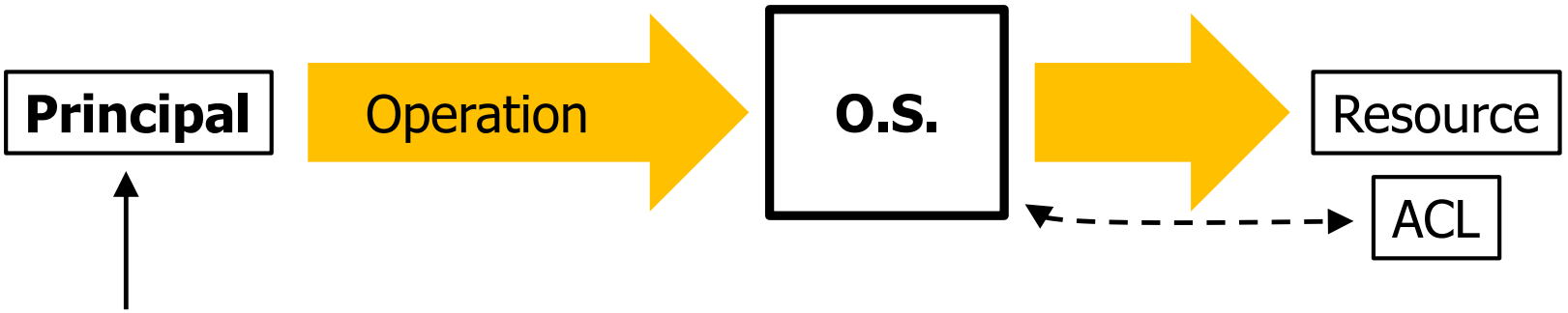
Principle of Complete Mediation

Access Control (REMIND)



- Account
- Which executable
- How it was authenticated
- Local / Network
- …

The O.S. can take **different** decisions for the **same** (Account, Operation, Resource)

Important question (IV) (REMIND)

- User U executes GUI / Shell
- How can you make sure that the GUI / Shell can **only** execute operations **allowed to U**?

- Resource access is **mediated** by the O.S.
- O.S. grants/denies based on Resource.ACL
- Resource.ACL describes what U can and cannot do

Important question (VI) (REMIND)

- Web server
- User U logged on a **webapp** (e.g., Banking)
- How can you make sure that U can **only** access **"his/her" data**?

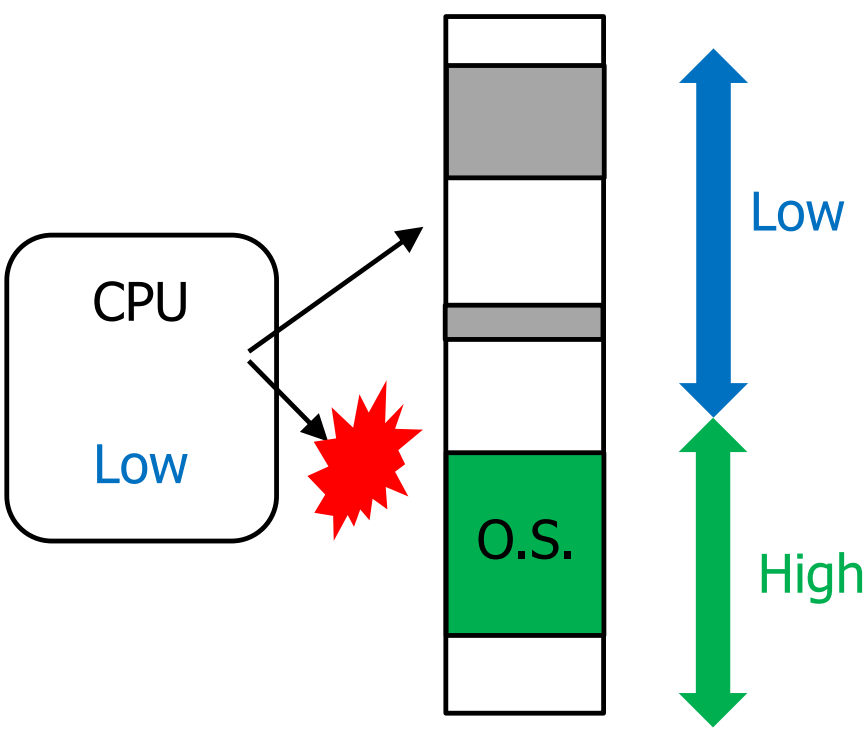
- Resource access is **mediated** by the application server
- Application server grants/denies based on Resource.ACL
- Resource.ACL describes what U can and cannot do

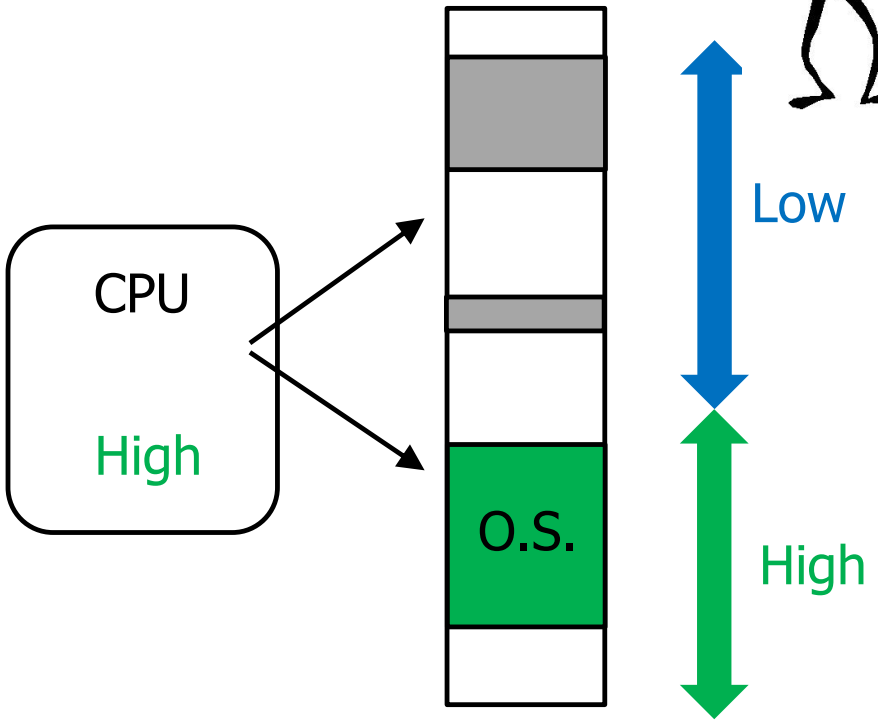
Important question (V) (REMIND)

- User U executes some program P
- How can you make sure that P cannot **modify** the internal code/data **of the o.s.**?

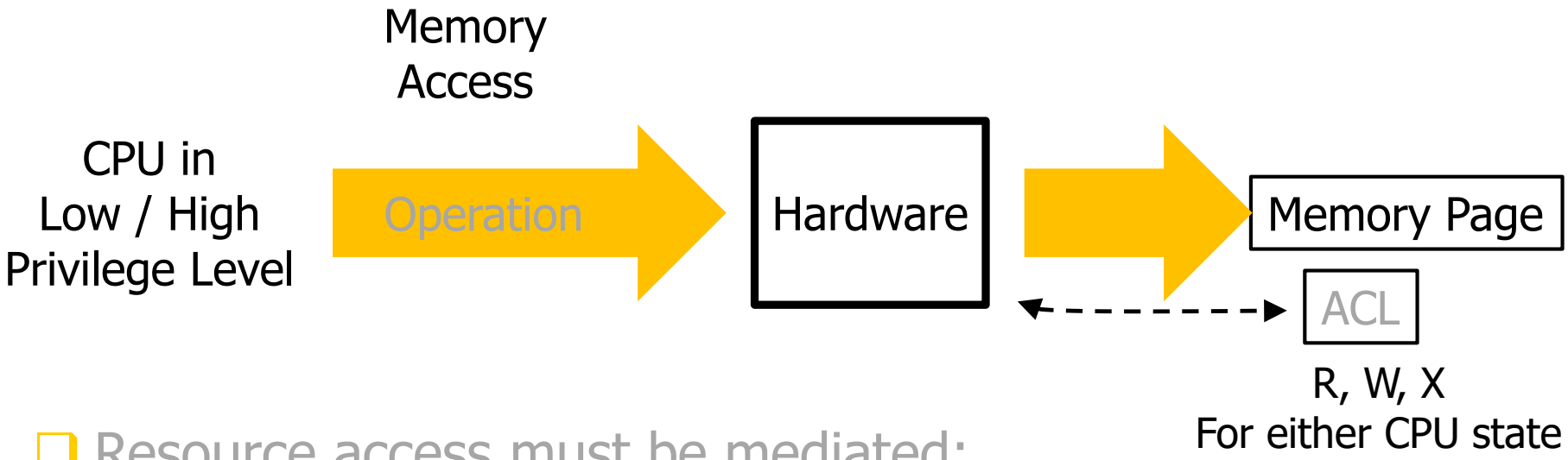
- CPU privilege level
- Memory access rights
- ...but how can **the memory** know which CPU privilege level can access it?
- ...and how **enforced**?

Hhmmm...



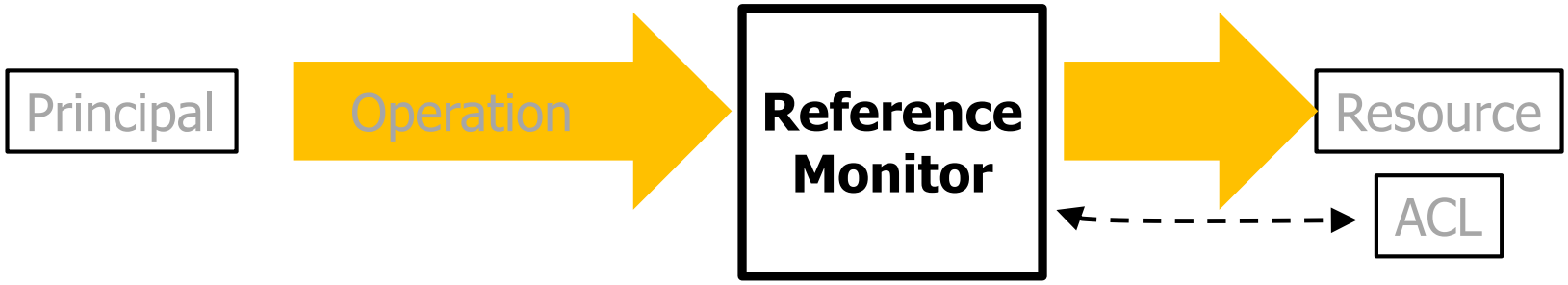


Access Control: Hardware



- Resource access must be mediated:
  - Hardware level
  - Operating system level
  - Application level
- Mechanisms **independent of each other**

Access Control: Abstract (=GENERAL) Model (I)



- Every access to **resources** is mediated (**guarded**) by the Reference Monitor
- Every resource has an **ACL**
- Reference Monitor decides whether to execute the operation:
  - Principal, Operation, Resource.ACL

Access Control: Abstract (=GENERAL) Model (II)

Username Authenticated Session	HTTP Request	Web Server	URL
Authenticated Username	SMTP / POP Request	Mail Server	Mailbox
Account	System call	O.S.	O.S. Resource
CPU state	Memory access	Hardware	Memory page

Access Control

- **FUNDAMENTAL** feature of computer systems
- **ENFORCES** the **security policy**: "who can do what"

- Occurs at **multiple** and **different** levels:
  - Application
  - Operating system
  - Hardware

- Each level:
  - Is **independent** of the other levels
  - Has **its own** mechanisms

Saltzer and Schroeder (1974)

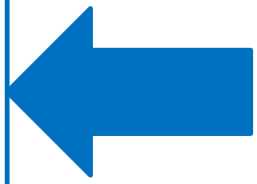
- **Complete mediation: Every access to every object must be checked for authority.**

- This principle, when systematically applied, **is the primary underpinning** of the protection system...
- It implies that **a foolproof method of identifying the source of every request** must be devised.

- Please take a moment to reflect and admire its depth and generality
- We will find more examples of its relevance

Keep in mind

- Different **operational scenarios**
  - One machine
  - Many machines in a single organization
  - Many machines in many organizations
  - Web apps
  - Web apps with delegated authentication / authorization
  - Cloud services (AWS, Azure, GCP,...)
  - ...



- **Every access** to **every object**. Period.

But this is obvious…!

- Complete mediation: Every access to every object must be checked for authority.

Hhhmmm…really?

GPDP | GARANTE PER LA PROTEZIONE DEI DATI PERSONALI

Provvedimento del 23 marzo 2023 [9883731]

- …anyone, after having gone through the computer authentication procedures within the portal, could view, select and open one or more documents in the ESF **of another specific assisted person**, simply **by entering the tax code of that assisted person** in the `patient_id` parameter.

- `https://....it/fse/webapi/xds/getuserdocuments?`
  `patient_id=XXXXXXXXXXXXXX``&`
  `date_from=YYYYYY&date_to=YYYYYYY&`
  `language=it&_=1617638439347`

A few words about Discretionary vs Mandatory

Security Policy Example (I)

- ***An intern*** *cannot have any access to files related to project A*
- Should be defined on the **ACL of each** *"file related to project A"*
- Inconvenient
- How to make sure **file owners** collaborate?

Security Policy Example (II)

- *HR people can only modify files **from certain devices***
- *No account can have access right A and access right B **on the same resource** (separation of duties / two-person rule)*
- Should be defined on the **ACL of each** relevant resource
- Inconvenient
- How to make sure **resource owners** collaborate?

Global Constraints

- *__An intern__ cannot have any access to files related to project A*
- *HR people can only modify files __from certain devices__*
- *No account can have access right A and access right B __on the same resource__ (separation of duties / two-person rule)*

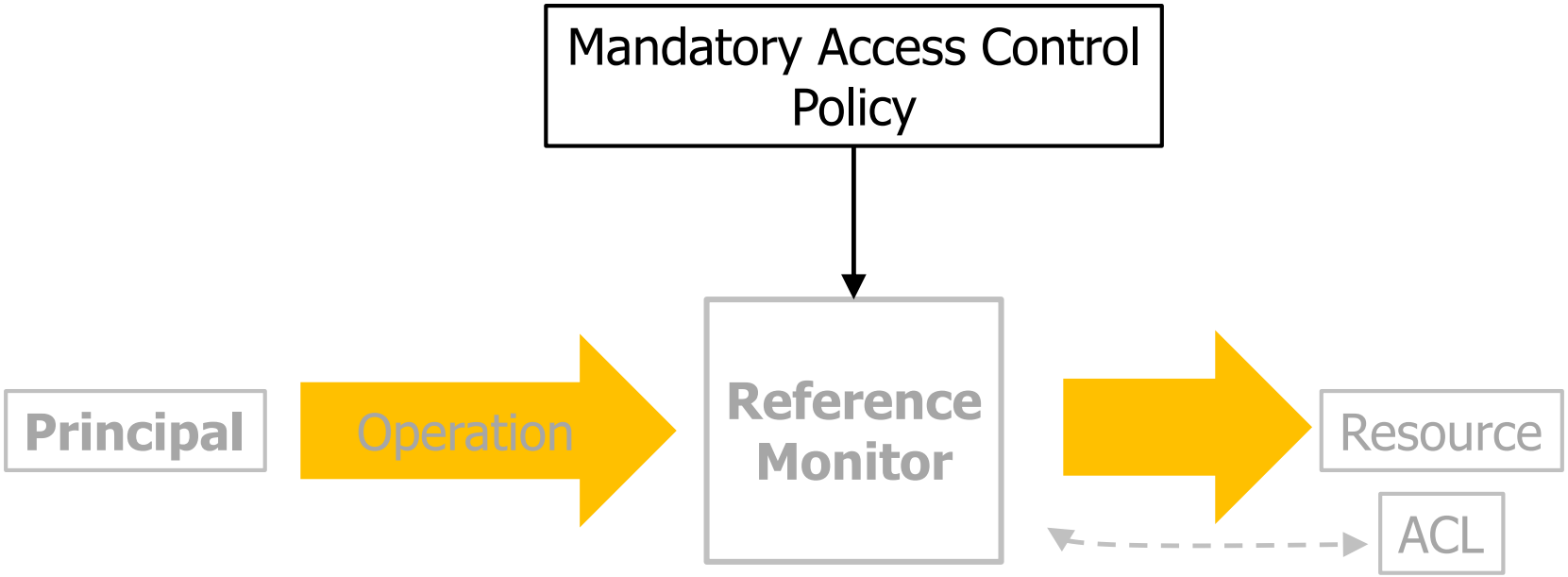
- Security policy requirements: **Global** constraints specified at a **central** level
- Access control mechanisms: specified at a **local** level (each single resource)

- Not a good fit

Discretionary vs Mandatory

- **Discretionary** Access Control (DAC)
  - Resource owners manage resource ACLs
  - What we have seen so far
- **Mandatory** Access Control (MAC)
  - Allow **defining** and **enforcing global** requirements
  - Take precedence over DAC
- Real o.s. and cloud services support a mix of them
- Out of scope

Access Control

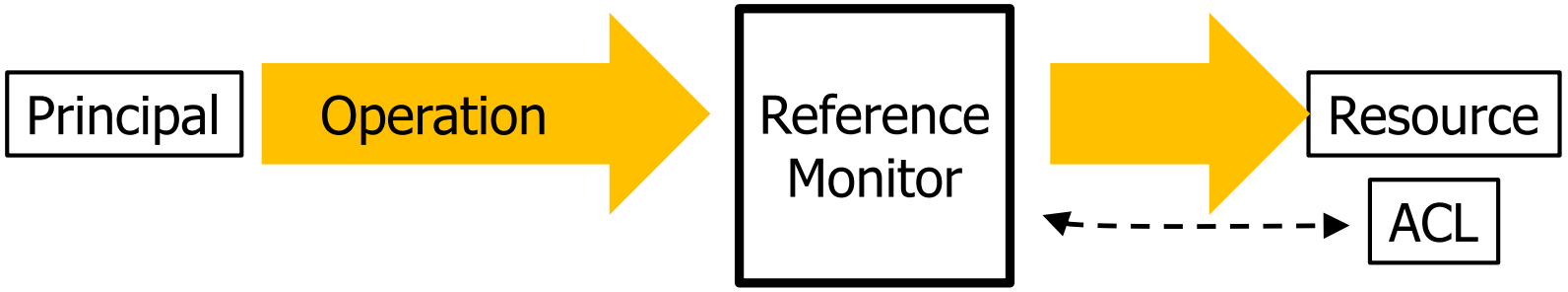


Understanding Access Control in Cybersecurity

Access Control = Authorization (≠ Authentication)

- Principal is an **input** data (it is "certain"):
  it is determined **prior** to issuing the OpRequest
- How it is determined is a **different** problem
  - **Authentication** is usually required

Everything is perfect (I)

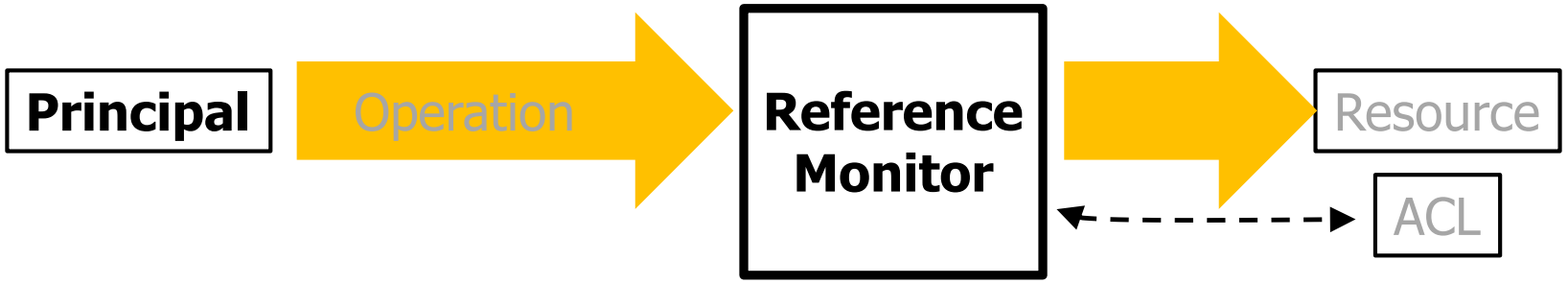


- The security policy described in the ACLs of all resources is the **intended** one:
  - No principal is allowed to do what it should **not** be allowed to do.

Everything is perfect (II)

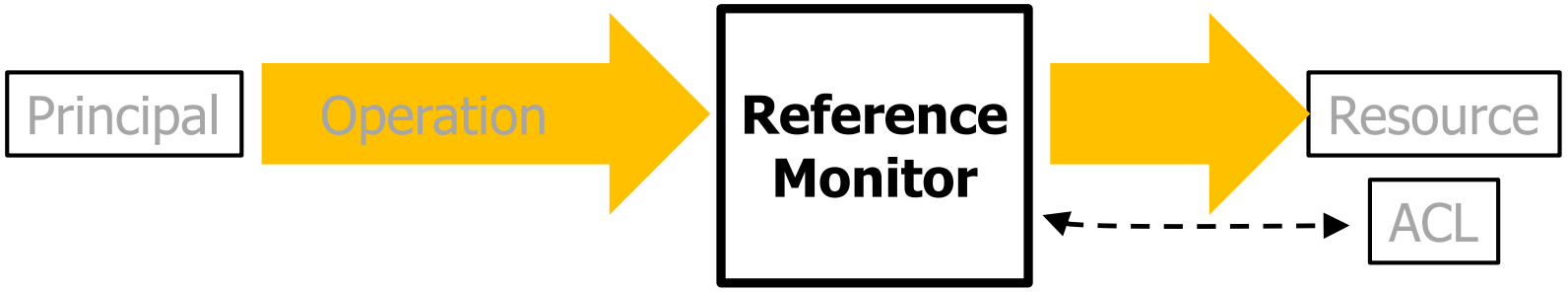
- Principals do not **abuse** their access rights to do **bad** things (they always behave as we expect them to):
  - You do not expect your browser to steal your data (e.g., read it and send it somewhere)

Everything is perfect (III)



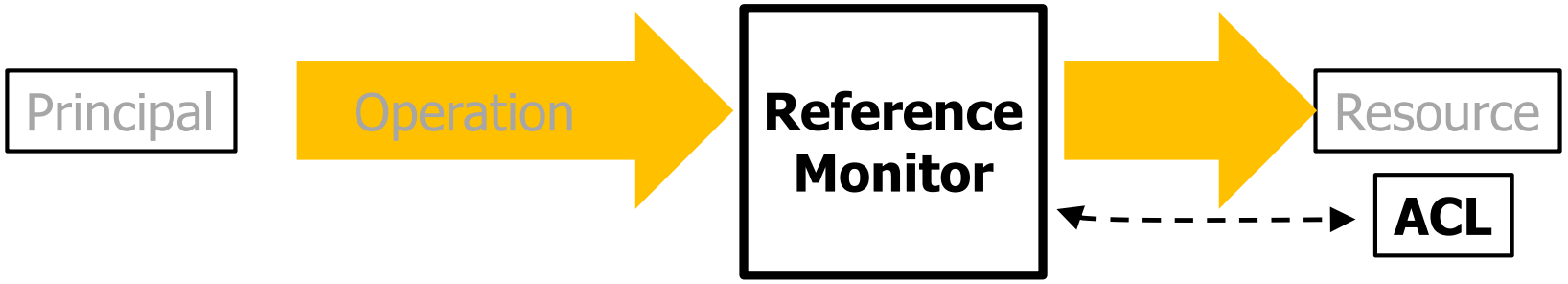
- A given Principal cannot appear to the Reference Monitor as a **different** Principal

Everything is perfect (IV)



- Reference Monitor:
  - No way of **bypassing** it
  - No **mistakes**

Everything is perfect (V)



- Principals are **not** able to **modify**:
  - Reference Monitor
  - ACLs
    (unless through authorized operations)

Why Cybersecurity is an issue? (I)

- IF Everything was perfect
- THEN Cybersecurity would **not** be an issue

- The problem is that something is not perfect
  - Often **a lot** of things

Example (I)

- "Midnight Blizzard attack to Microsoft" on the companion website:
  - Test application → Senior leadership Cybersec people email and docs

- **Actual** Security policy **different** from the **intended** one
- Principals **abused** their access rights

Example (II)

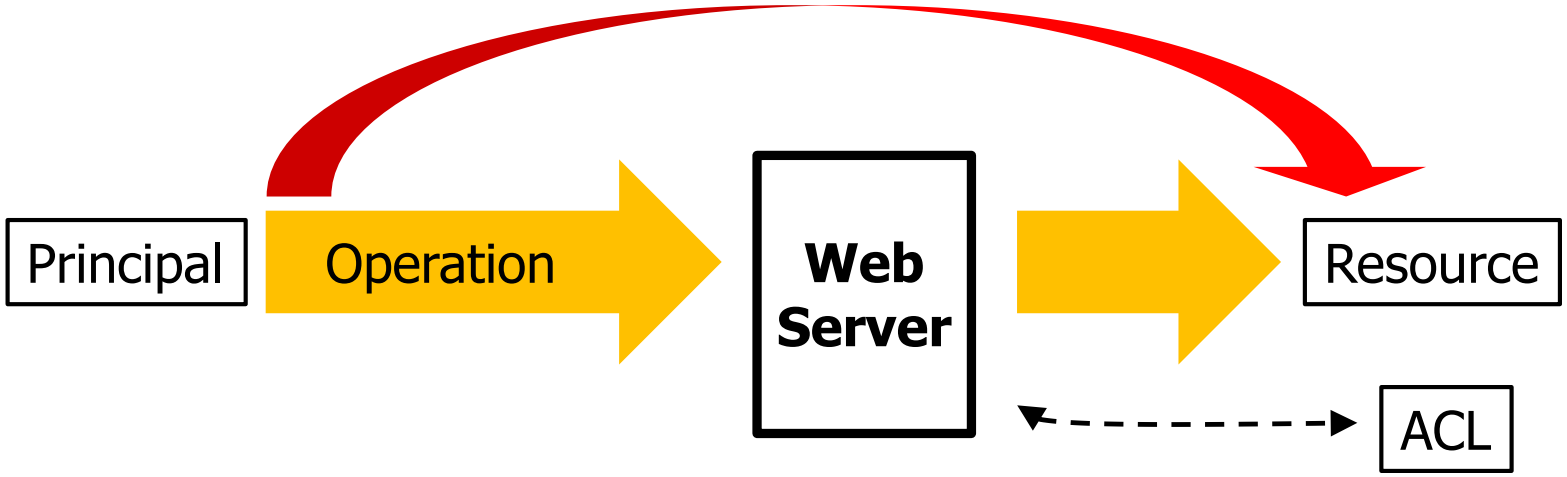
- Incident at a company in Trieste (27K ransom paid)
  - Secretary receives pdf invoice with malware from (unsuspecting) commercial partner
  - Malware encrypts all files in all folders of the company filesystem

- **Actual** Security policy **different** from the **intended** one
- Principals **abused** their access rights

Example (III)

GPDP | GARANTE PER LA PROTEZIONE DEI DATI PERSONALI

Provvedimento del 23 marzo 2023 [9883731]



- Reference Monitor:
  - ~~No way of **bypassing** it~~

Keep in mind

- Cybersecurity is mostly about **mistakes**

Principle of Least Privilege

Common Server Config. (up to a few years ago)

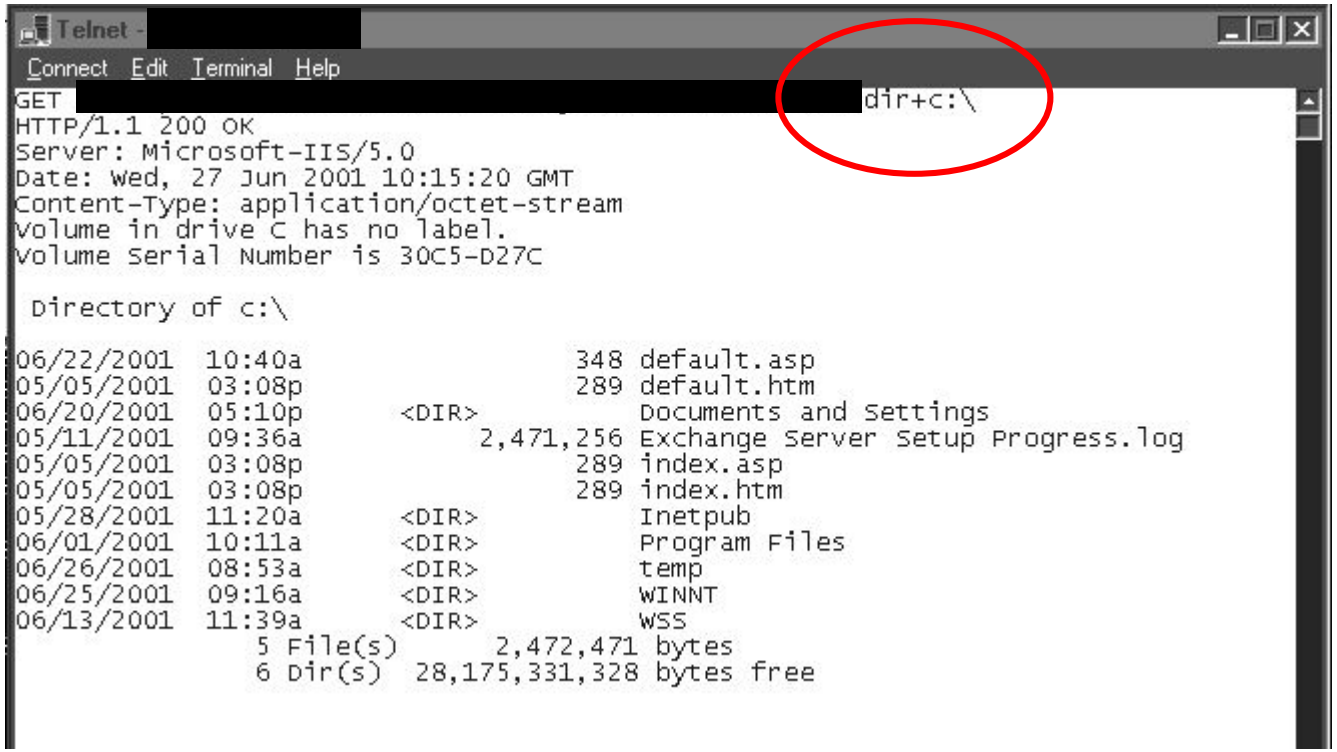
Remote Shell
Web Server
File Server
Mail Server
...

Example (Old but interesting) (I)

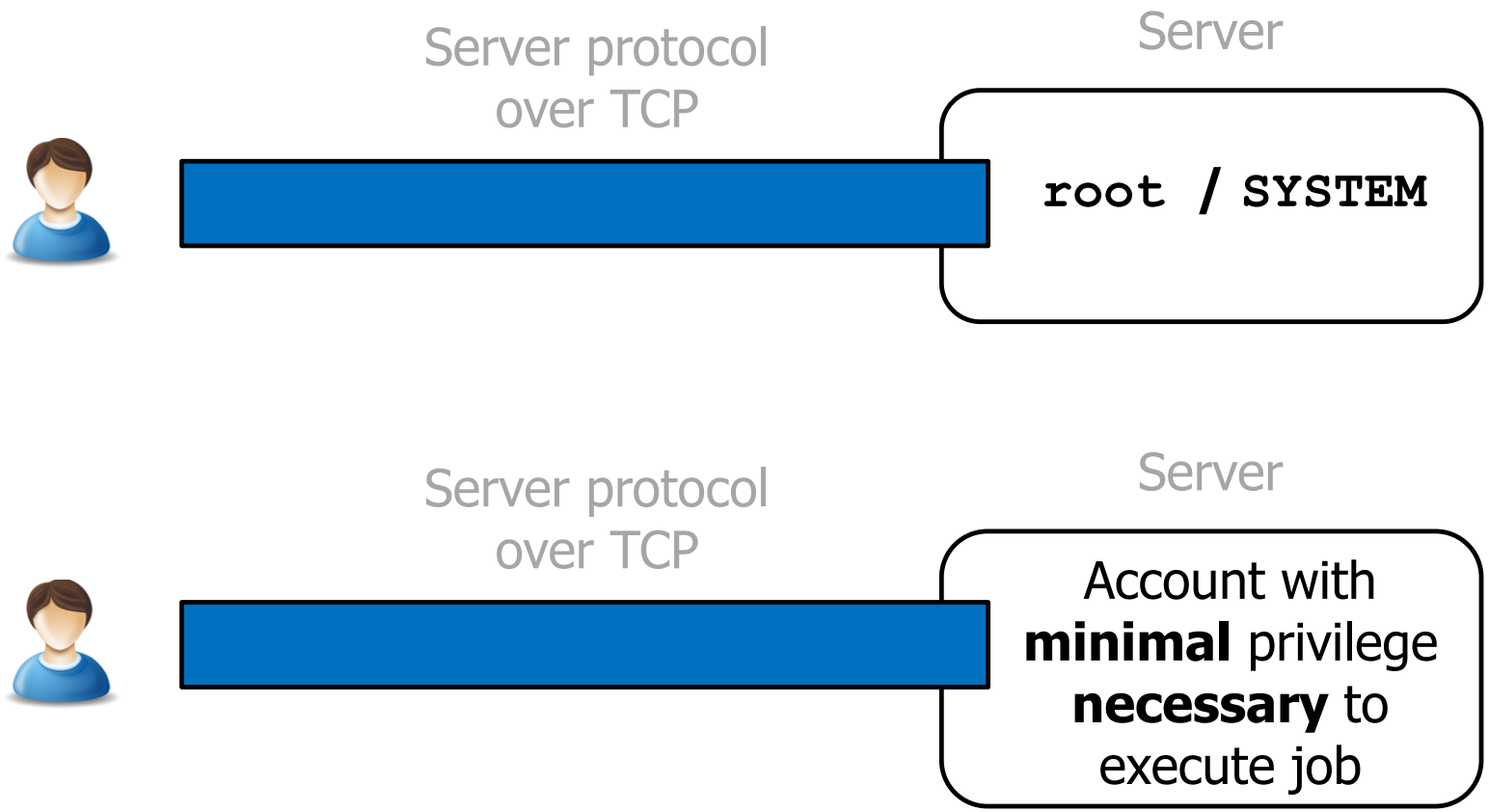
HTTP Request
with "long and wrong URL"
ending with command

Execute command

Example (Old but interesting) (II)



Which approach is wiser?



Principle of Least Privilege

- **Every** program and every user of the system should operate using the **least** set of privileges **necessary** to complete the job...
- It also reduces the number of potential interactions among privileged programs to **the minimum for correct operation**, so that **unintentional**, **unwanted**, or **improper** uses of privilege are **less likely** to occur...

- *Saltzer and Schroeder **1974 (!)***

- Please take a moment to reflect and admire its depth and generality
- We will find more examples of its relevance

But this is obvious…!

- **Least privilege: Every** program and every user of the system should operate using the **least** set of privileges **necessary** to complete the job

Hhhmmm...

EMERGENCY DIRECTIVES

March 03, 2021

ED 21-02: Mitigate Microsoft Exchange On-Premises Product Vulnerabilities

CYBERSECURITY & INFRASTRUCTURE SECURITY AGENCY

- Mail Server used by **a myriad of organizations**
- **Necessarily exposed to the Internet**

- An **unauthenticated** attacker can **execute arbitrary commands** on Microsoft Exchange Server ("ProxyLogon")

Hhhmmm…really?

EMERGENCY DIRECTIVES

March 03, 2021

ED 21-02: Mitigate Microsoft Exchange On-Premises Product Vulnerabilities

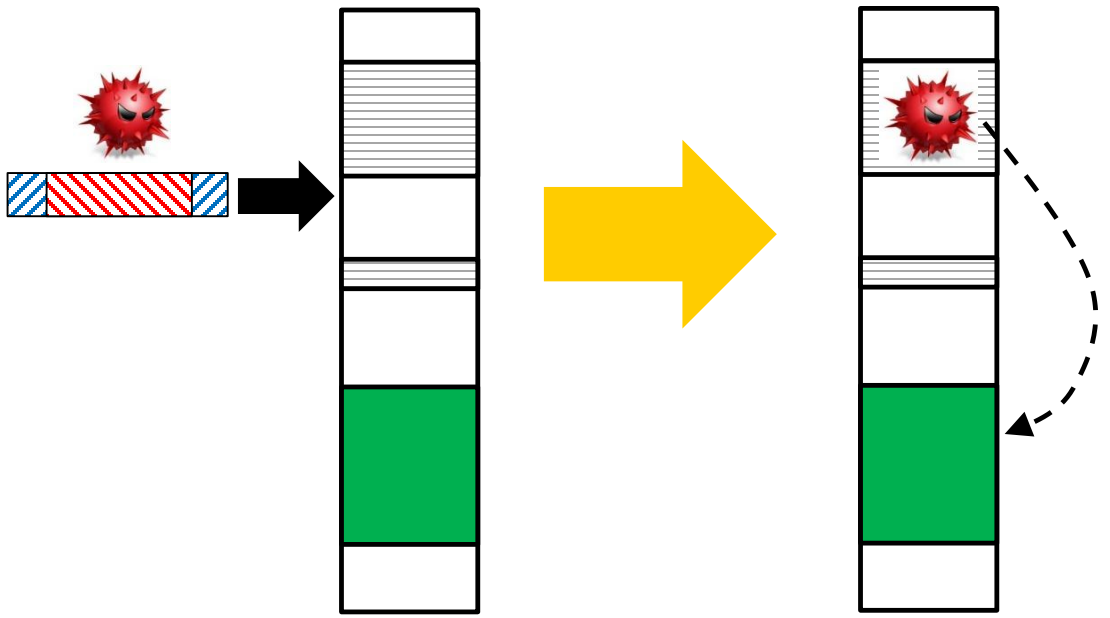
CYBERSECURITY & INFRASTRUCTURE SECURITY AGENCY

- Mail Server used by **a myriad of organizations**
- **Necessarily exposed to the Internet**

- An **unauthenticated** attacker can **execute arbitrary commands** on Microsoft Exchange Server ("ProxyLogon")

- "Exchange is, **by default**, installed with **some of the most powerful privileges** in Active Directory" (`SYSTEM`)

Remark: RCE vulnerability



Malware executes actions with
the **identity of the vulnerable process**

Hhhmmm...REALLY?

CVE-2024-3400 Detail

Description

A command injection as a result of arbitrary file creation vulnerability in the GlobalProtect feature of Palo Alto Networks PAN-OS software for specific PAN-OS versions and distinct feature configurations may enable an unauthenticated attacker to execute arbitrary code with root privileges on the firewall. Cloud NGFW, Panorama appliances, and Prisma Access are not impacted by this vulnerability.

Cybersecurity & Economics

Hhmmm…

- *Principle of Least Privilege:* ***1974***
- *Why in many practical scenarios it is still* ***not*** *enforced,* ***50 years later?***

Security is NEVER the ONLY objective (I)

- **Every** choice must be a tradeoff among:
  1. Security
  2. Cost
  3. Functionality
- Design, Development, Deployment, Usage, Maintenance

- In many practical cases, Security is sacrificed

Security is NEVER the ONLY objective (II)

- In many practical cases, Security is sacrificed
- The chosen tradeoff might be wrong (perhaps retrospectively)
- ...but it often is **economically rational**
  - More Security $\Rightarrow$ More short term costs
  - Long term savings uncertain
  - Market forces could penalize short term costs

Think in Economical Terms

- To understand cybersecurity **never** think only in **technical** terms
  - Or, worse, in "moral" terms
- **Always** think in **economical** terms

- What is the cost?
  - Attack, Defense, Incident
- Who pays?

- **Money is what drives the world**
  - It may sound cynical…but thinking in these terms is very helpful

Keep in mind: Much easier said than done

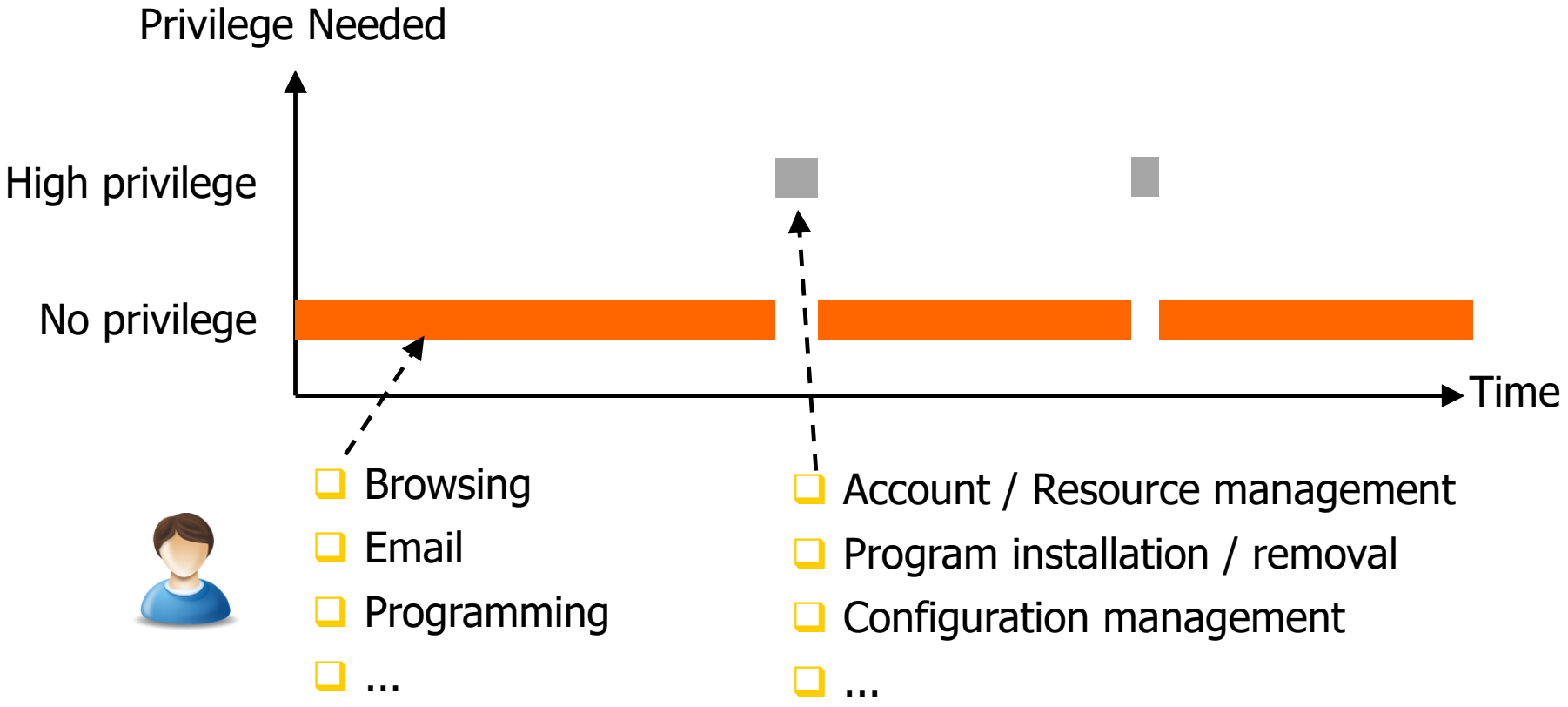
- **Every** program … should operate using the **least** set of privileges **necessary** to complete the job…

- I have written a Python script to automatically generate random sets of exam questions

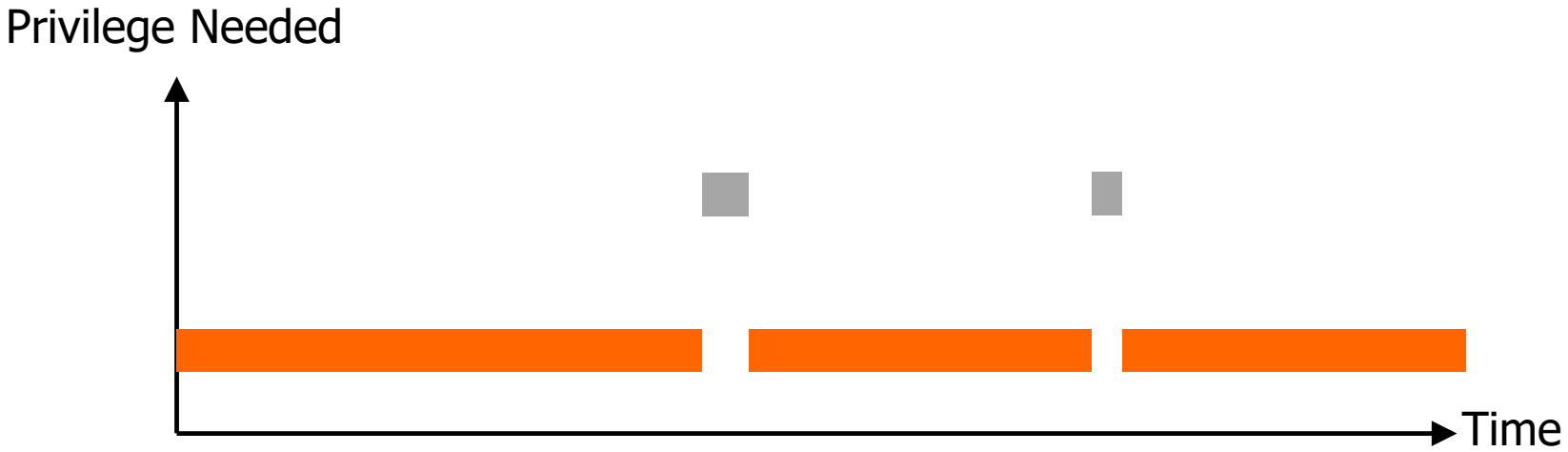
- Why should this script have the privilege to **write to any directory** that I can write to?

Temporary Privilege Elevation

Key practical scenario



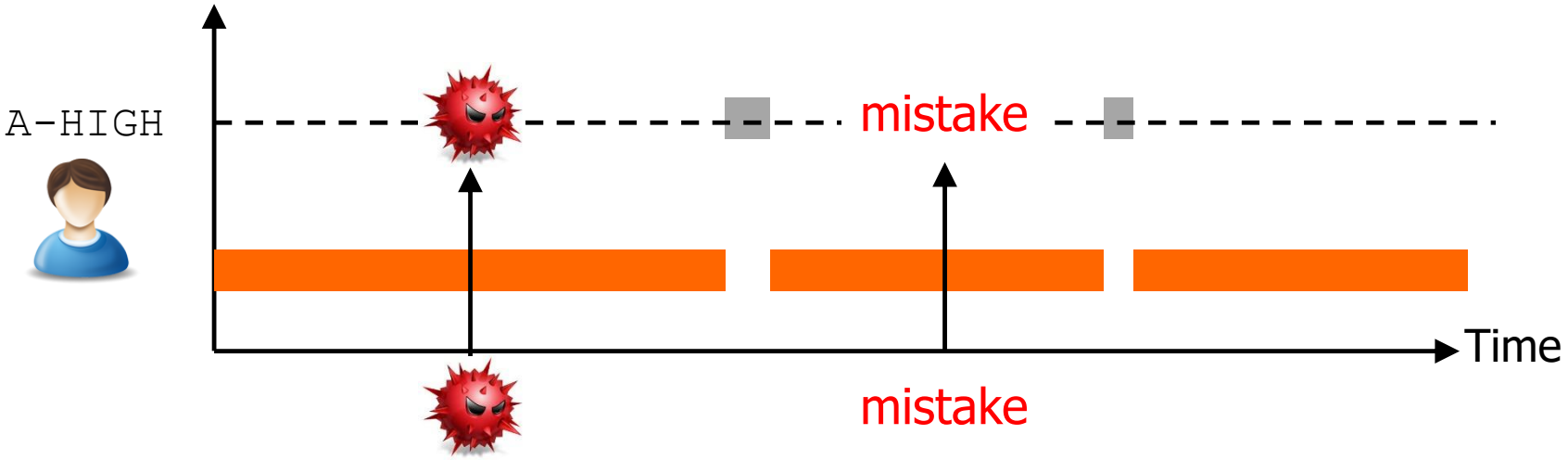
Which account?



- Two accounts available: `A-LOW`, `A-HIGH`
- `A-LOW` is not enough: sometimes `A-HIGH` is needed

- Is it wise to **always** use `A-HIGH`?

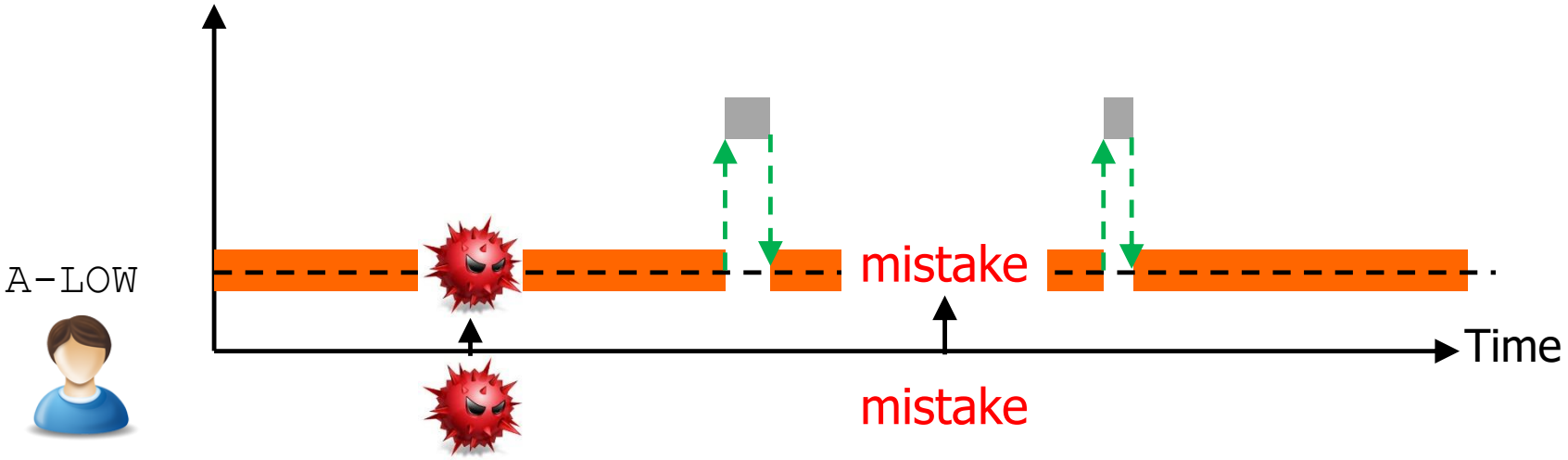
No, no, no!



- **Unwanted** or **Unintentional** actions
- ...with identity `A-HIGH`

- Huge violation of principle of least privilege

What we need



- Unwanted or Unintentional actions
- ...with identity `A-LOW`

+

- **Temporary privilege elevation**

Basic idea

- Executable F:
  - Created by an account `A-H` with high privileges
  - Marked with "**elevation**"

- Process P owned by an account **different** from `A-H` :
  1. Creates P1 that executes F
  2. P1 has "elevated privileges"

- Rationale:
  - `A-H` has encoded certain actions in F
  - `A-H` trusts that F can be executed safely with high privileges

Fundamental Risk

- Rationale:
  - A-H has encoded certain actions in F
  - A-H trusts that F can be executed safely with high privileges

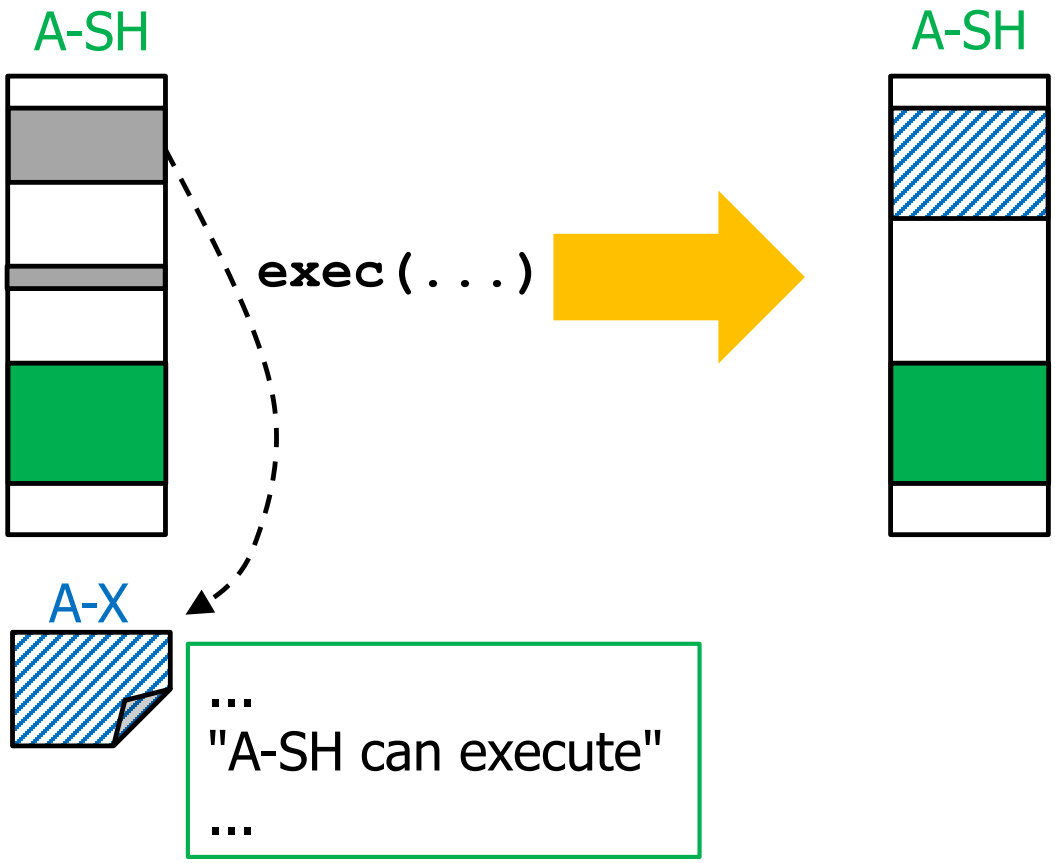
- F might not behave as intended
  - Mistakes (vulnerabilities)

Temporary Privilege Elevation: Linux

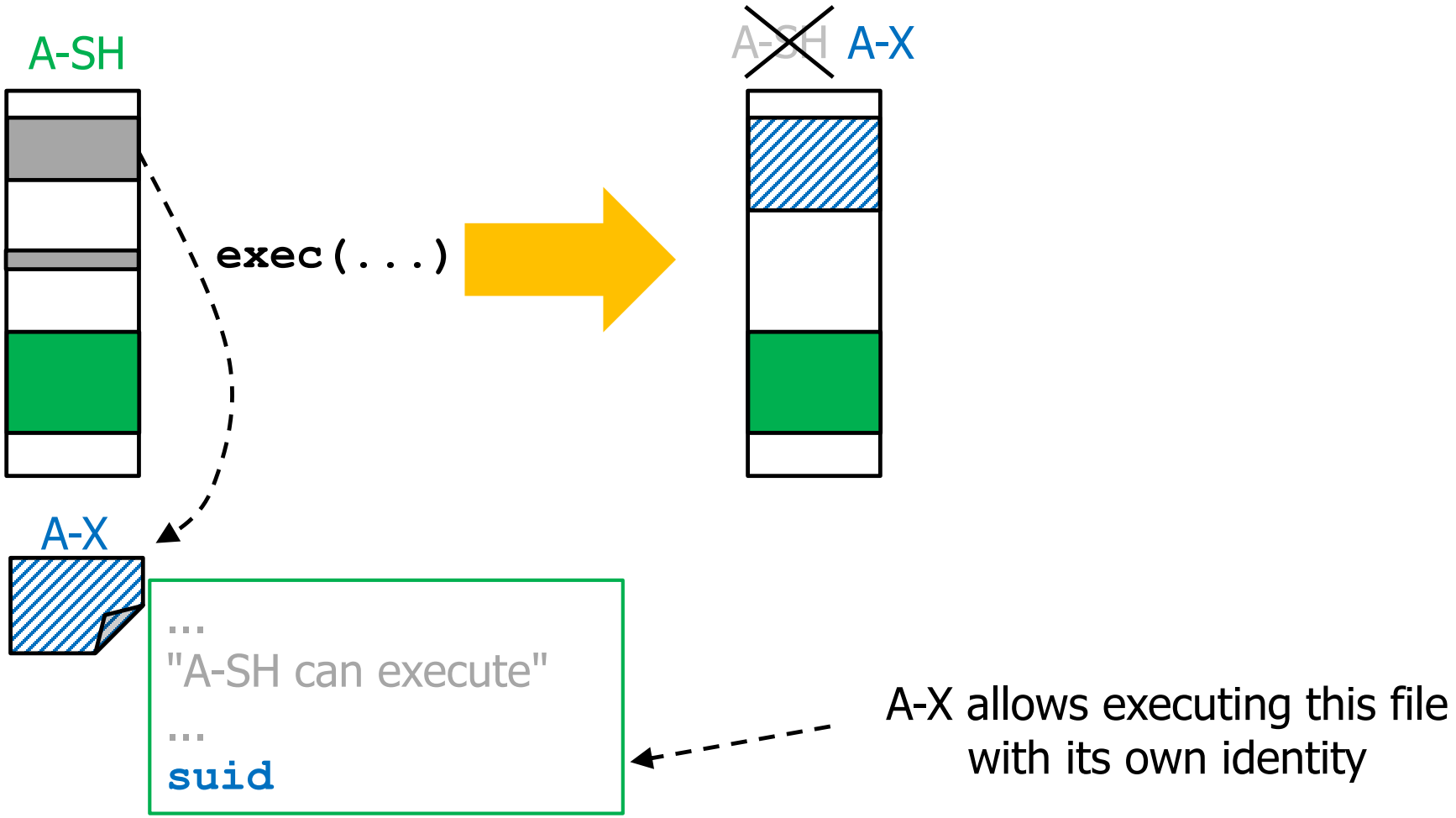
Linux `suid`

- Executable F:
  - Owned by `A-F`
  - With **set user id** attribute (`suid`)
- Process P owned by an account **different** from `A-F` :
  1. Creates P1 that executes F
  2. P1 owned by `A-F`
- Fully automatic: `A-F` credentials **not** needed
- `A-F=root` ⇒ privilege elevation

Linux `exec` (file WITHOUT `suid`)

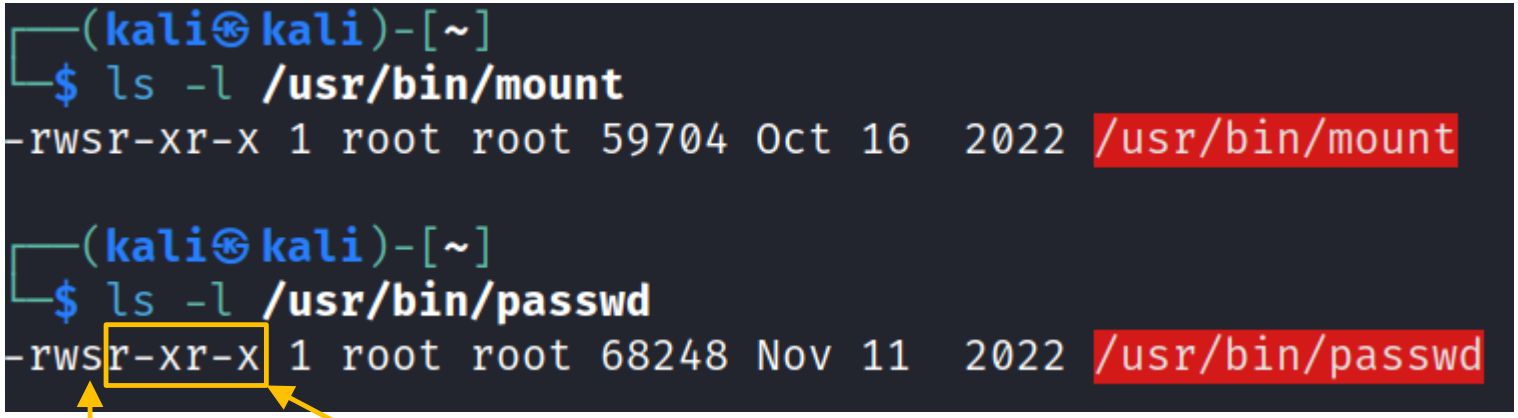


Linux `exec` (file WITH `suid`)



Common Use Case

- `A-X` is **high privilege** (`root`)
  - Impersonation = Elevation



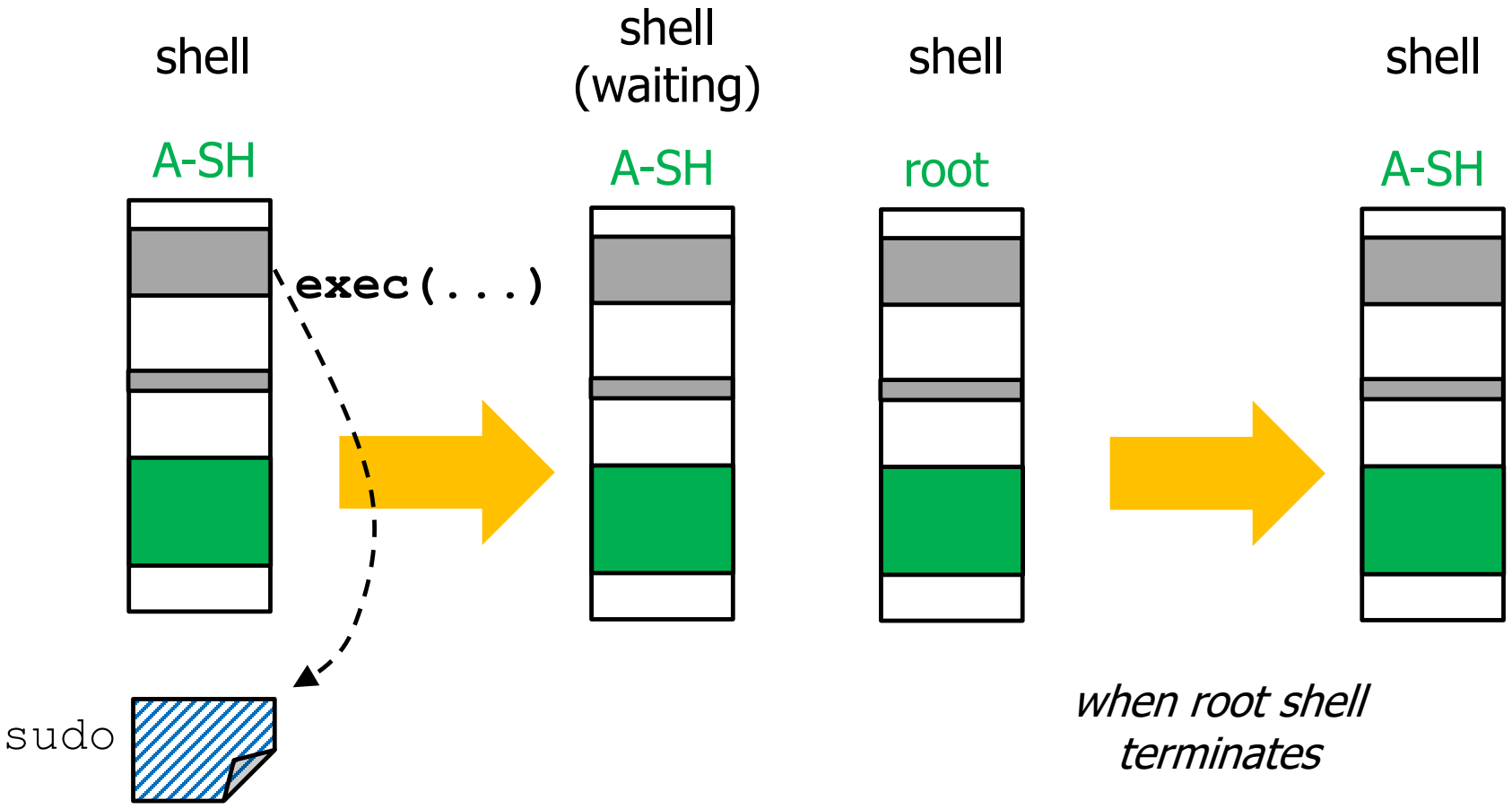
Executable file **with `suid`**

Can be read and executed (but **not modified**) by any account

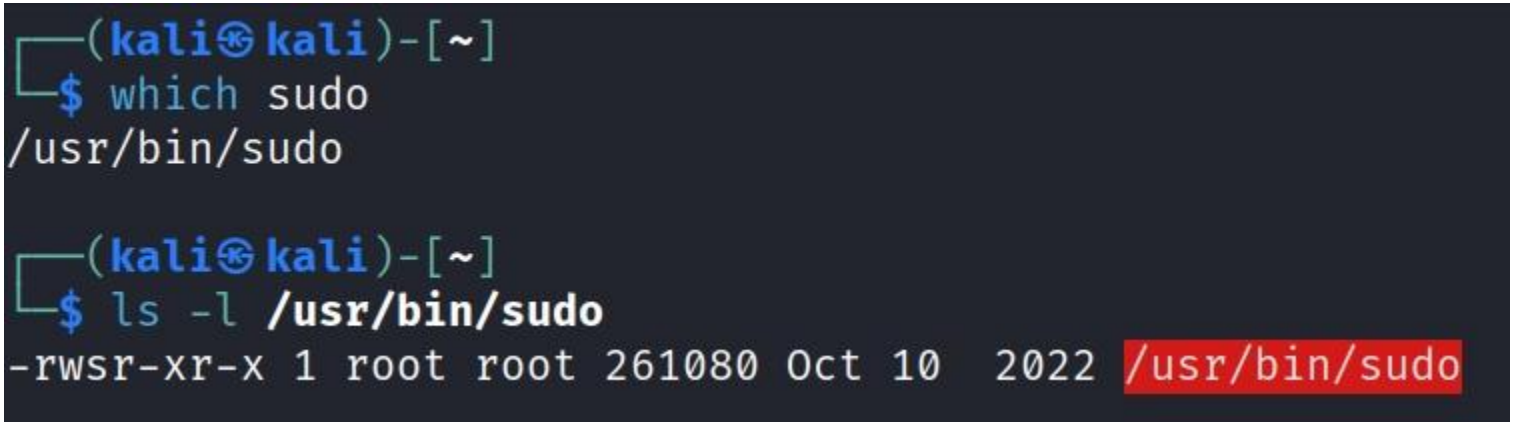
Linux `sudo` (I)

- Executable file `sudo`
- Behavior depends on **invocation arguments** and **configuration**
- Common invocation: No arguments
  - Spawns a **shell** owned by `root`
  - Password of the **invoking account** `A-SH` **required**
- Configuration: `A-SH` must belong to **`sudoers`** group
  - Normal users: **not** inserted in `sudoers`
  - Administrators: inserted in `sudoers`

Linux `sudo` (II)



How `sudo` works (outline) (I)

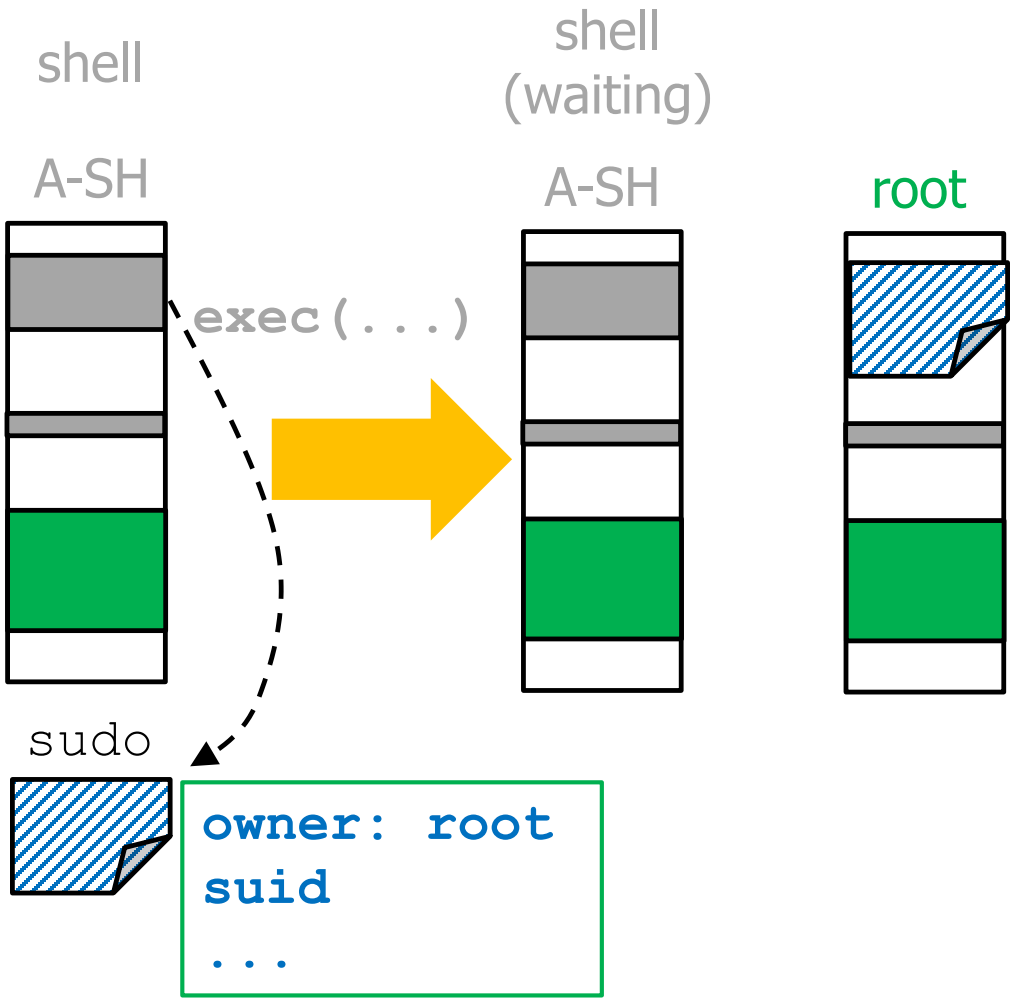


How `sudo` works (outline) (II)

1. Verify if process account is in `sudoers`
2. Ask account credentials
3. Verify credentials
4. exec("`/bin/sh`")

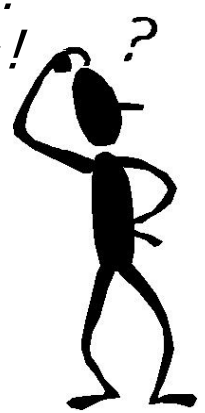

```
owner: root
suid
...
```

How `sudo` works (outline) (III)



1. Verify if process account is in `sudoers`
2. ...

How???
Account is `root`!



Linux `uid` (in a nutshell)

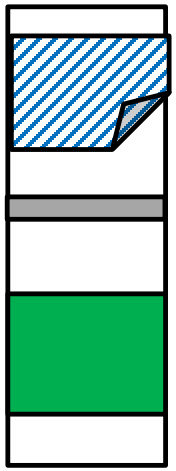
- Each process is associated with **two** account identifiers (`uid`)
  - Effective `uid` — Access control
  - Real `uid` — Account that created the process

- Always identical…**except** when created from `suid` file
- Example: `sudo`
  - Effective `uid` — `root`
  - Real `uid` — Account that invoked `sudo`

How `sudo` works (outline) (IV-a)

real UID = `A-SH`
effective UID = `root`

1. Verify if **real UID** is in `sudoers`
2. ...



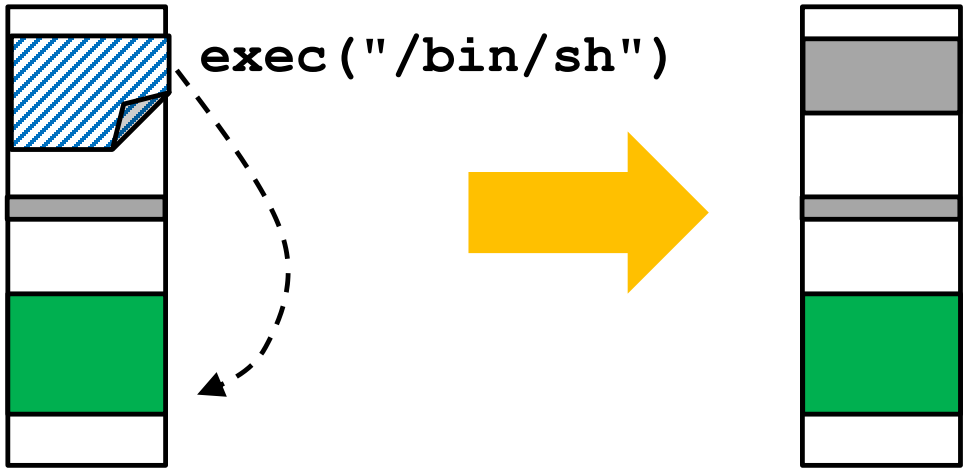
How `sudo` works (outline) (IV-b)

shell

real UID = `A-SH`
effective UID = `root`

real UID = `A-SH`
effective UID = `root`

1. Verify if real UID is in `sudoers`
2. Ask account credentials
3. Verify credentials
4. exec("`/bin/sh`")



Keep in mind

- F might not behave as intended
  - Mistakes (vulnerabilities)

CVE-2025-32463 Detail

Base Score: 9.3 CRITICAL

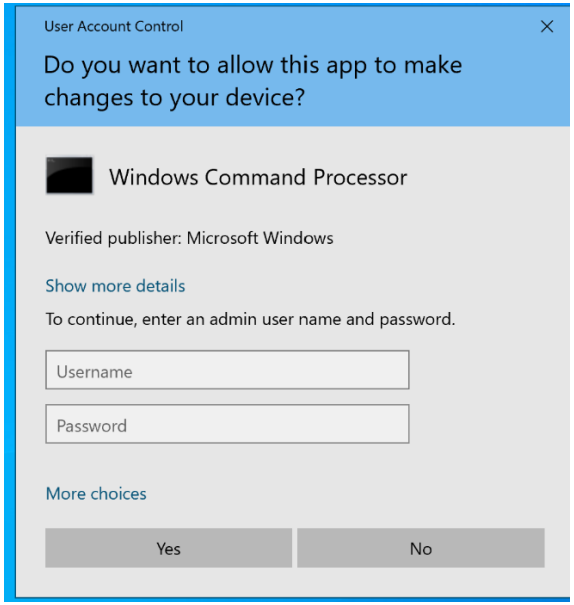
A flaw was found in `sudo`. A local attacker may trick `sudo` into executing arbitrary commands as `root` even if not included in `sudoers`.

Temporary Privilege Elevation: Windows

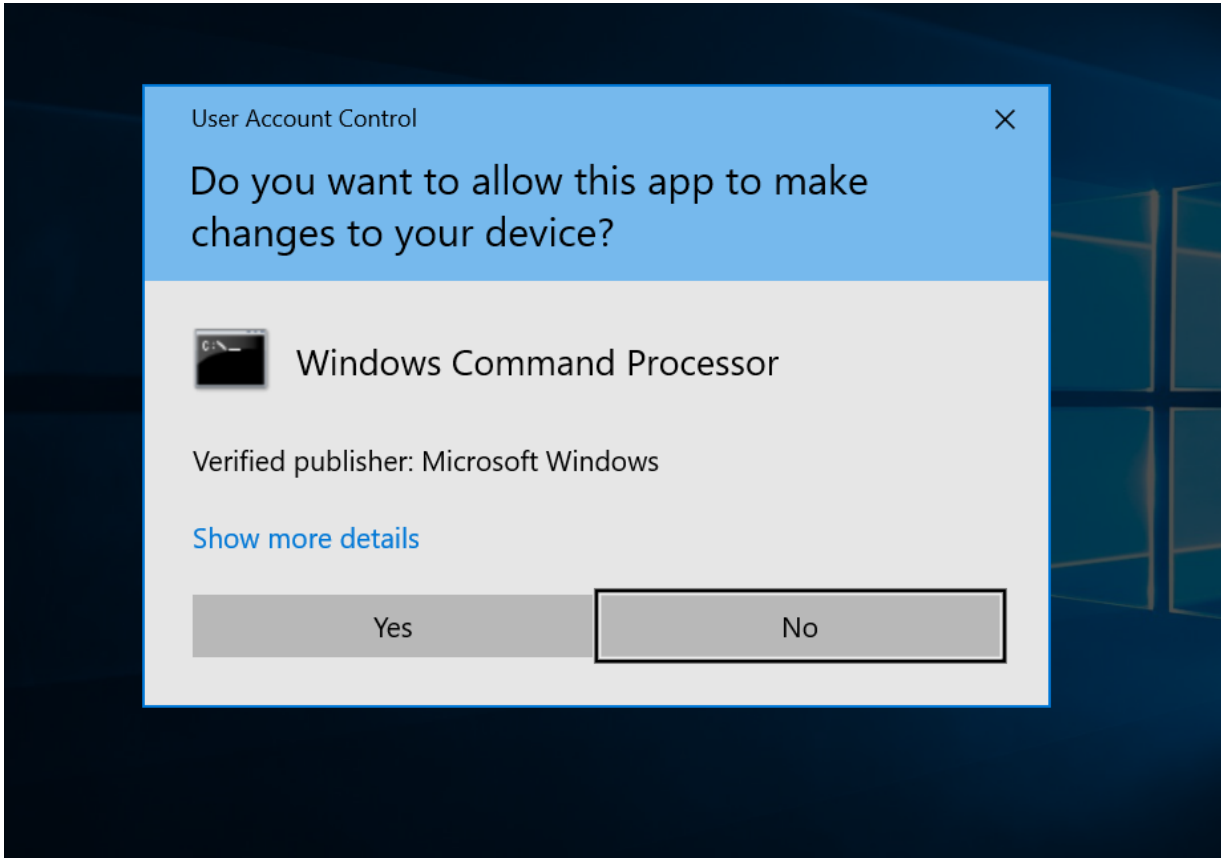
Windows `sudo`

- Very recent addition
- Must be enabled

- `sudo` *`command`*
  - Only for `Administrator`
  - Password **required**



UAC:
User Account Control (I)



UAC: User Account Control (II)

- Executable F:
  - Owned by `Administrator`
  - Marked with `AsInvoker` / **`RequireAdmin`**
- When **`RequireAdmin`**:
  - `AutoElevate` True: No explicit consent, no credentials
  - `AutoElevate` False: Explicit consent, credentials

```
PS C:\Users\alberto> Import-Module NtObjectManager
PS C:\Users\alberto> ls C:\Windows\System32\*.exe | Get-Win32ModuleManifest

Name                                AutoElevate ExecutionLevel
----                                ----------- --------------
bdeunlock.exe                       False       asInvoker
BitLockerDeviceEncryption.exe       False       requireAdministrator
BitLockerWizard.exe                 False       asInvoker
BitLockerWizardElev.exe             True        requireAdministrator
```

UAC Implementation Outline (I)

Temporary Privilege Elevation does **not** change **account**

- Account **Token**
- Which executable
- How it was authenticated
- Local / Network
- ...

(Token, Operation, Resource)

The O.S. can take **different** decisions for the **same** (Account, Operation, Resource)

UAC Implementation Outline (II)

- **GUI / shell** owned by Administrator
- Every process has **two** tokens
  - **Limited** Administrator groups and most privileges **removed**
  - **Full** All groups and privileges
- Every process uses the **limited** token
- A process uses the **full** token **only** when executing files with `requireAdministrator`

Temporary Privilege Elevation Summary

- Linux
  - Change to **account** with more privileges
- Windows
  - Change **privileges** of the account

- Elevation triggered by an executable
  - It must be checked very carefully

- Windows
  - Autoelevation (no user consent / no credentials) **only** on Microsoft-approved executables