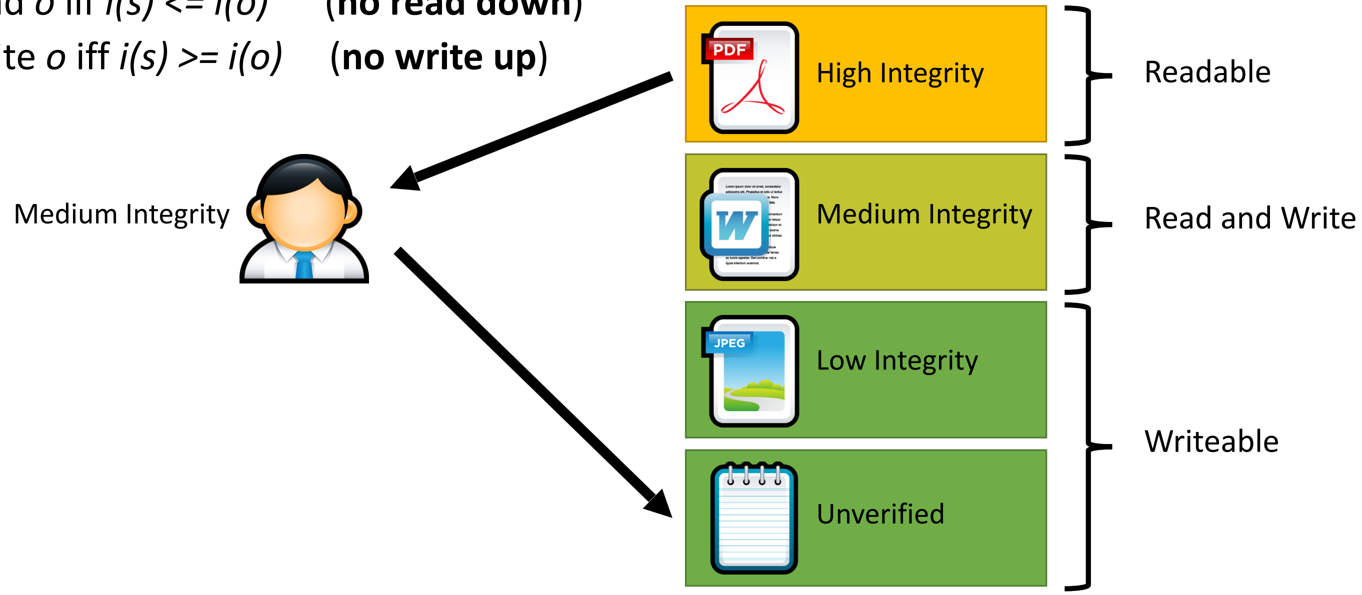

Practical Example of Biba Integrity

- Military chain of command
  - Generals may issue orders to majors and privates
  - Majors may issue orders to privates, but not generals
  - Privates may only take orders

Comparison

BPL	Biba
Offers confidentiality	offers integrity
"Read down, write up"	"read up, write down"
Focuses on controlling reads	controlling writes
Theoretically, no requirement that subjects be trusted	

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Biba

- Offers integrity
- “Read up, write down”
- Focuses on controlling writes
- Subjects must be trusted
  - A malicious program can write bad information

Covert and Side Channels

Caveats of Bell-LaPadula

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- ★-property prevents **overt** leakage of information
  - Does not address covert channels

Caveats of Bell-LaPadula

- ★-property prevents **overt** leakage of information
  - Does not address covert channels
- What does this mean?

Covert Channels

- Access control is defined over “legitimate” channels
  - Read/write an object
  - Send/receive a packet from the network
  - Read/write shared memory
- However, isolation in real systems is imperfect
  - Actions have observable side-effects

Covert Channels

- Access control is defined over “legitimate” channels
  - Read/write an object
  - Send/receive a packet from the network
  - Read/write shared memory
- However, isolation in real systems is imperfect
  - Actions have observable side-effects
- External observations can create covert channels
  - Communication via unintentional channels
  - Examples:
    - Existence of file(s) or locks on file(s)
    - Measure the timing of events
    - CPU cache (e.g. Meltdown and Spectre)

Simple Example

Unclassified

Bell-LaPadula MAC

Top Secret

Secret

Confidential

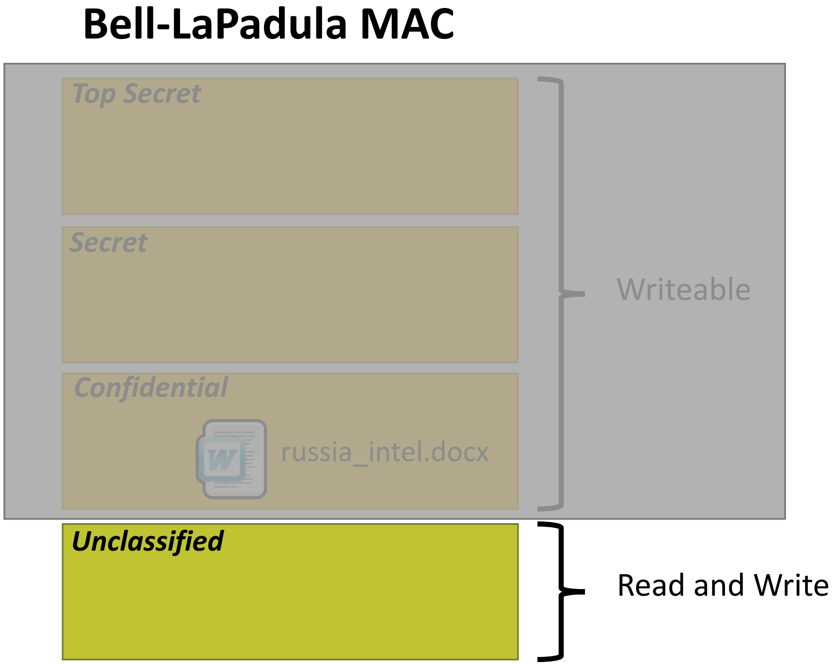
russia_intel.docx

Unclassified

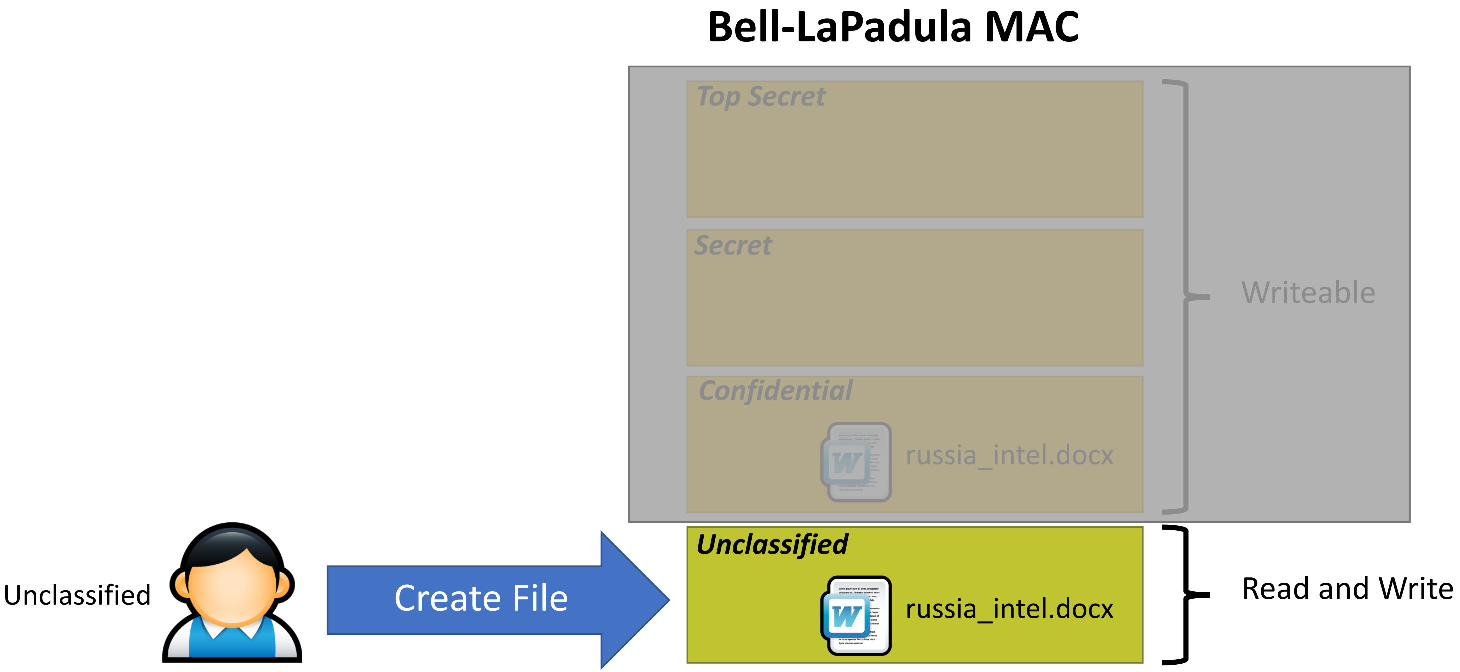
Writeable

Read and Write

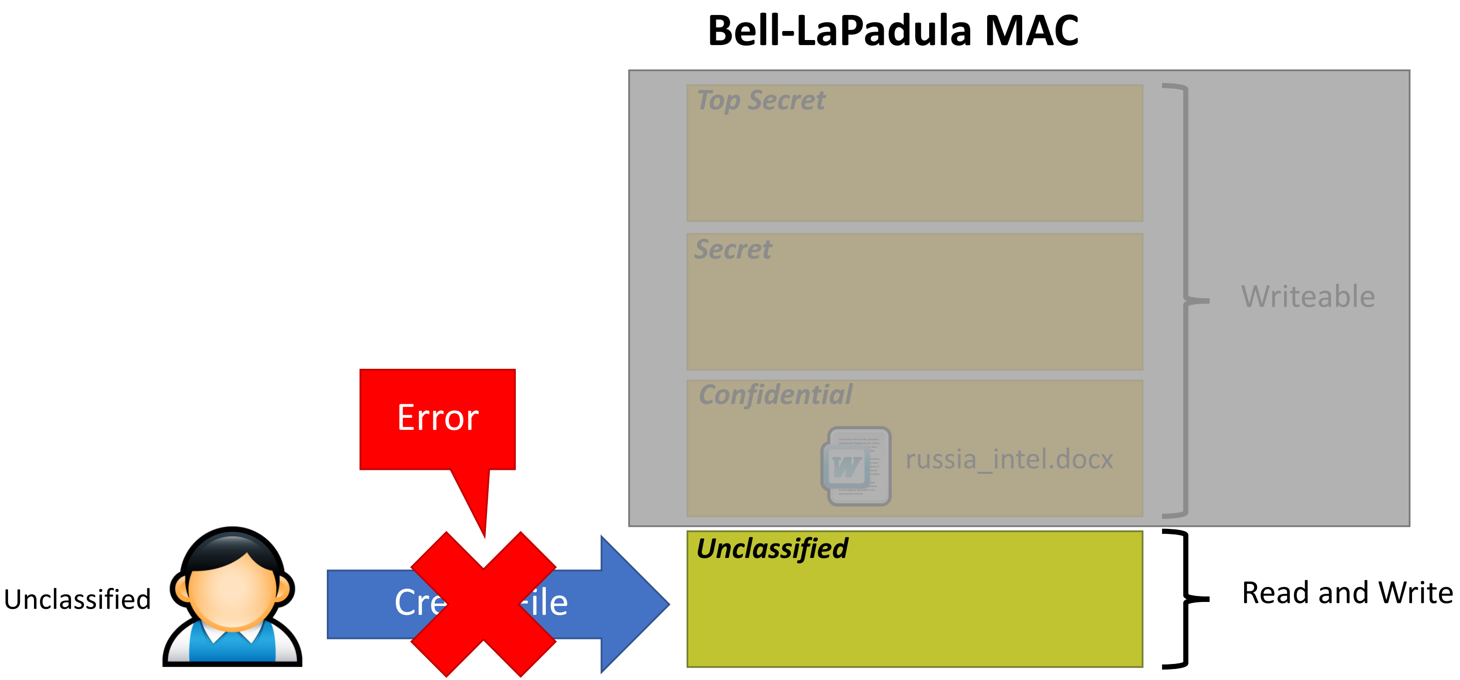
Simple Example



Simple Example



Simple Example



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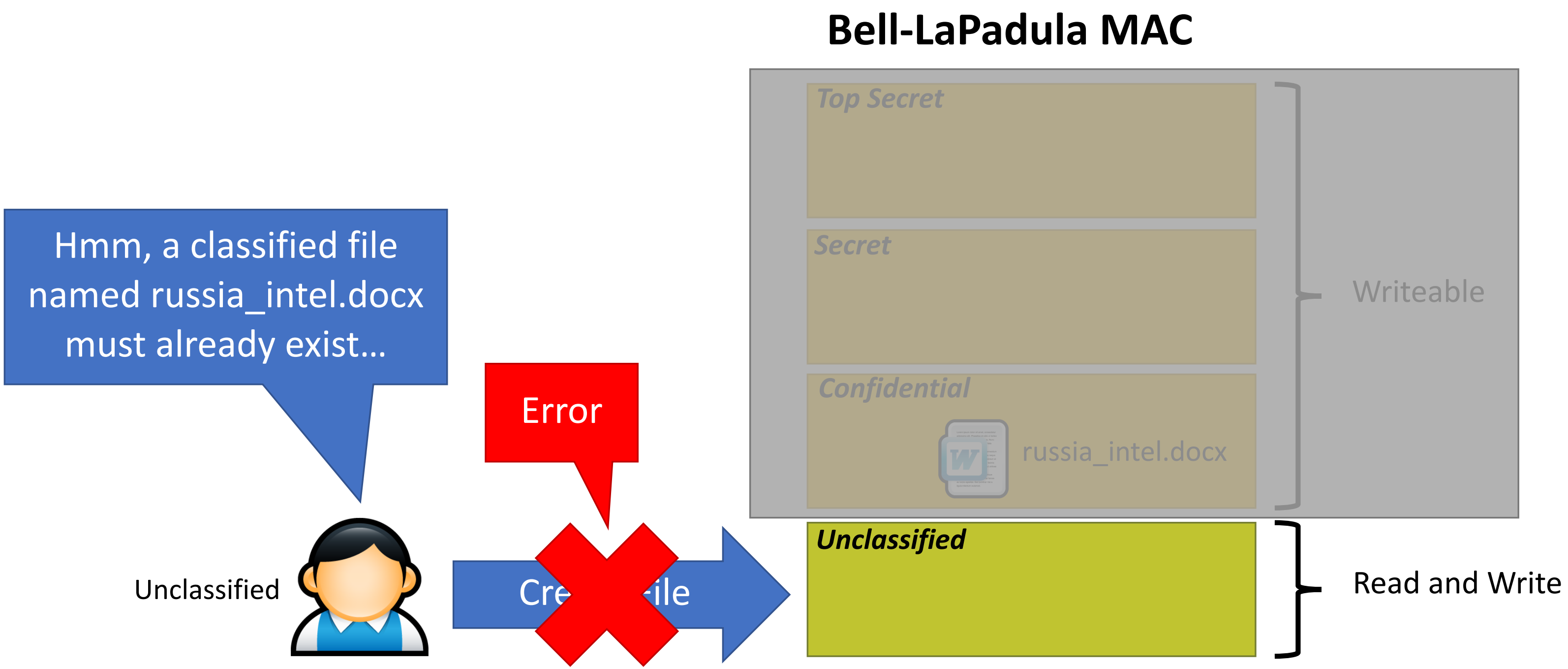
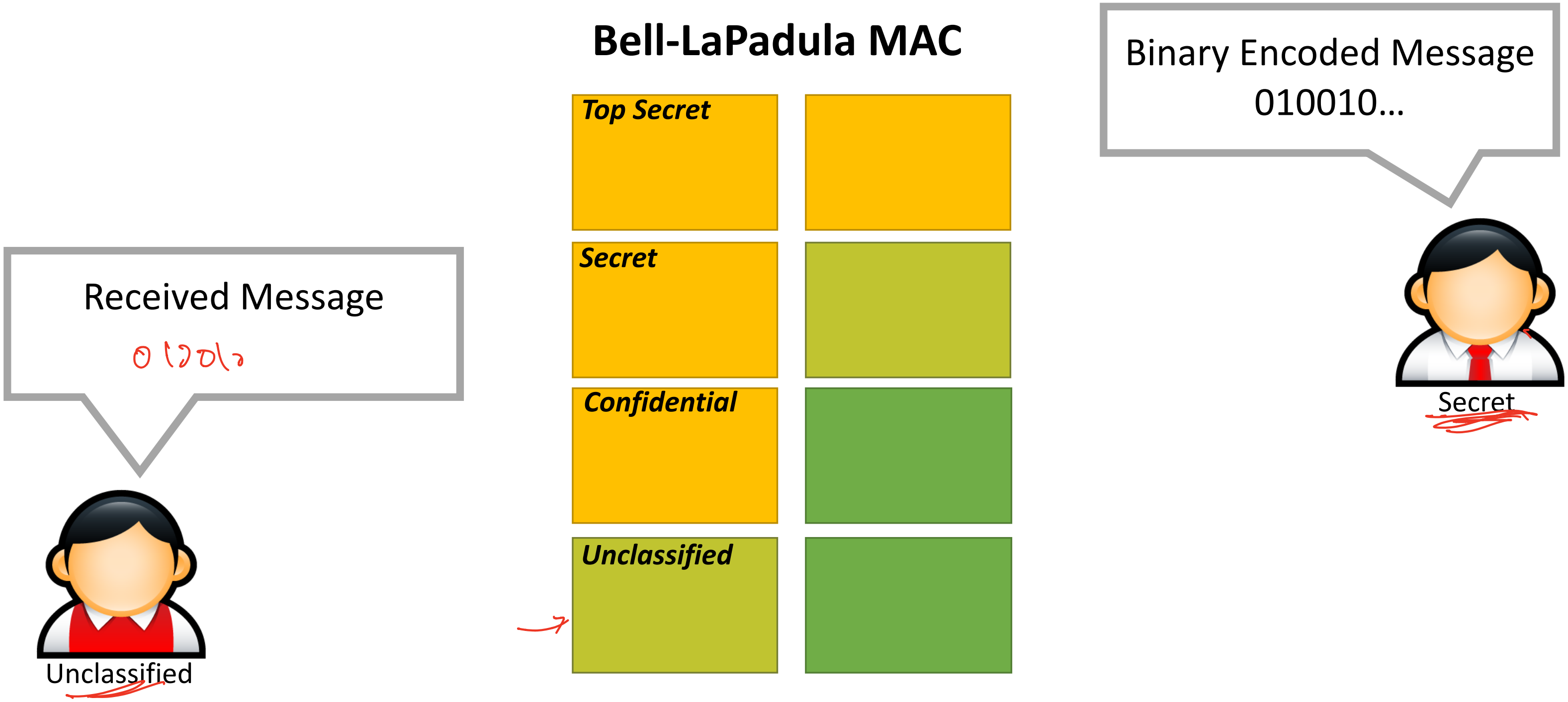


Exploiting a Covert Channel



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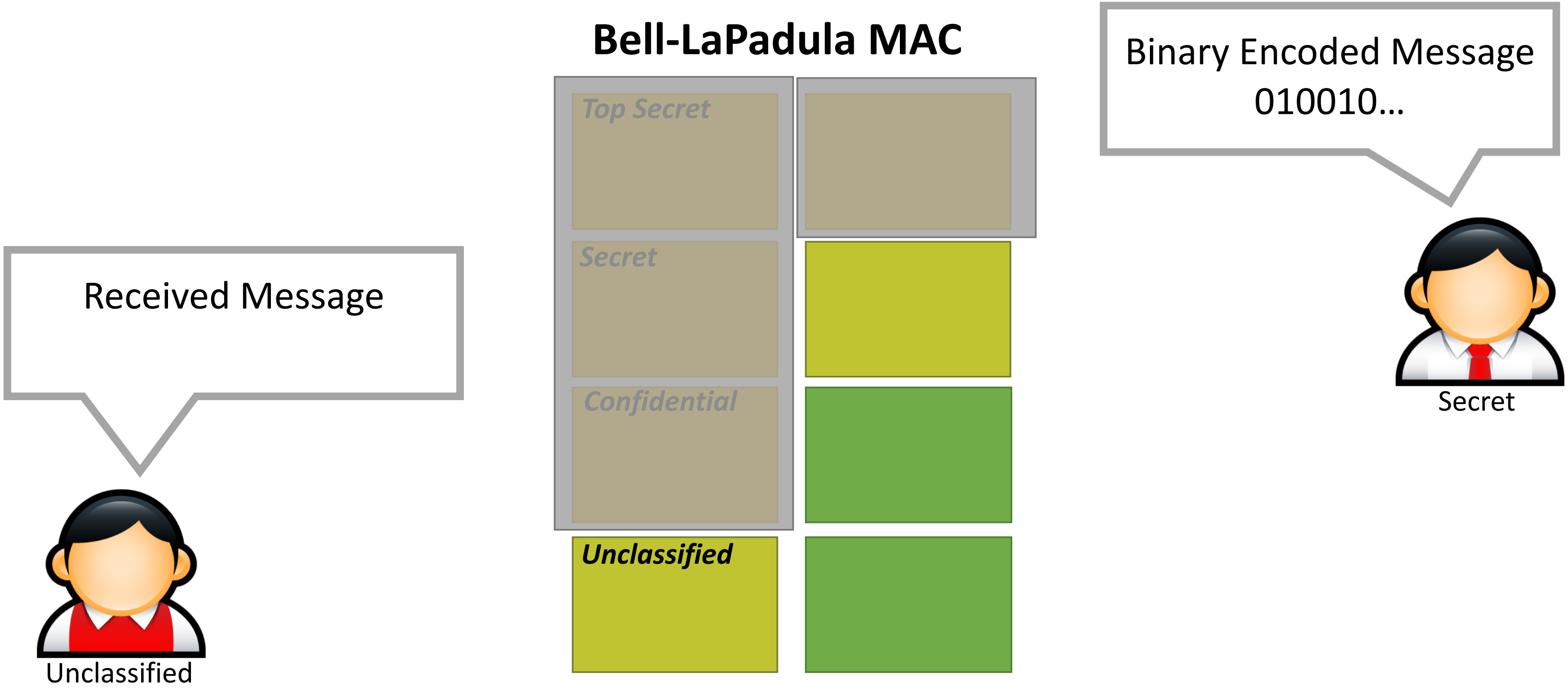

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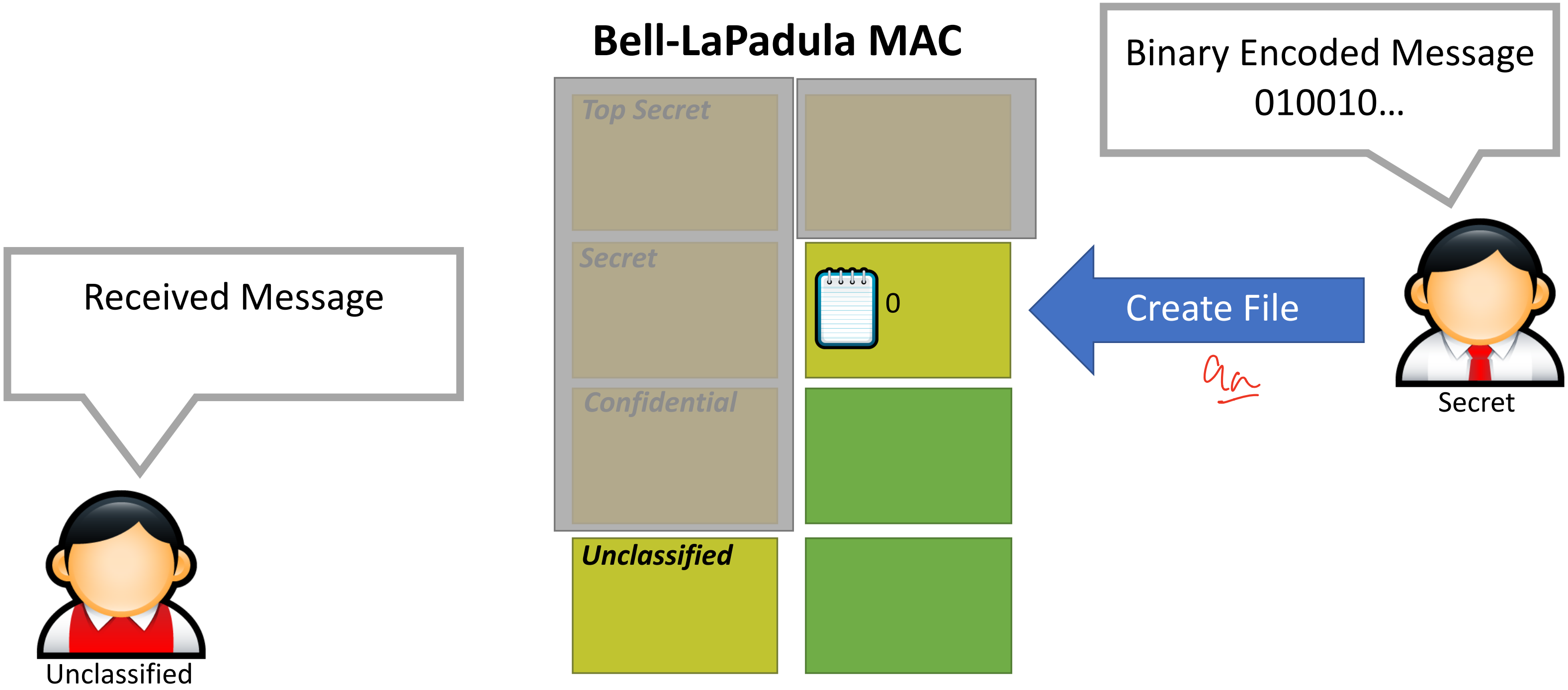

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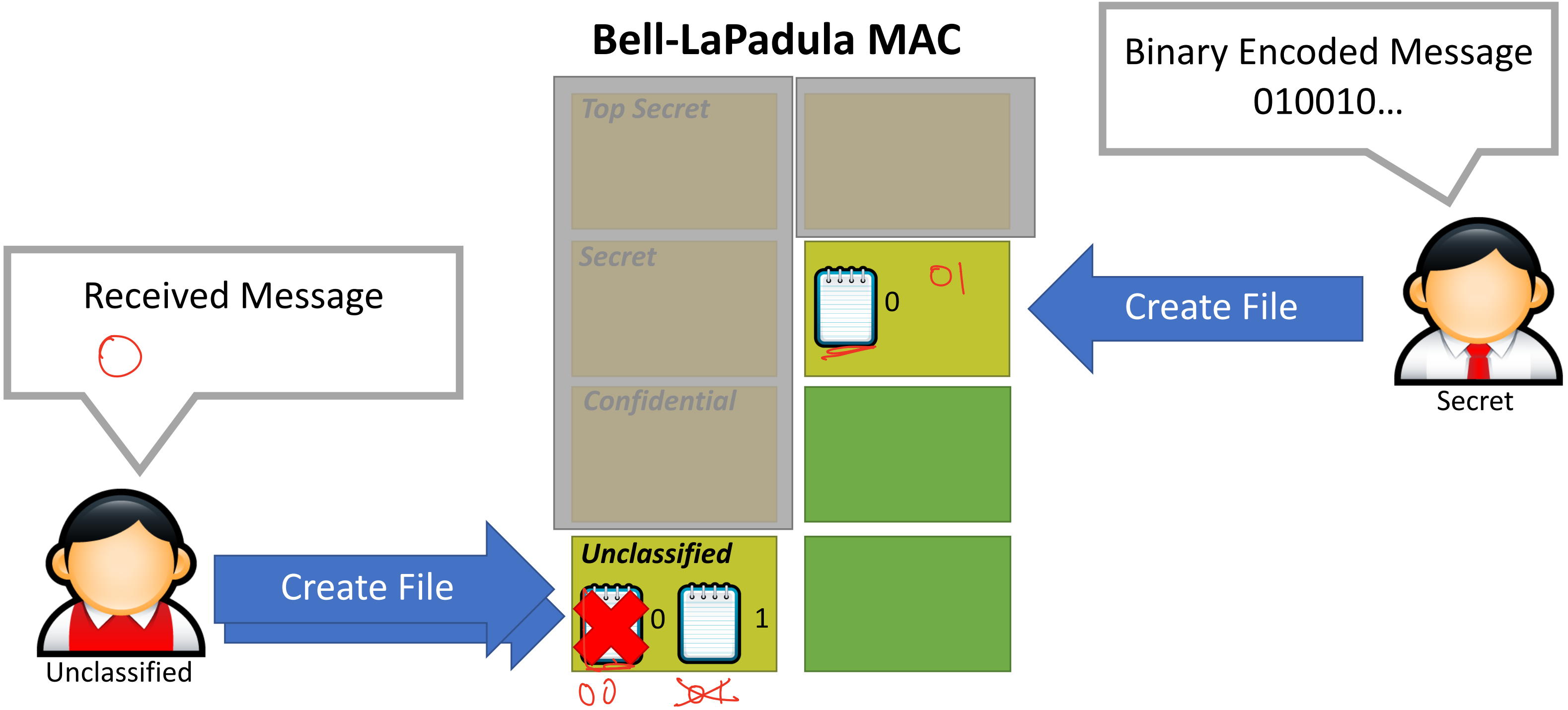
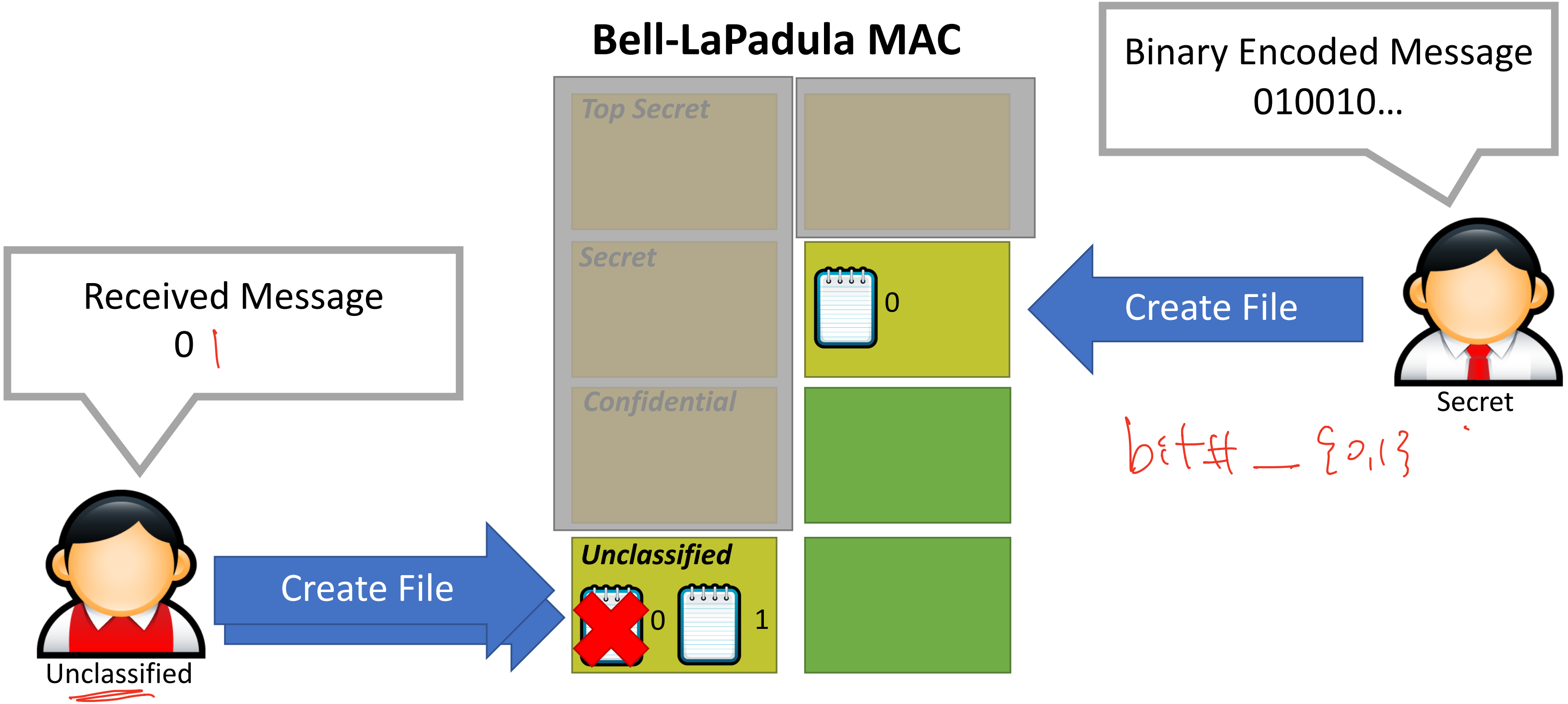


Exploiting a Covert Channel

Slow

low bandwidth



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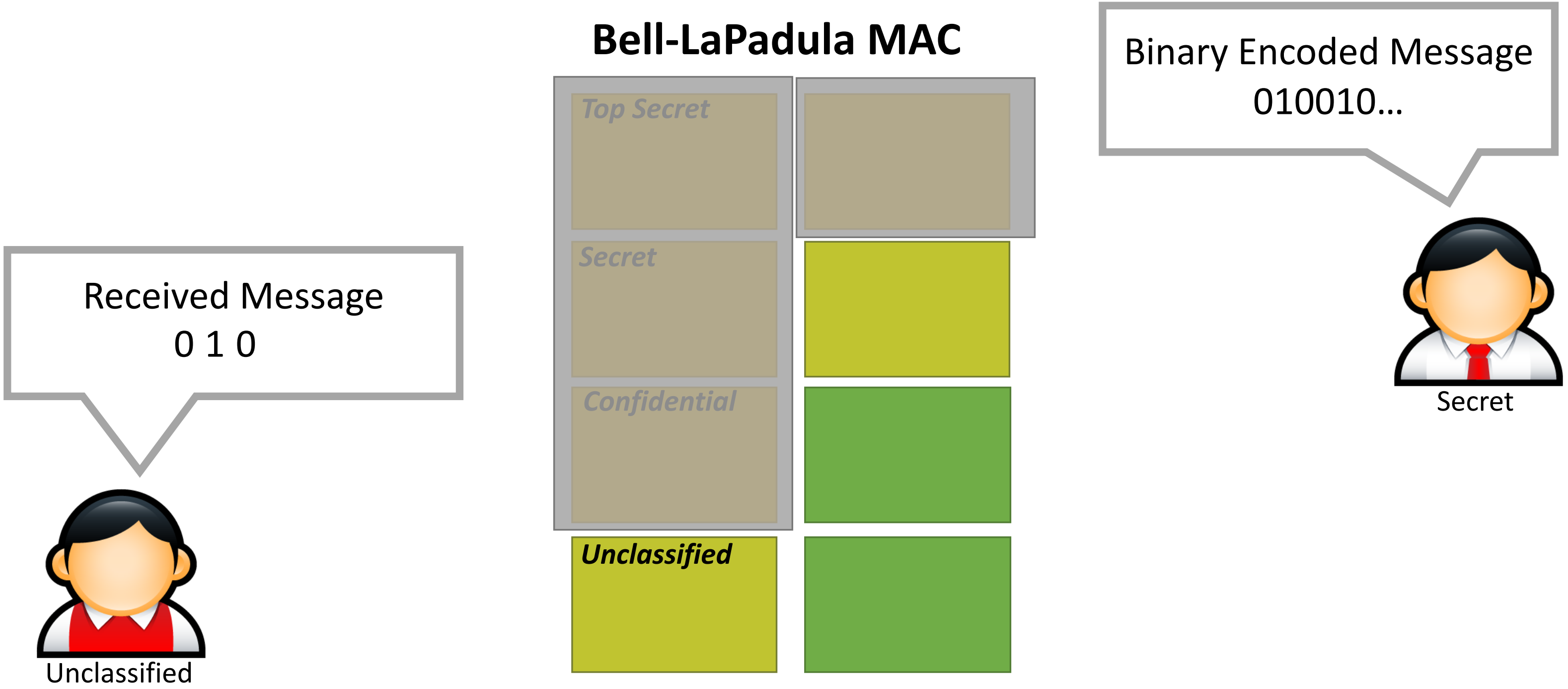

Leveraging Covert Channels

- Covert channels are typically noisy
  - Based on precise timing of events
  - May result in encoding errors, i.e. errors in data transmission
  - Communication is probabilistic
- Information theory and coding theory can be applied to make covert channels more robust
  - Naïve approach: duplicate the data *n* times
  - Better approach: uses Forward Error Correction (FEC) coding
  - Zany approach: use Erasure Coding

Bell-LaPadula and Covert Channels

- Covert channels are not blocked by the ★-property
- It is very hard, perhaps impossible, to block all covert channels
  - May appear in program code
  - Or operating system code
  - Or in the hardware itself (e.g. CPU covert channels)

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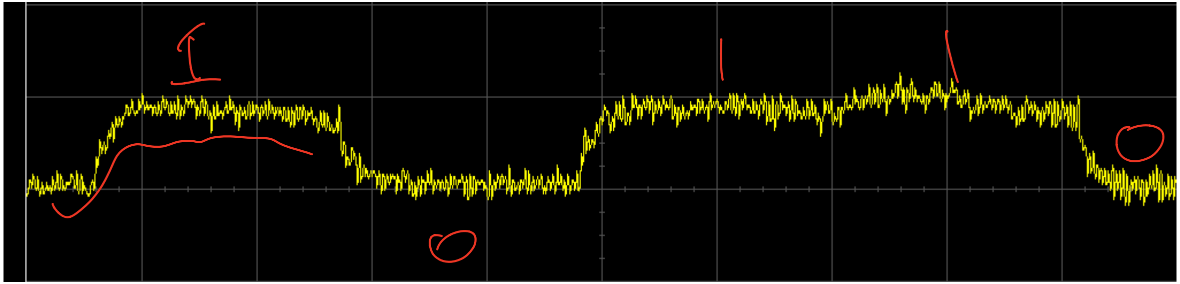
  - Or operating system code
  - Or in the hardware itself (e.g. CPU covert channels)
- Potential mitigations:
  - Limit the bandwidth of covert channels by enforcing rate limits
    - Warning: may negatively impact system performance
  - Intentionally make channels noisier by using randomness to introduce “chaff”
    - Warning: slows down attacks, but may not stop them
  - Use anomaly detection to identify subjects using a covert channel
    - Warning: may result in false positives
    - Warning: no guarantee this will detect all covert channels

Side Channel Attacks

- Side channels result from inadvertent information leakage
  - Timing – e.g., password recovery by timing keystrokes
  - Power – e.g., crypto key recovery by power fluctuations
  - RF emissions – e.g., video signal recovery from video cable EM leakage
- Virtually any shared resource can be used

Side Channel Attack Example

- Victim is decrypting RSA data
  - Key is not known to the attacker
  - Encryption process is not directly accessible to the attacker
- Attacker is logged on to the same machine as the victim
  - Secret key can be deciphered by observing the CPU voltage
  - Short peaks = no multiplication (0 bit), long peaks = multiplication (1 bit)



Real Side Channel Attacks

- CPU voltage attacks against RSA
- Keystroke timing attacks against SSH
- Timing and CPU cache attacks against AES
- RF radiation attacks against computer monitors!
  - Attacker can observe what is on your screen
- CPU cache attacks against process isolation
  - Meltdown and Spectre
  - Also leverage a covert channel ;)