2550 Intro to cybersecurity

L6: Authorization

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Thanks Christo for slides!

Authentication:

Authorization

After Authenticating a subject, what next?

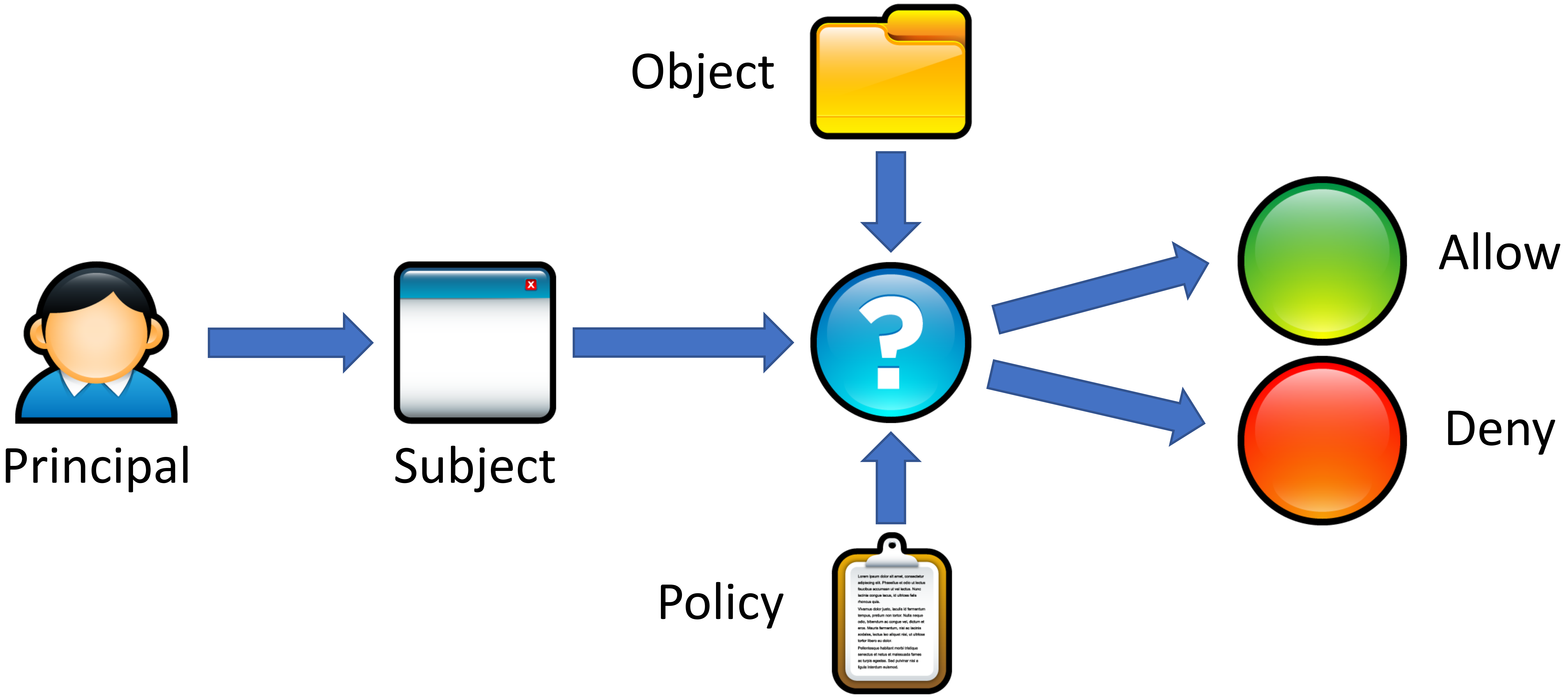
Access Control

- 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},

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

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

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."

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

Access Control List (ACL)

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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

	D:\Music	*D:\Images*	*D:\Documents*
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Administrators	RW	RW	RW
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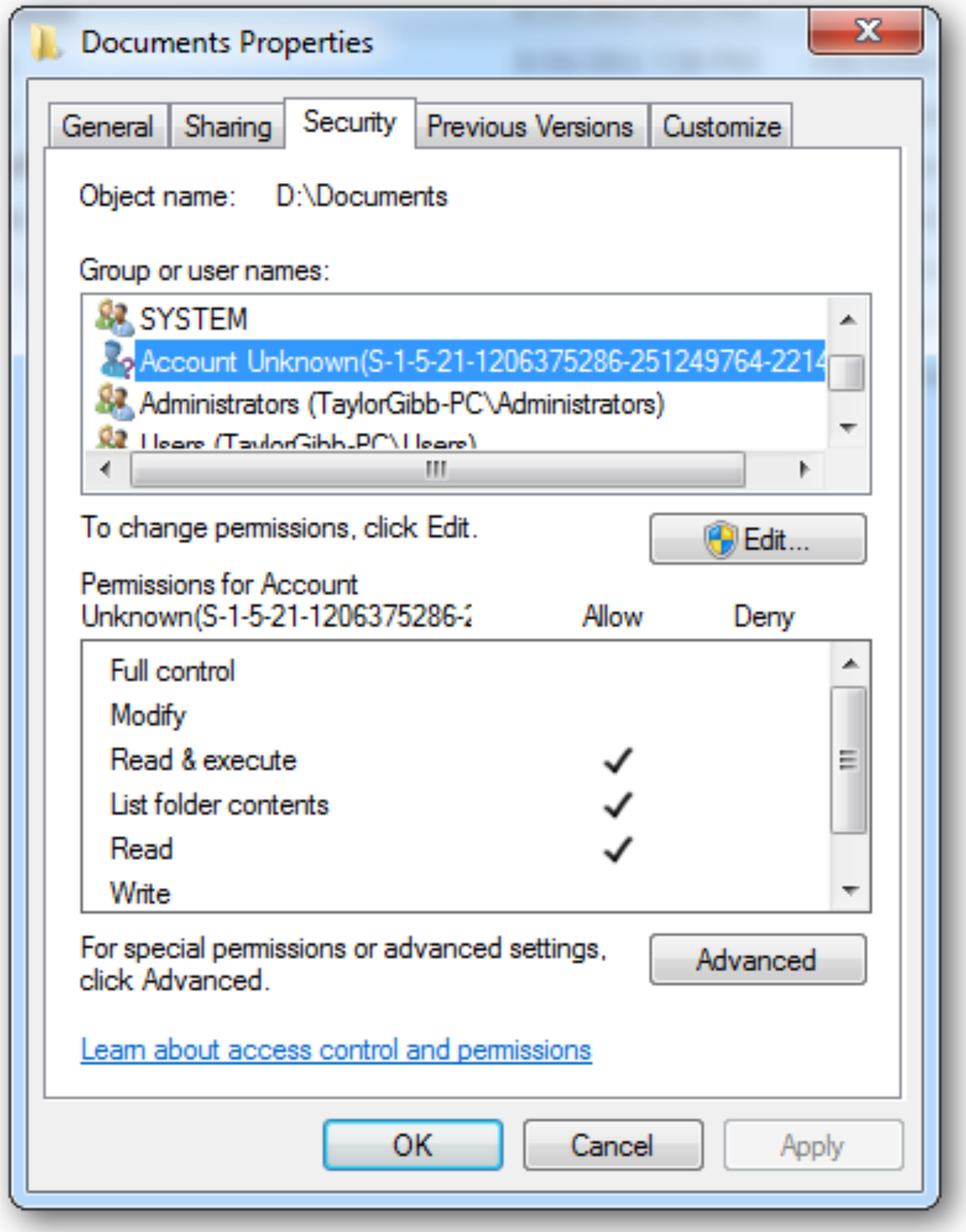


Documents Properties

Object name: D:\Documents

Group or user names:

SYSTEM
Account Unknown(S-1-5-21-1206375286-251249764-2214
Administrators (TaylorGibb-PC\Administrators)
Users (TaylorGibb-PC\Users)

To change permissions, click Edit.

Permissions for Account Unknown(S-1-5-21-1206375286-2	Allow	Deny
Full control		
Modify		
Read & execute	✓	
List folder contents	✓	
Read	✓	
Write		

For special permissions or advanced settings, click Advanced.

Learn about access control and permissions

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

The Good

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

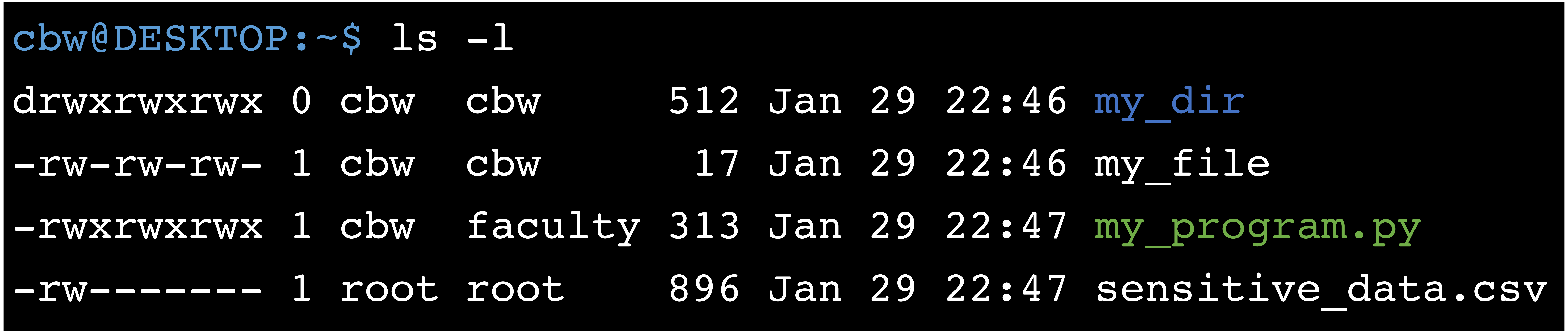
The Bad

- 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



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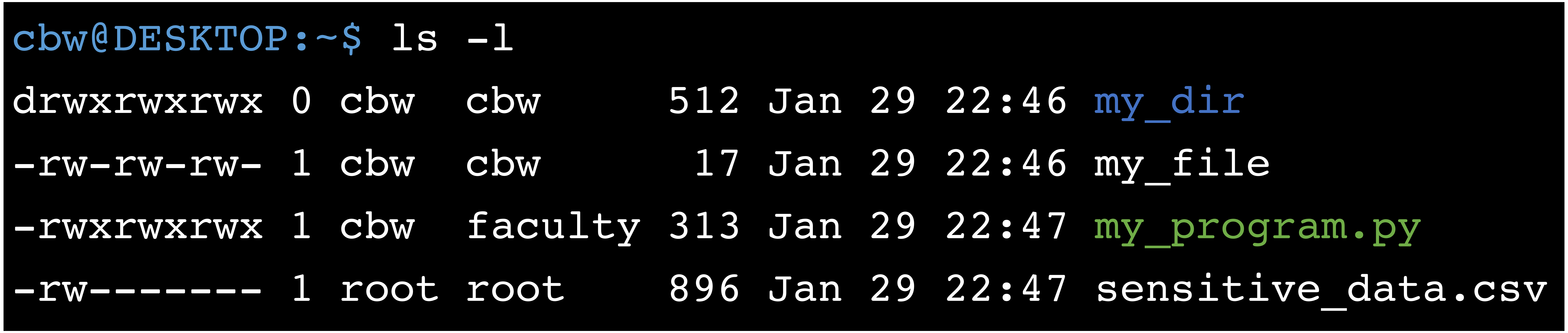
```

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

Unix Permissions



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Owner

d → Directory

r → Read w → Write x → eXecute

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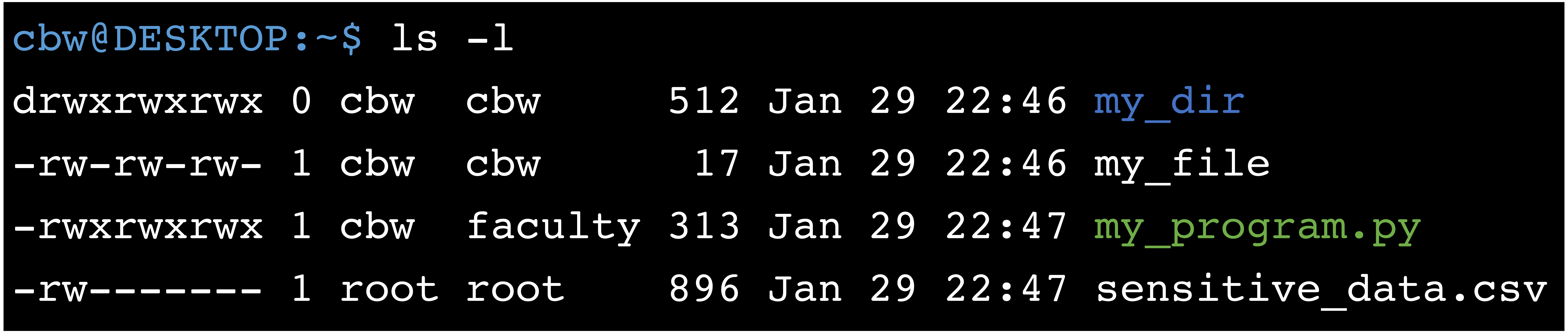

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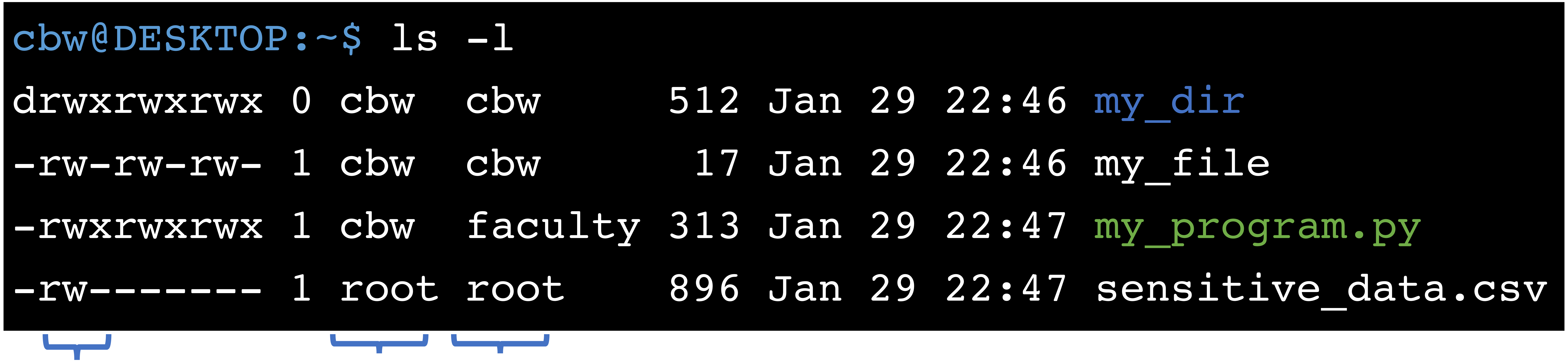

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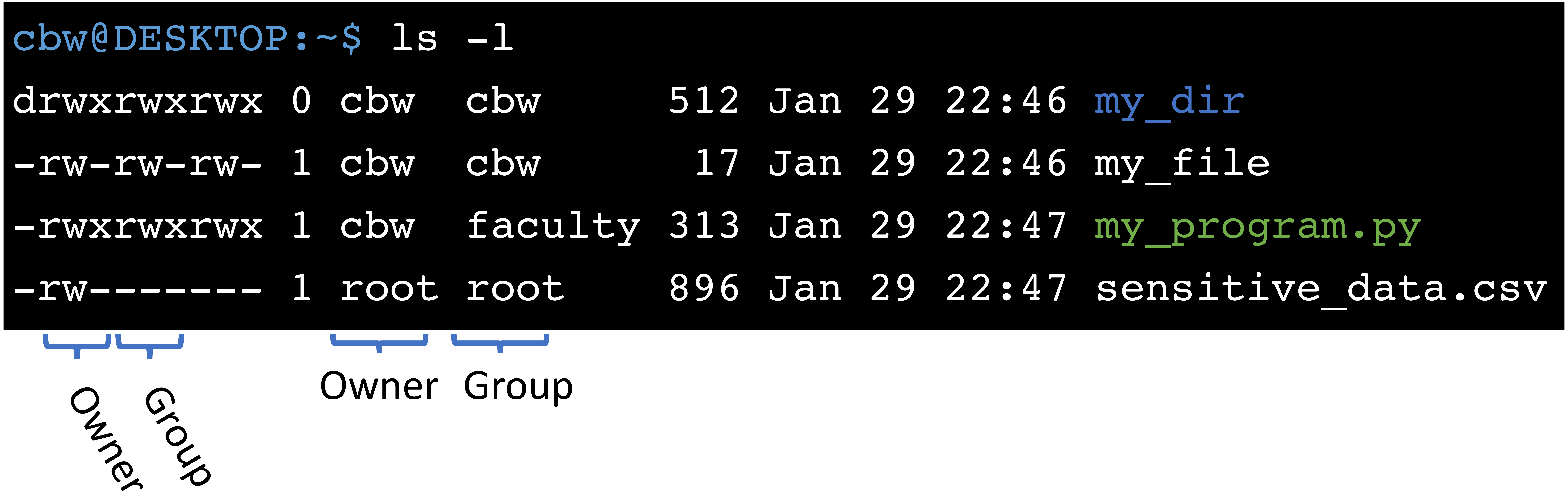
Owner

Owner Group

d → Directory

r → Read w → Write x → eXecute

Unix Permissions



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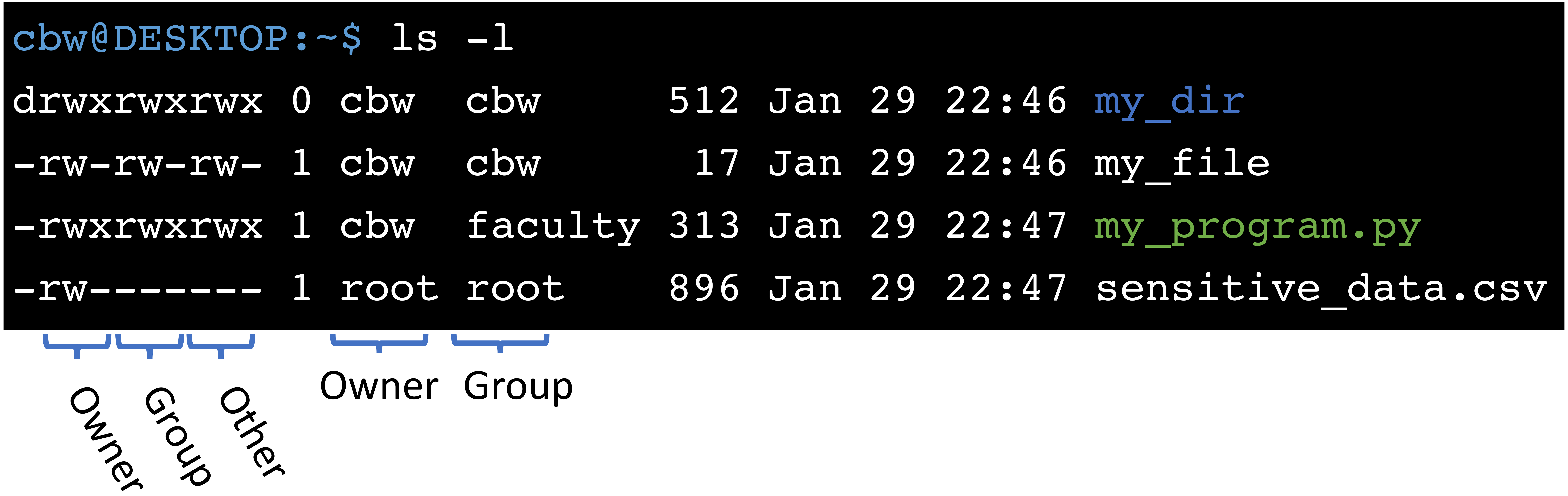
Unix Permissions



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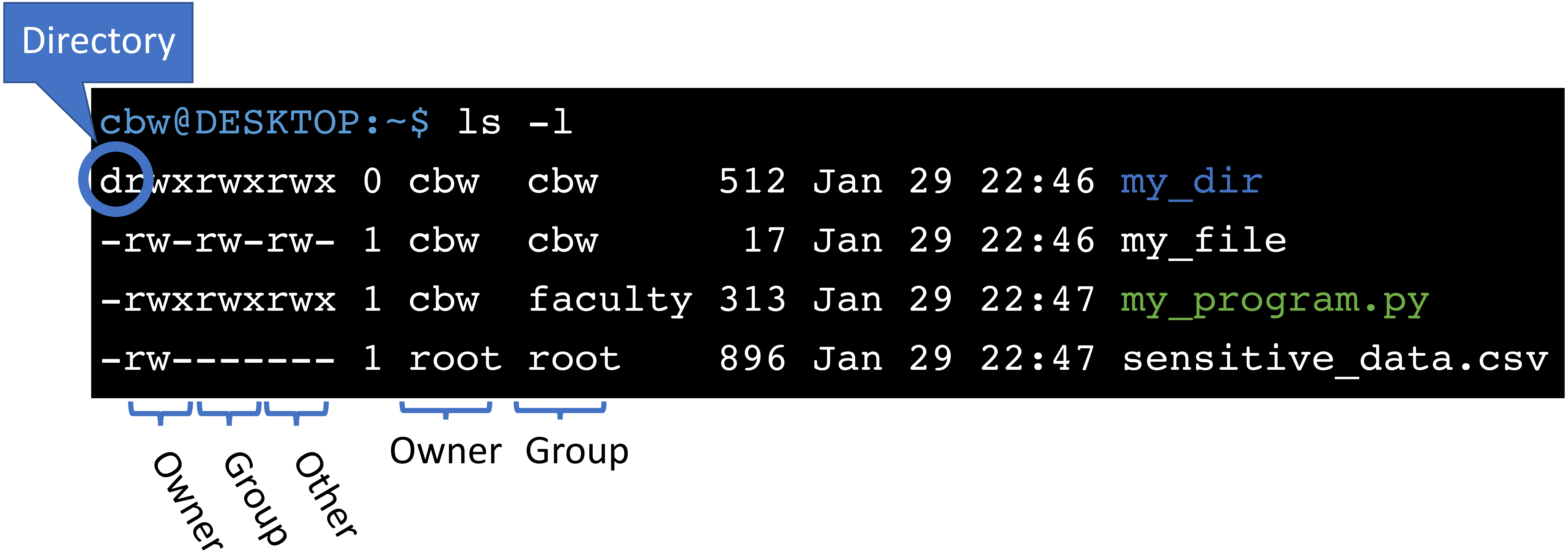

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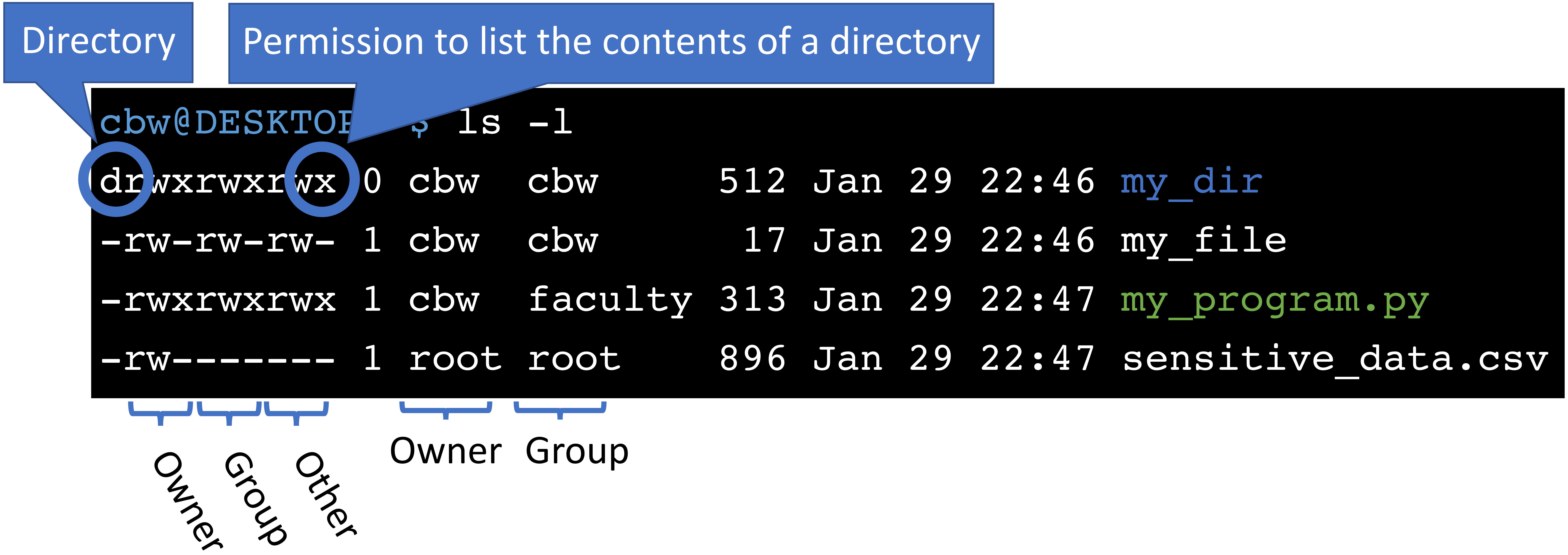
Unix Permissions



Directory

Permission to list the contents of a directory

```
cbw@DESKTOP  $ ls -l
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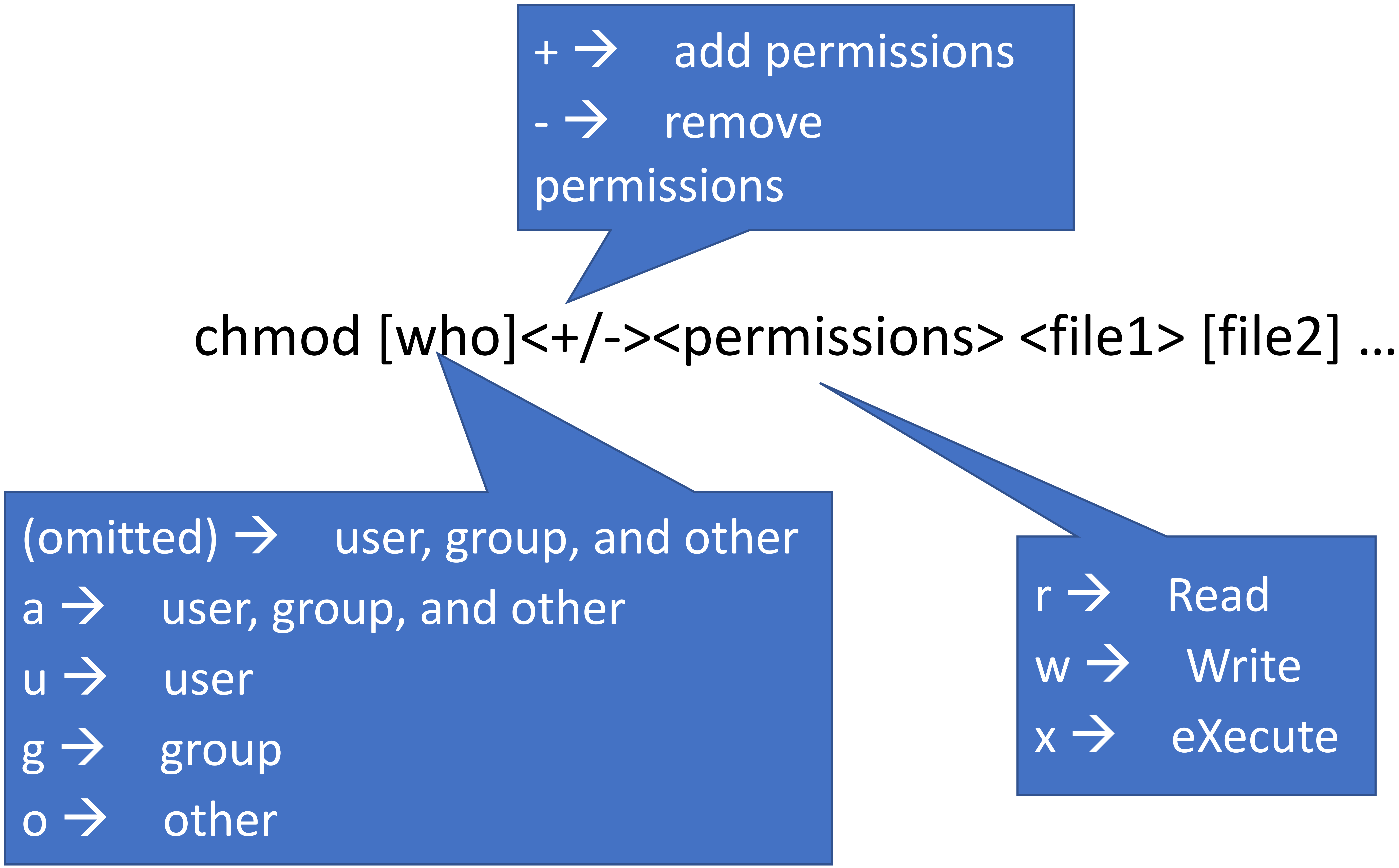
Setting Permissions



+ → add permissions

- → remove permissions

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

(omitted) → user, group, and other

a → user, group, and other

u → user

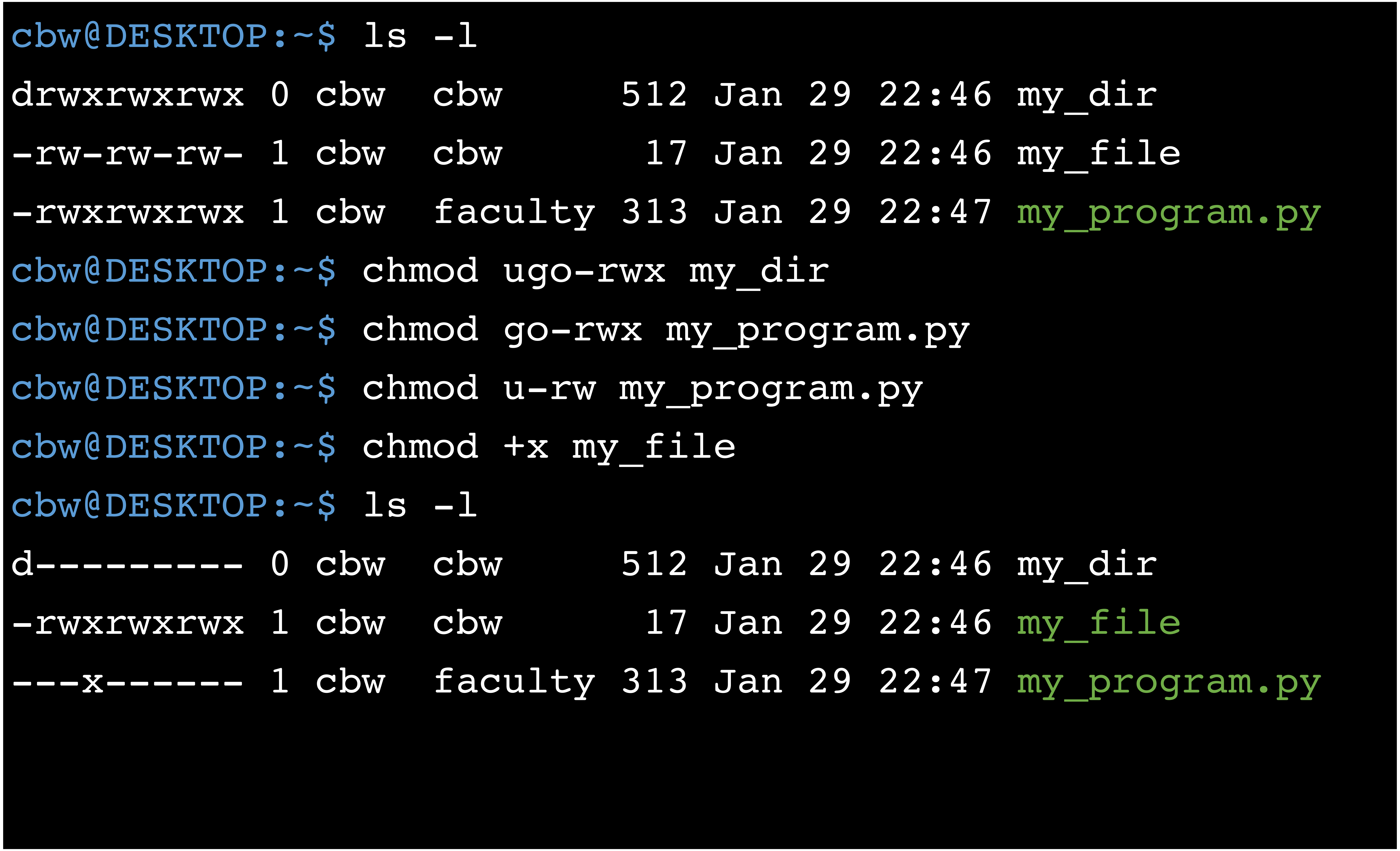
g → group

o → other

r → Read

w → Write

x → eXecute



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

Alternate Form of Setting Permissions

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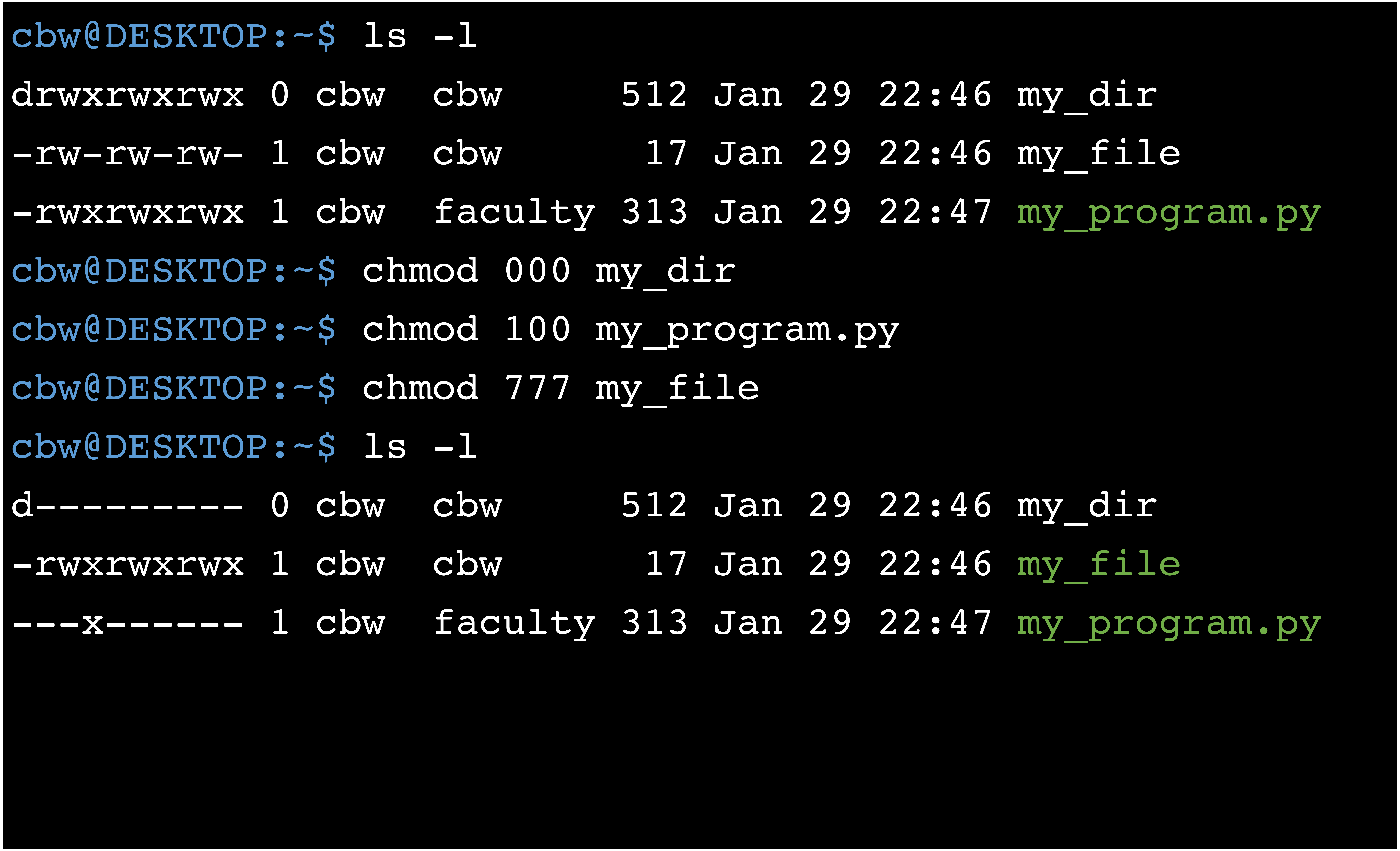
- What if you want to set something as read, write, and execute?
  - 1 + 2 + 4 = 7



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cbw@DESKTOP:~$ chmod 000 my_dir
cbw@DESKTOP:~$ chmod 100 my_program.py
cbw@DESKTOP:~$ chmod 777 my_file
cbw@DESKTOP:~$ ls -l
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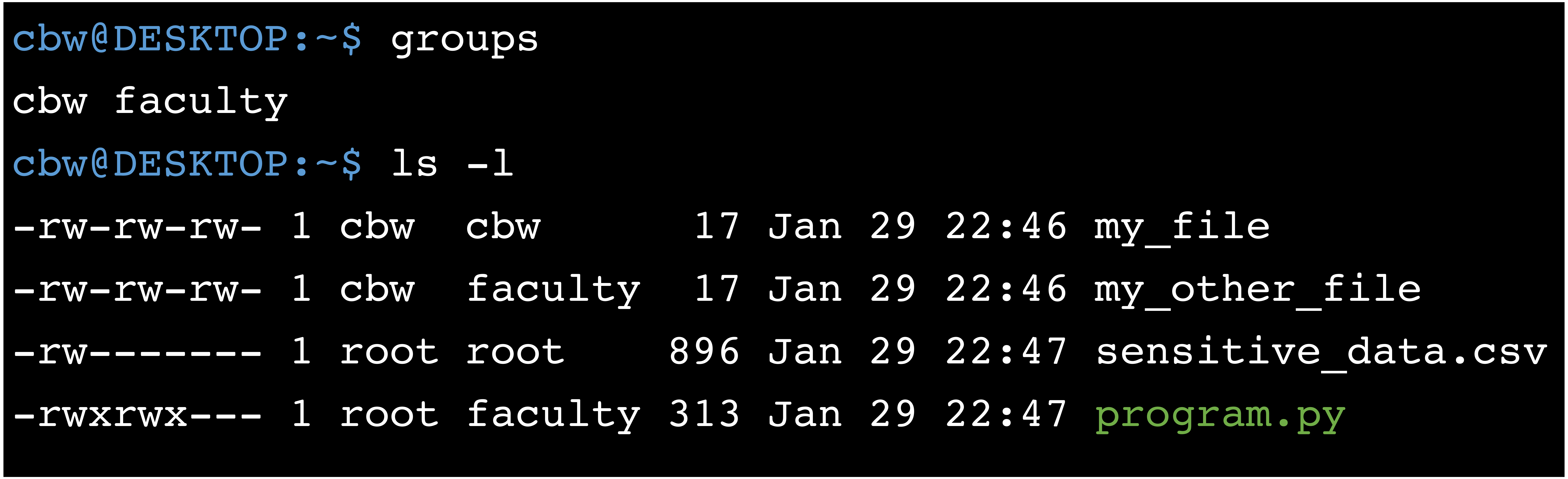
Who May Change Permissions?



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cbw@DESKTOP:~$ groups
cbw faculty
cbw@DESKTOP:~$ ls -l
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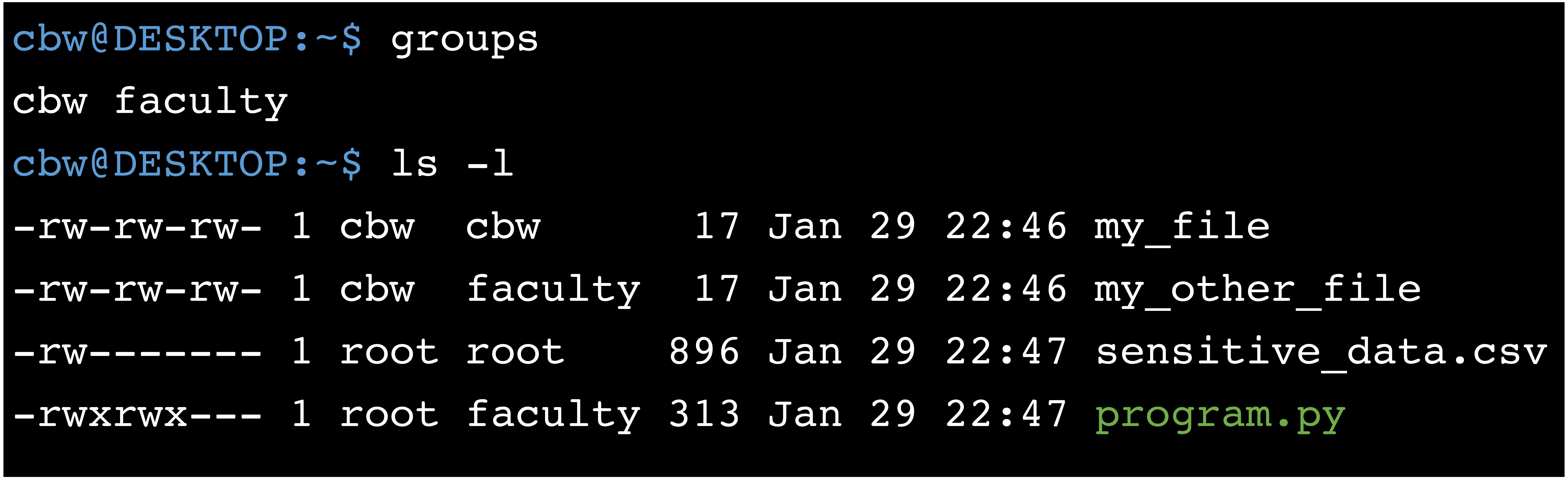
- Which files is user *cbw* permitted to *chmod*?

Who May Change Permissions?



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```

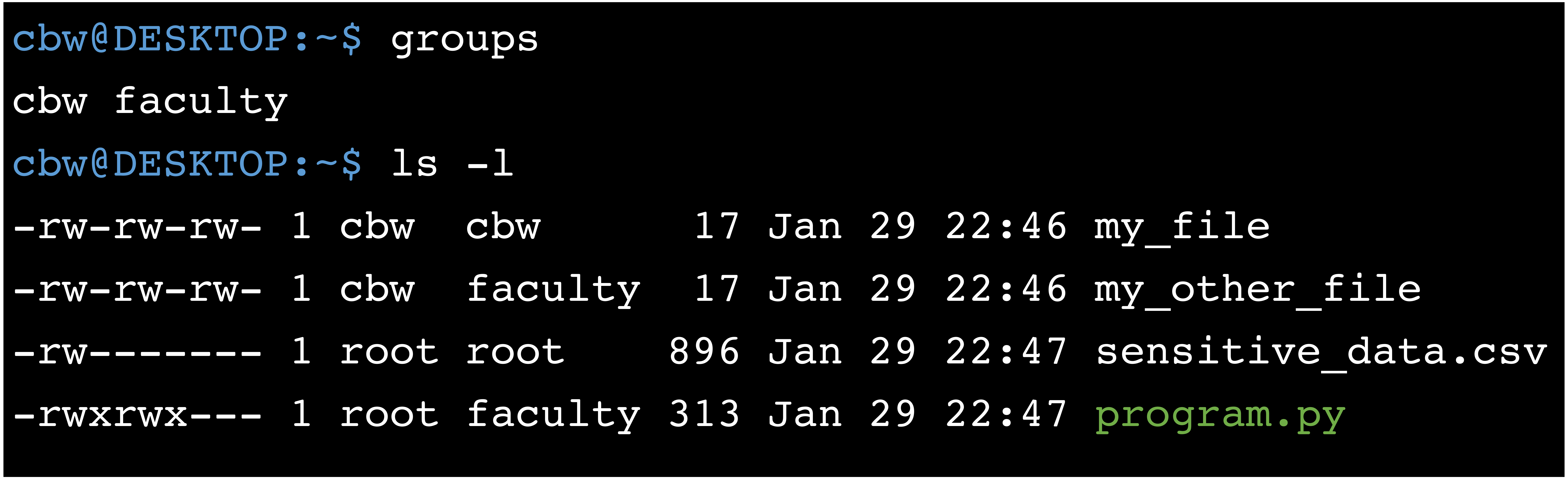
- Which files is user *cbw* permitted to *chmod*?
  - Only owners can *chmod* files
  - *cbw* can *chmod my_file* and *my_other_file*
  - Group membership doesn’t grant *chmod* ability (cannot *chmod program.py*)

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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- Which operations are permitted?

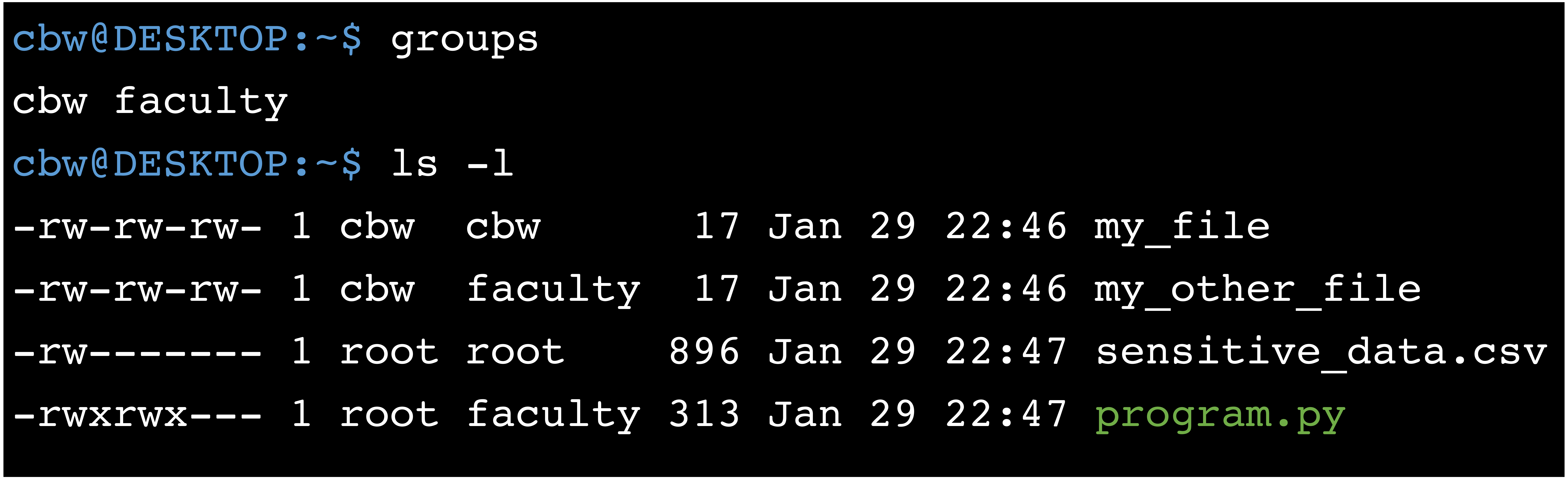
chown cbw:faculty my_file

chown root:root my_other_file

chown cbw:cbw sensitive_date.csv

chown cbw:faculty program.py

Who May Change Ownership?



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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--

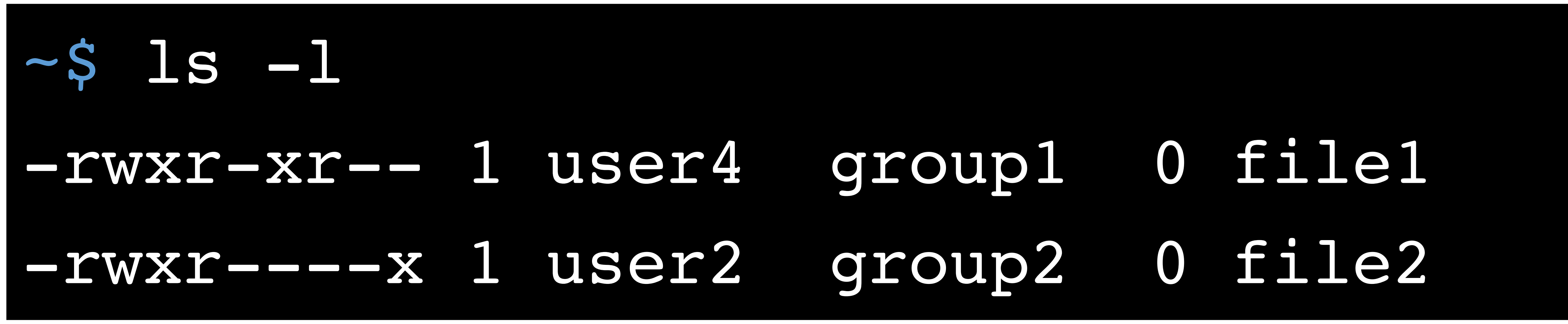
Unix Access Control Exercise (2)

- 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?

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

- *file2*: four distinct privilege levels
    - Maximum of three levels (user, group, other)

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

- *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 themselve 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

The Bad

Unix Access Control Review

The Good

- Very simple model
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The Bad

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

Unix Access Control Review

The Good

- 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

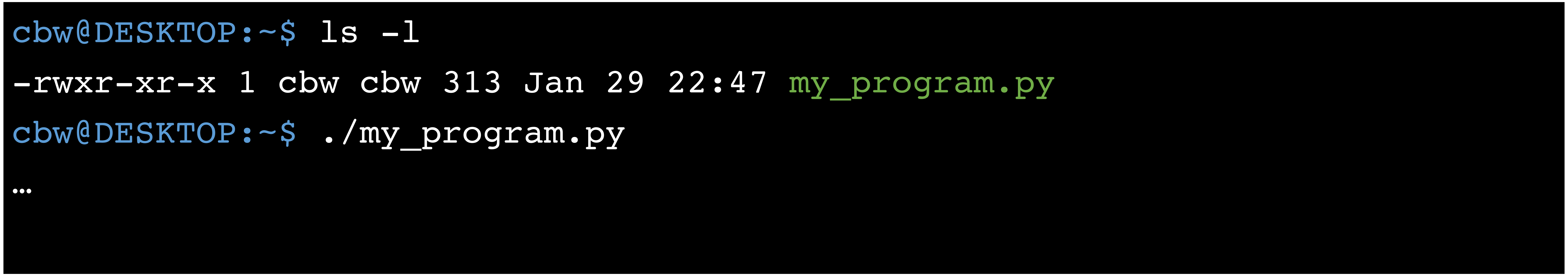
The Confused Deputy Problem

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



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cbw@DESKTOP:~$ ./my_program.py
…
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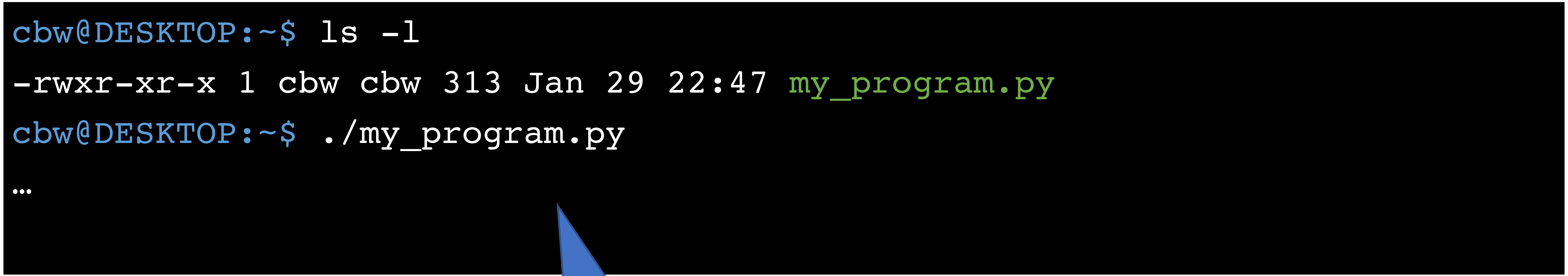
Process Owners



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Who is the owner of this process?

Process Owners

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cbw@DESKTOP:~$ ./my_program.py
…
```
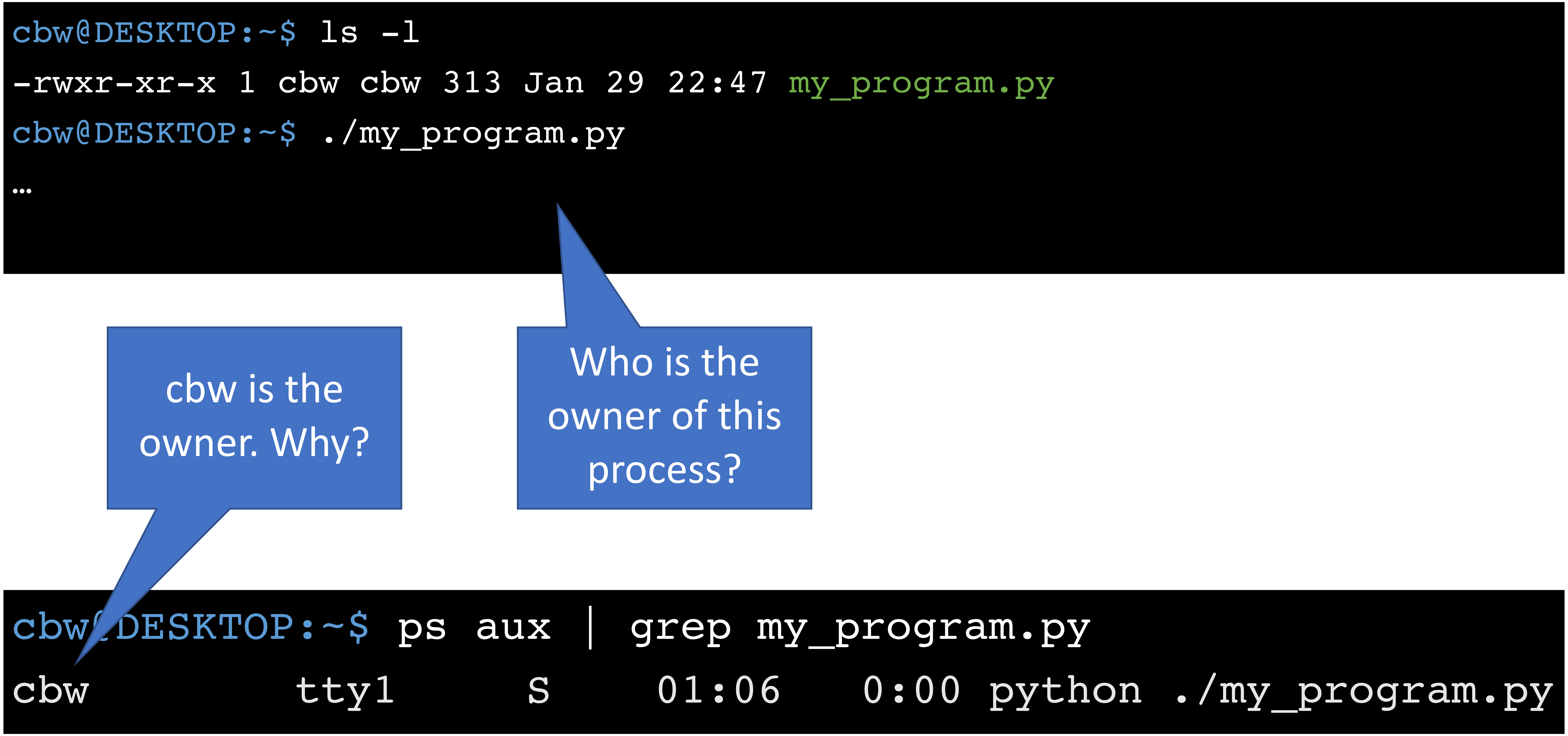

Who is the owner of this process?

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

Process Owners



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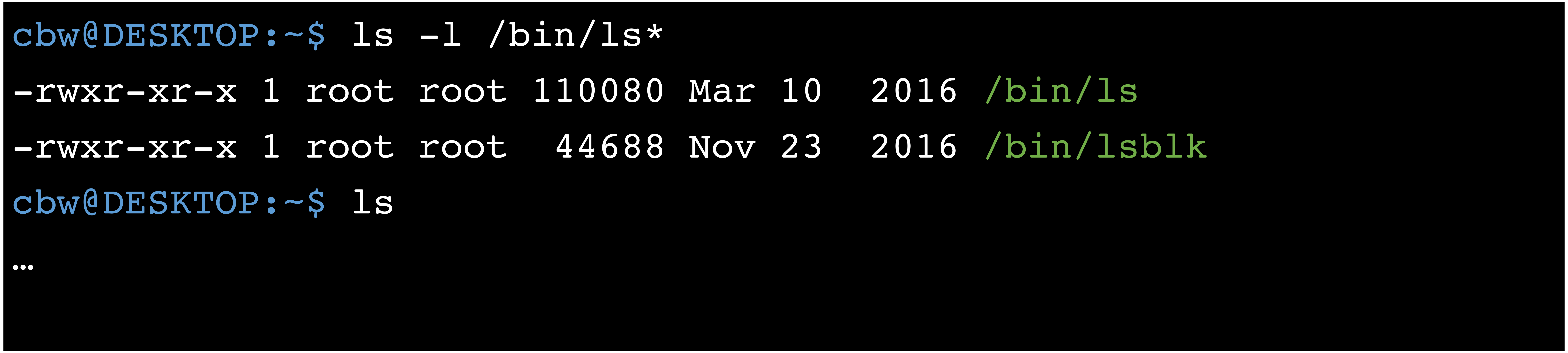
cbw@DESKTOP:~$ ls -l
-rwxr-xr-x 1 cbw cbw 313 Jan 29 22:47 my_program.py
cbw@DESKTOP:~$ ./my_program.py
…
```

cbw is the owner. Why?

Who is the owner of this process?

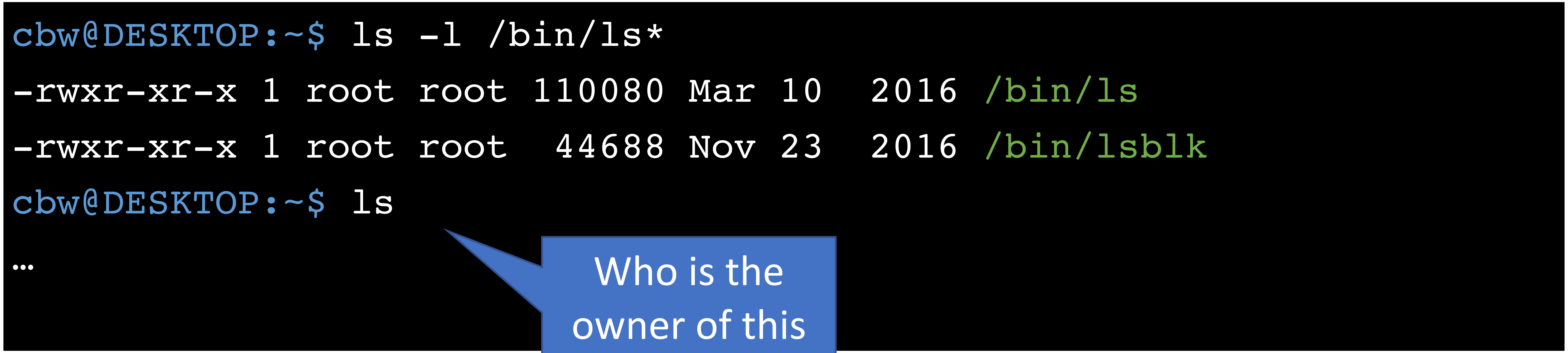
```
cbw@DESKTOP:~$ ps aux | grep my_program.py
cbw          tty1      S      01:06     0:00 python ./my_program.py
```

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
…
```

Process Owners



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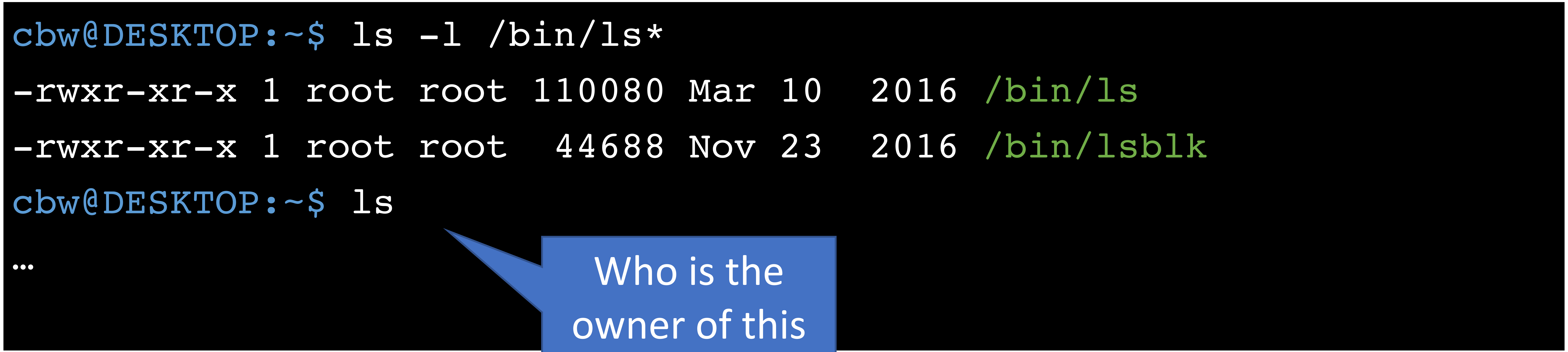
Who is the owner of this process?

Process Owners



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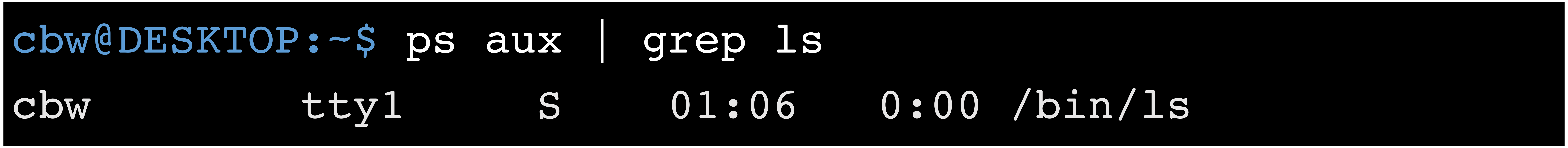

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cbw@DESKTOP:~$ ps aux | grep ls
cbw          tty1      S     01:06    0:00 /bin/ls
```

Process Owners

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Who is the owner of this process?

cbw is the owner. Why?

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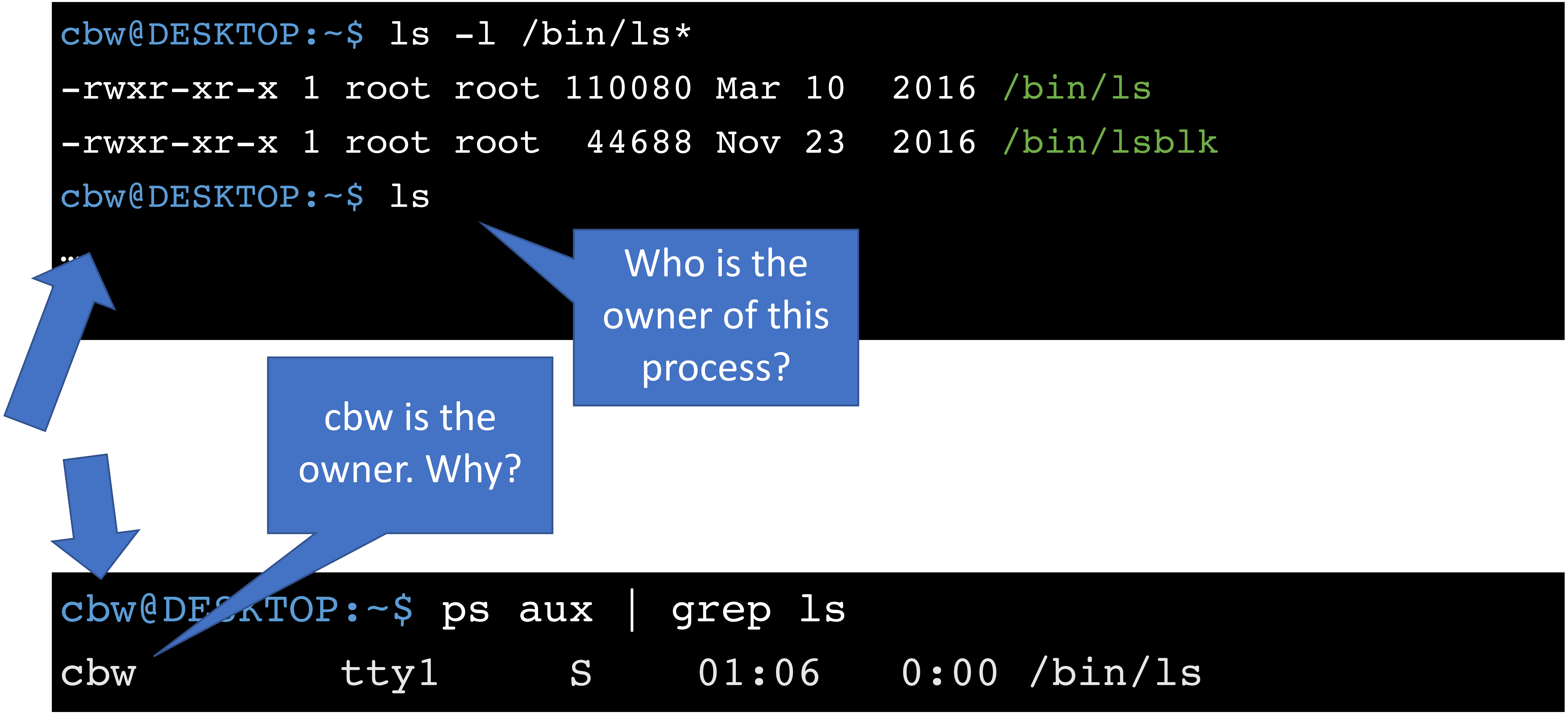
Process Owners



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Subject Ownership

Subject Ownership

- 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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cbw@DESKTOP:~$ ls -l /bin/bash
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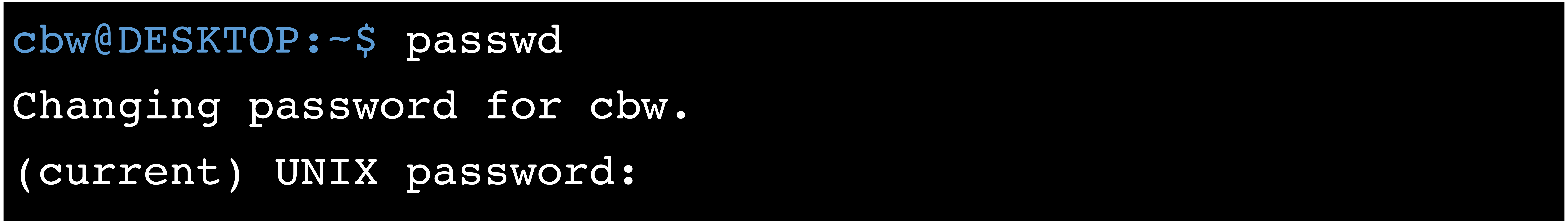
```

Corner Cases



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

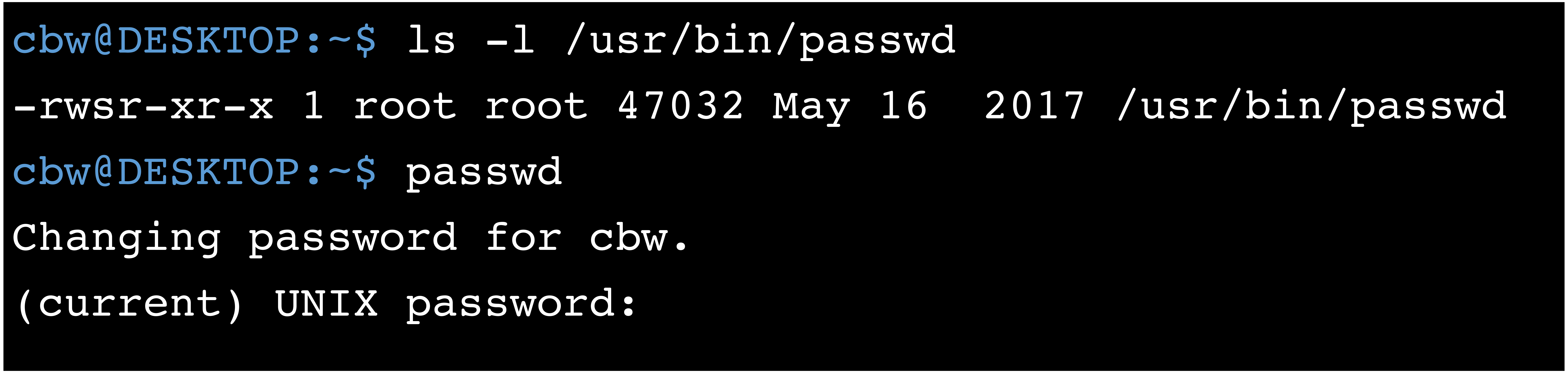
Corner Cases

```
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

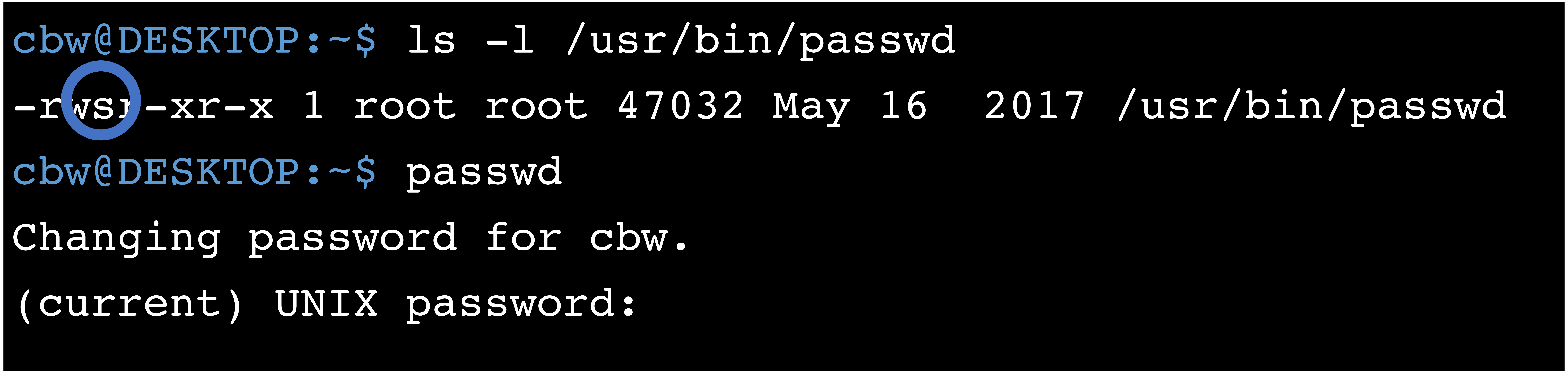
```
cbw@DESKTOP:~$ ls -l /etc/shadow
-rw-r----- 1 root shadow 922 Jan  8 14:56 /etc/shadow
```

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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setuid

- Objects may have the *setuid* permission
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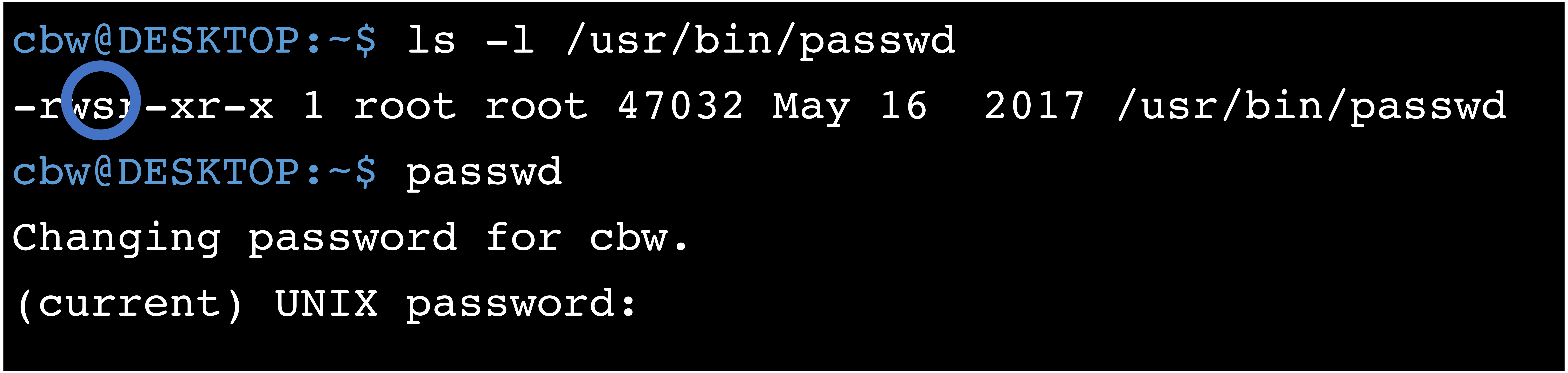

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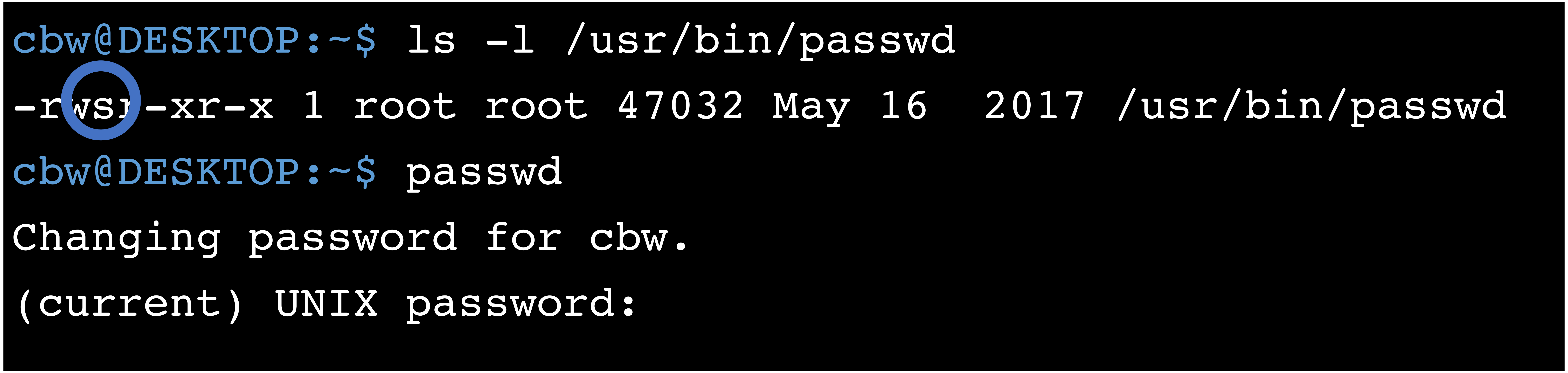

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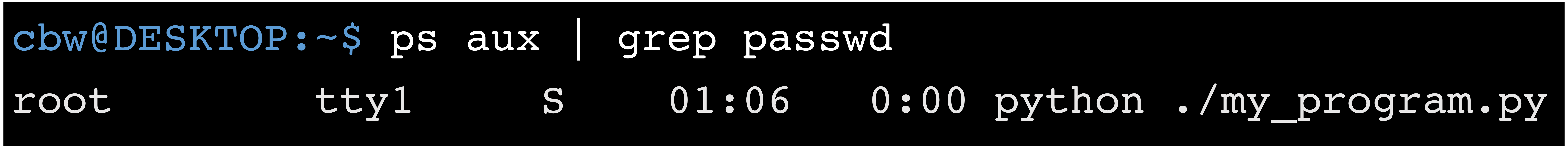

```
cbw@DESKTOP:~$ ps aux | grep passwd
root          tty1     S     01:06    0:00 python ./my_program.py
```

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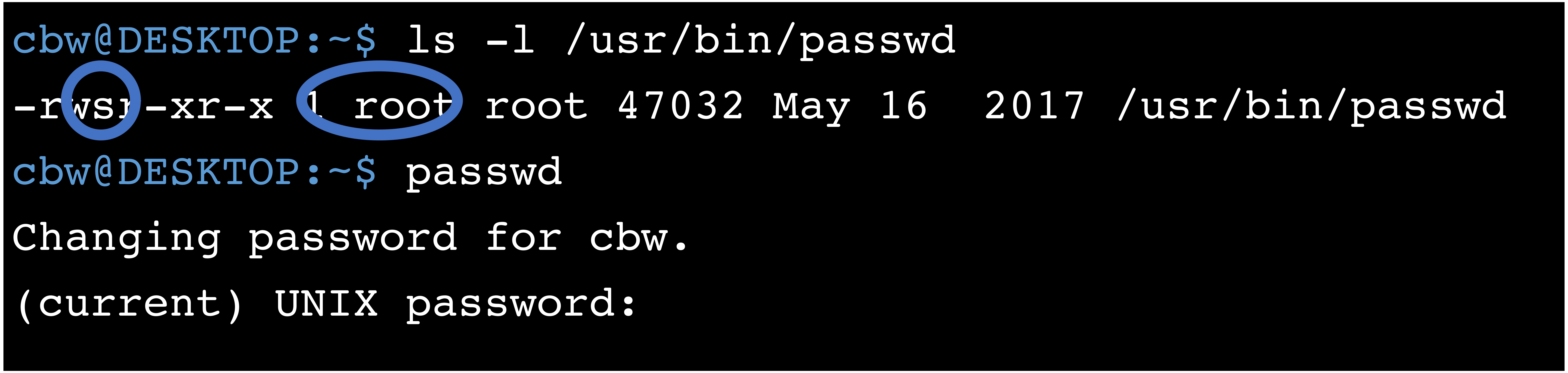

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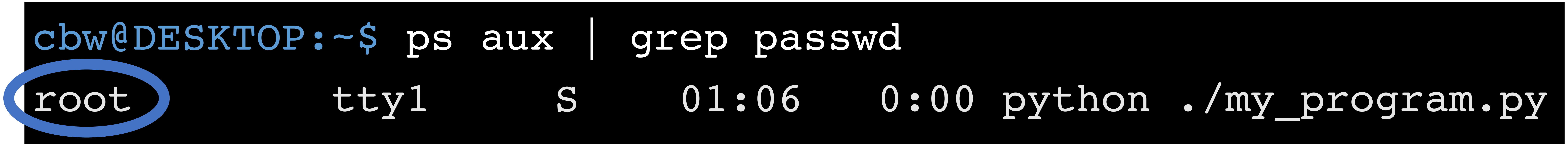

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```

chmod Revisited

- How to add *setuid* to an object?

```
chmod u+s <file1> [file2] …
chmod 2### <file1> [file2] …
```

chmod Revisited

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```
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

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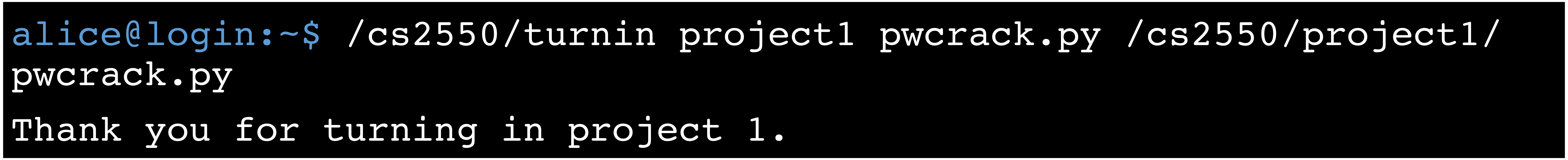
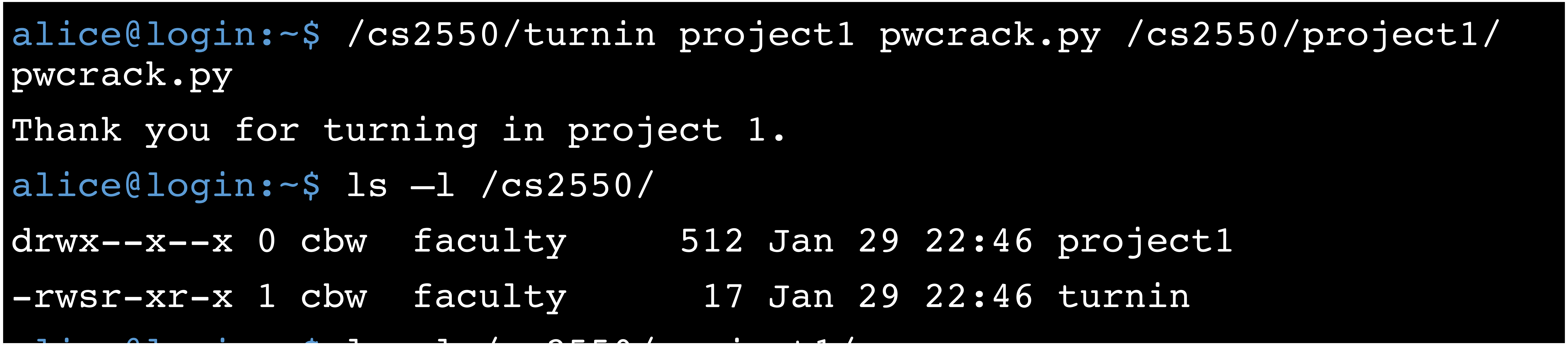
1. Copies *<in_file>* to *<out_file>*
2. Grades the assignment
3. Writes the grade to */cs2550/<project#>/grades*

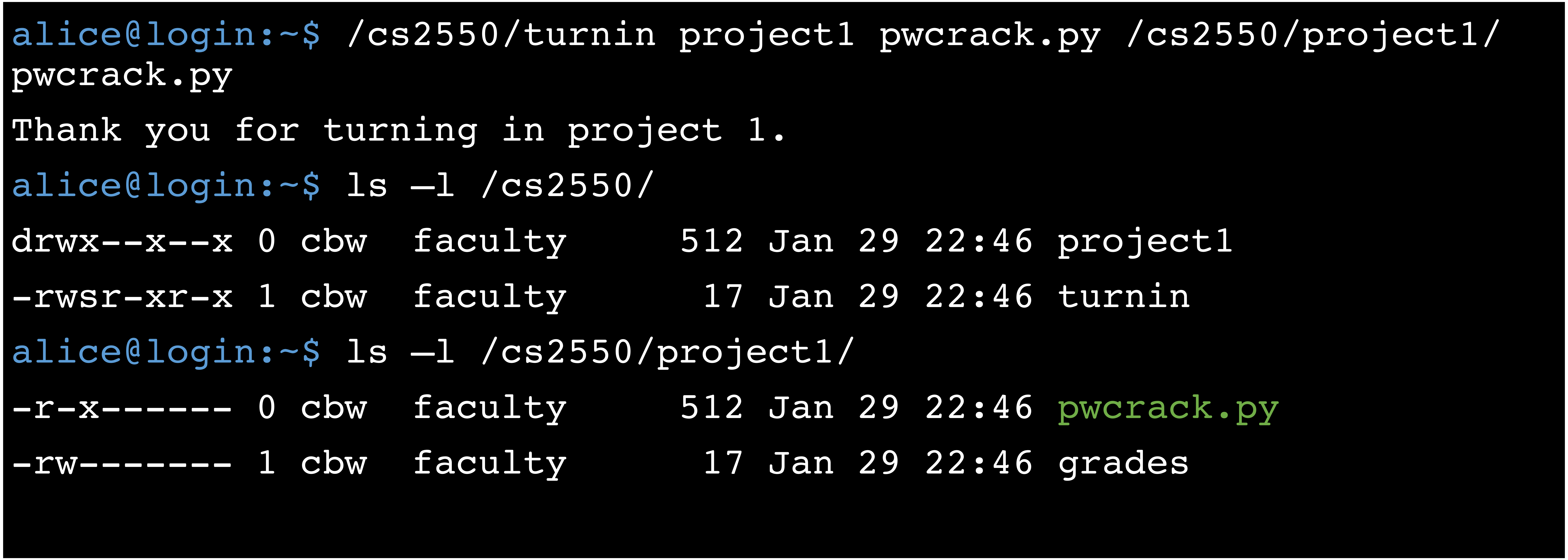
- Challenge: students cannot have write access to project directories or grade files
  - *turnin* program must be *setuid*



```
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/
pwcrack.py
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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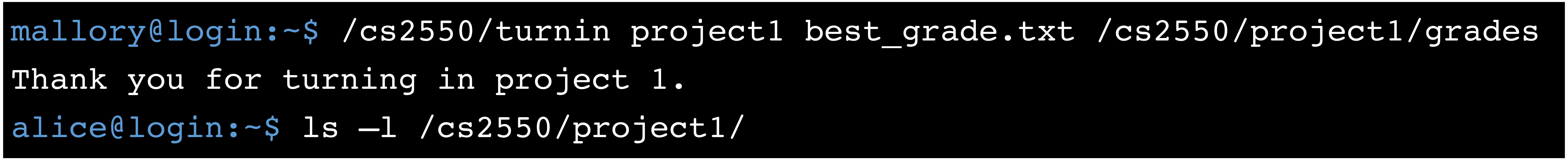
-rw------- 1 cbw  faculty      17 Jan 29 22:46 grades
```

Ambient Authority

Ambient Authority

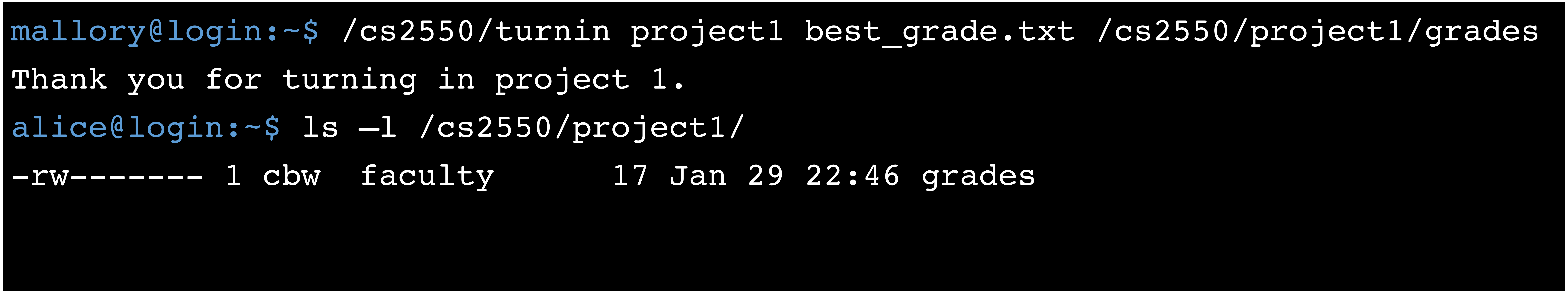
- Ambient authority
  - A subject’s permissions are automatically exercised
  - No need to select specific permissions
- Systems that use ACLs or Unix-style permissions grant ambient authority
  - A subject automatically gains all permissions of the principal
  - A setuid subject also gains permissions 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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```

- 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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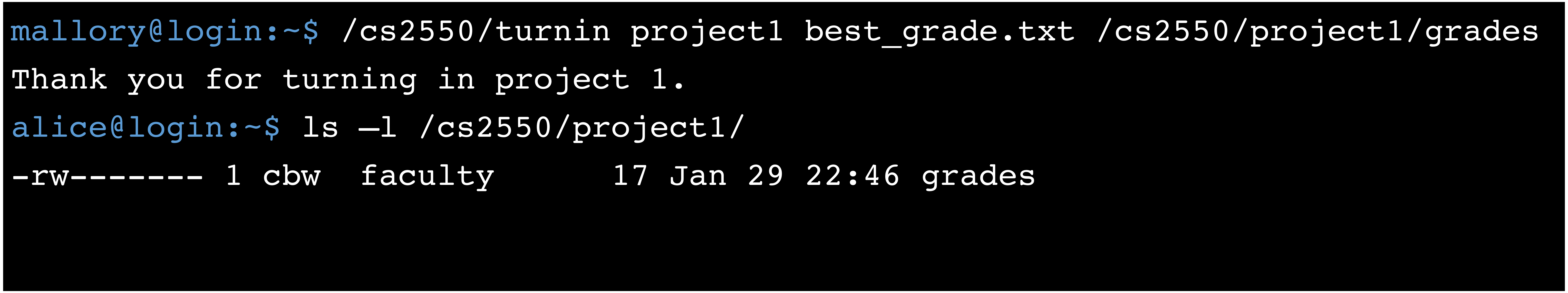

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  - *mallory* cannot directly access */cs2550/project1/grades*
  - However, *cbw* can access */cs2550/project1/grades*
- Key problem: the subject cannot tell which principal it is serving when it performs a write

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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ACL for o_2

	o_1	o_2	o_3
s_1	RW	RX	
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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

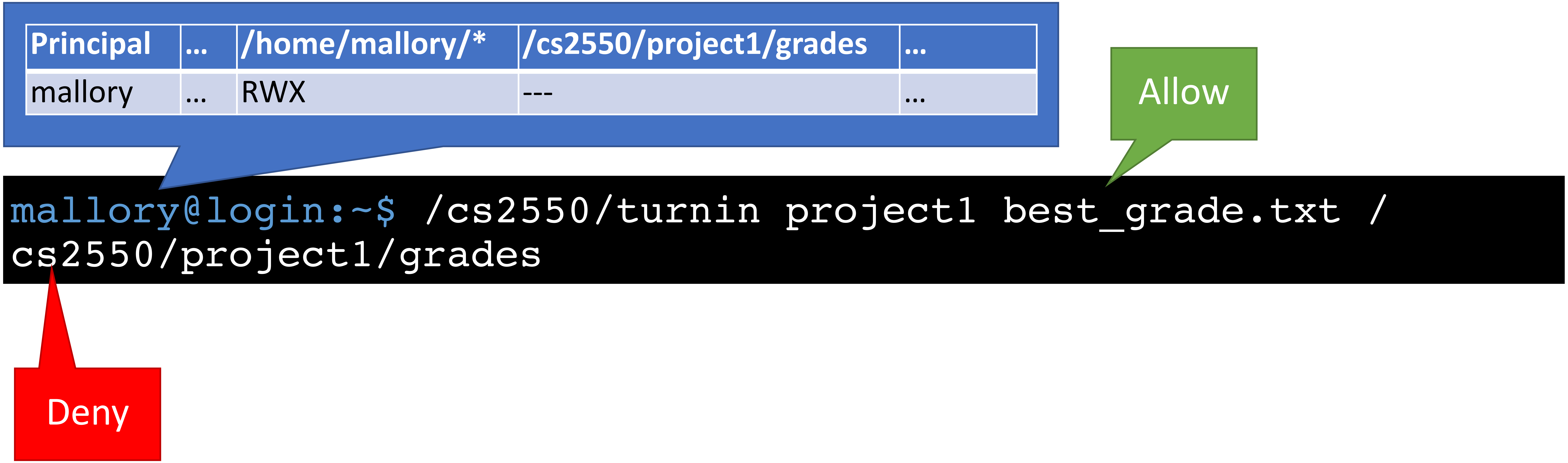
```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
cs2550/project1/grades
```

Confused Deputy Revisited

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

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

Confused Deputy Revisited



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mallory	…	RWX	---	…

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

Allow

Deny

Confused Deputy Revisited

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

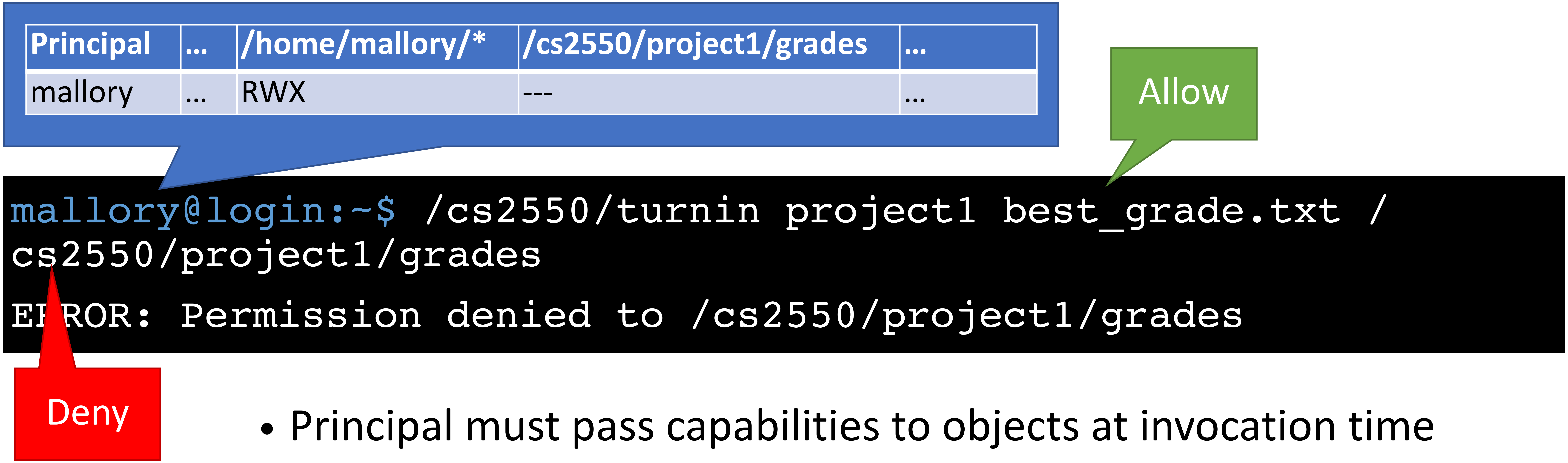
```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
cs2550/project1/grades

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

Allow

Deny

Confused Deputy Revisited



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mallory	…	RWX	---	…

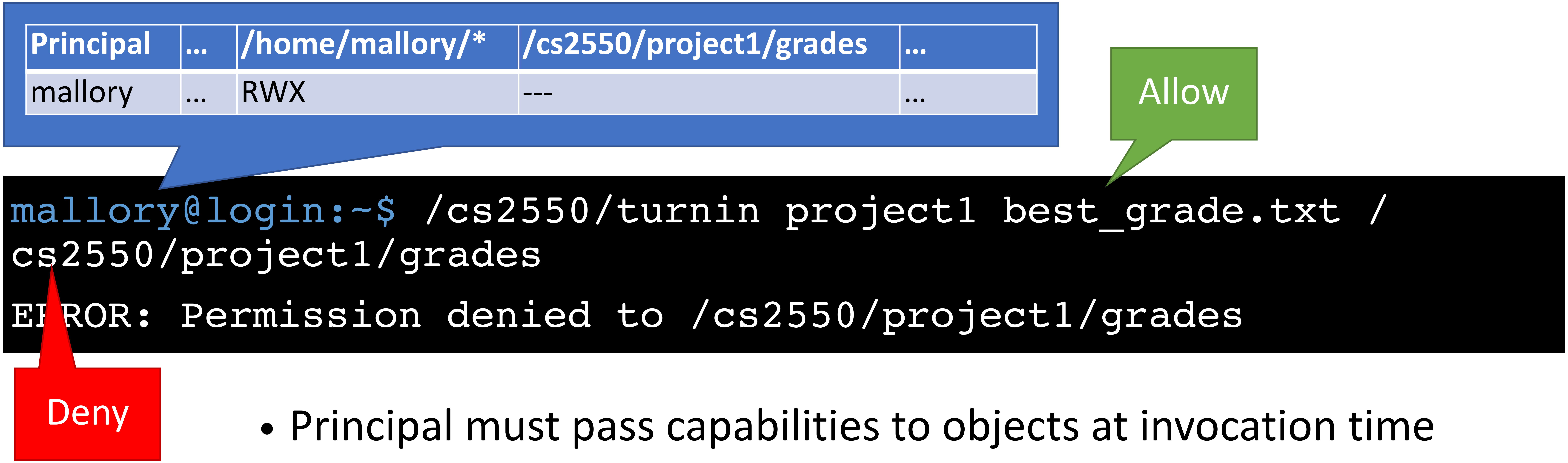
```
mallory@login:~$ /cs2550/turnin project1 best_grade.txt /
cs2550/project1/grades

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

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



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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*
- 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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- ACL system
- Ambient authority to access all authorized accounts

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- Capability system
- No ambient authority

Capabilities IRL

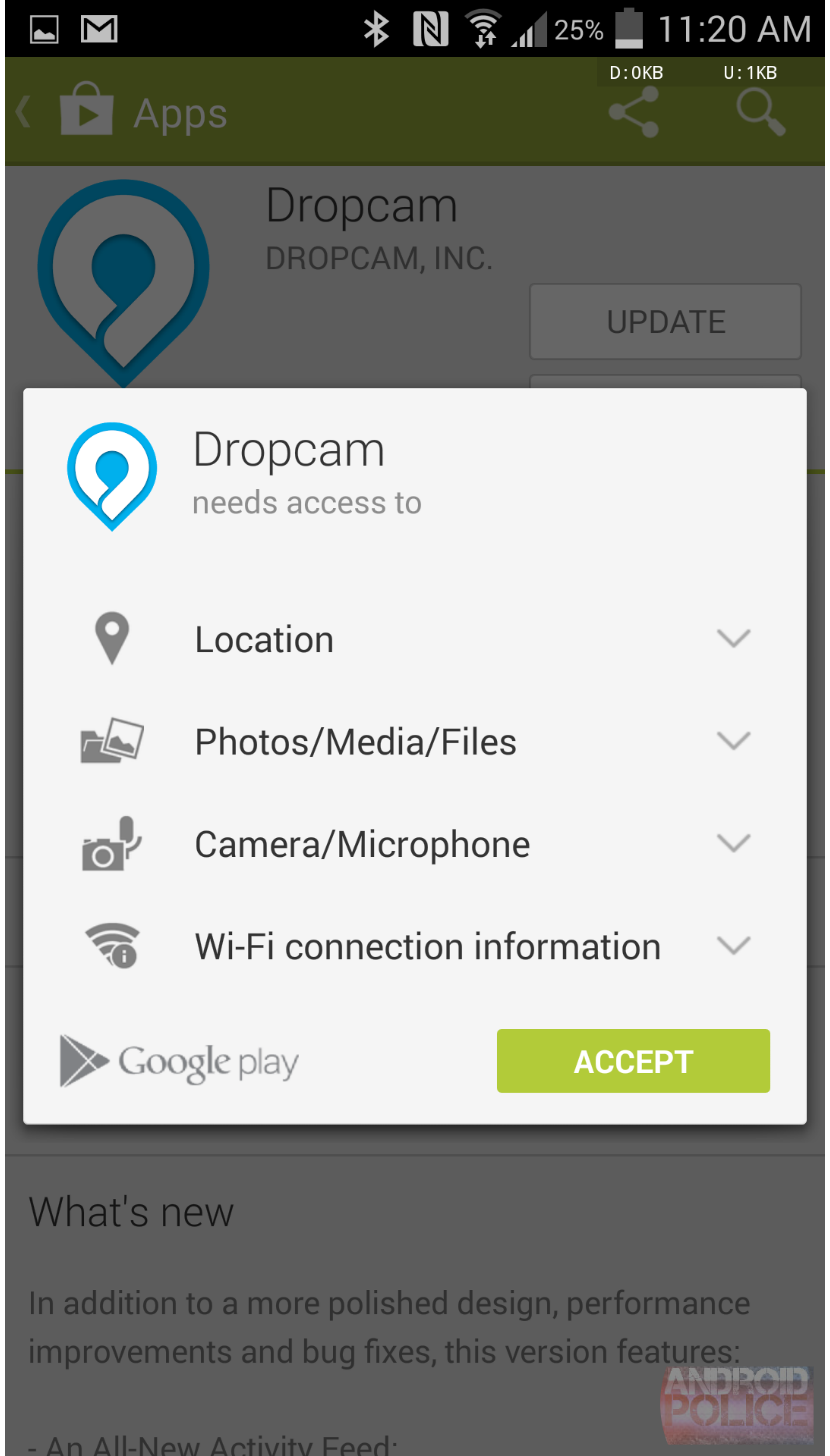
- From a security perspective, capability systems are more secure than ACL and Unix-style systems
- … and yet, most major operating systems use the latter
- Why?
  - Easier for users
    - ACLs are good for user-level sharing, intuitive
    - Capabilities are good for process-level sharing, not untuitive
  - 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



Dropcam
DROPCAM, INC.

Dropcam
needs access to

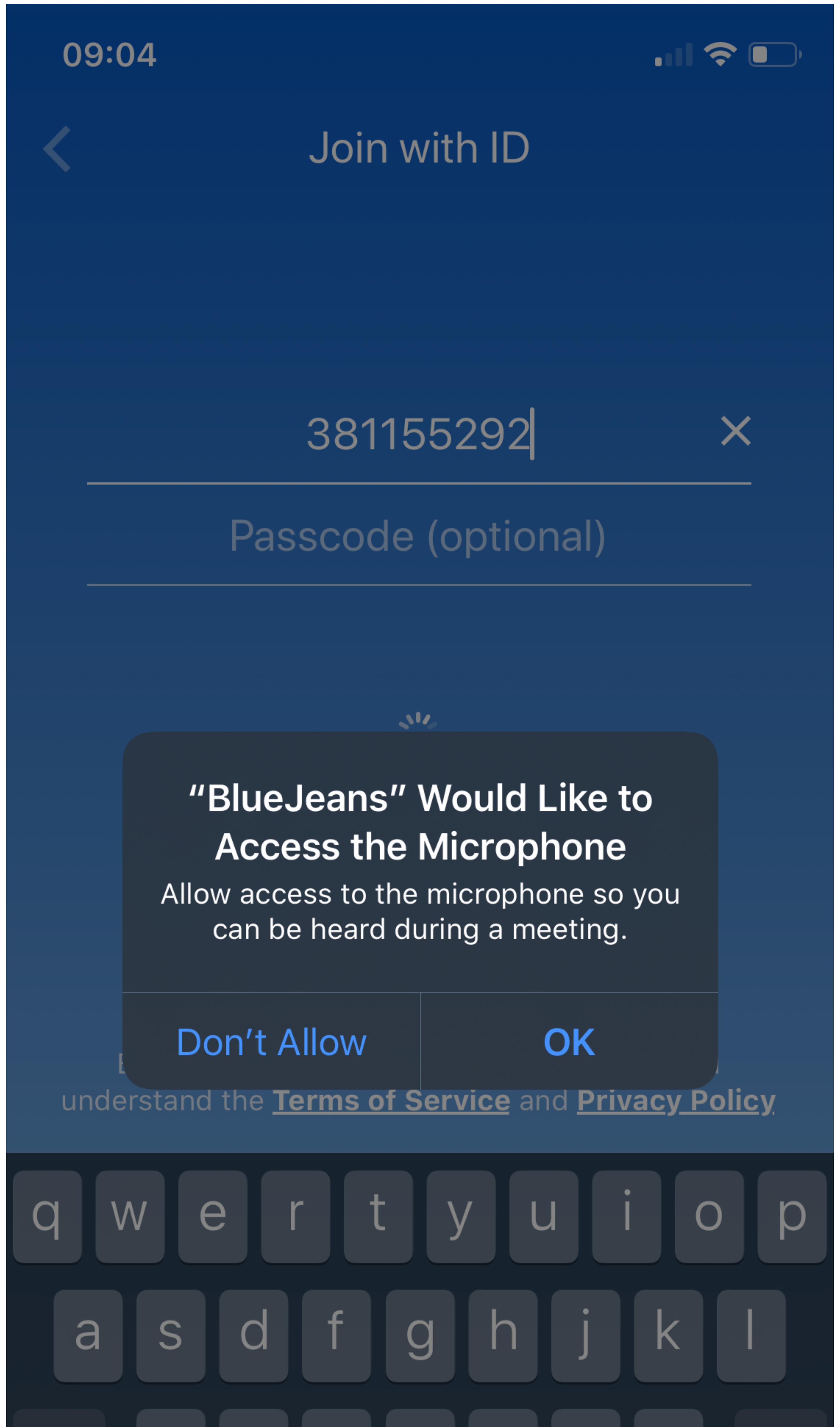
Location
Photos/Media/Files
Camera/Microphone
Wi-Fi connection information

What's new

In addition to a more polished design, performance improvements and bug fixes, this version features:

- An All-New Activity Feed:

Android/IOS just-in-time capability



09:04

Join with ID

381155292

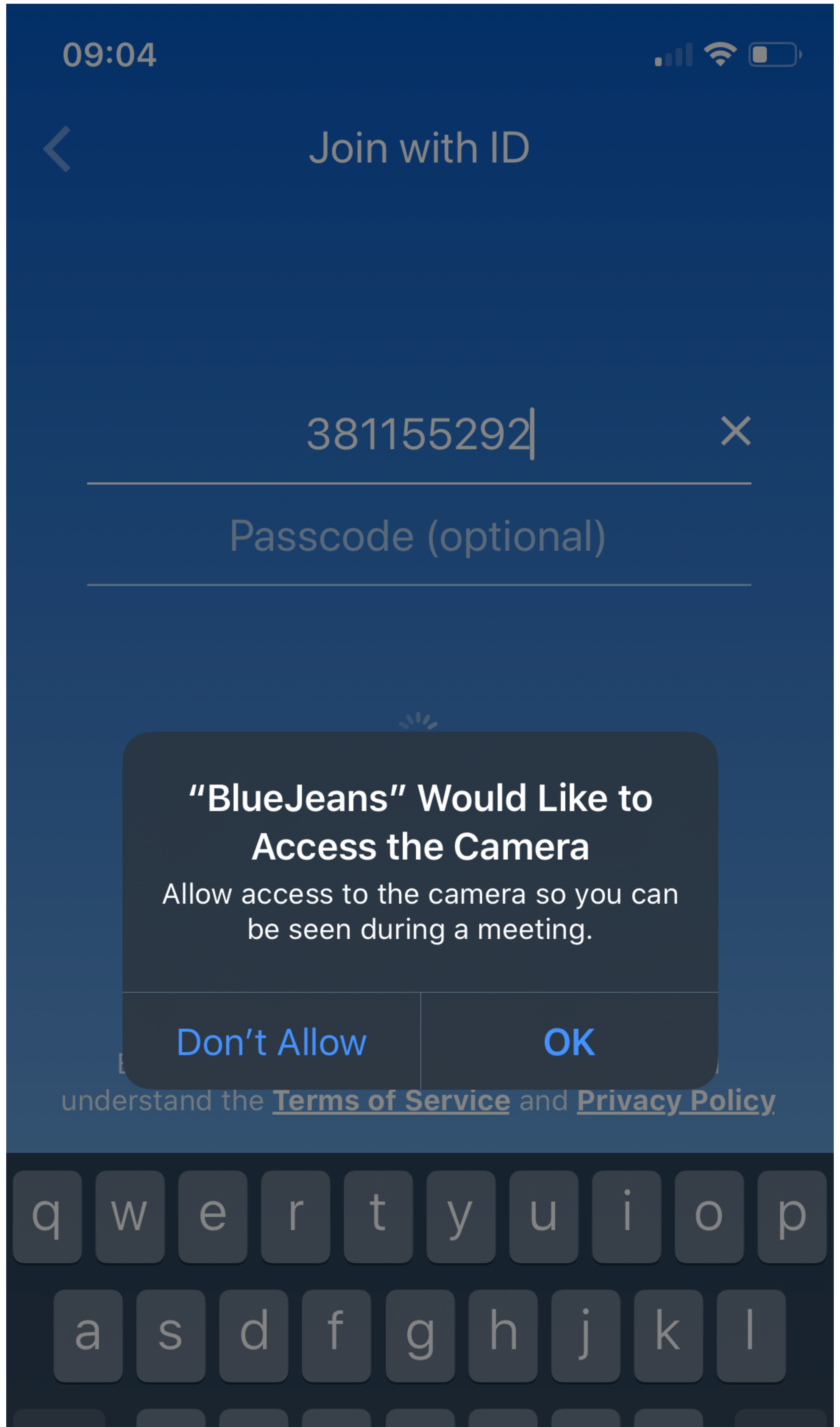
Passcode (optional)

"BlueJeans" Would Like to Access the Microphone

Allow access to the microphone so you can be heard during a meeting.

Don't Allow | OK

understand the **Terms of Service** and **Privacy Policy**



09:04

Join with ID

381155292

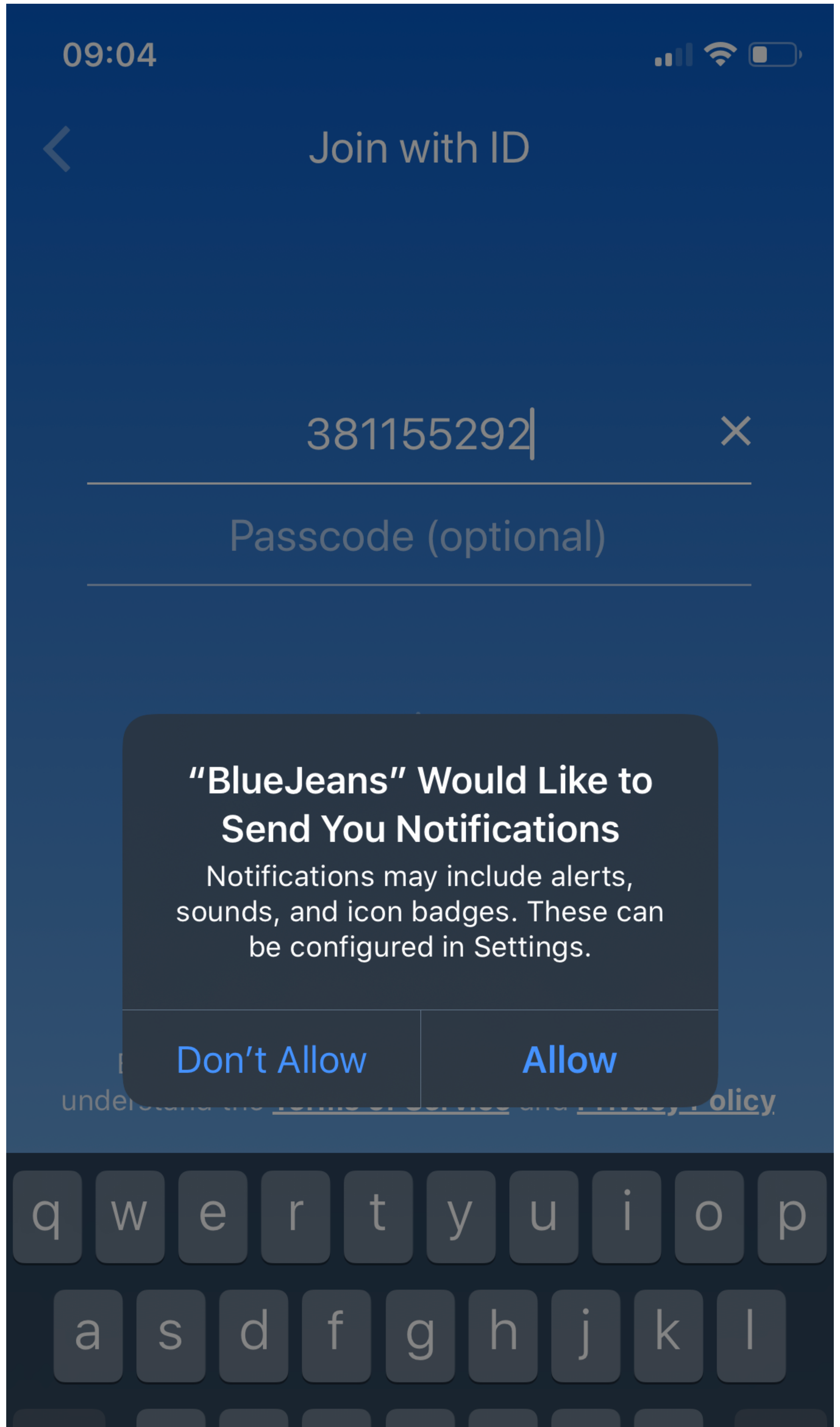
Passcode (optional)

"BlueJeans" Would Like to Access the Camera

Allow access to the camera so you can be seen during a meeting.

Don't Allow | OK

understand the **Terms of Service** and **Privacy Policy**



09:04

Join with ID

381155292

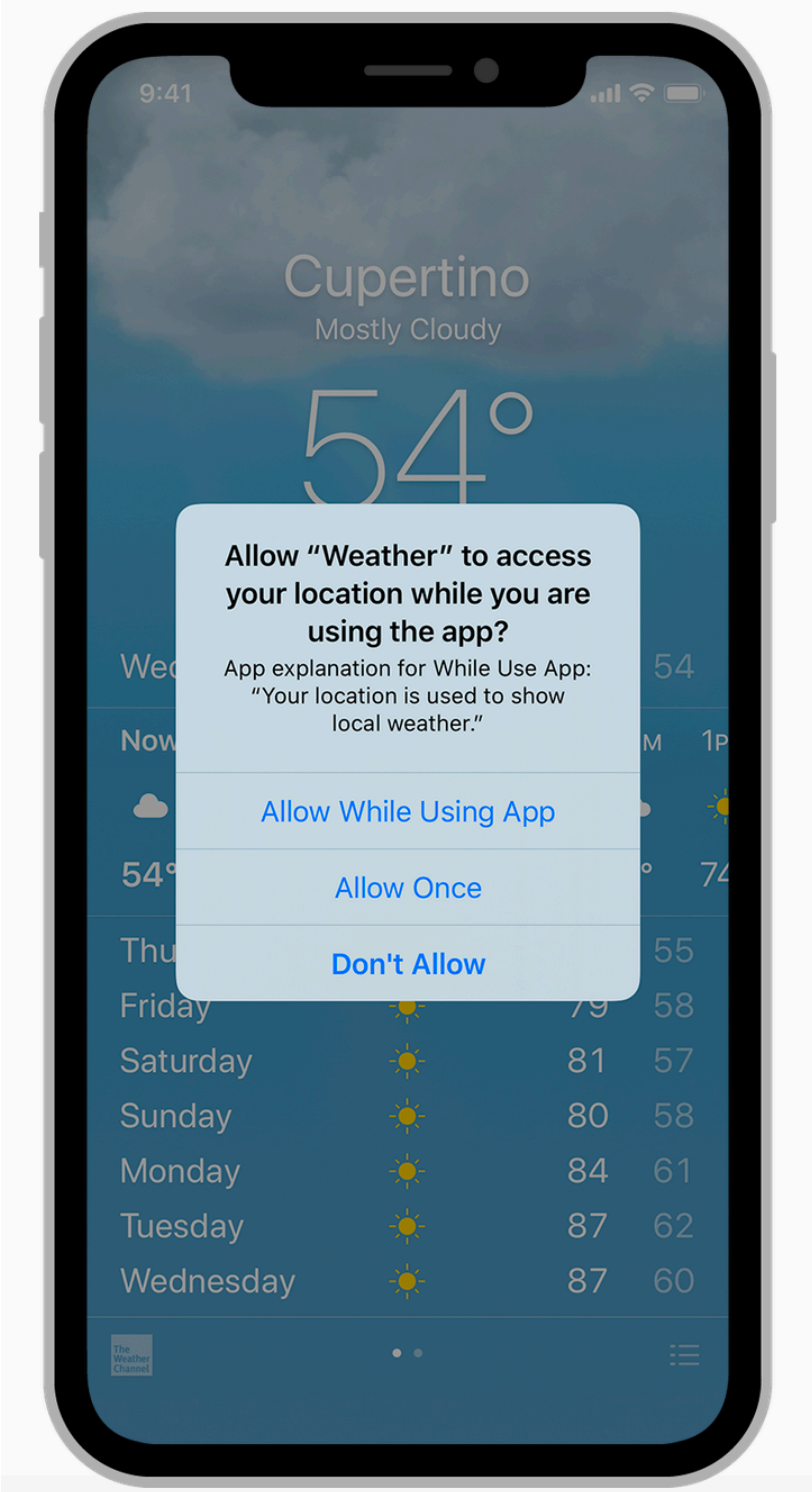
Passcode (optional)

"BlueJeans" Would Like to Send You Notifications

Notifications may include alerts, sounds, and icon badges. These can be configured in Settings.

Don't Allow | Allow

Per-event capability



Allow “Weather” to access your location while you are using the app?

App explanation for While Use App: “Your location is used to show local weather.”

Allow While Using App

Allow Once

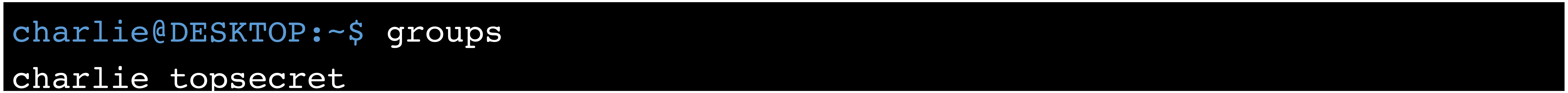
Don't Allow

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?



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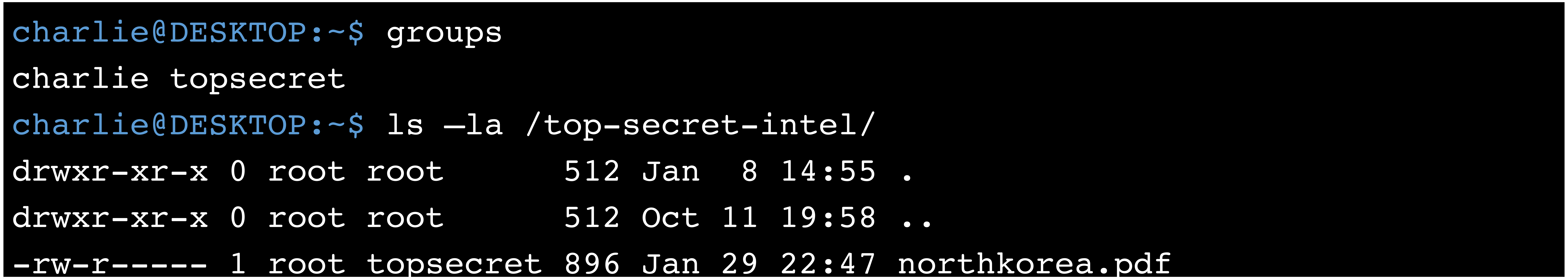

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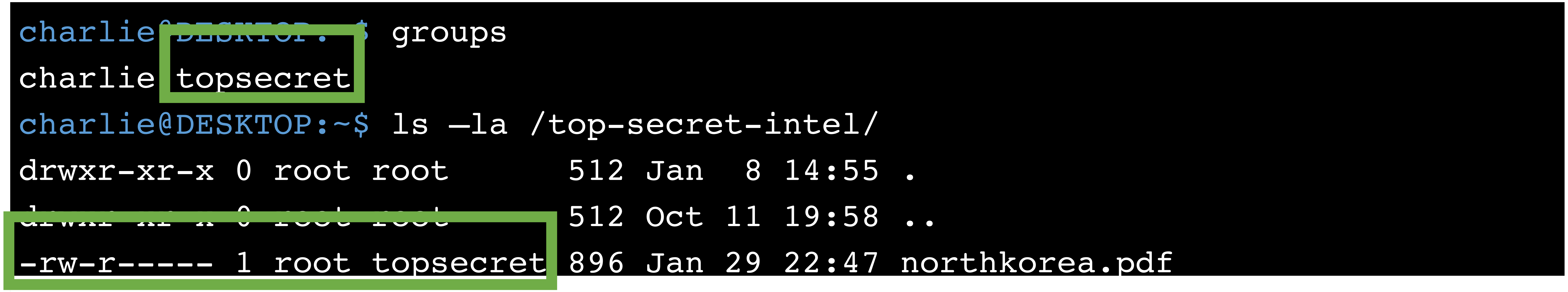

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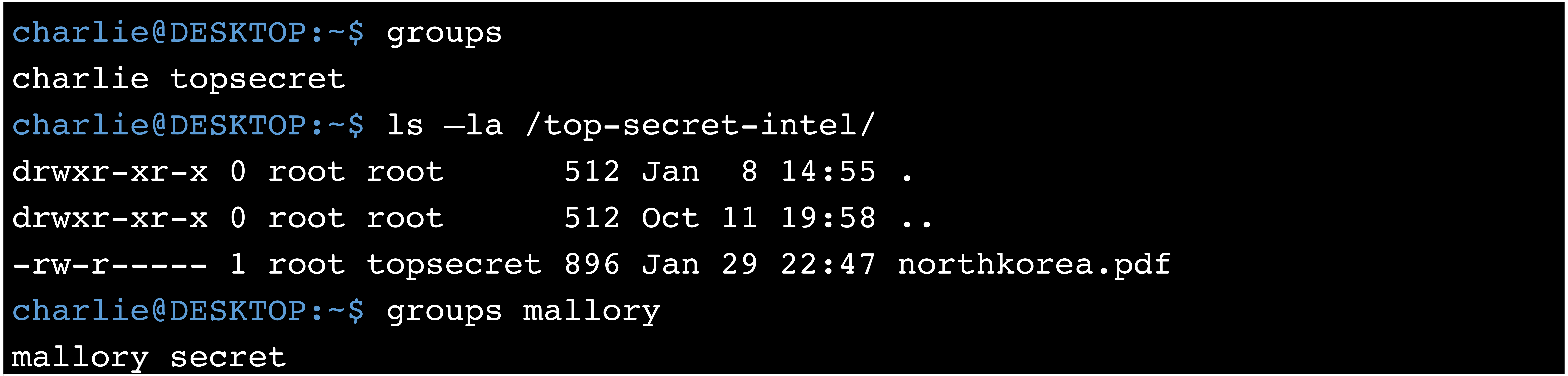

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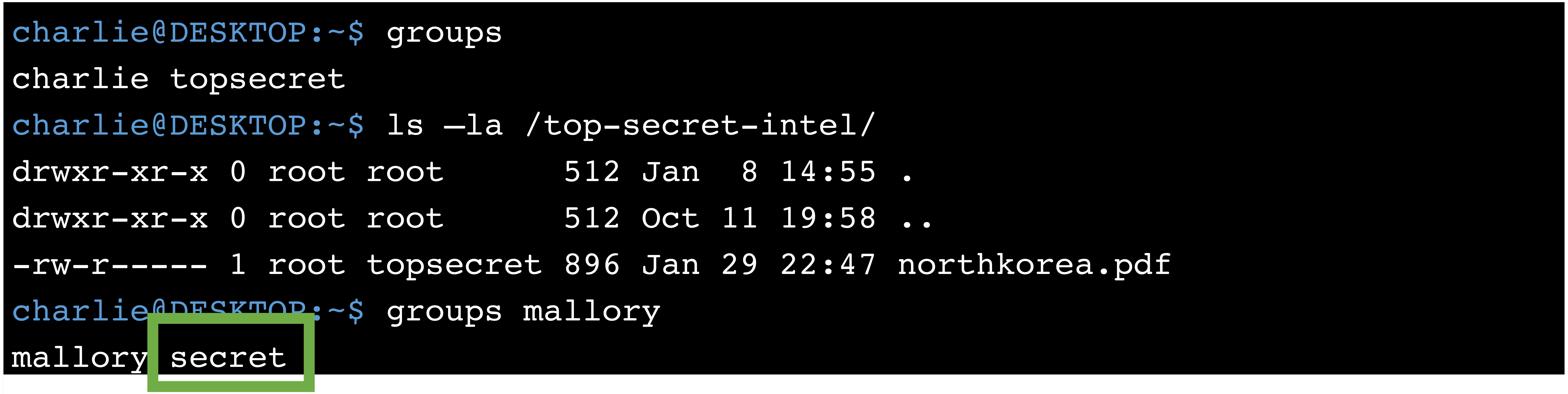

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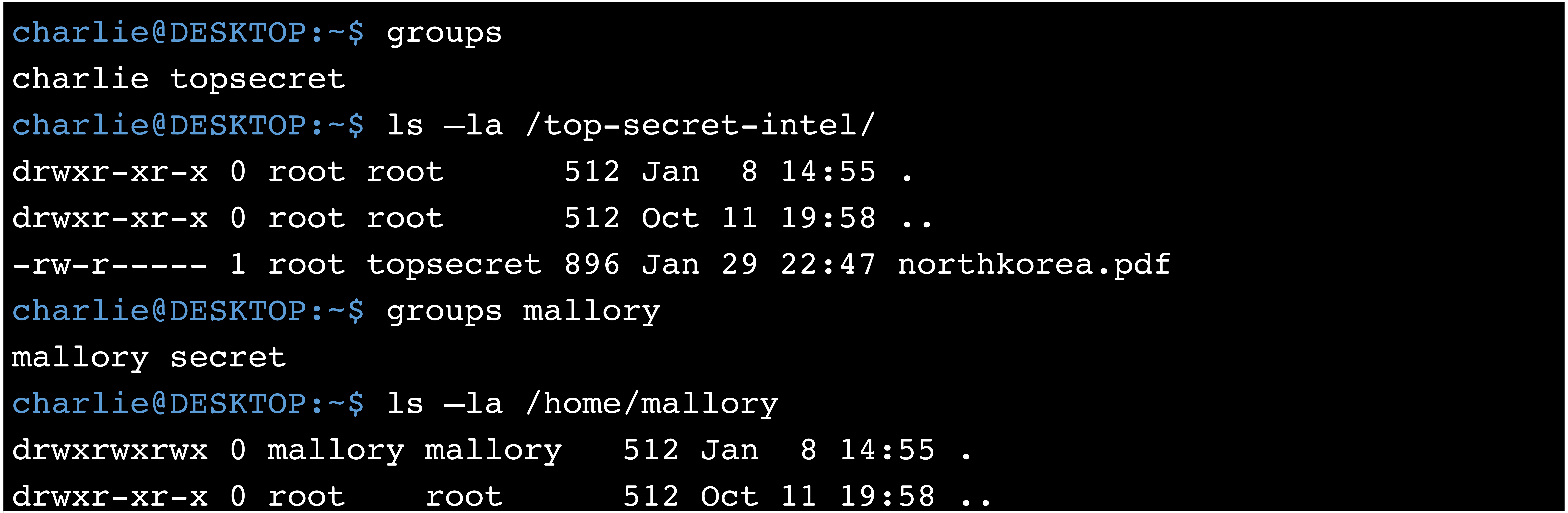

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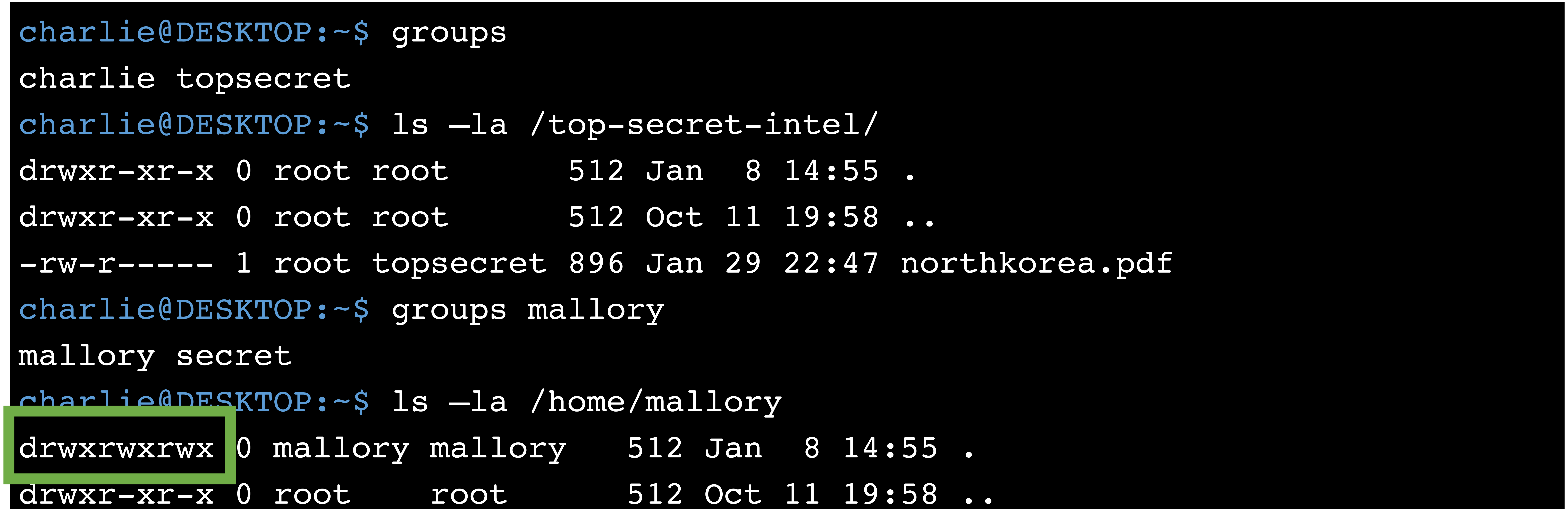

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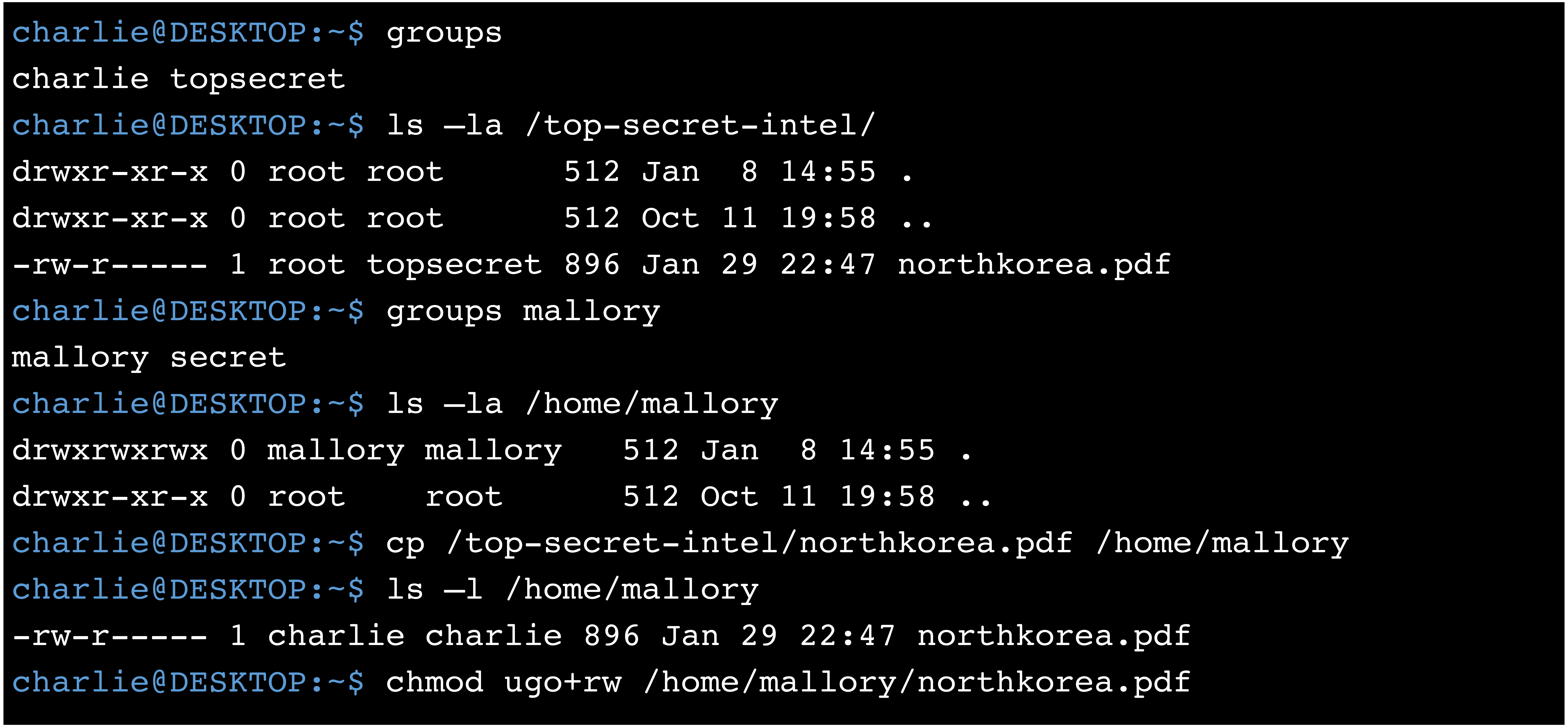

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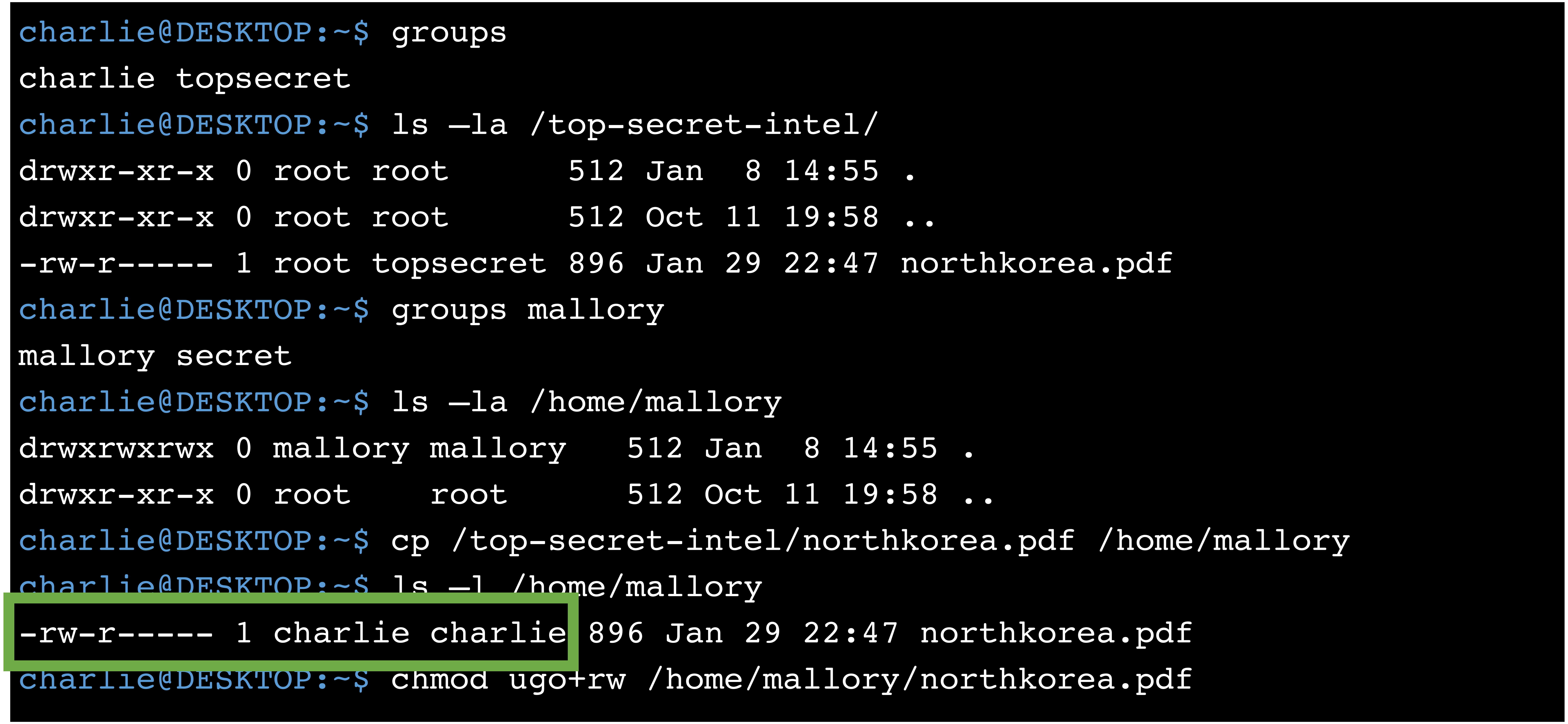

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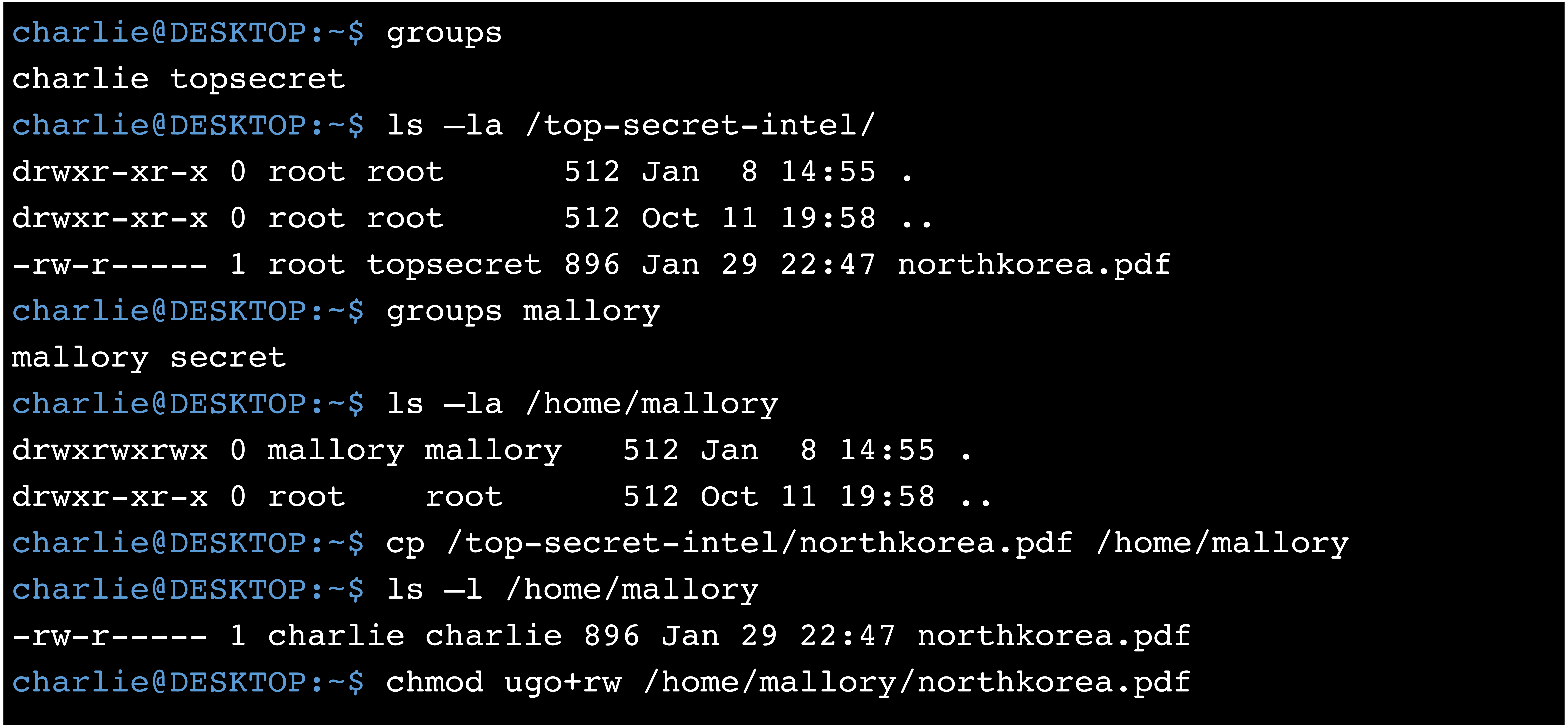

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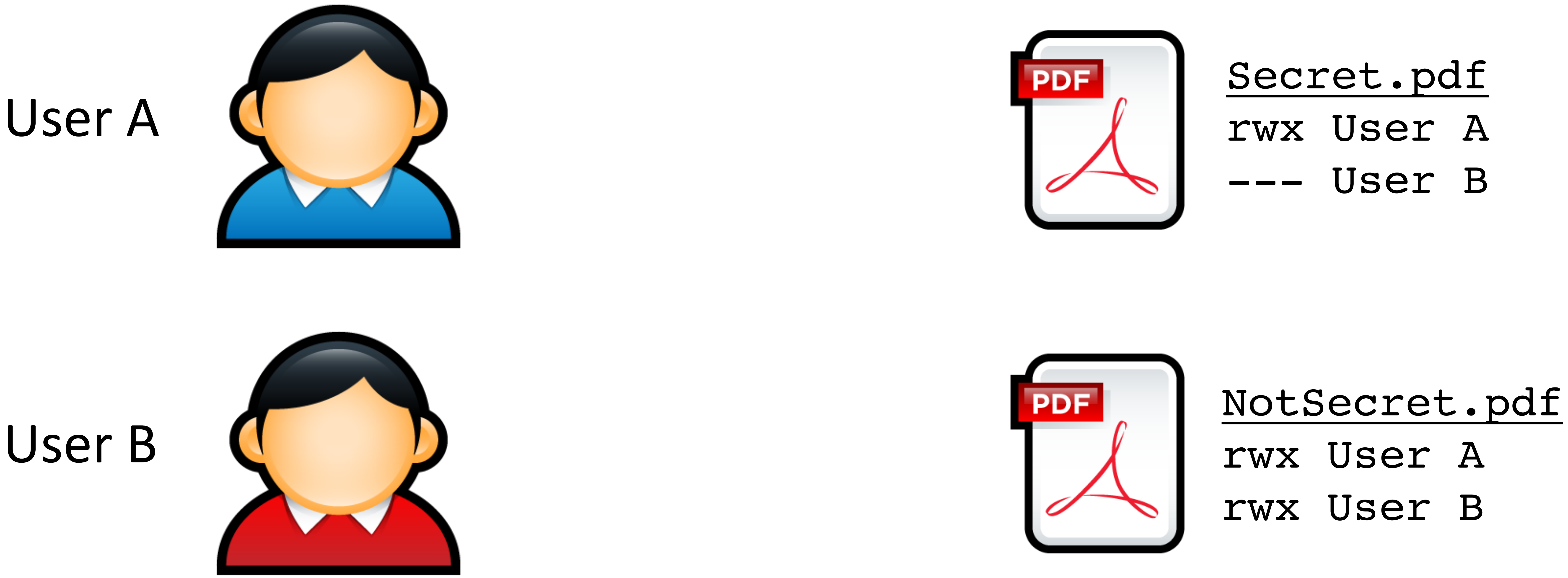
Failure of DAC

- DAC cannot prevent the leaking of secrets



User A

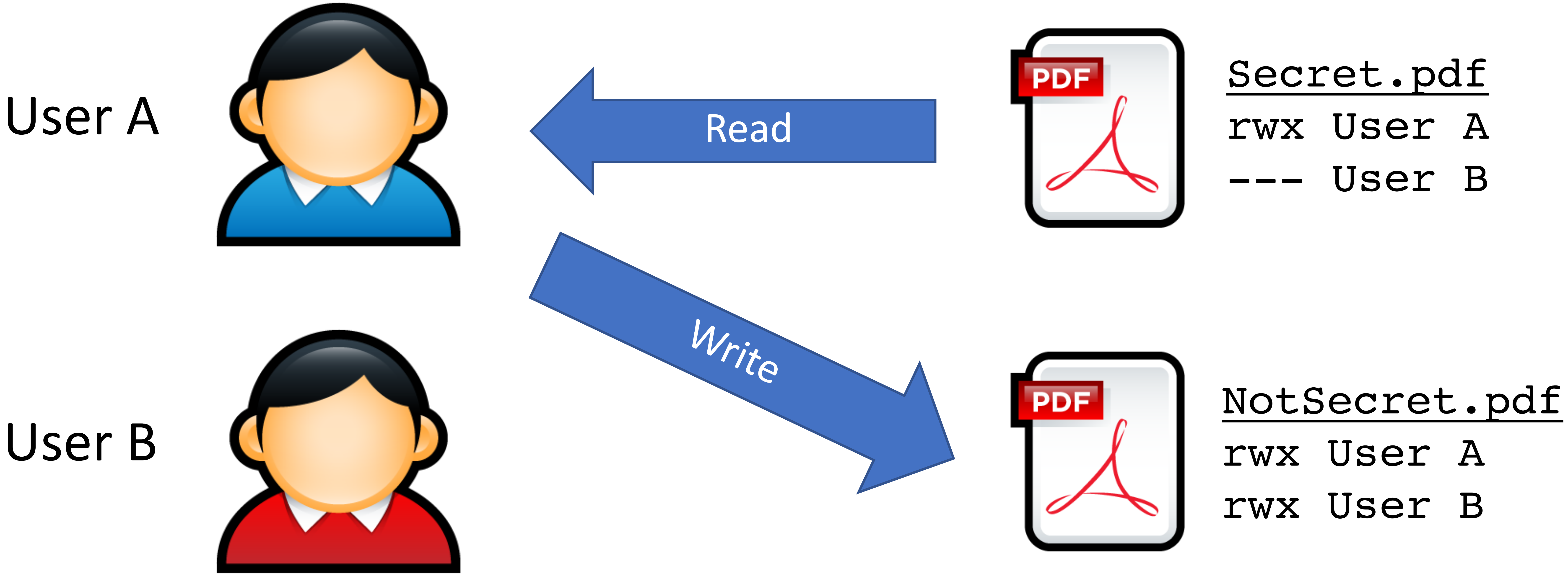
User B

<u>Secret.pdf</u>
```
rwx User A
--- User B
```

<u>NotSecret.pdf</u>
```
rwx User A
rwx User B
```

Failure of DAC

- DAC cannot prevent the leaking of secrets



User A

Read

Write

User B

<u>Secret.pdf</u>
rwx User A
--- User B

<u>NotSecret.pdf</u>
rwx User A
rwx User B

Failure of DAC

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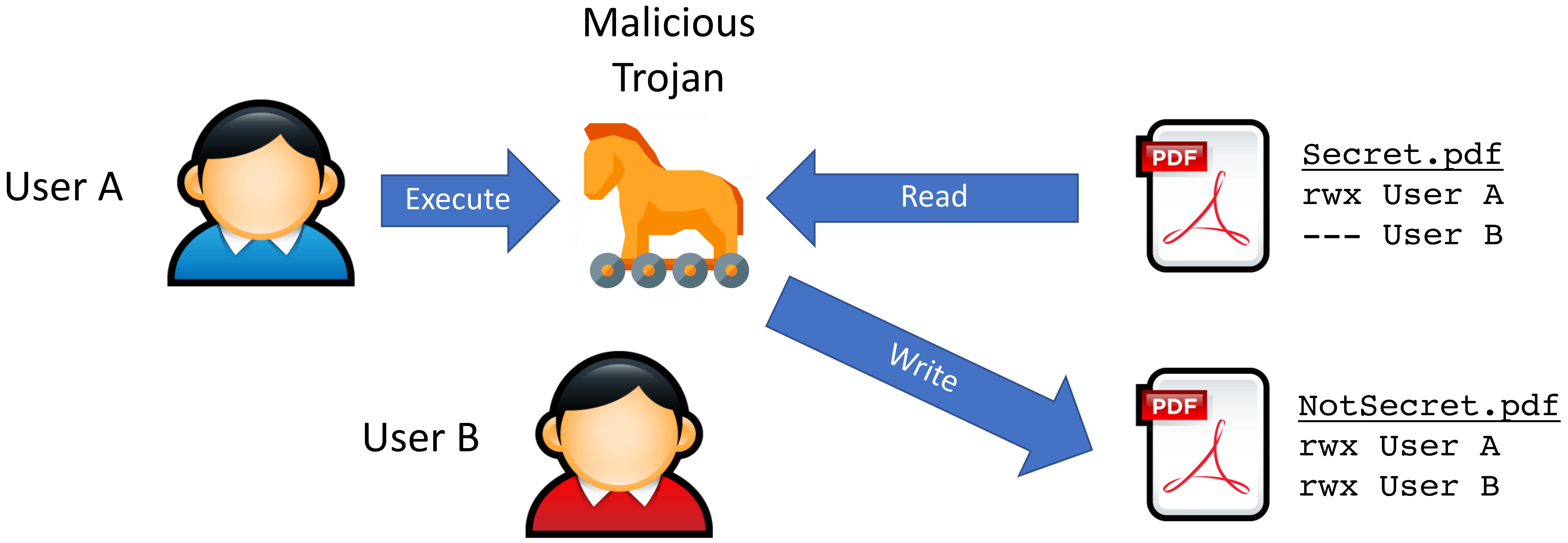


Mandatory Access Control

Mandatory Access Control Goals

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

Bell-Lapadula (1973)

“No read , no write ”

System Model:

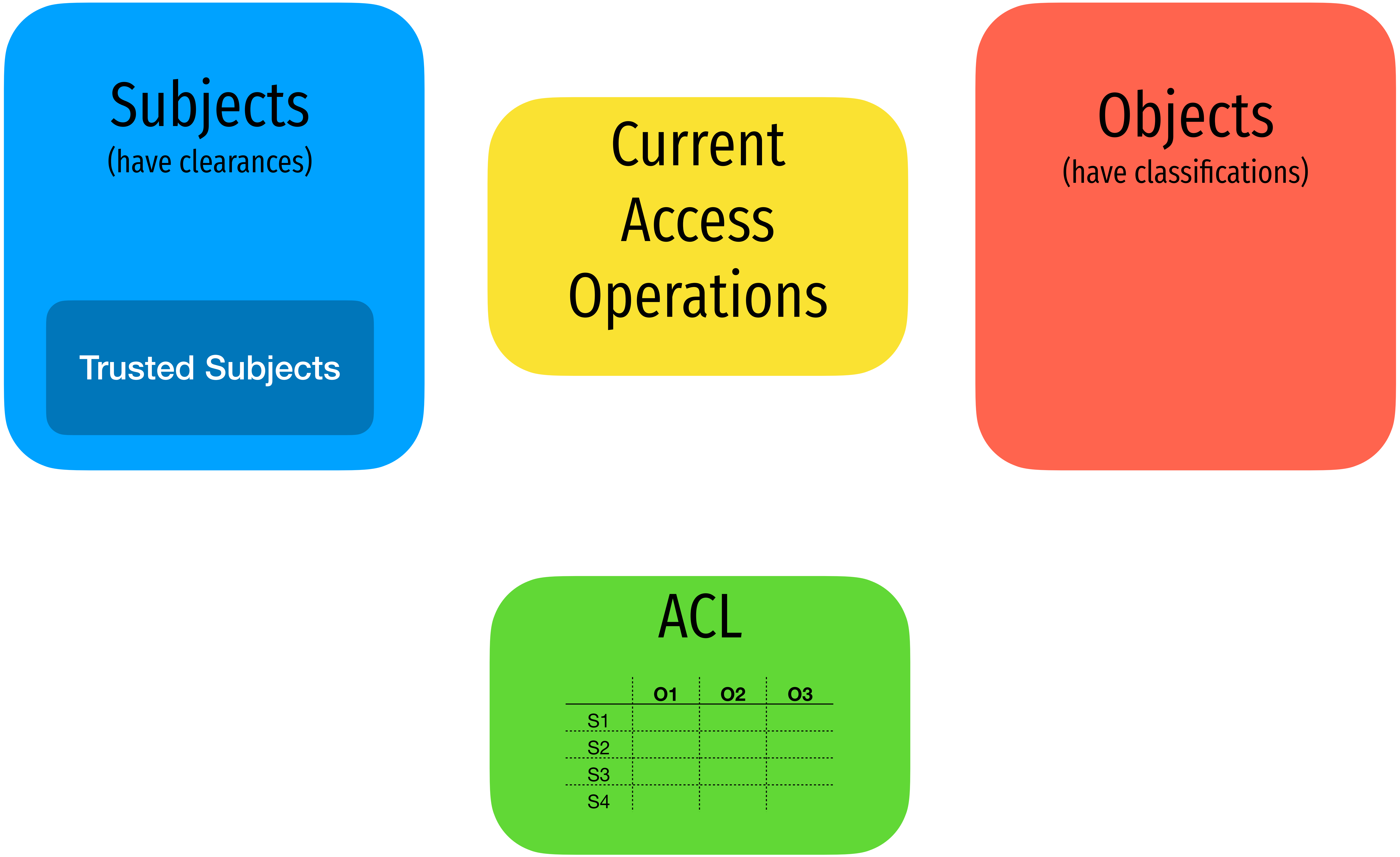
Security Policy:

BLP System Model

Clearances:

Classifications:

BLP System State



Subjects
(have clearances)

Trusted Subjects

Current Access Operations

Objects
(have classifications)

ACL

	O1	O2	O3
S1			
S2			
S3			
S4			

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

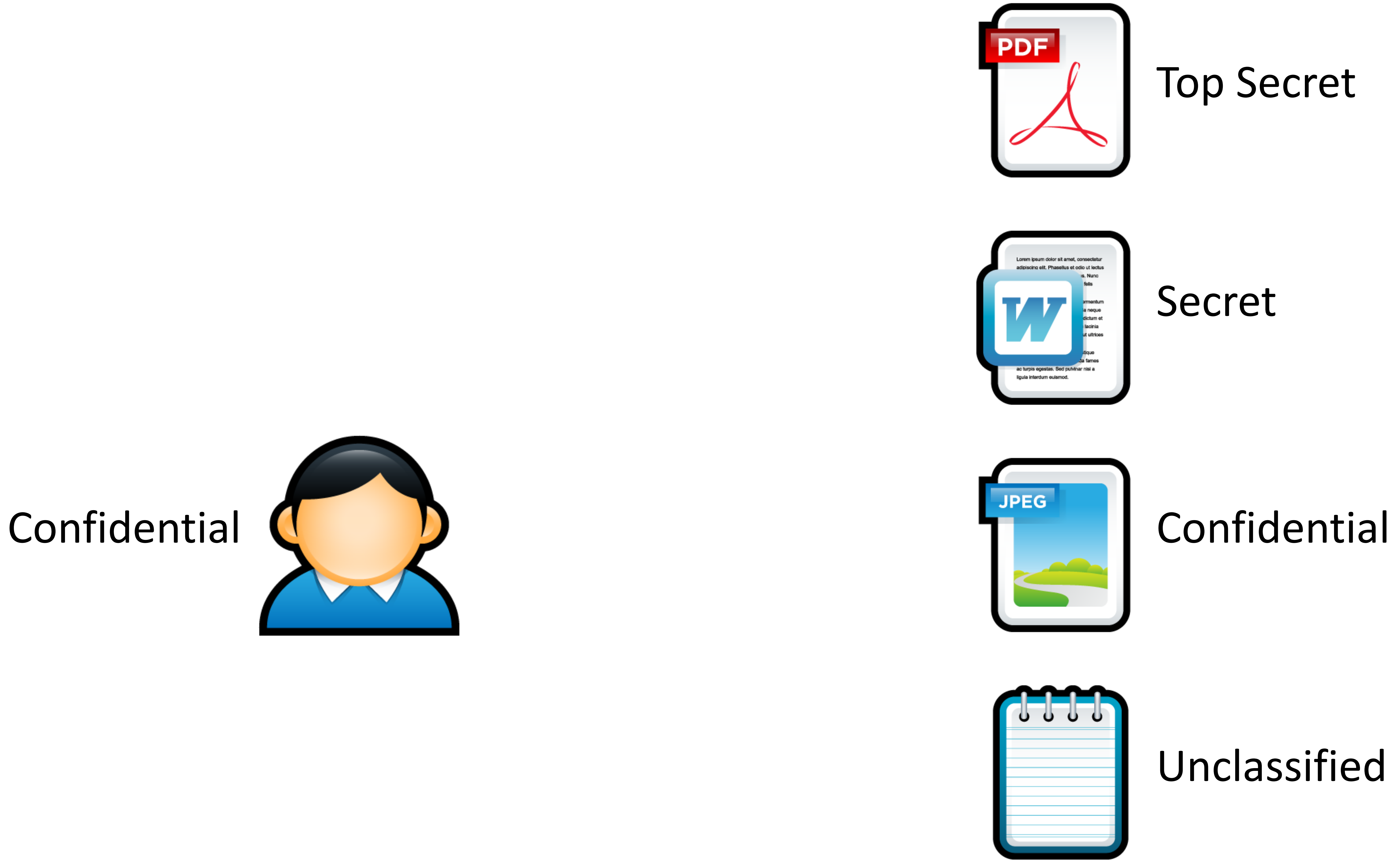
Secret

Confidential

Unclassified

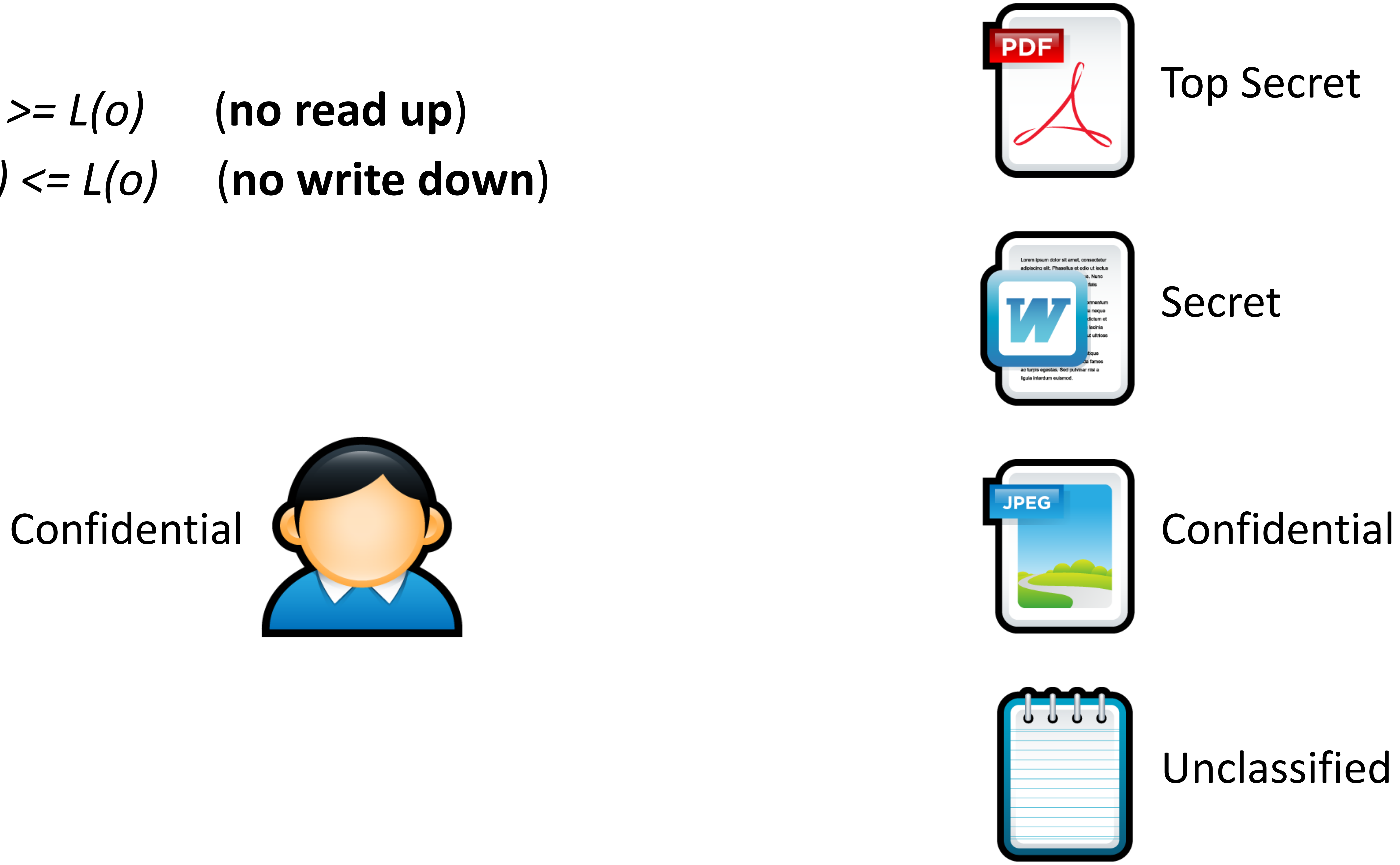
Simplified Bell-LaPadula Example

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



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**)



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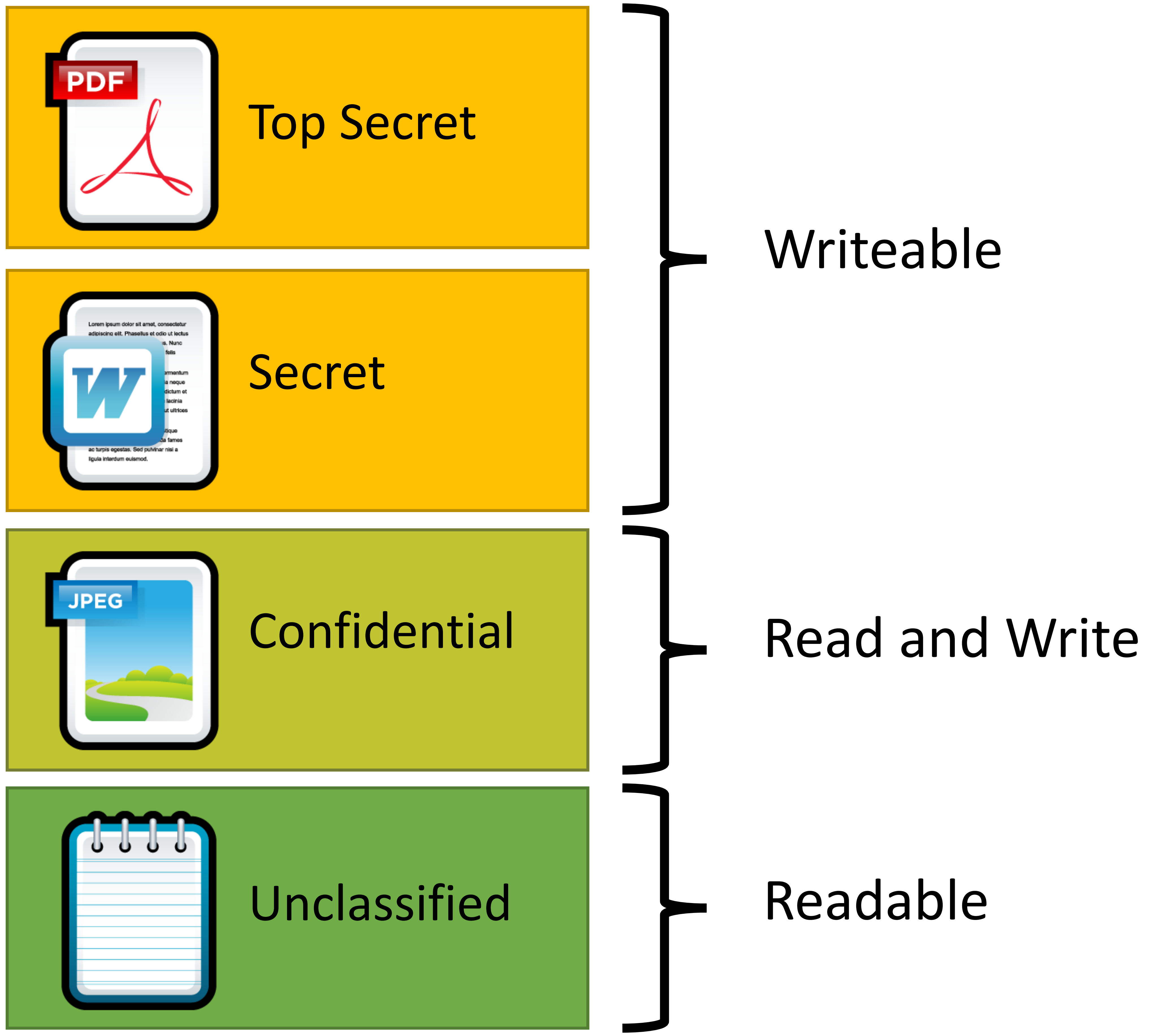

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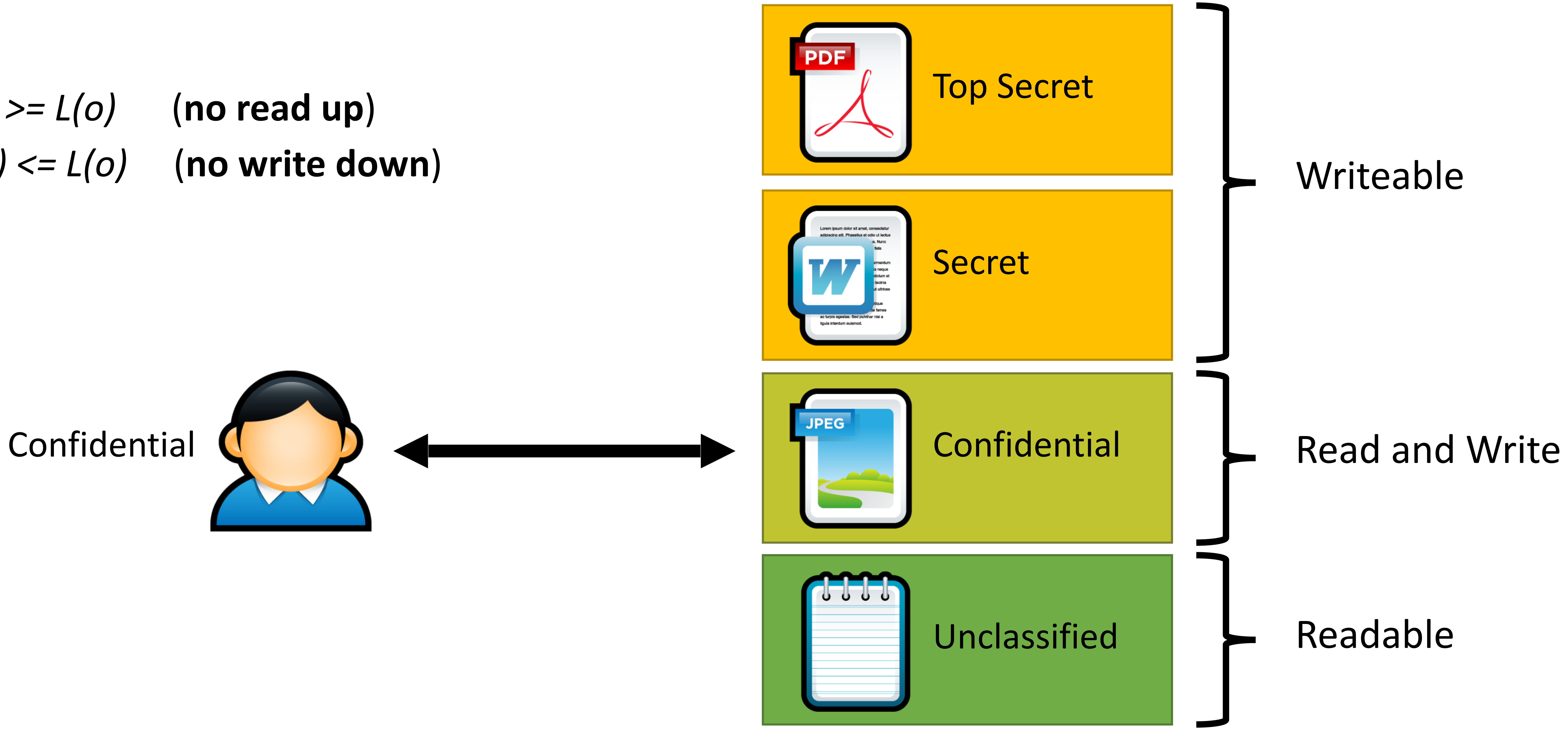

Confidential

Top Secret

Secret

Confidential

Unclassified

Writeable

Read and Write

Readable

Simplified Bell-LaPadula Example

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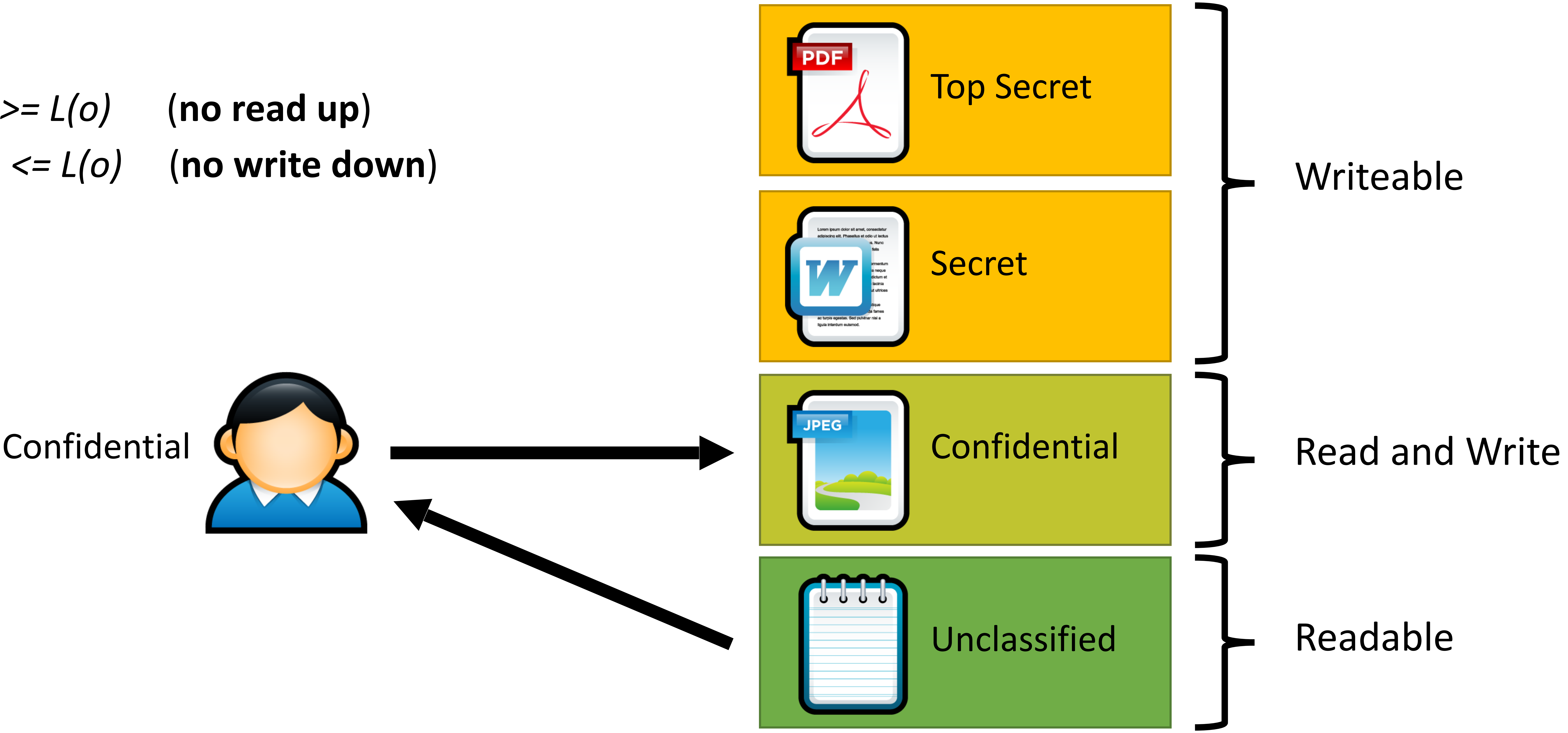

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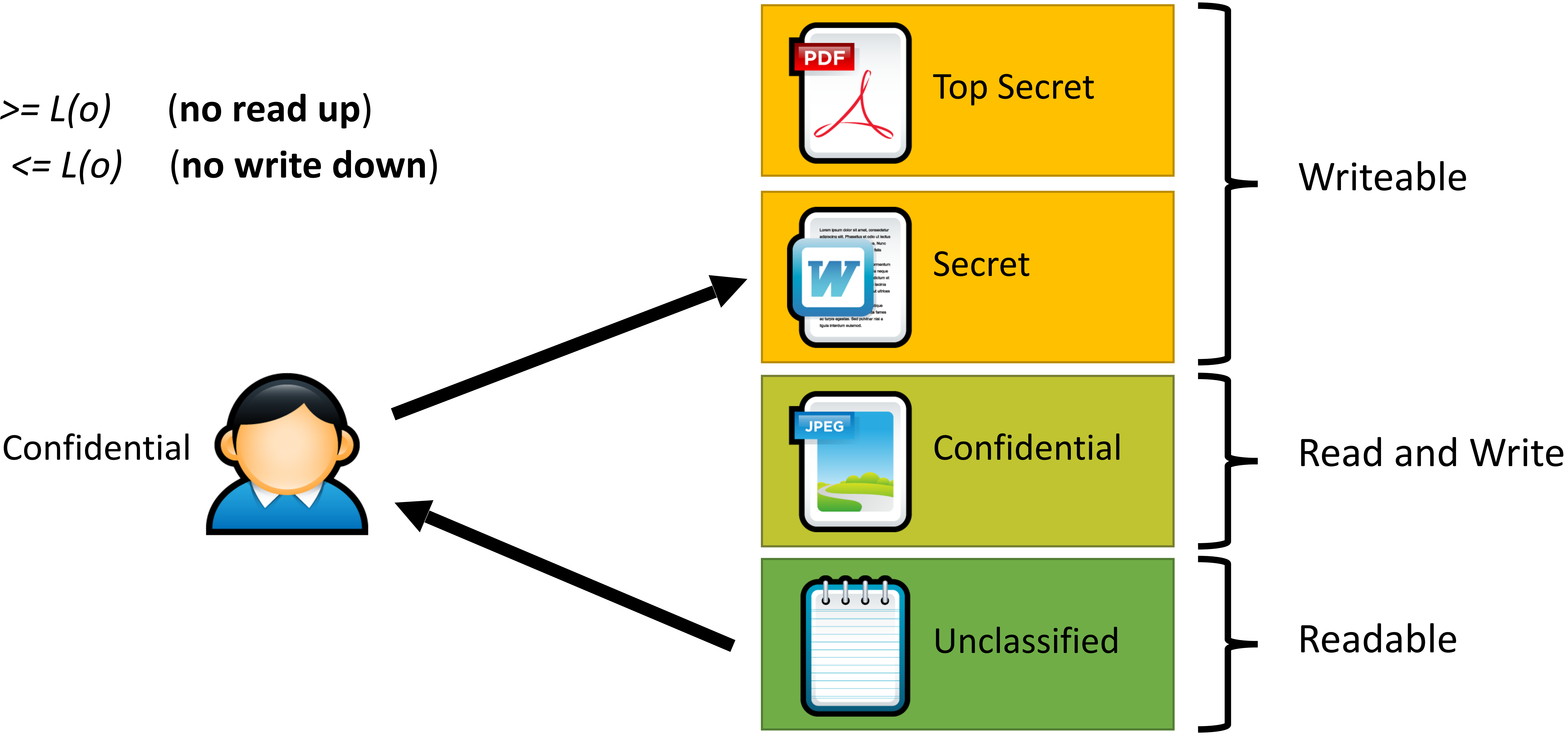


BLP Idea

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:

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

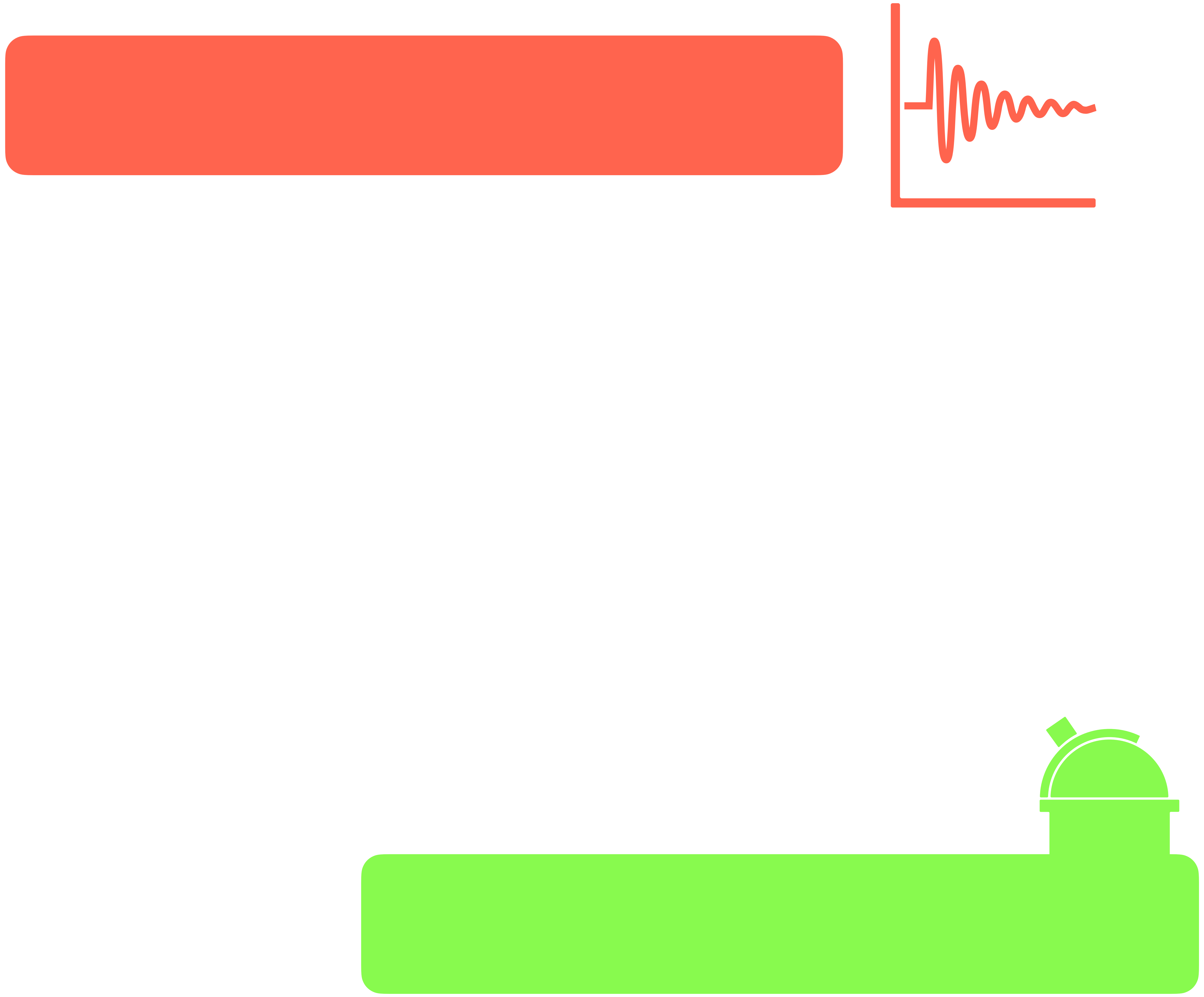
Subjects are not trusted. (Malware)

Not Enough

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

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

Not Enough: Covert channels

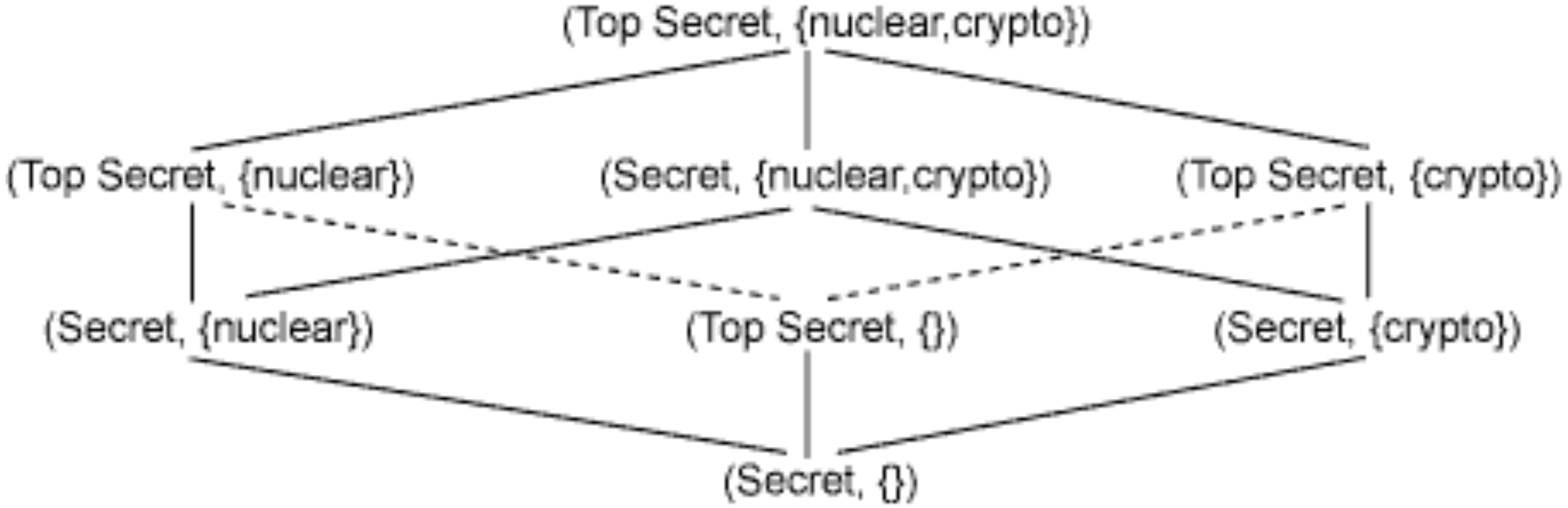


Security Lattice

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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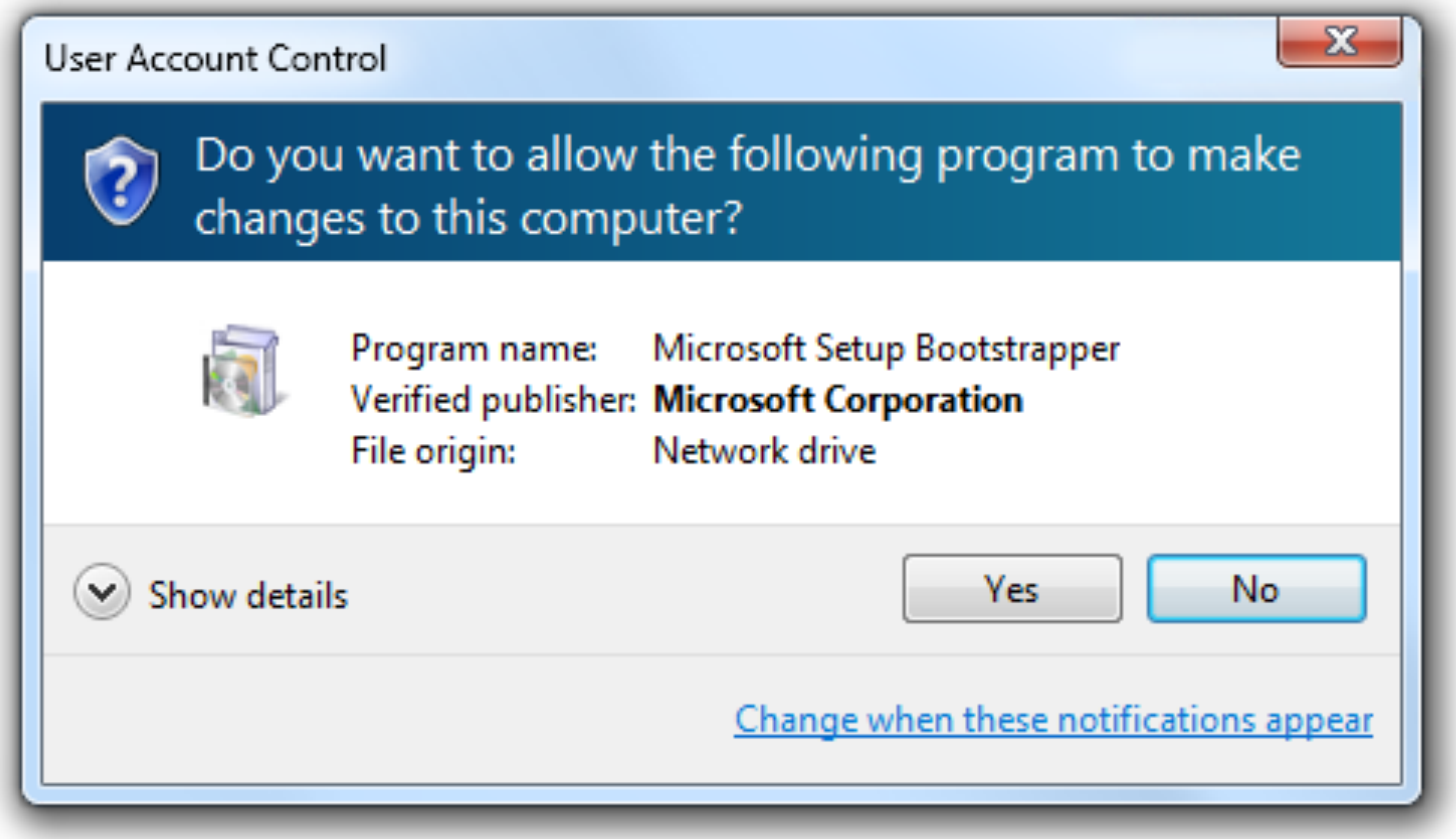

User Account Control

Do you want to allow the following program to make changes to this computer?

Program name: Microsoft Setup Bootstrapper
Verified publisher: **Microsoft Corporation**
File origin: Network drive

Hybrid

SELinux, TrustedBSD: MAC + DAC system

Confidentiality? What else?

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**)
   - *s* can write *o* iff *i(s) >= i(o)* (**no write up**)

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2. Subject low-water mark
   - *s* can always read *o*; afterward *i(s) = min(i(s), i(o))* (**subject tainting**)
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3. Object low-water mark
   - s can read o iif $i(s) <= i(o)$ (**no read down**)
   - s can always write o; afterward $o(s) = min(i(s), i(o))$ (**object tainting**)

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4. Low-water mark integrity audit
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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

- Strict integrity
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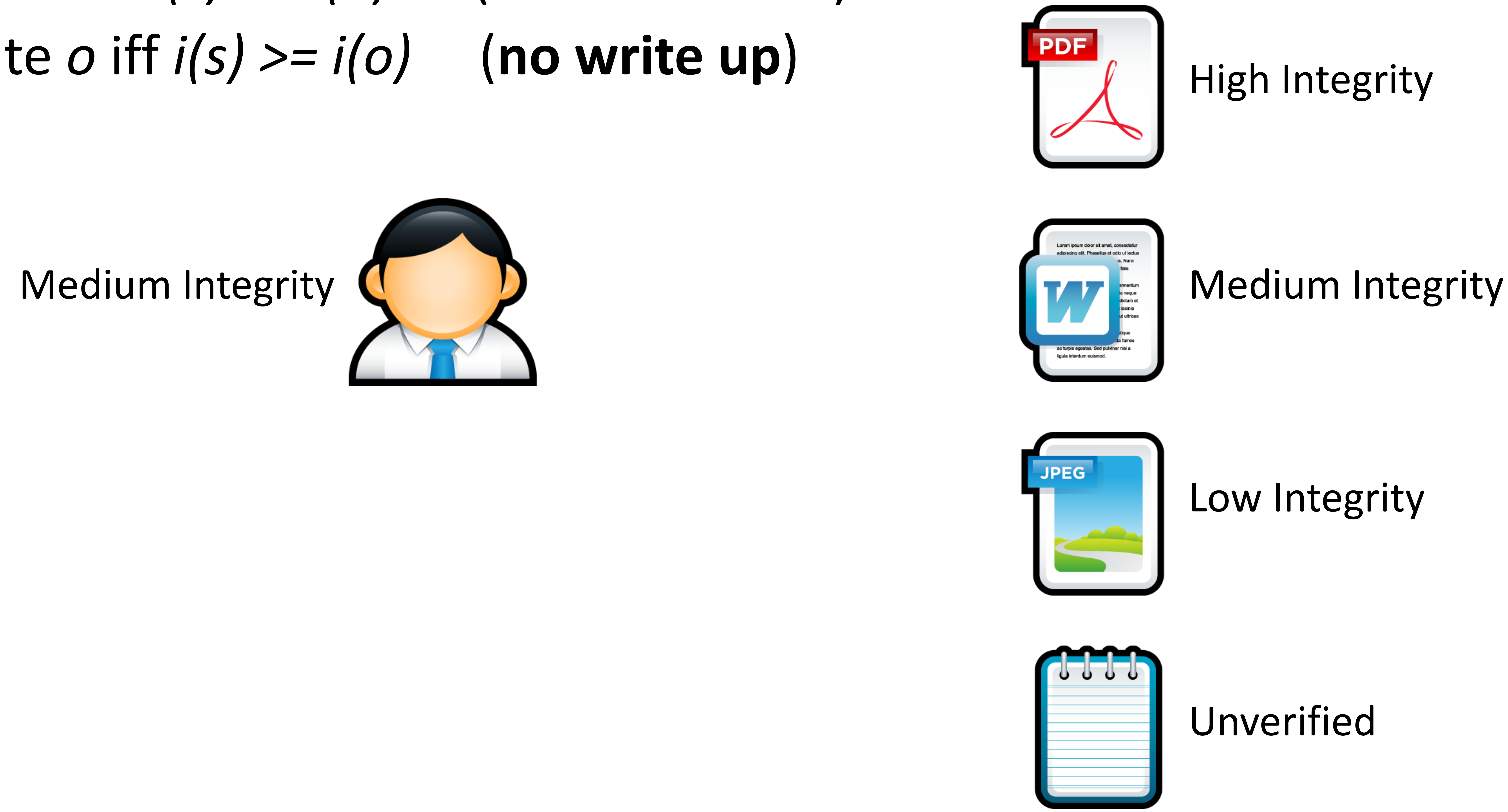

Medium Integrity

High Integrity

Medium Integrity

Low Integrity

Unverified

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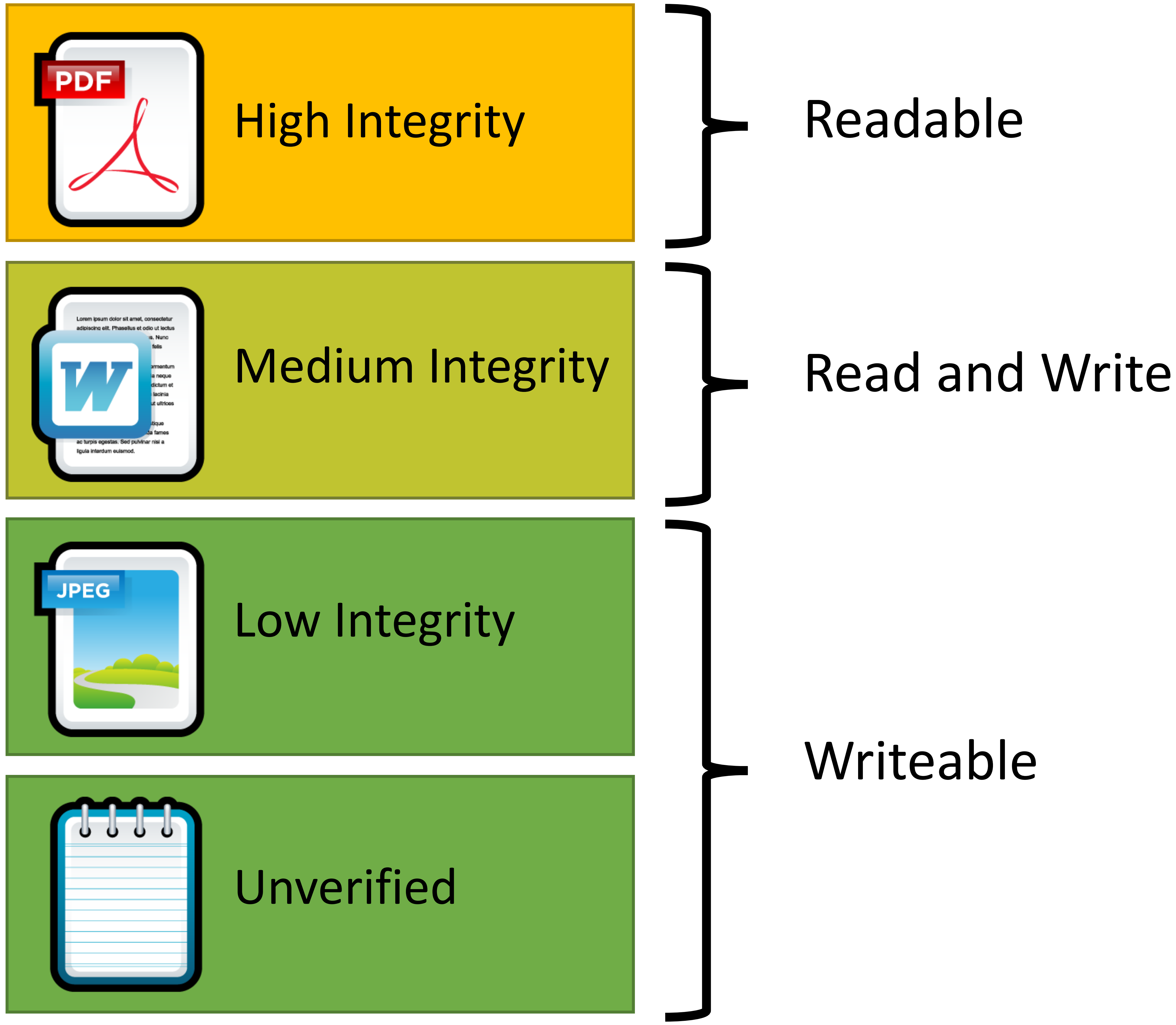

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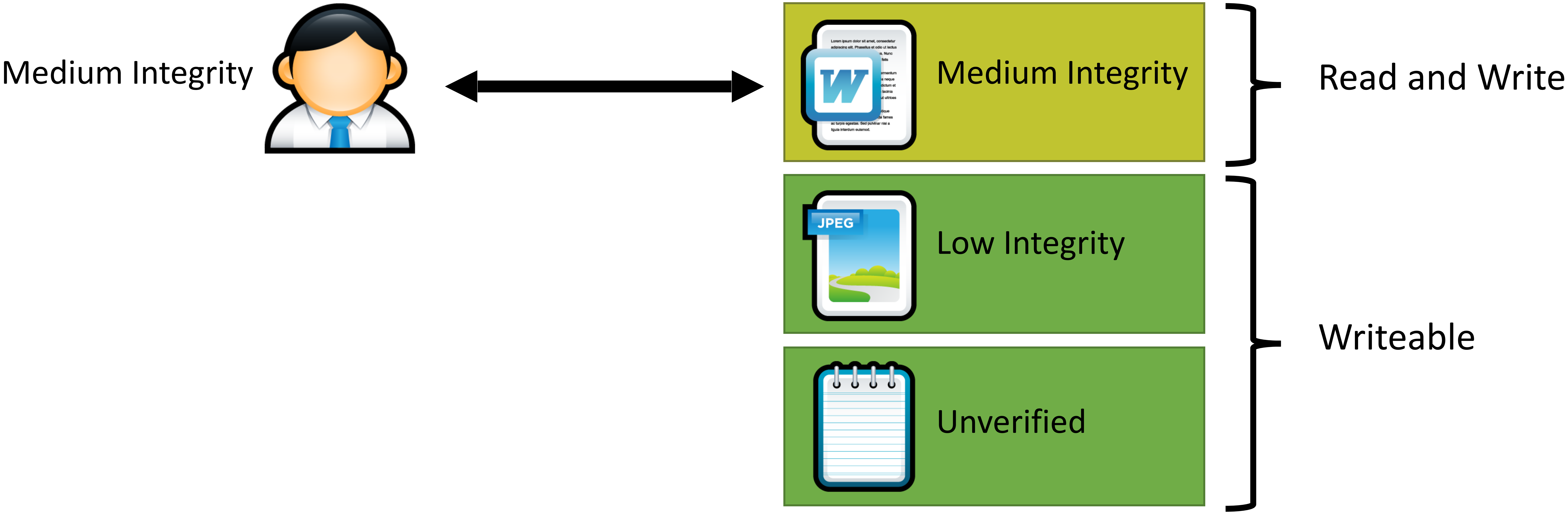

Medium Integrity

High Integrity

Medium Integrity

Low Integrity

Unverified

Readable

Read and Write

Writeable

Biba Strict Integrity Example

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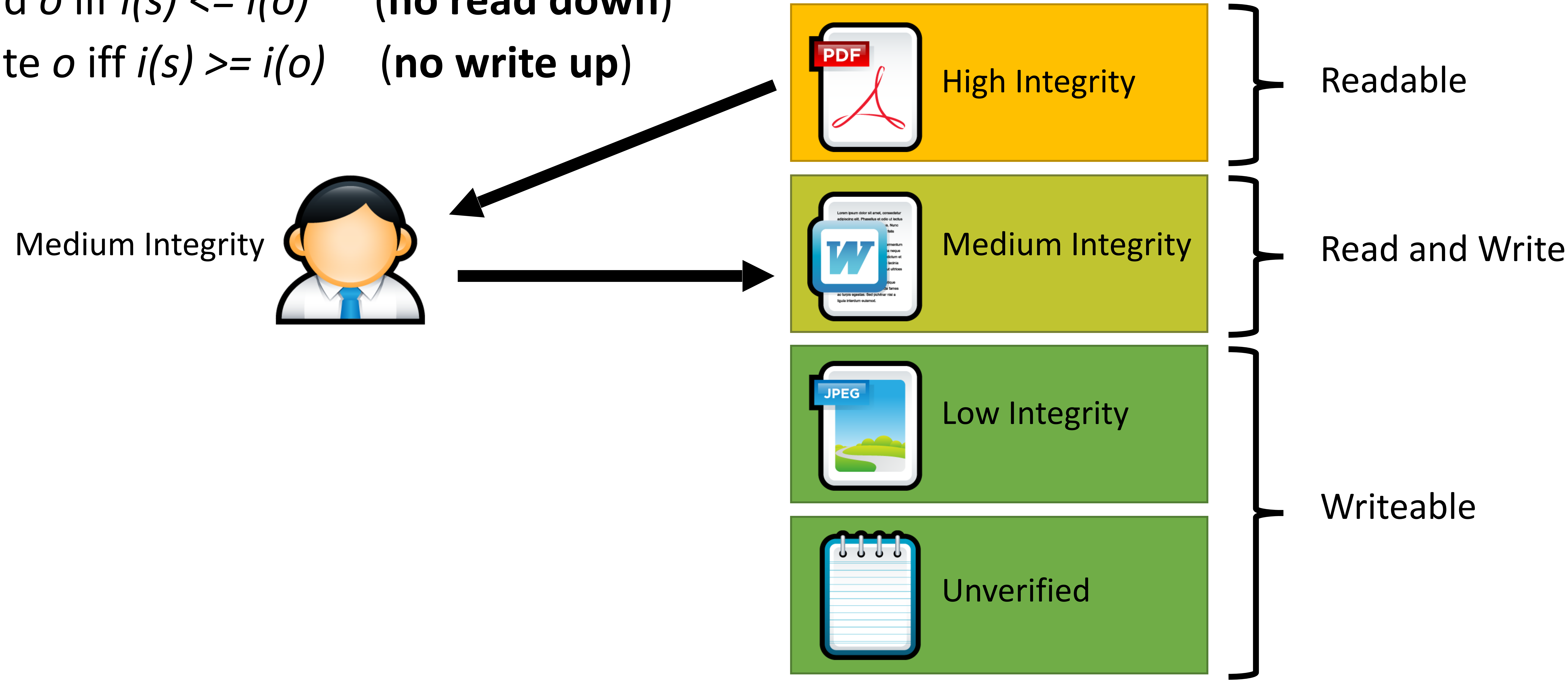

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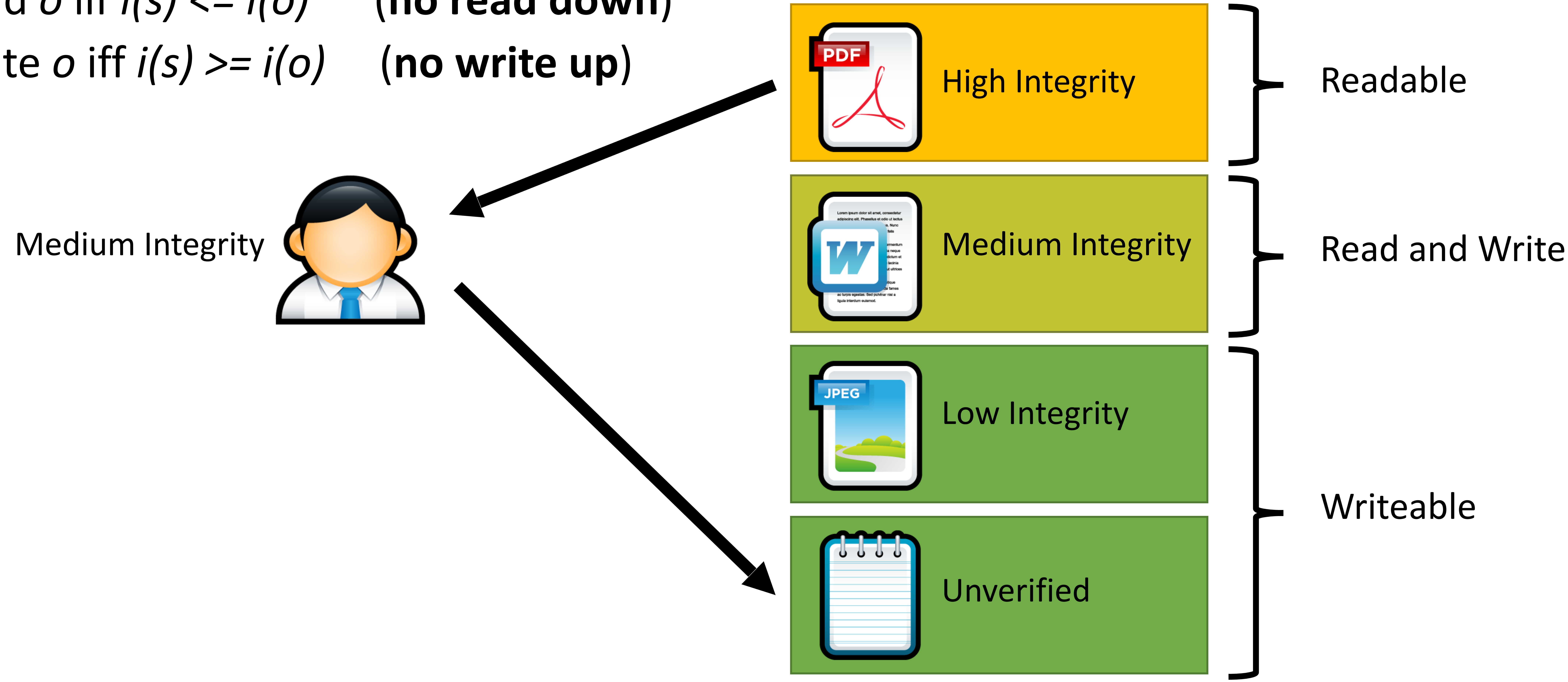

Practical Example of Biba Integrity

- 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

- Offers confidentiality
- “Read down, write up”
- Focuses on controlling reads
- Theoretically, no requirement that subjects be trusted
  - Even malicious programs can’t leak secrets they don’t know

Biba

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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

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

Covert Channels

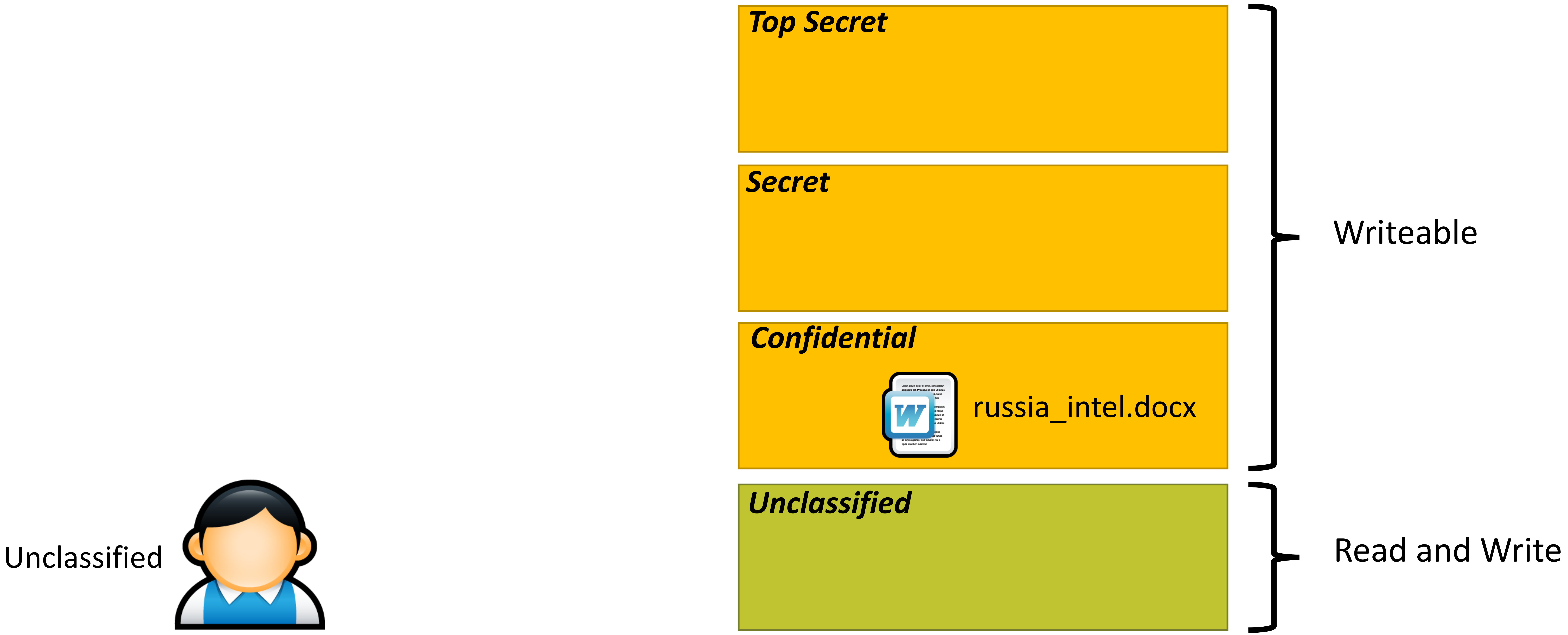
- Access control is defined over “legitimate” channels
  - Read/write an object
  - Send/receive a packet from the network
  - Read/write shared memory
- However, isolation in real systems is imperfect
  - Actions have observable side-effects

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

Bell-LaPadula MAC



Unclassified

Top Secret

Secret

Confidential

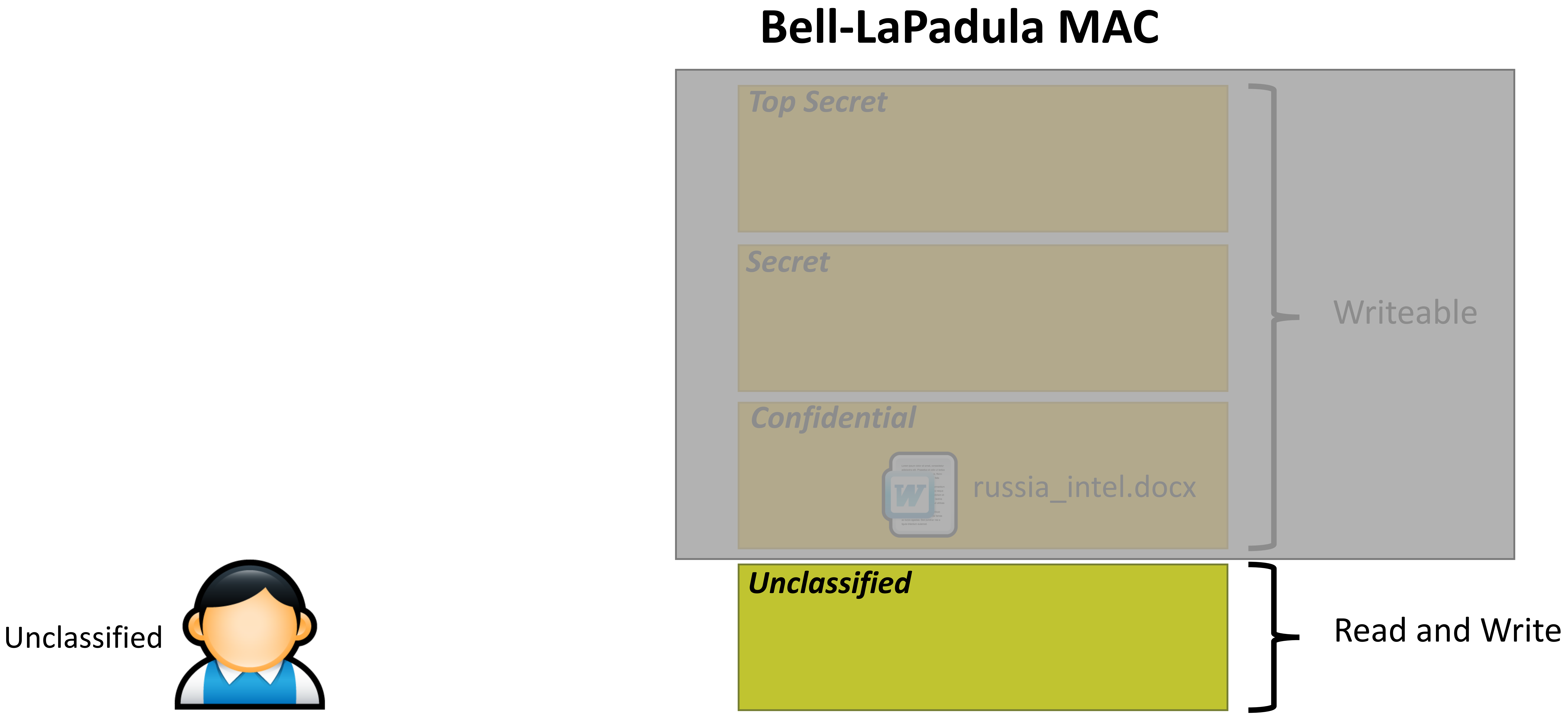
russia_intel.docx

Unclassified

Writeable

Read and Write

Simple Example



Bell-LaPadula MAC

Top Secret

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Confidential

russia_intel.docx

Writeable

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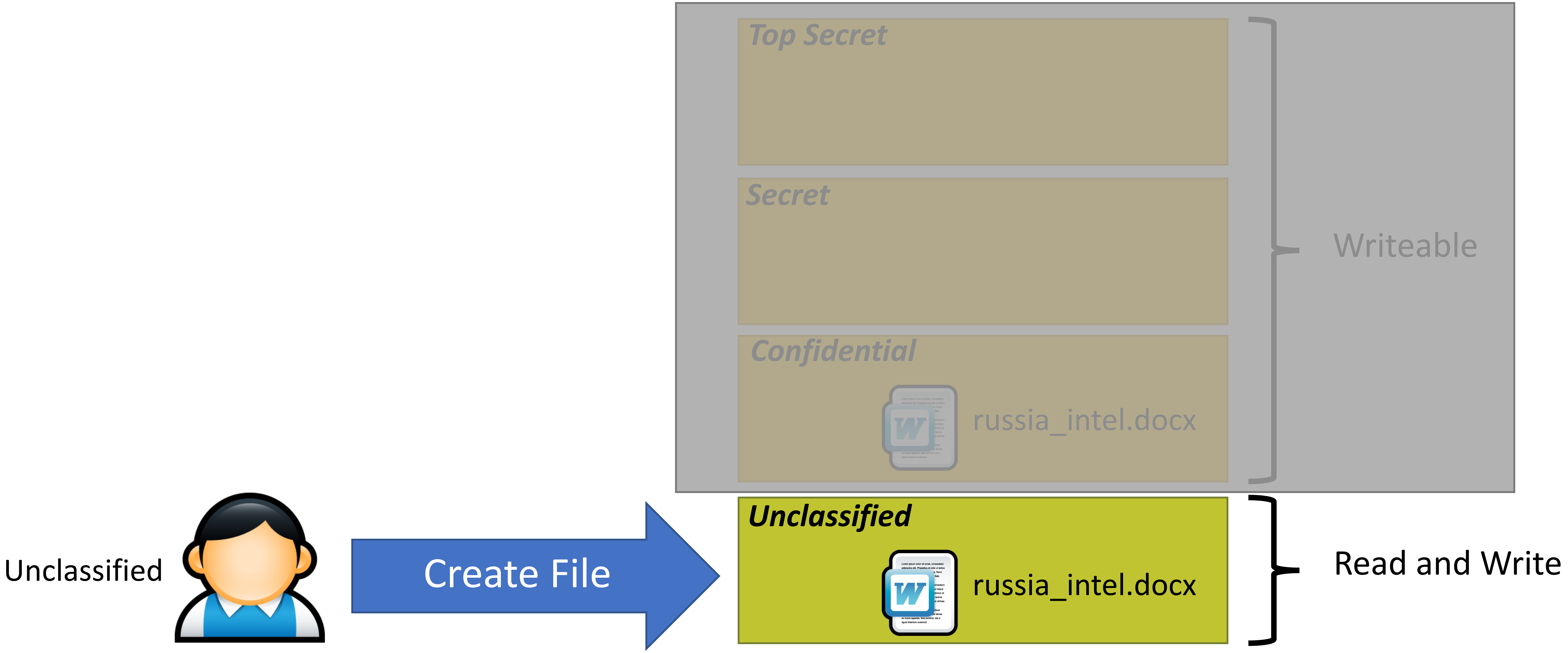
Simple Example

Bell-LaPadula MAC



Top Secret

Secret

Confidential

russia_intel.docx

Writeable

Unclassified

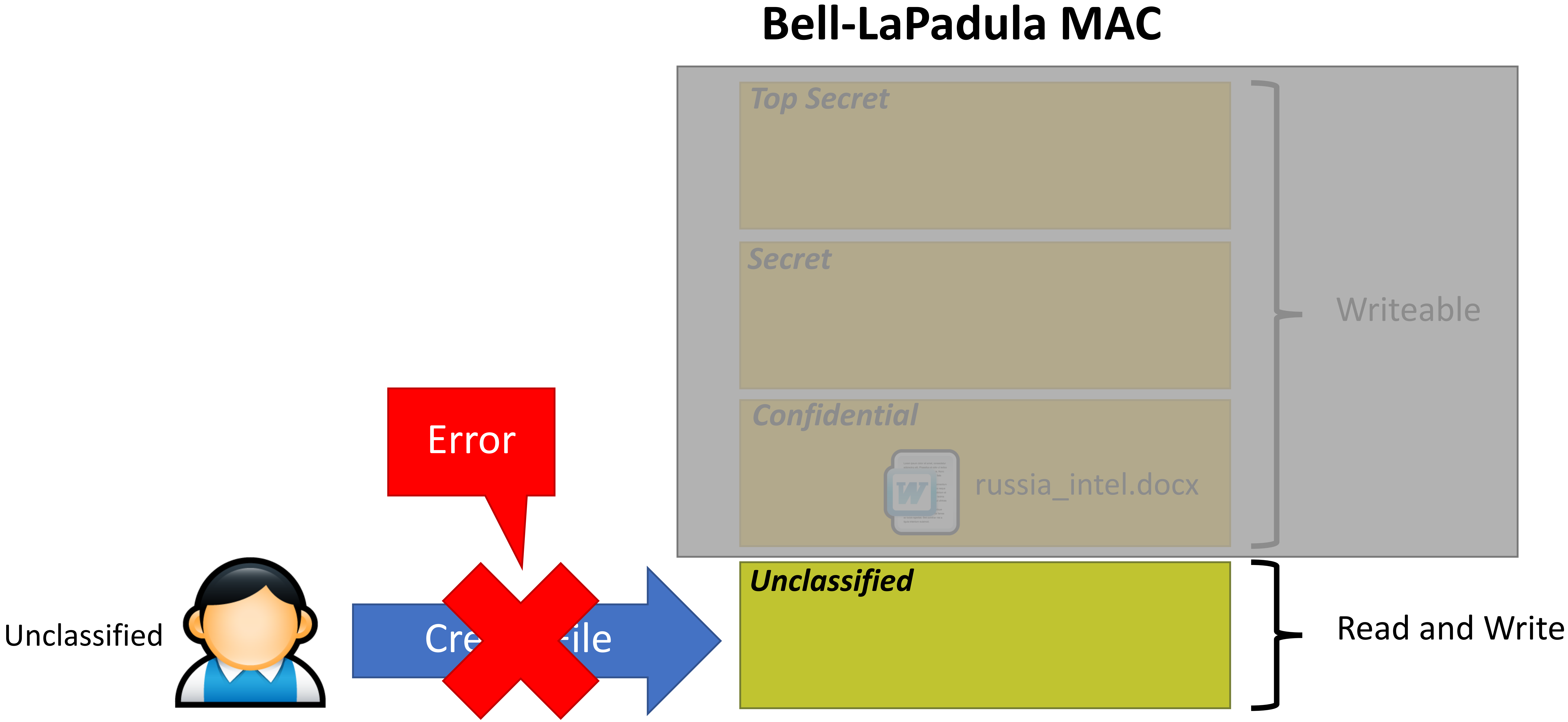
Create File

Unclassified

russia_intel.docx

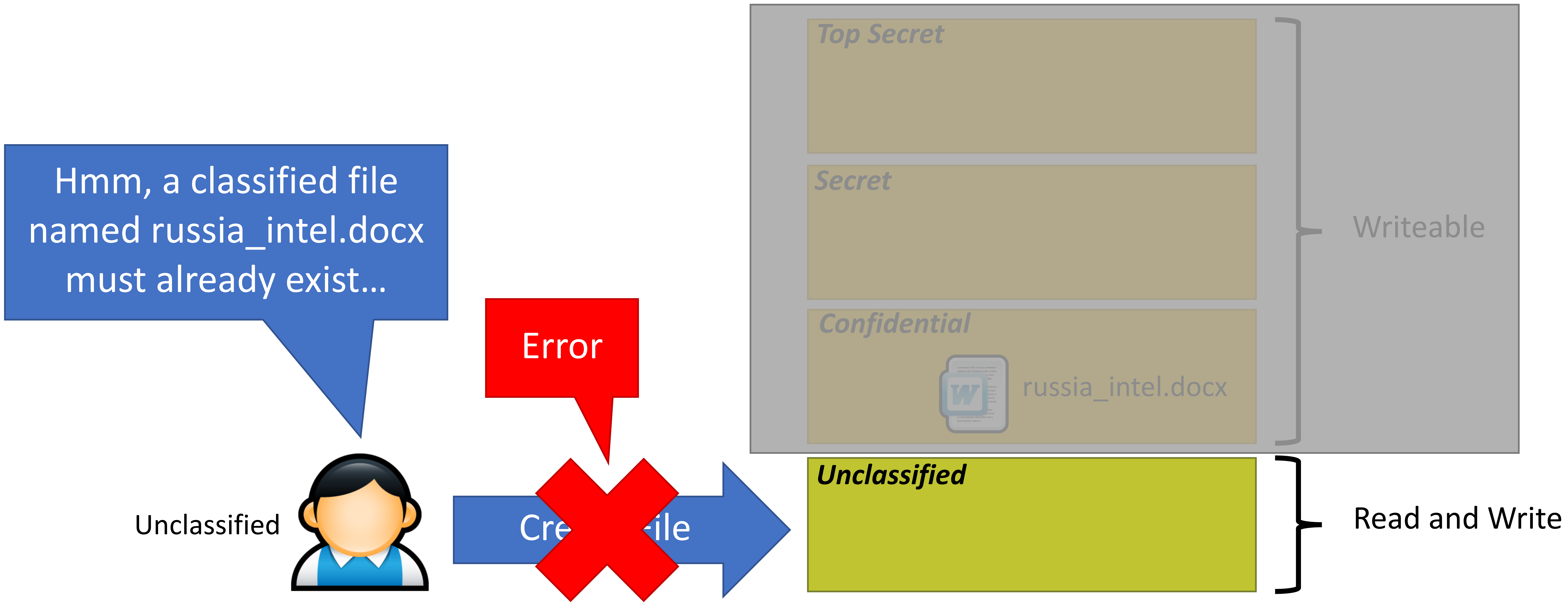
Read and Write

Simple Example



Simple Example

Bell-LaPadula MAC



Hmm, a classified file named russia_intel.docx must already exist…

Error

Unclassified

Cre File

Top Secret

Secret

Confidential

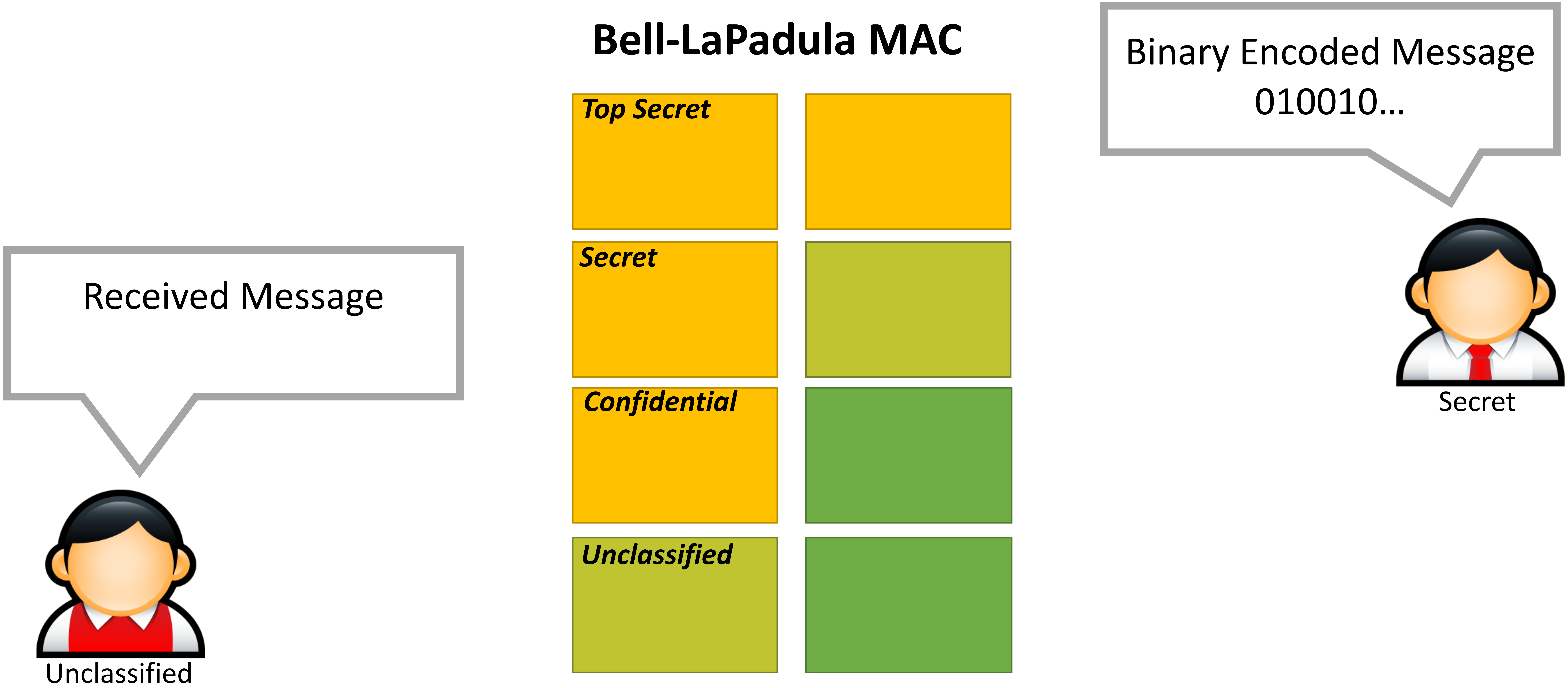
russia_intel.docx

Writeable

Unclassified

Read and Write

Exploiting a Covert Channel



Bell-LaPadula MAC

Top Secret

Secret

Confidential

Unclassified

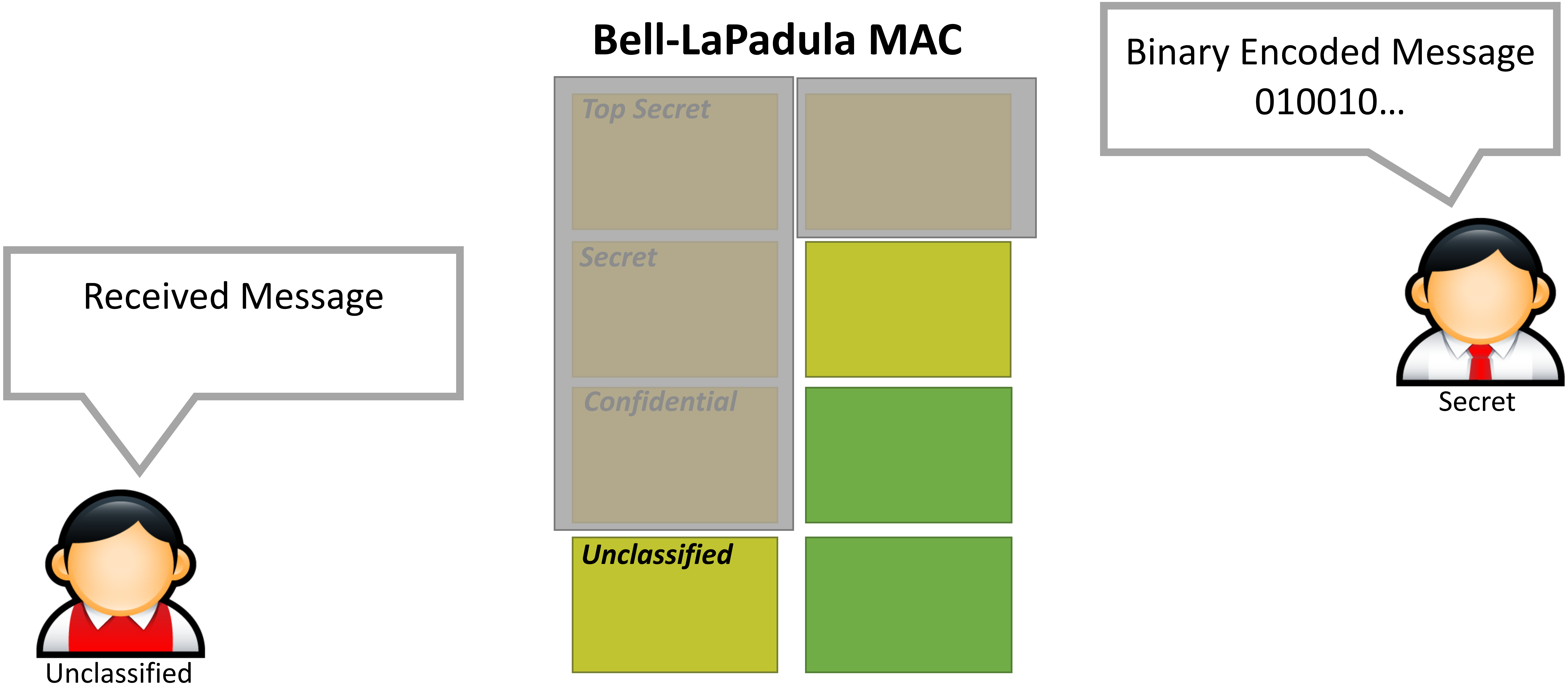
Binary Encoded Message
010010…

Secret

Received Message

Unclassified

Exploiting a Covert Channel

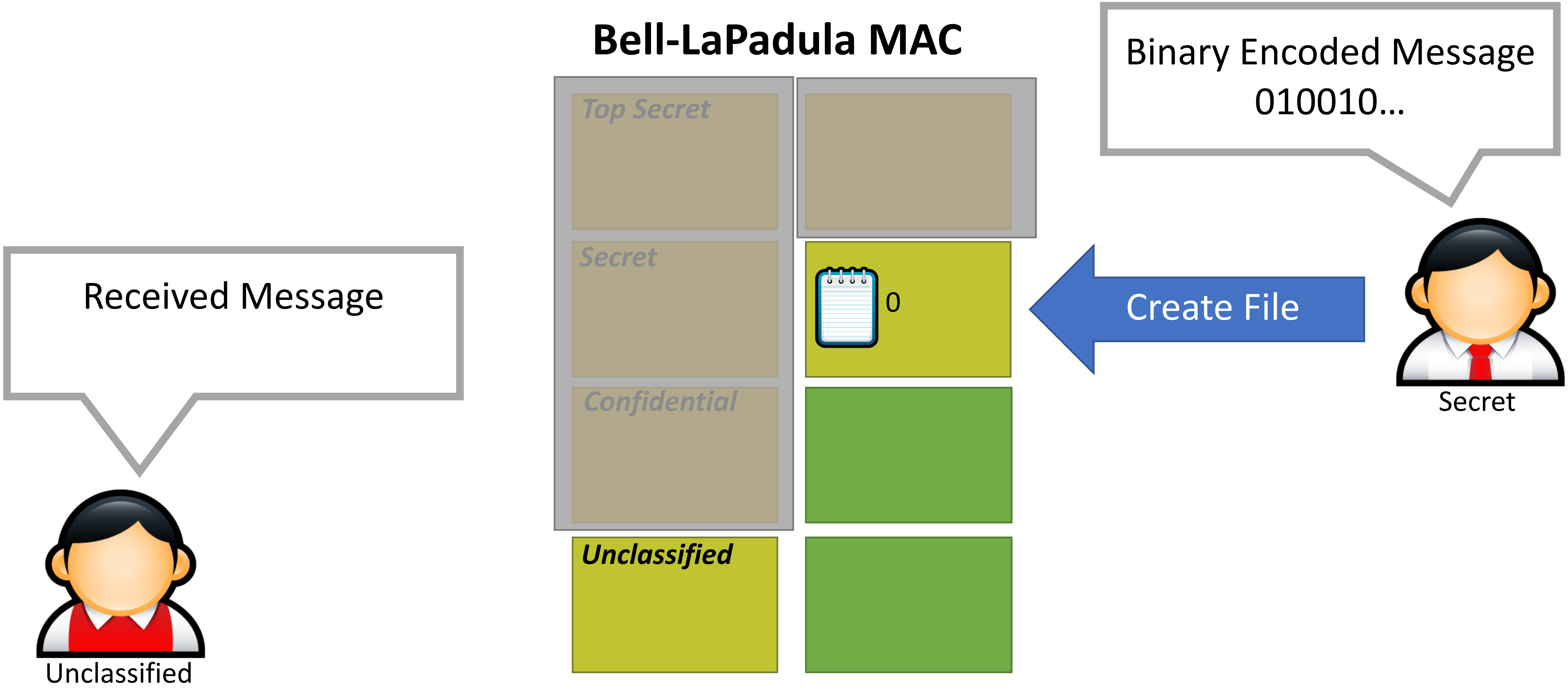


Bell-LaPadula MAC

Received Message

Binary Encoded Message
010010…

Exploiting a Covert Channel



Bell-LaPadula MAC

Top Secret

Secret

Confidential

Unclassified

0

Create File

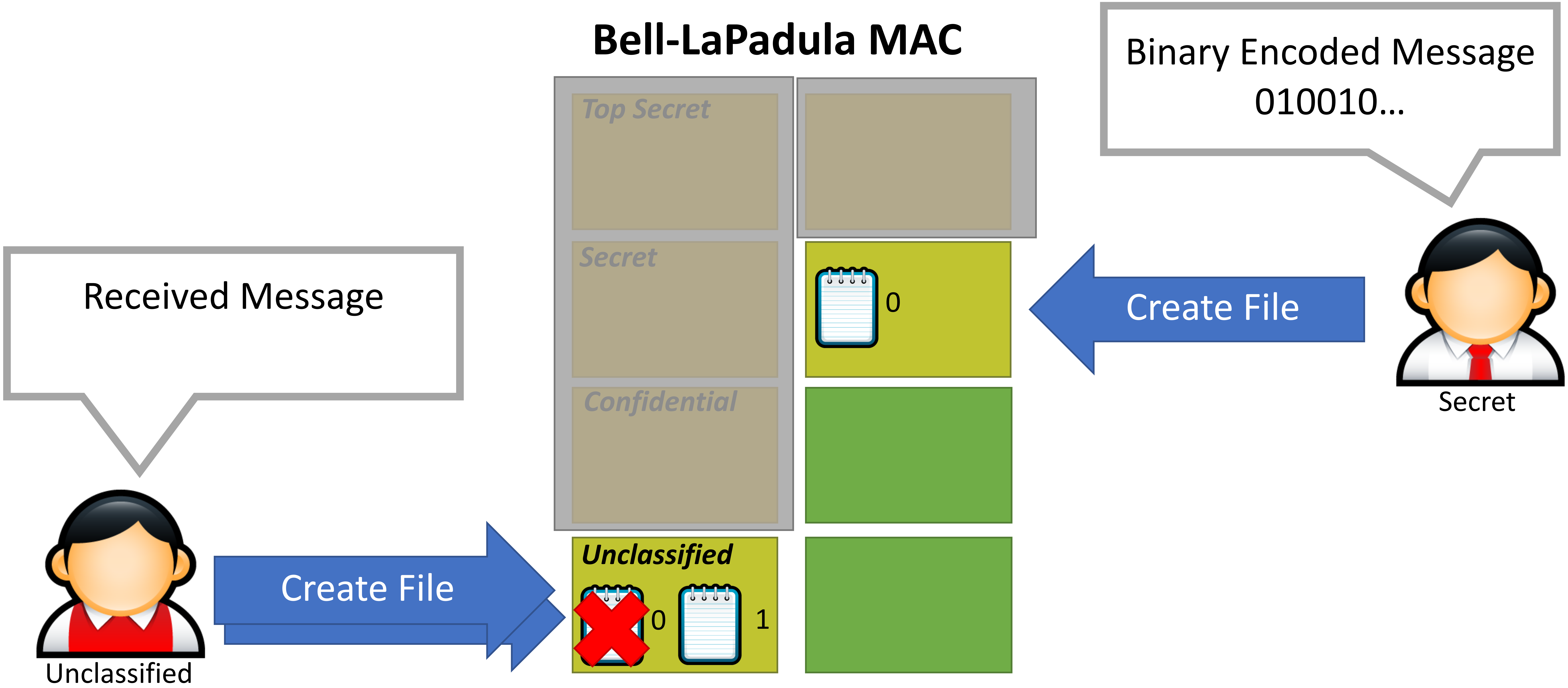
Binary Encoded Message
010010…

Received Message

Secret

Unclassified

Exploiting a Covert Channel



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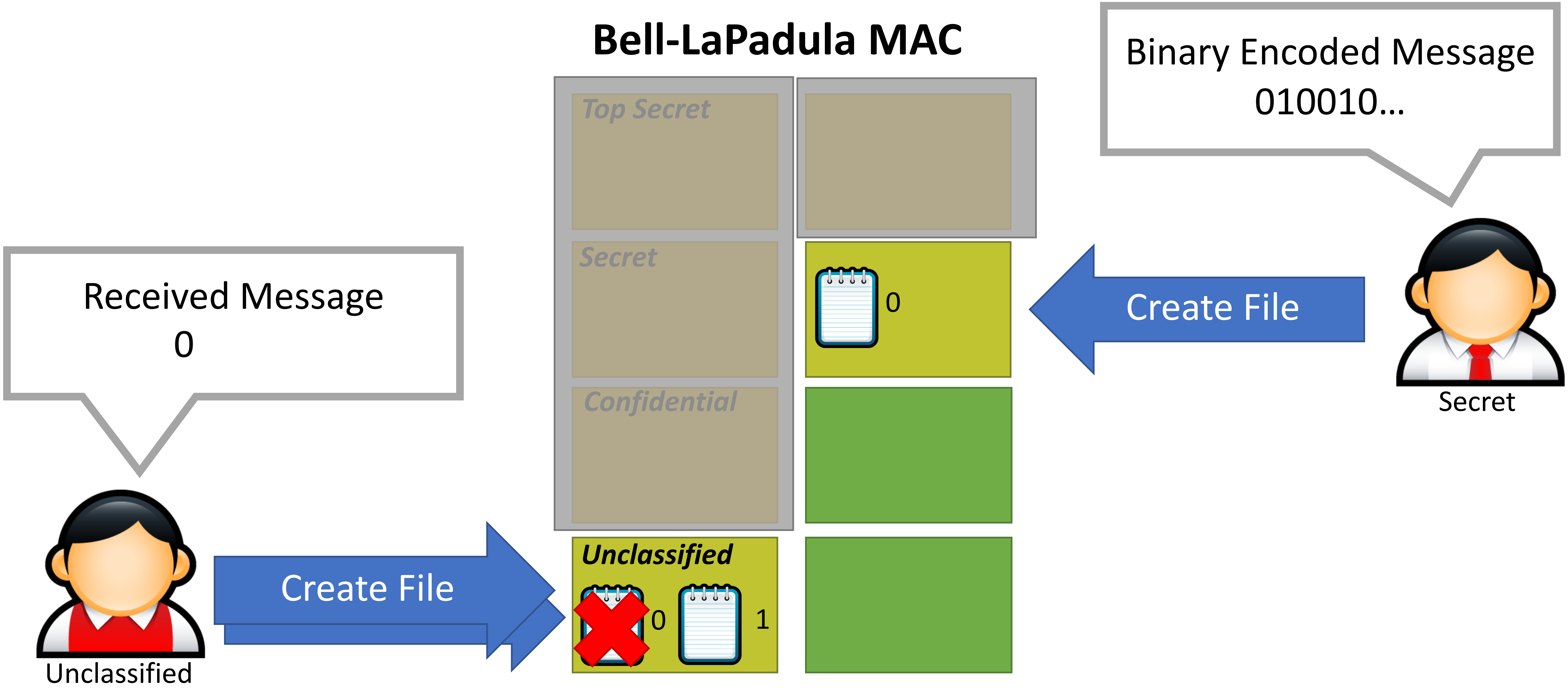
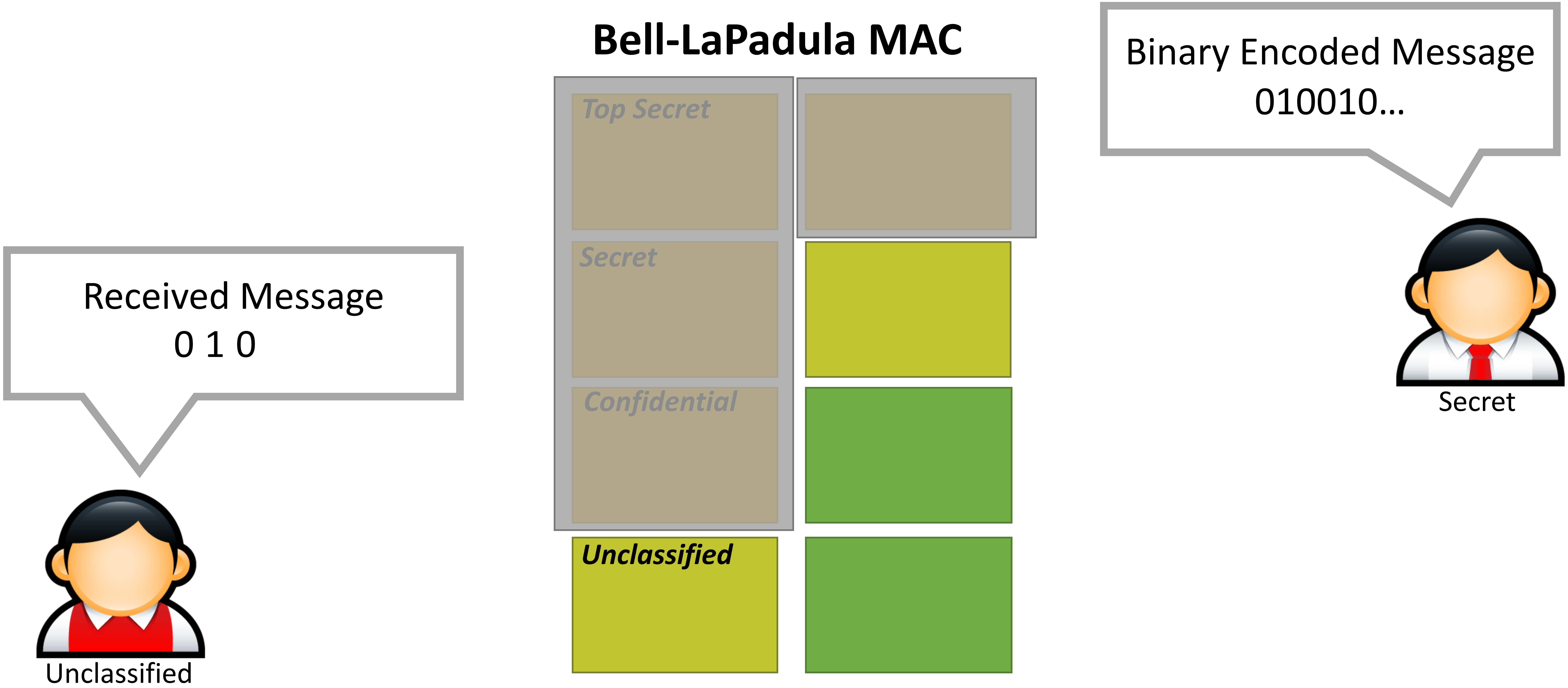


Exploiting a Covert Channel



Bell-LaPadula MAC

Top Secret

Secret

Confidential

Unclassified

Binary Encoded Message
010010…

Secret

Received Message
0 1 0

Unclassified

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)

Bell-LaPadula and Covert Channels

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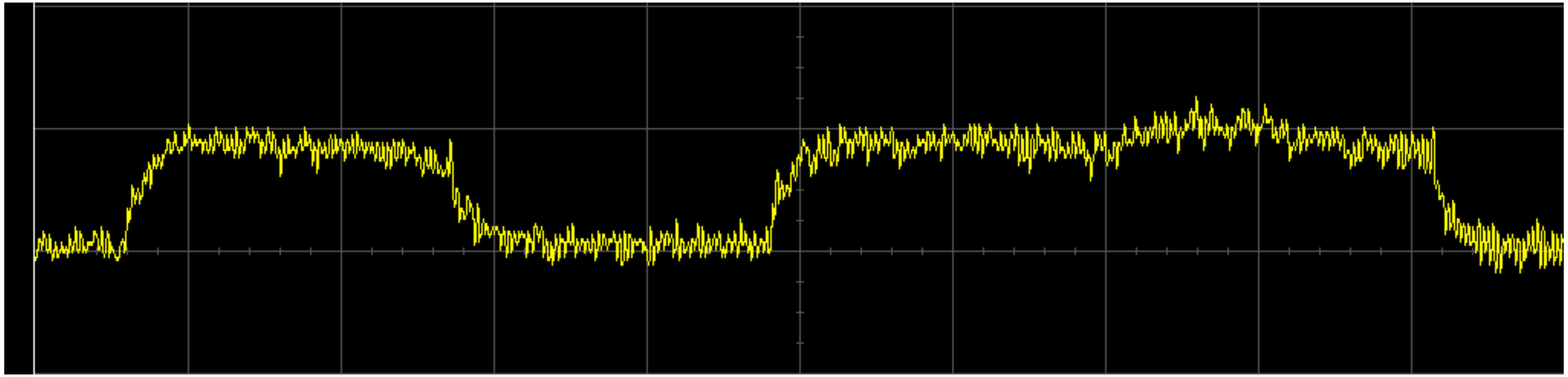
- It is very hard, perhaps impossible, to block all covert channels
  - May appear in program code
  - Or operating system code
  - Or in the hardware itself (e.g. CPU covert channels)
- Potential mitigations:
  - Limit the bandwidth of covert channels by enforcing rate limits
    - Warning: may negatively 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 ;)