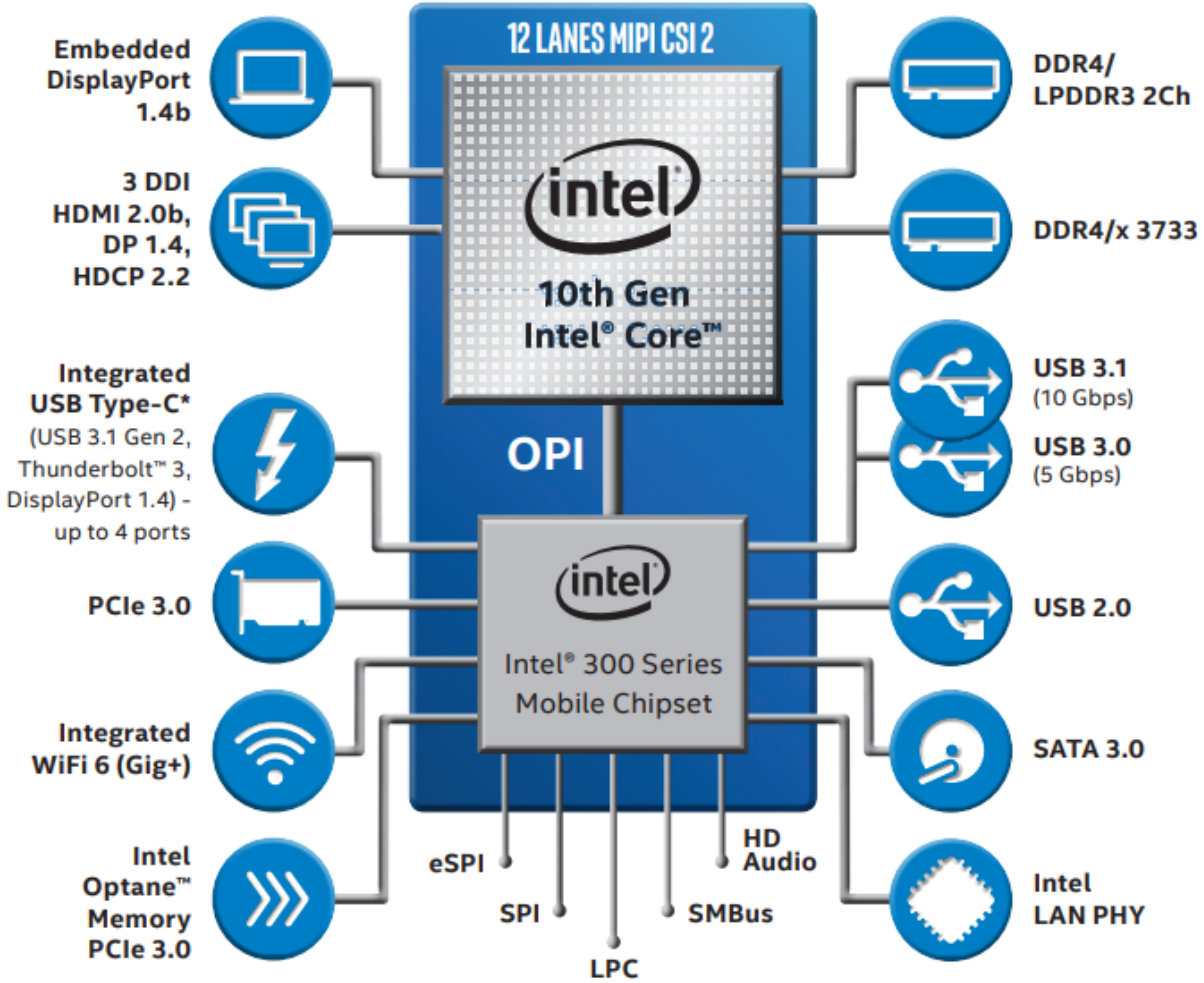
2550 Intro to cybersecurity

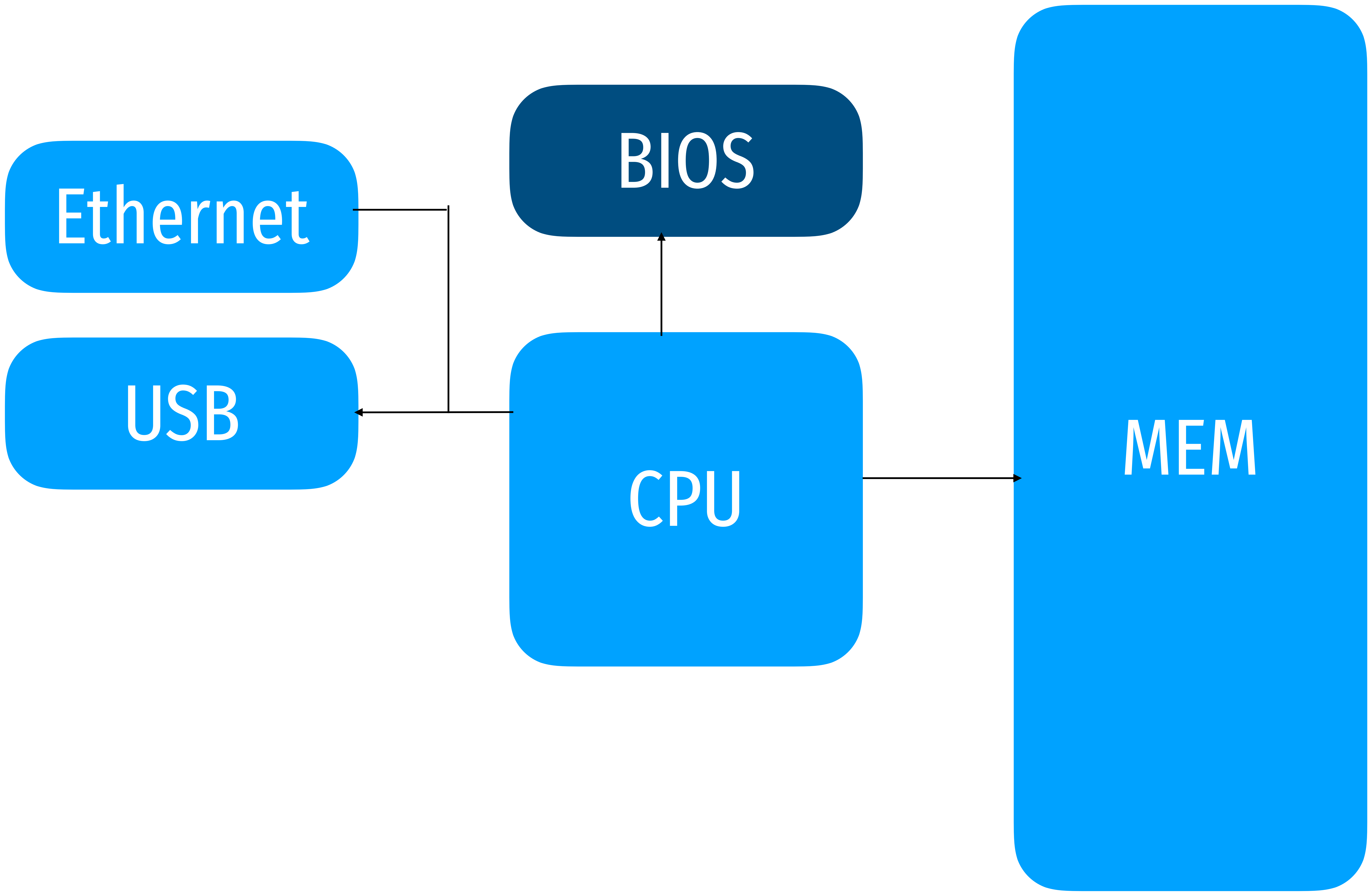
L20: systems

abhi shelat

Threat Model
Principles
Intro to System Architecture
Hardware Support for Isolation
Examples


IBM
IBM
IBM


12 LANES MIPI CSI 2
intel
10th Gen
Intel® Core™
OPI
intel
Intel® 300 Series
Mobile Chipset
Embedded DisplayPort 1.4b
3 DDI HDMI 2.0b, DP 1.4, HDCP 2.2
Integrated USB Type-C* (USB 3.1 Gen 2, Thunderbolt™ 3, DisplayPort 1.4) - up to 4 ports
PCIe 3.0
Integrated WiFi 6 (Gig+)
Intel Optane™ Memory PCIe 3.0
eSPI
SPI
LPC
SMBus
HD Audio
DDR4/ LPDDR3 2Ch
DDR4/x 3733
USB 3.1 (10 Gbps)
USB 3.0 (5 Gbps)
USB 2.0
SATA 3.0
Intel LAN PHY


BIOS
Ethernet
USB
CPU
MEM

What is Memory?

Memory is essentially a spreadsheet with a single column

- Every row has a number, called an address
- Every cell holds 1 byte of data

Address	Contents
114	
113	[illegible]
112	[illegible]
111	[illegible]
110	8
109	
108	[illegible]
107	[illegible]
106	[illegible]
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103	0xAF
102	0x3C
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int my_num = 8;

String my_str = "ABC";
while (my_num > 0) my_num--;
```

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114	
113	0
112	0
111	0
110	8
109	
108	0
107	C
106	B
105	A
104	
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Integers are typically four bytes (addresses 110–113)

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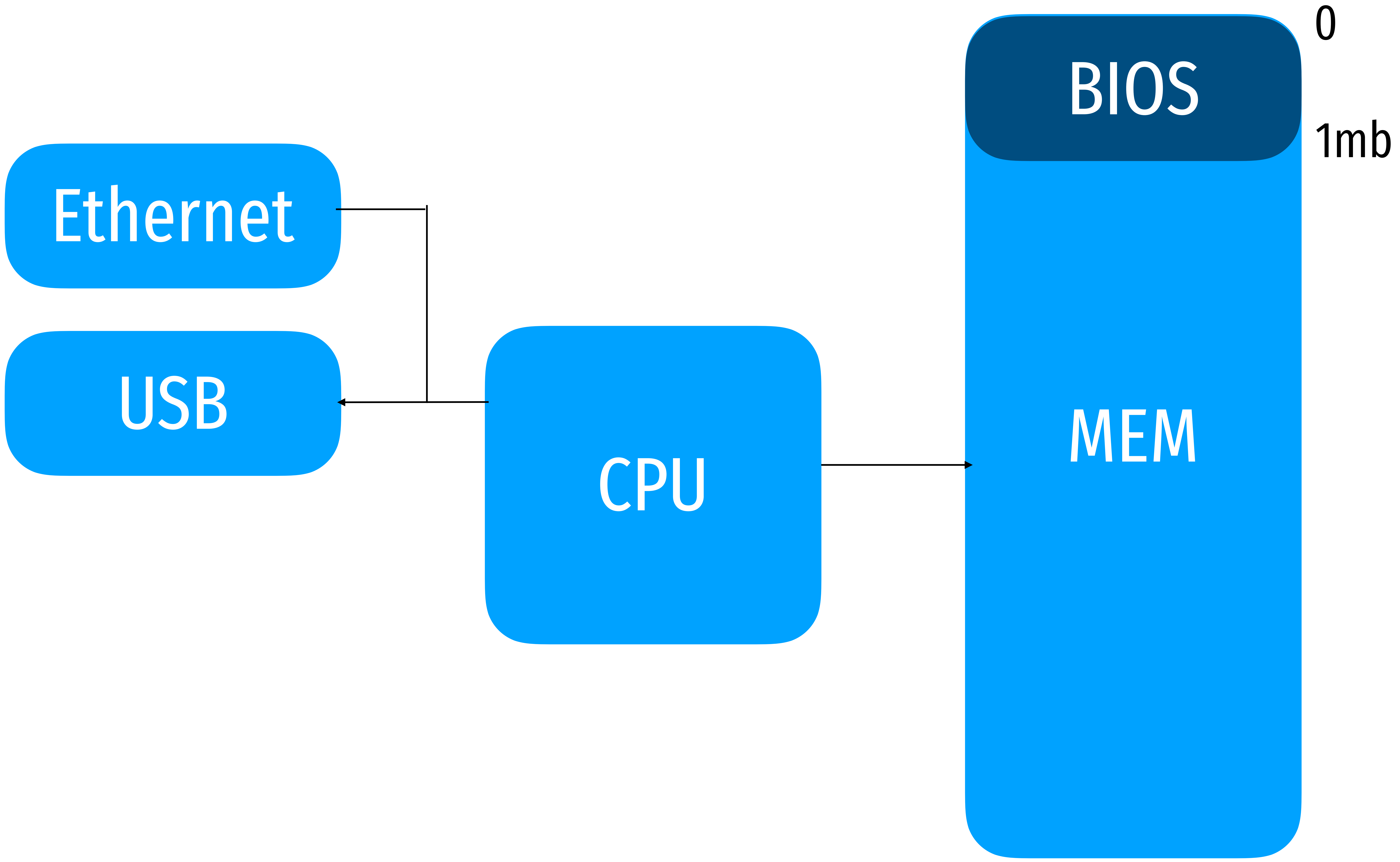
CPUs understand instructions in assembly language (addresses 100–103)

How does a computer boot?

https://youtu.be/MsKb0gR-4AM?t=36


0
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1mb
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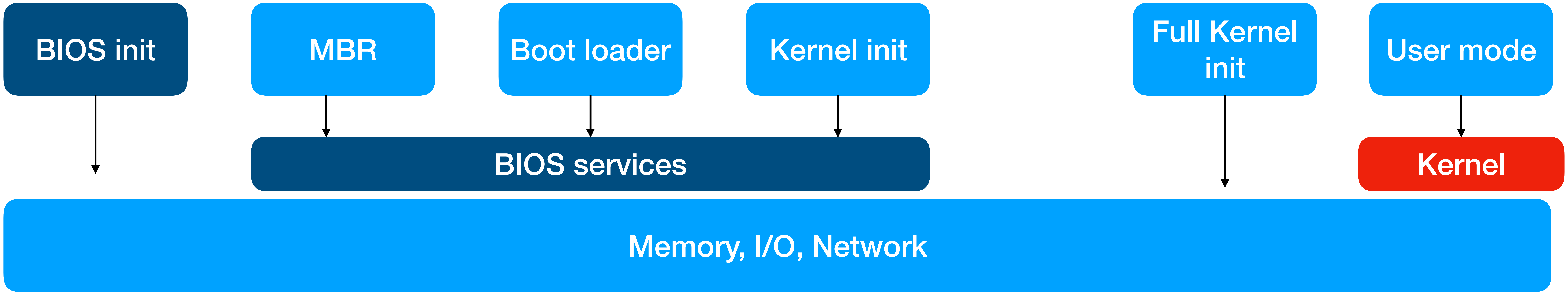
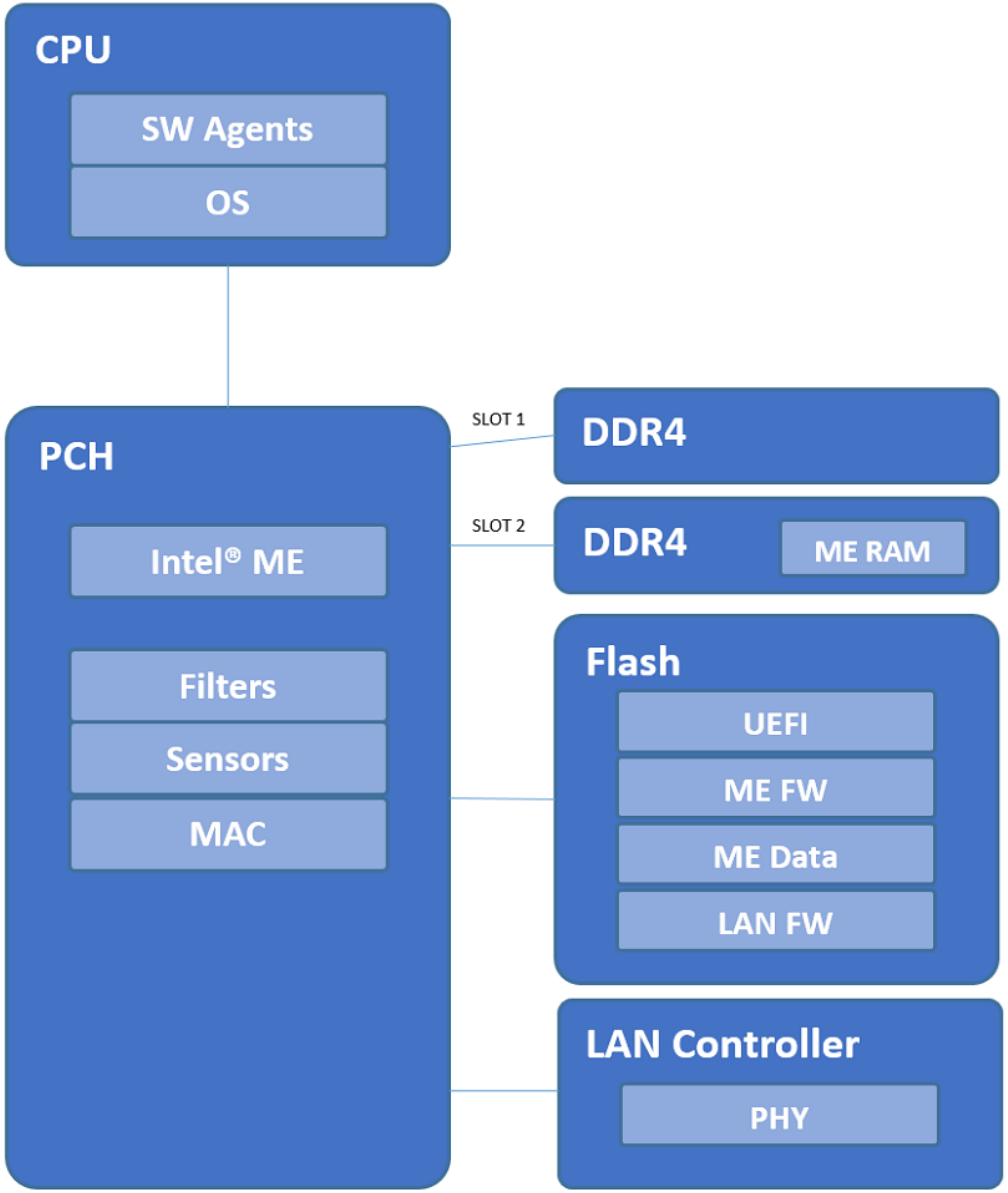
System Model: how does a computer boot?



https://www.intel.com/content/www/us/en/intelligent-systems/intel-boot-loader-development-kit/minimal-intel-architecture-boot-loader-paper.html

More details



Layout of memory at boot

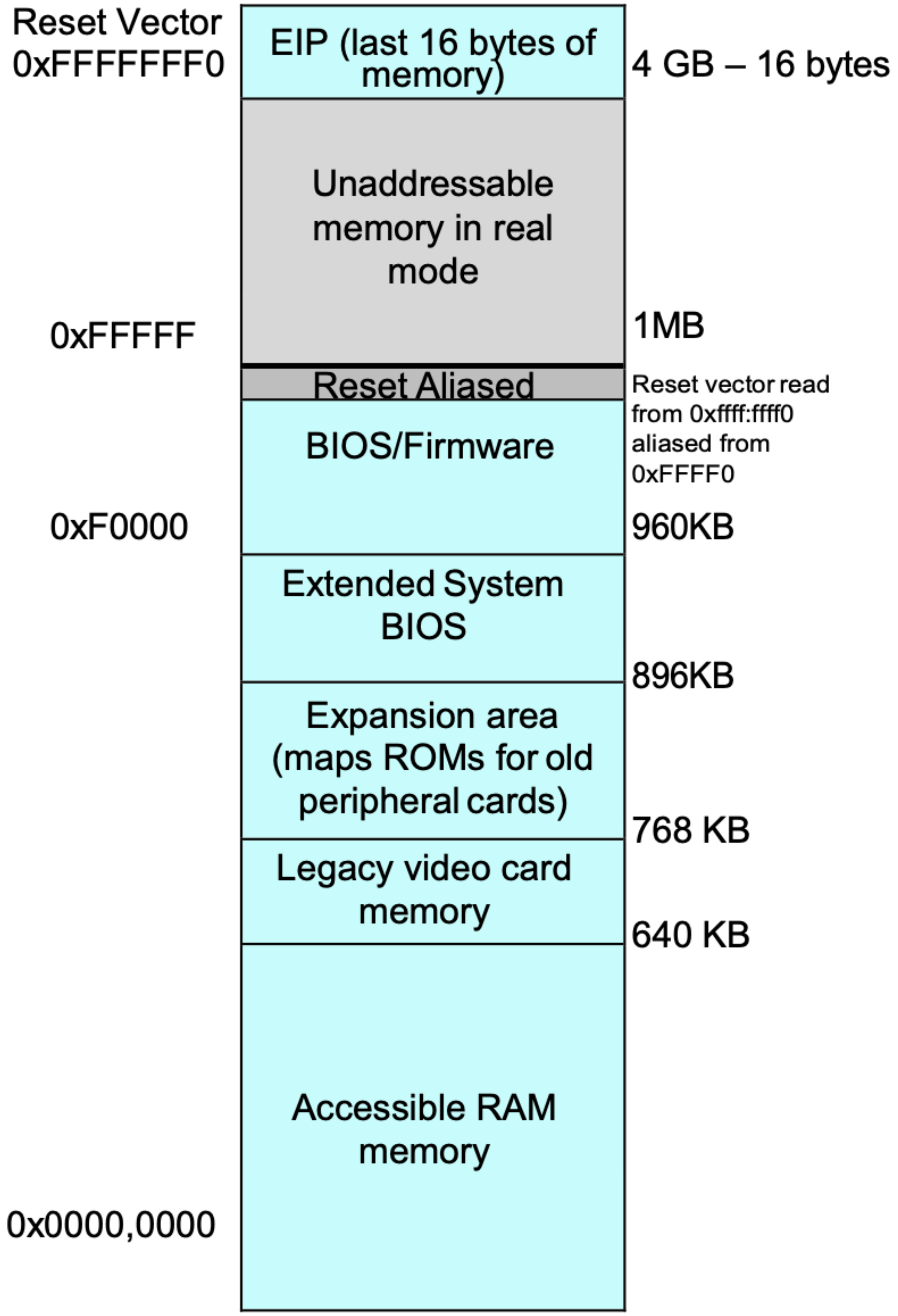
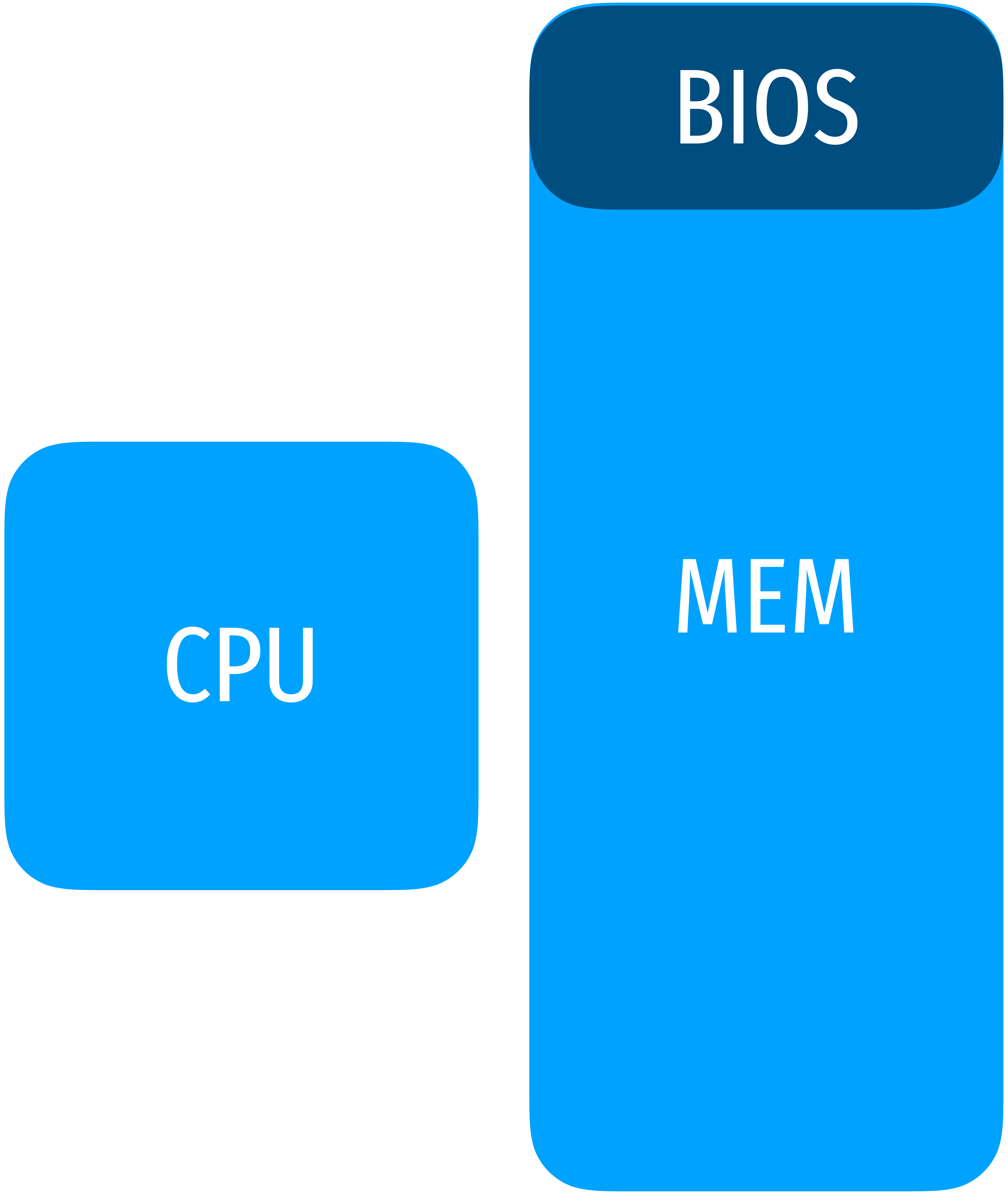


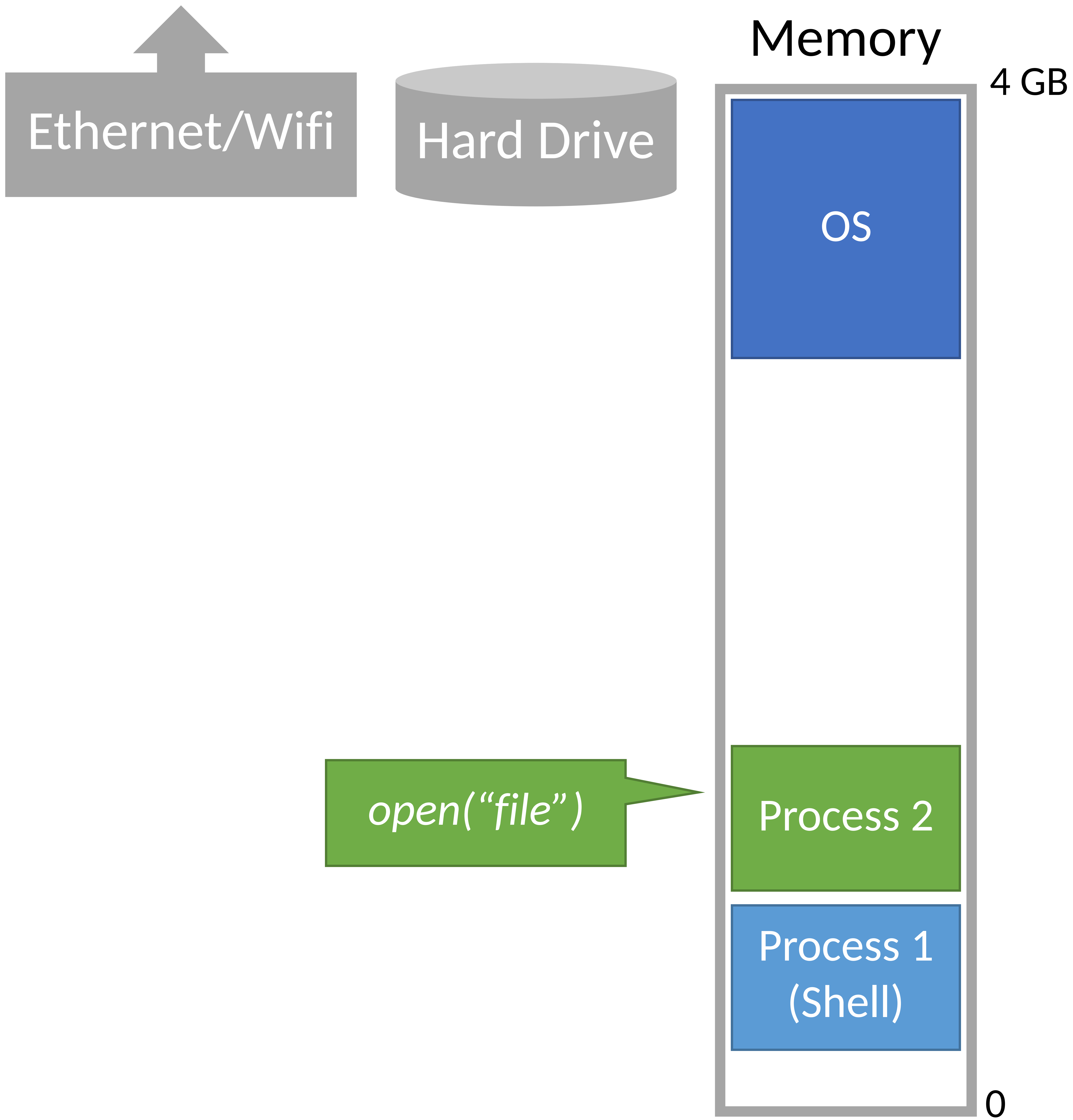
Figure 3 Intel® Architecture Memory Map at Power On

Details

CPU begins executing at f.fff0
BIOS firmware begins init of hw
Applies microcode patches
Execute Firmware Support Pkg (blob)
[Ram is setup]
Copy firmware to RAM
Begin executing in RAM
Setup interrupts, timers, clocks
Bring up other cores
Setup PCI
Setup ACPI tables
Execute OS loader



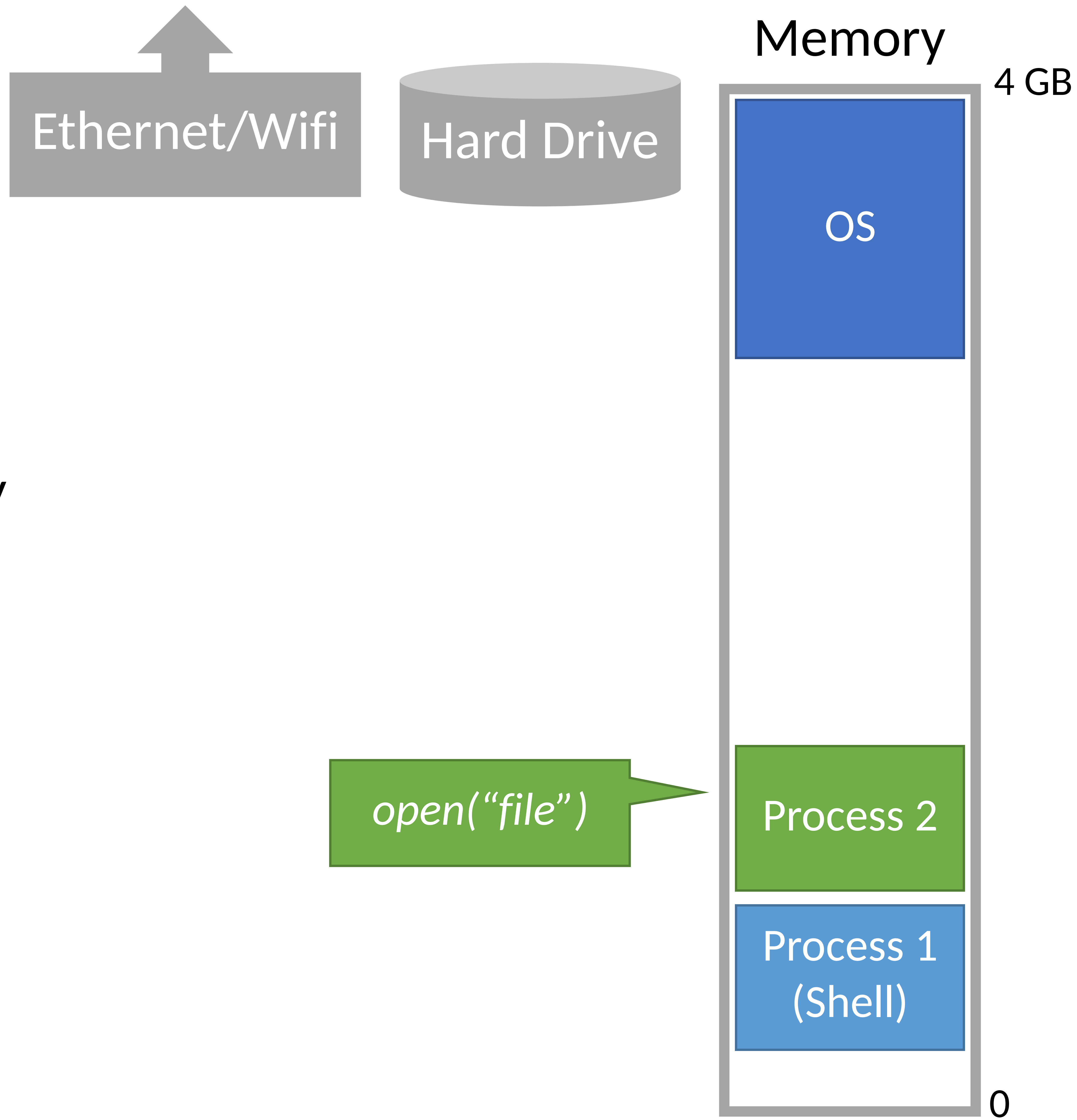
System Model



System Model

On bootup, the Operating System (OS) loads itself into memory

- eg. DOS (before hw isolation)
- Typically places itself in high memory



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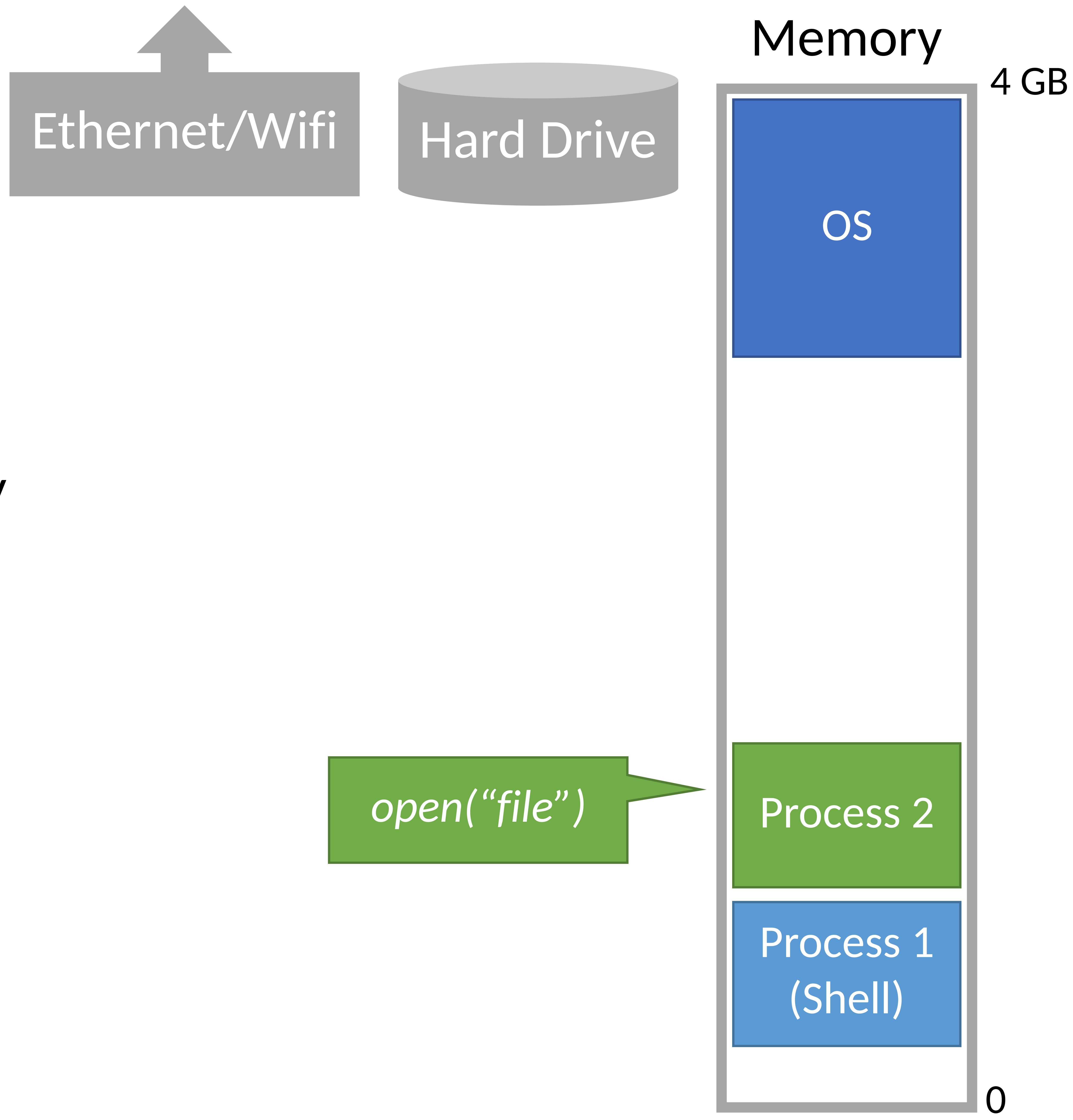
- Allow the user to run processes
- Often comes with a shell
  - Text shell like bash
  - Graphical shell like the Windows desktop
- Provides APIs to access devices
  - Offered as a convenience to application developers



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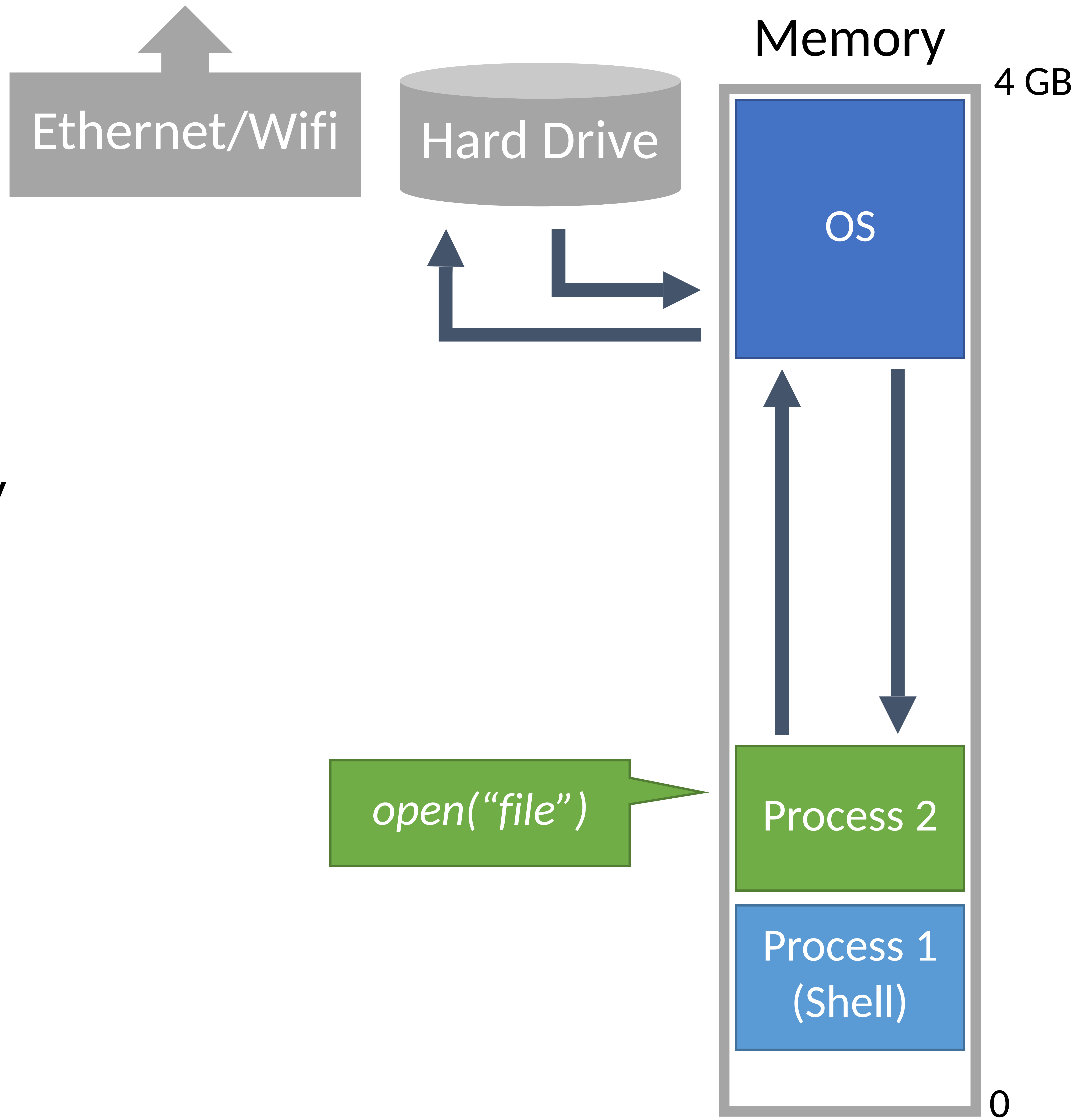
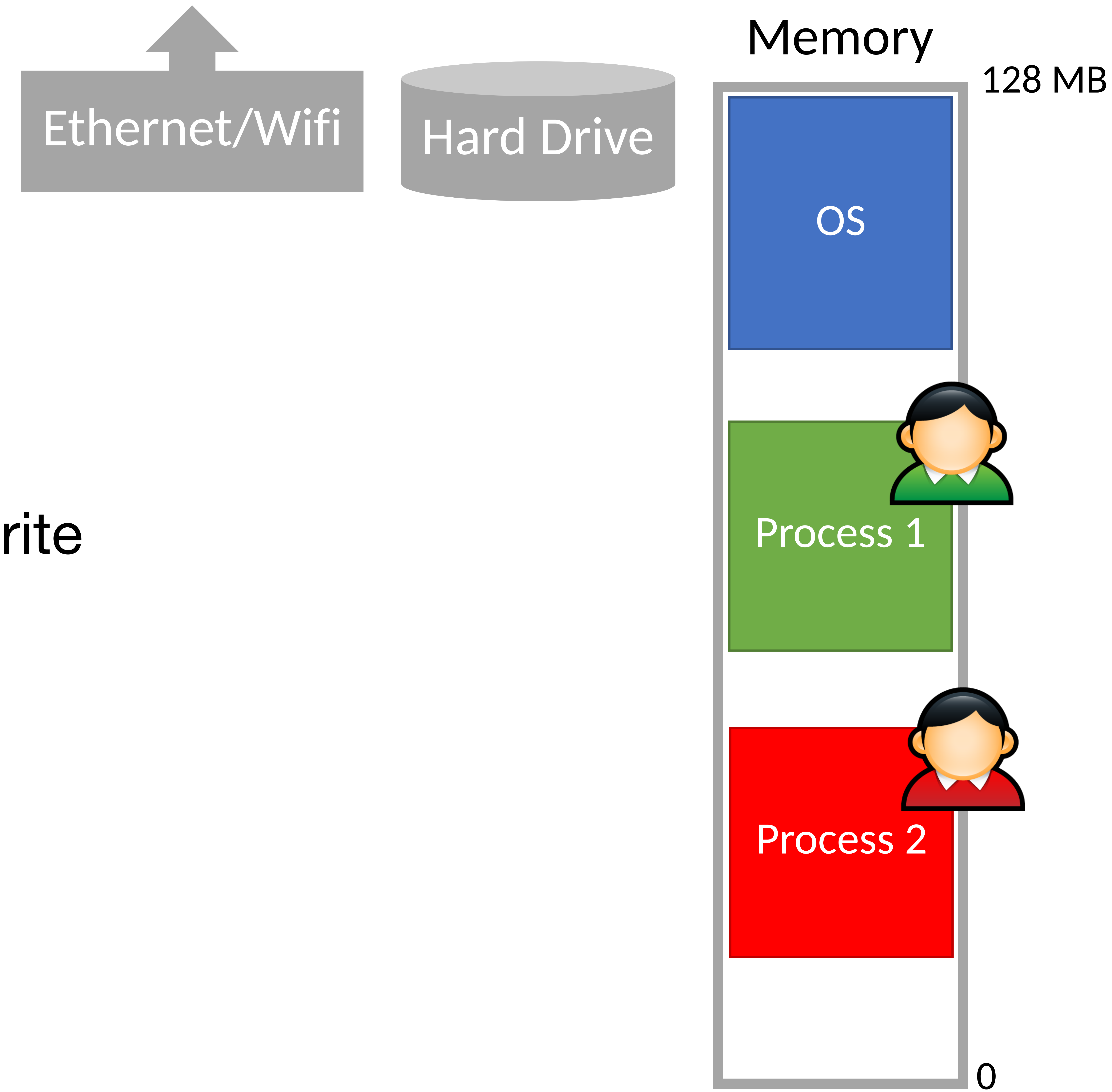


Memory Unsafety



Problem: any process can read/write any memory

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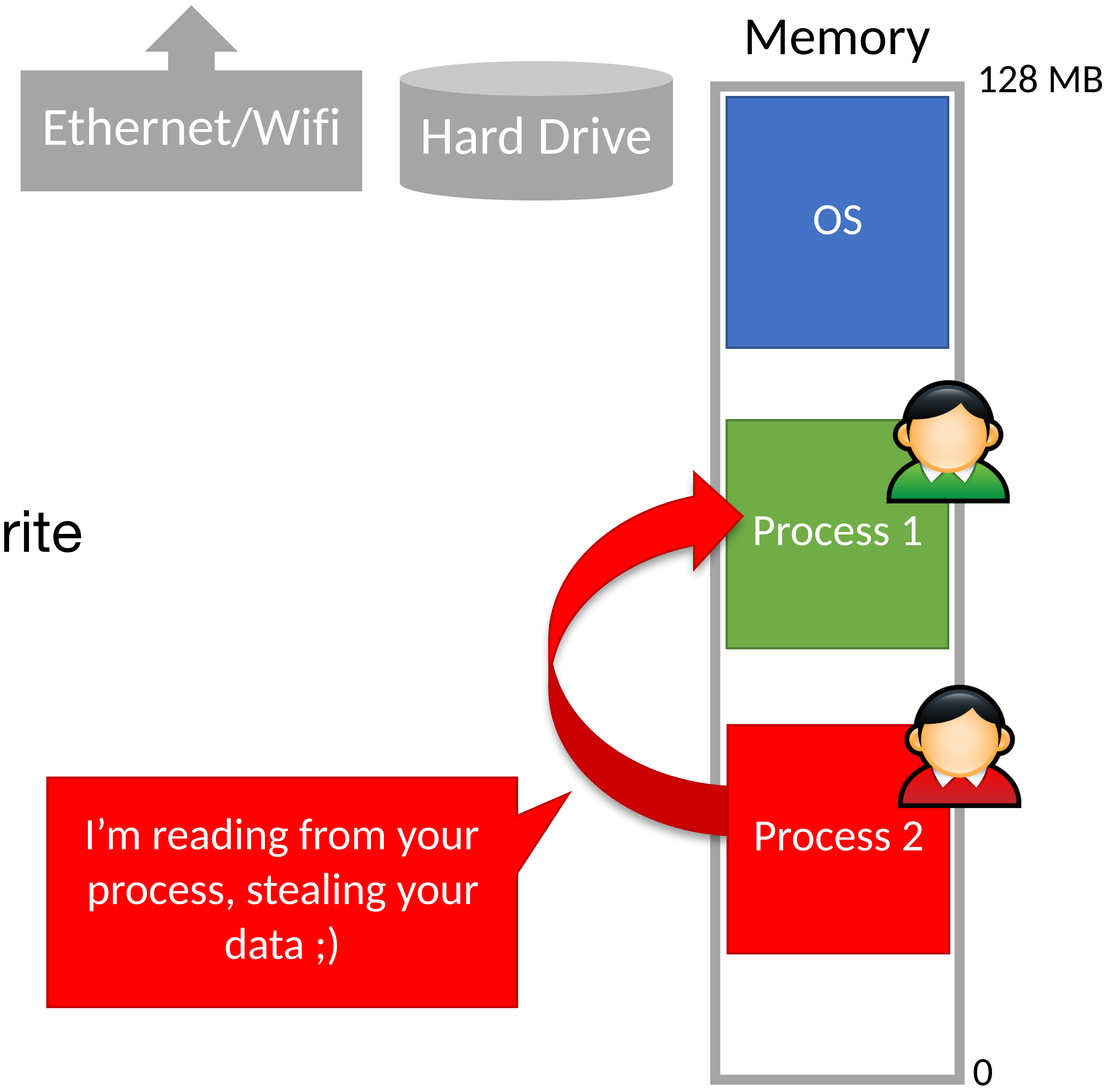

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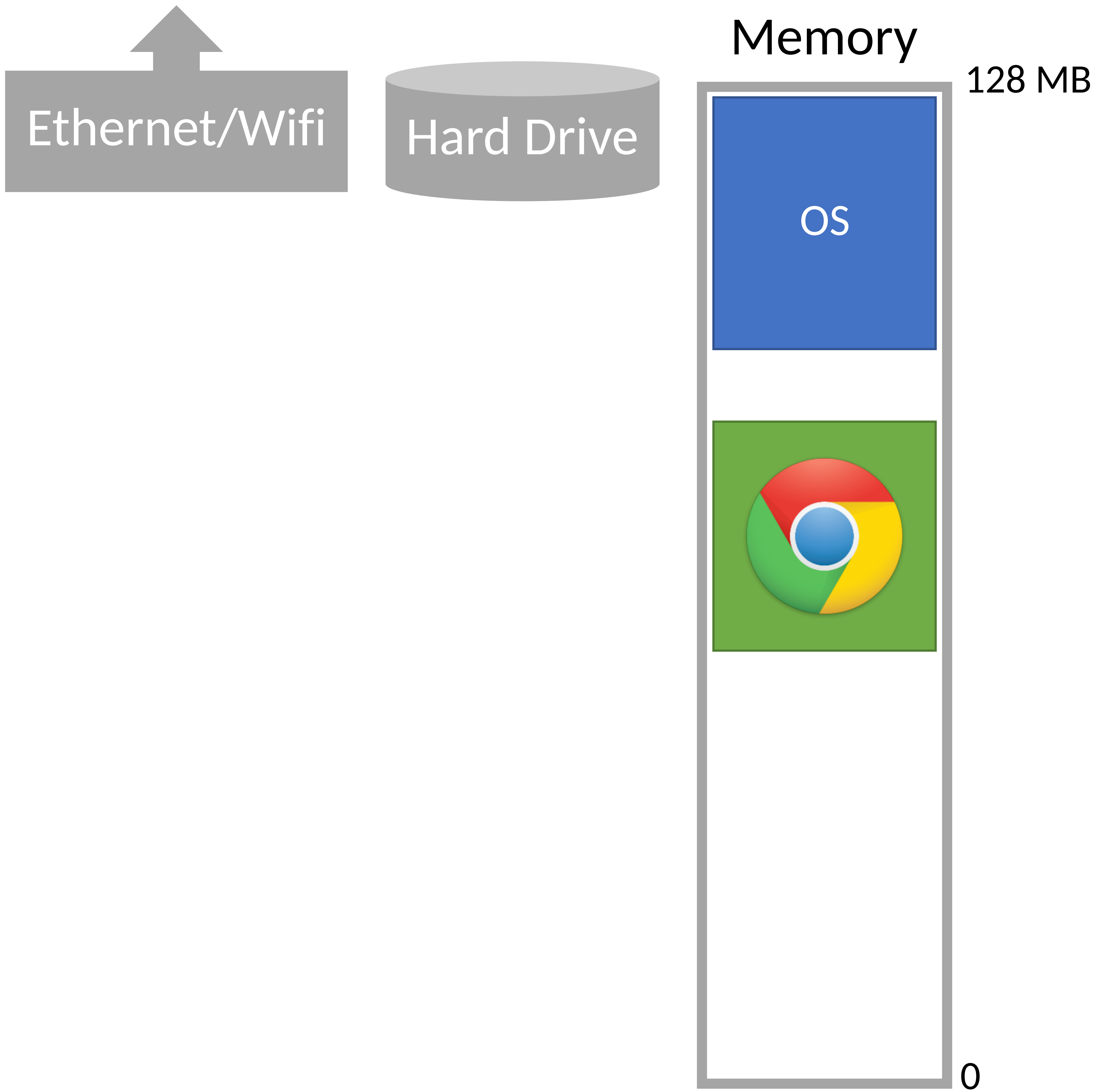

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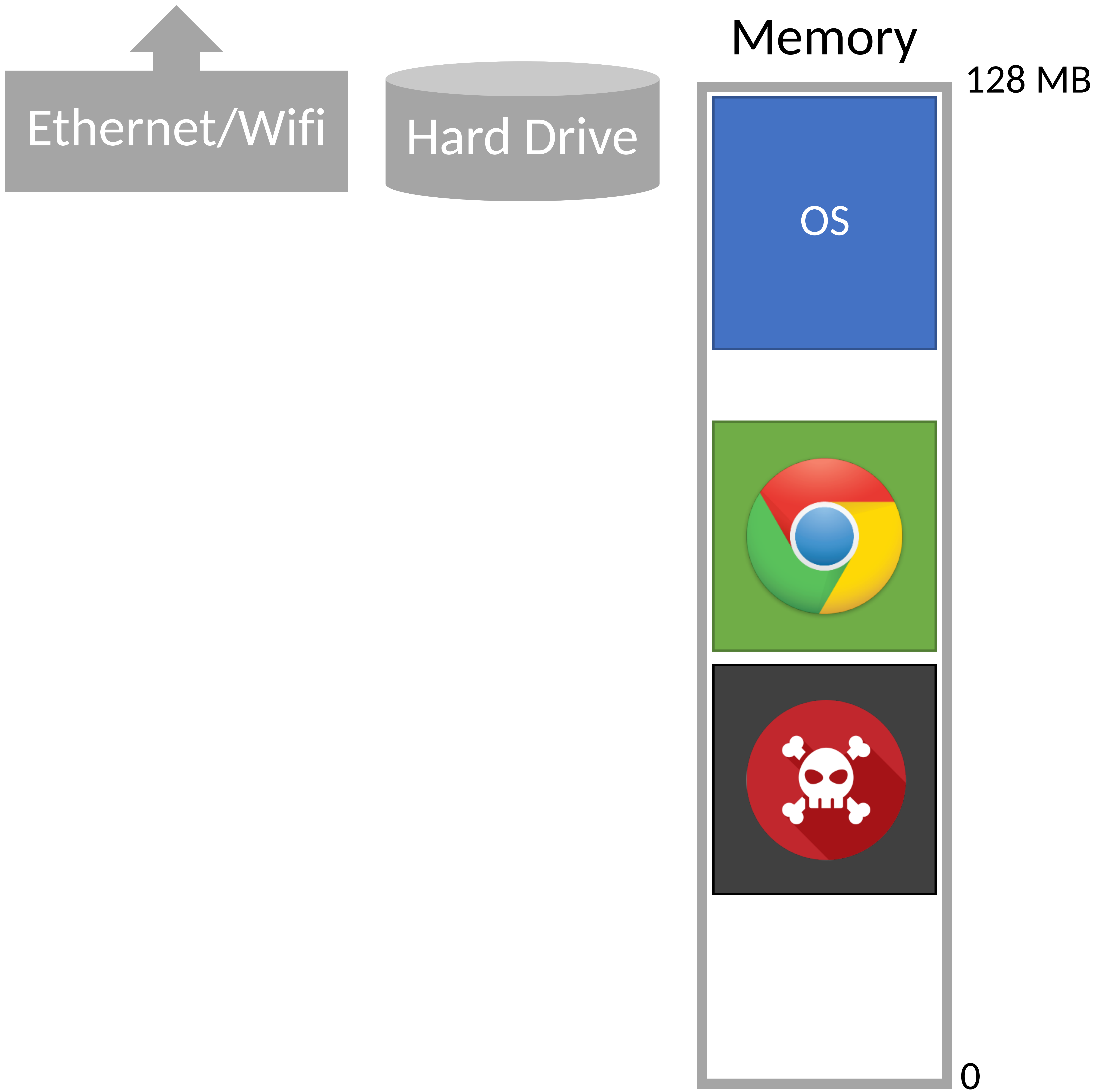

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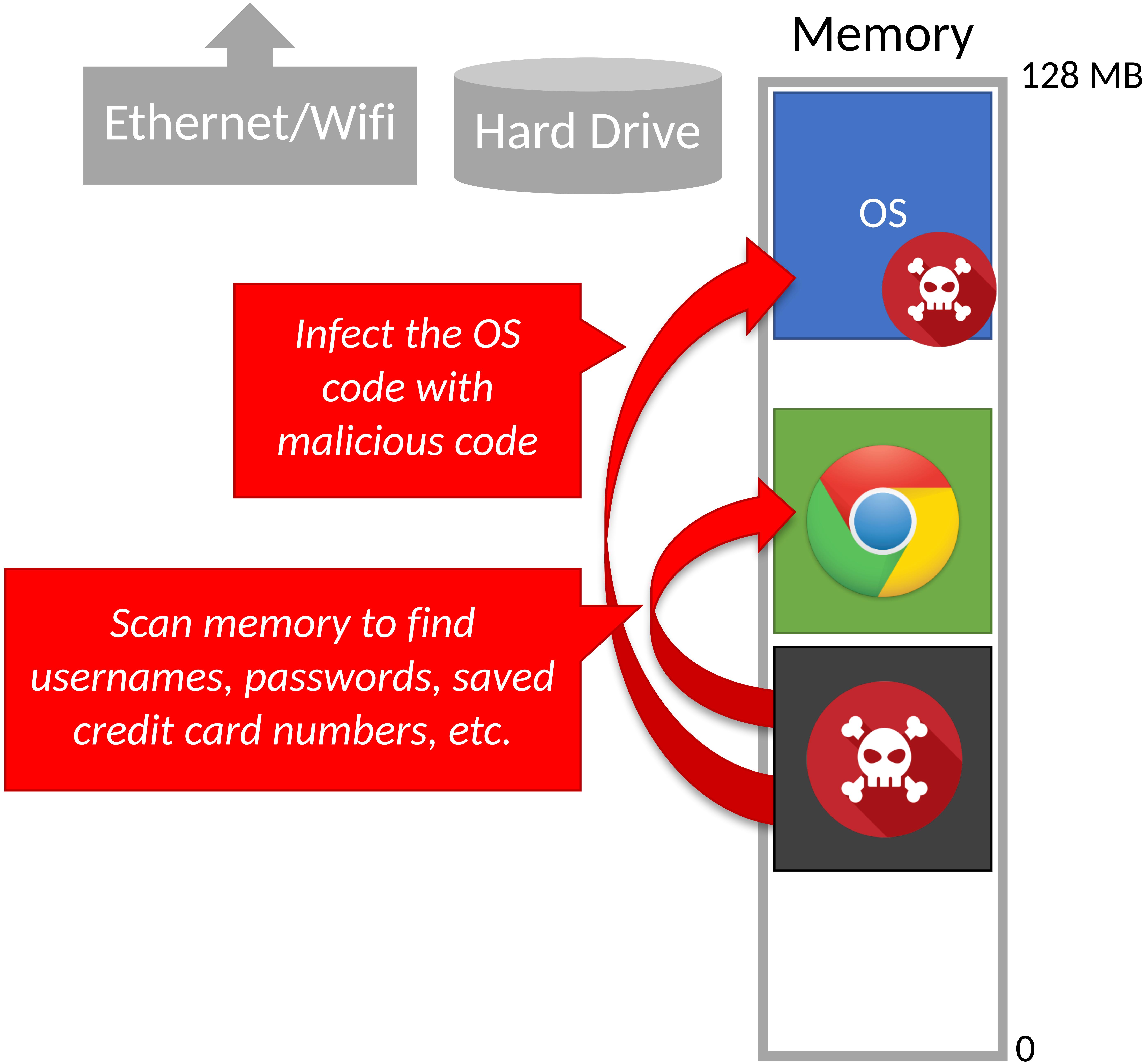

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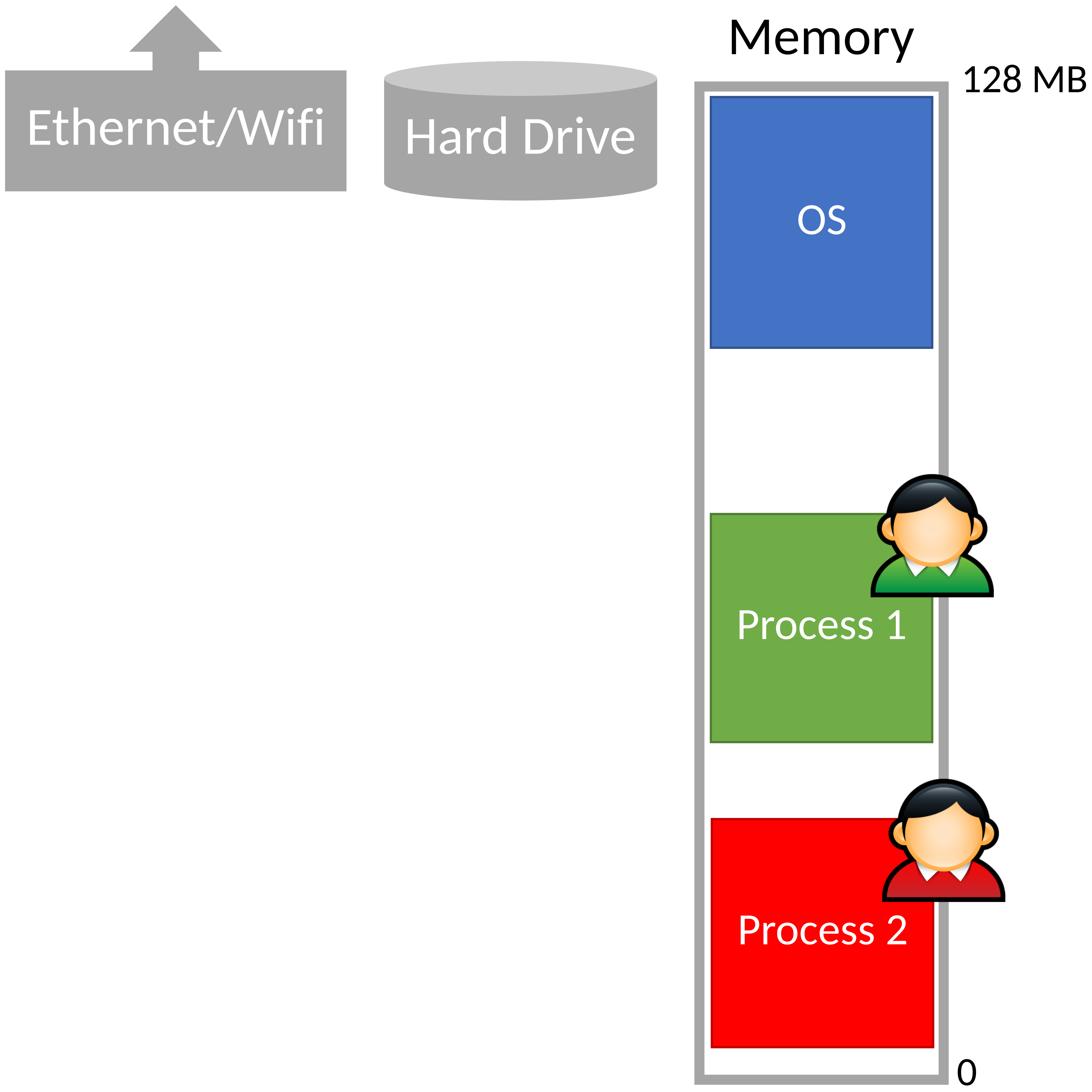

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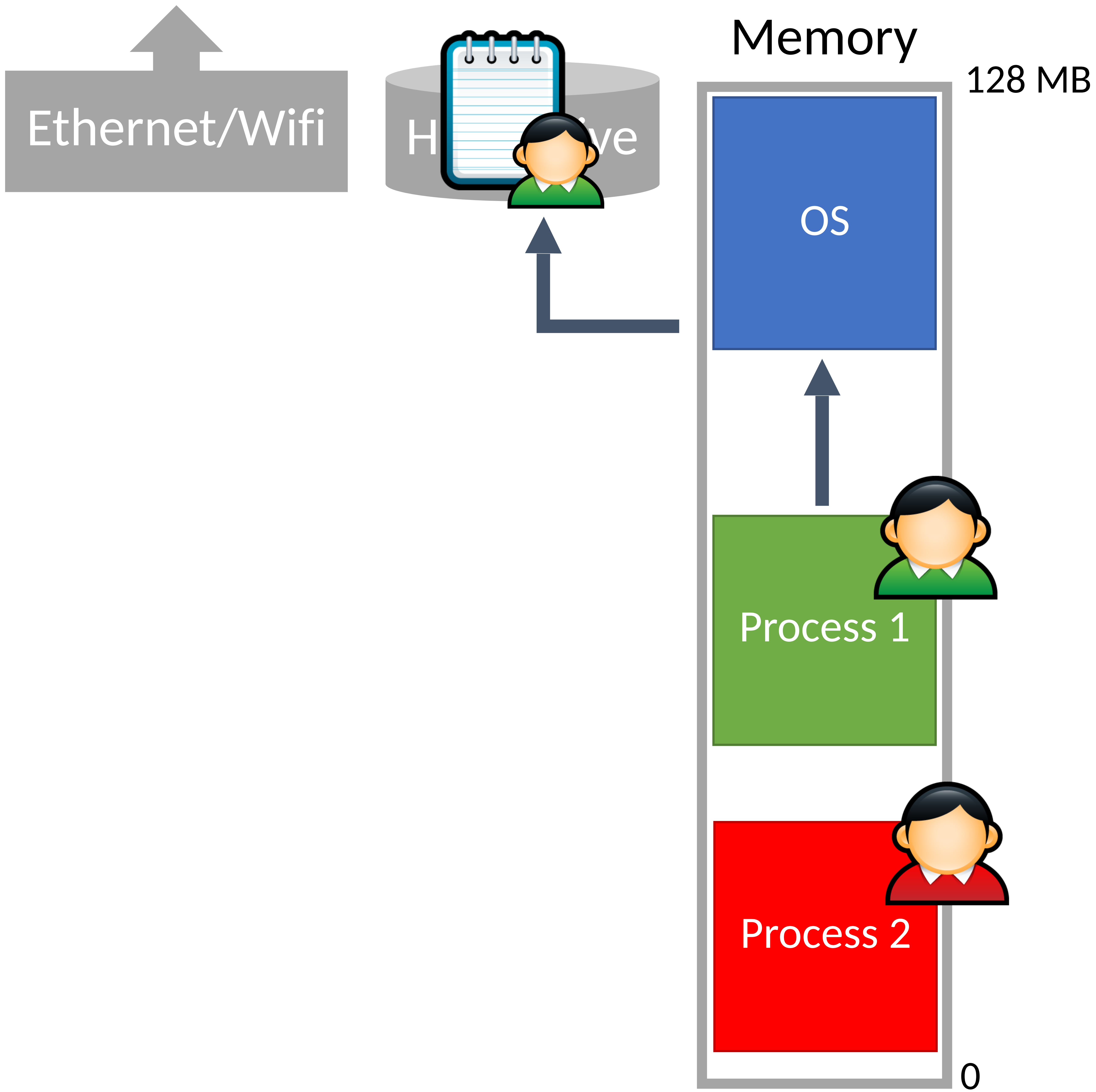

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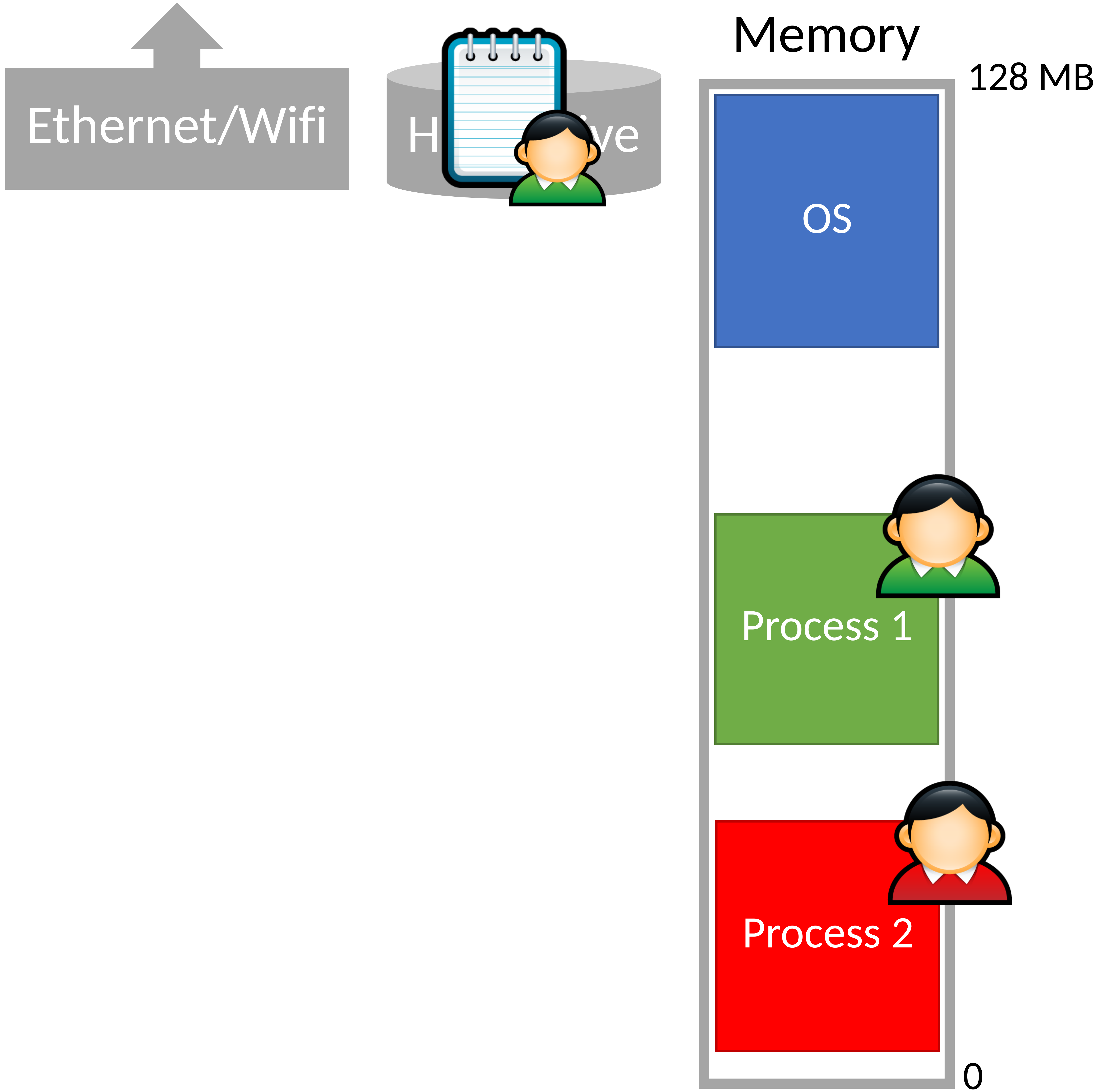

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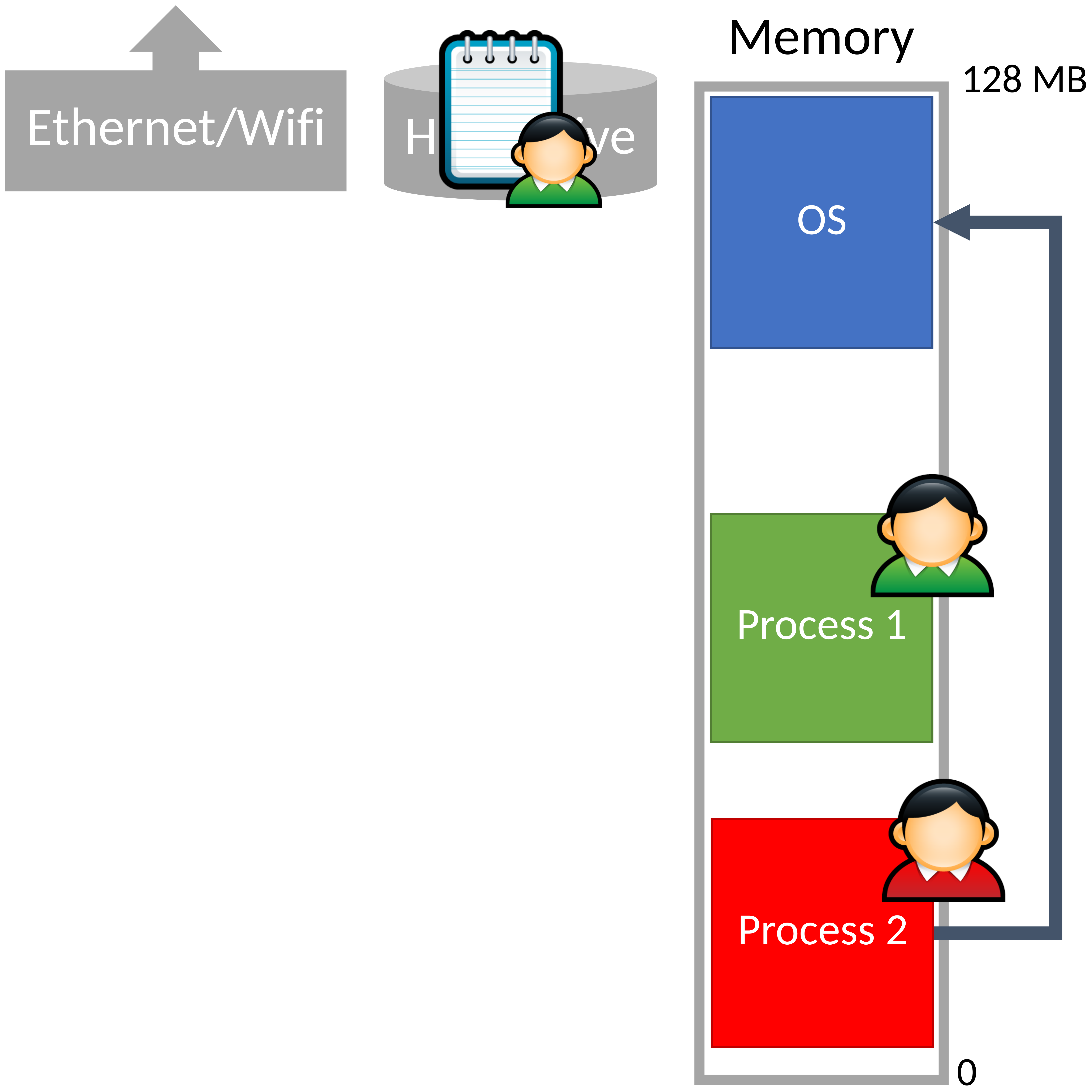

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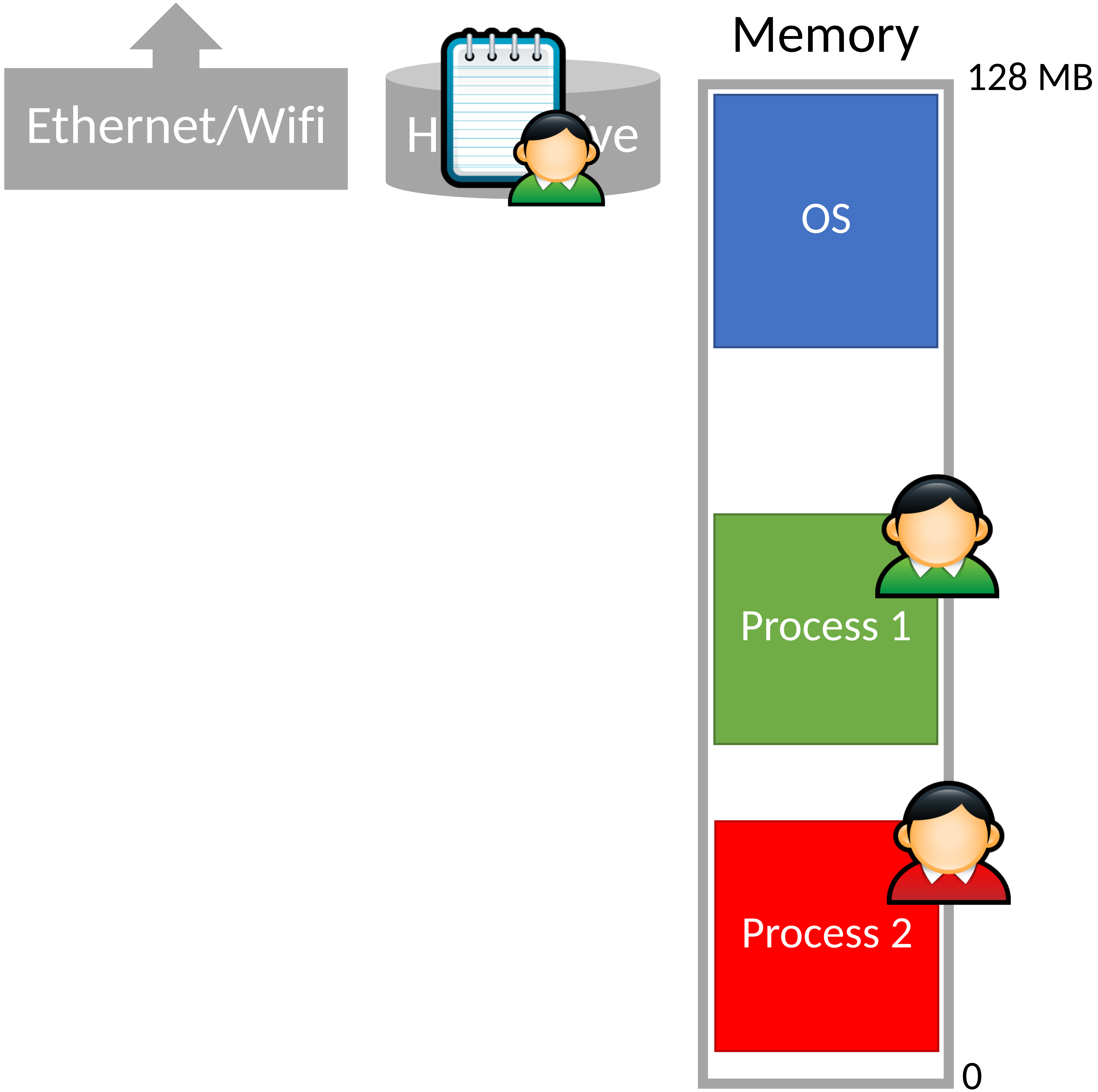

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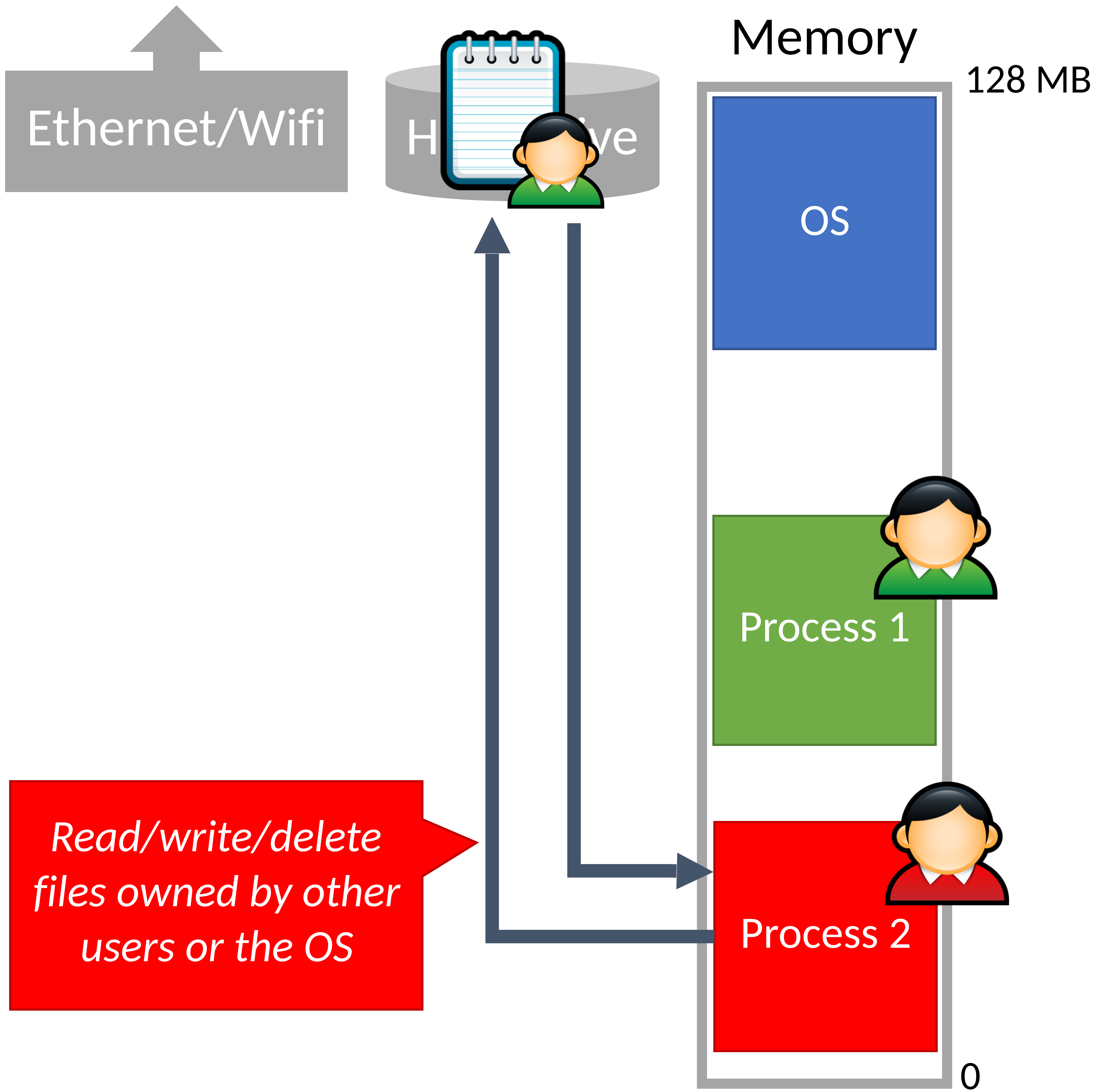

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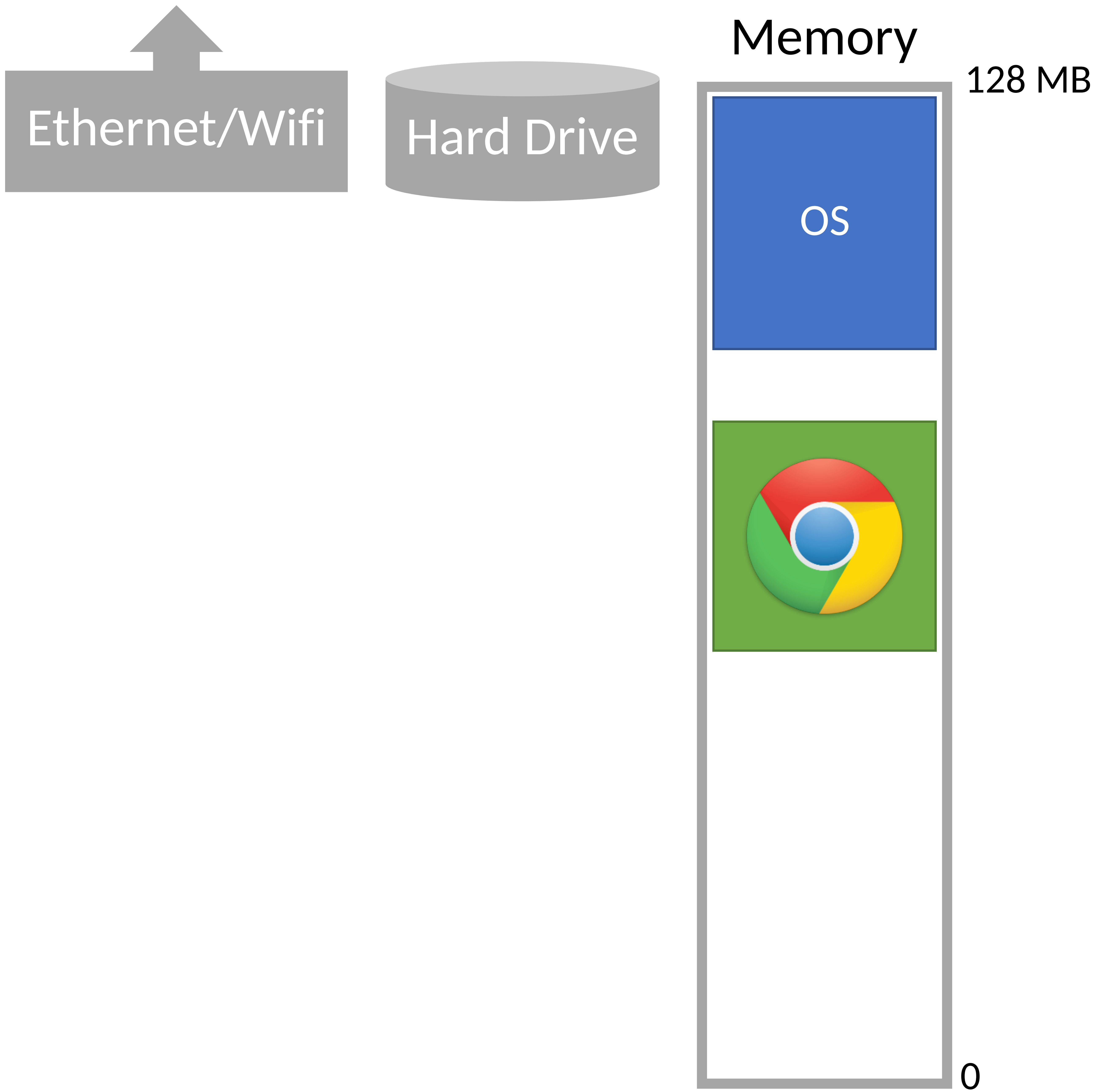

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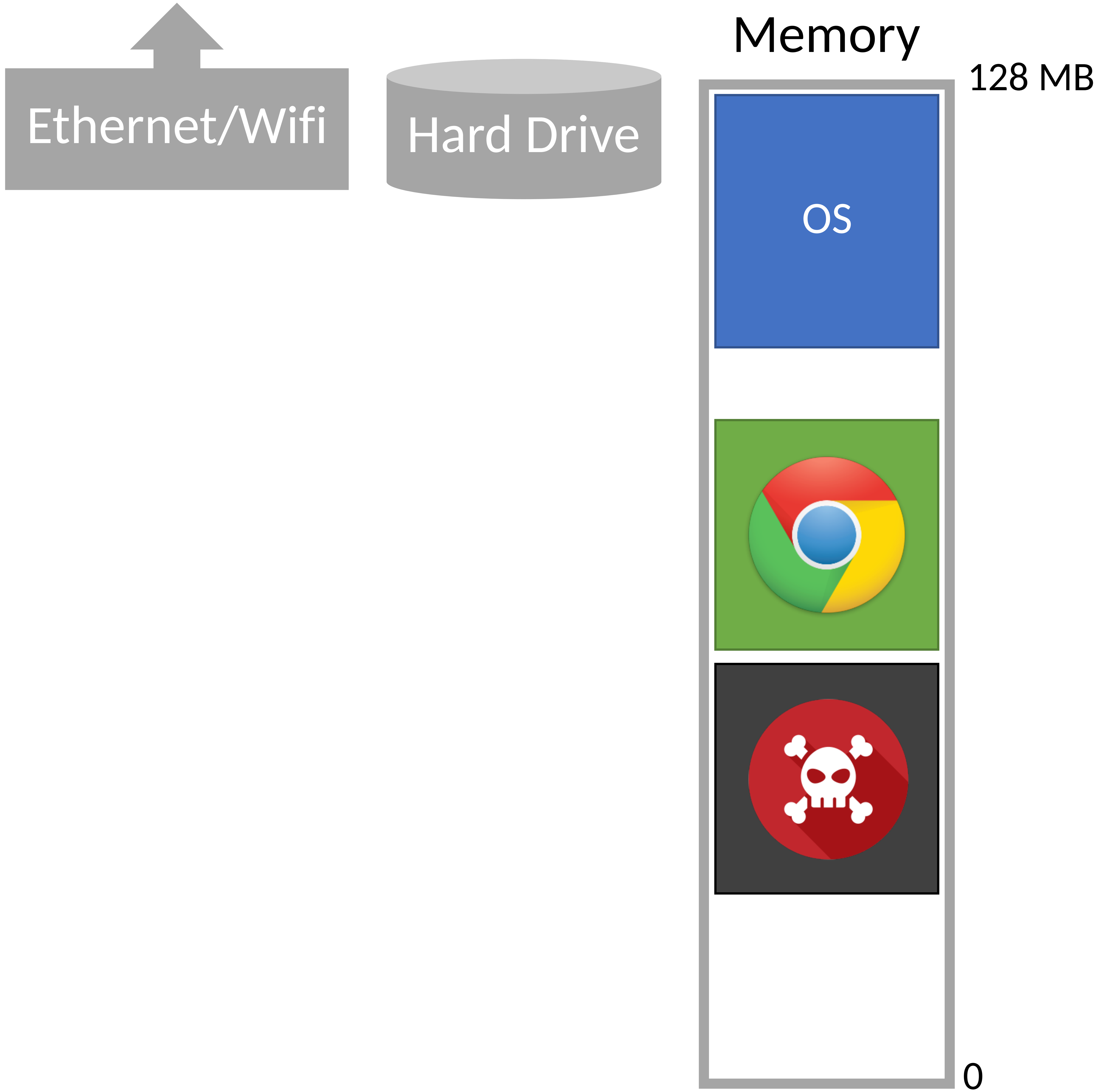

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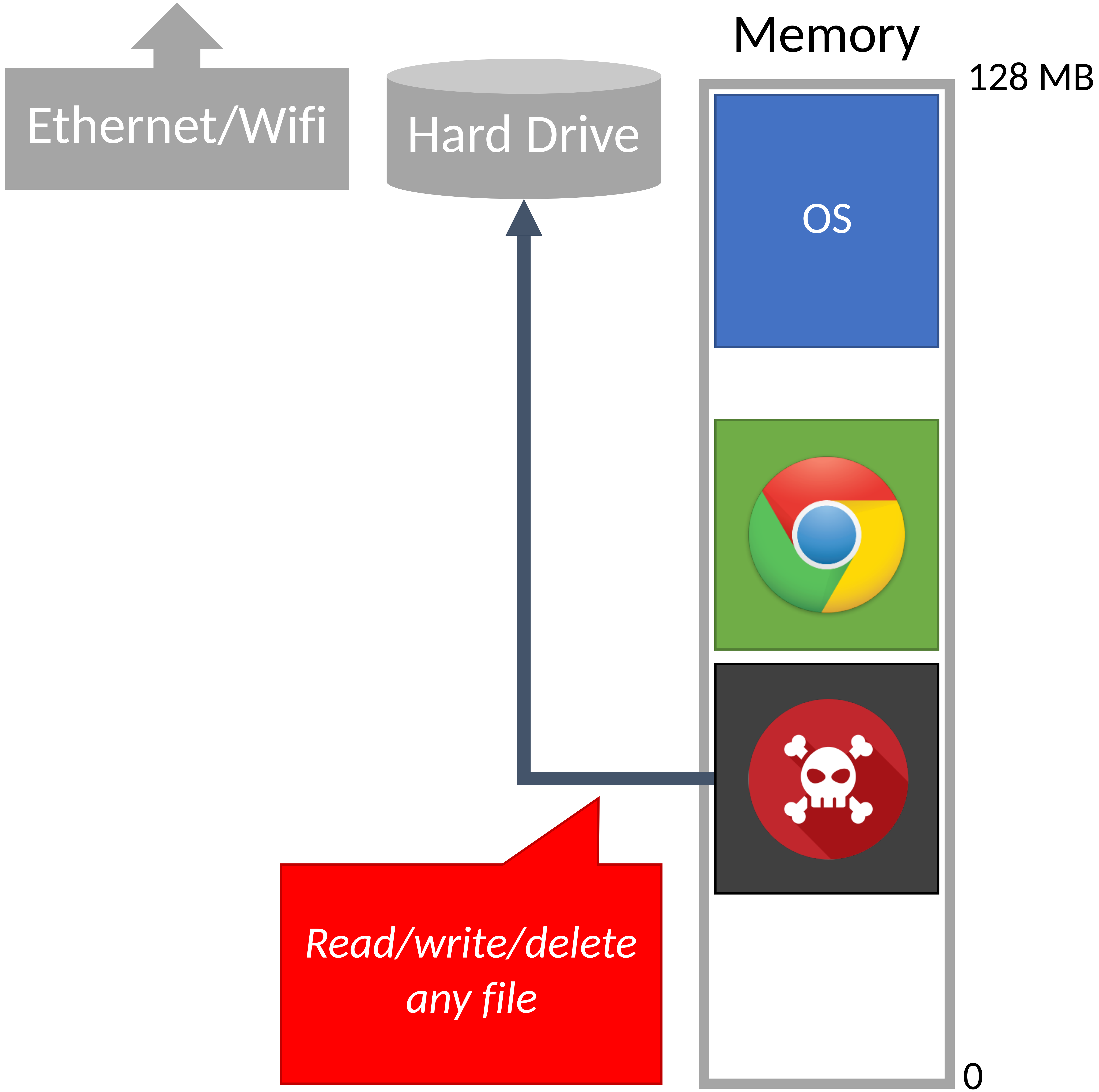

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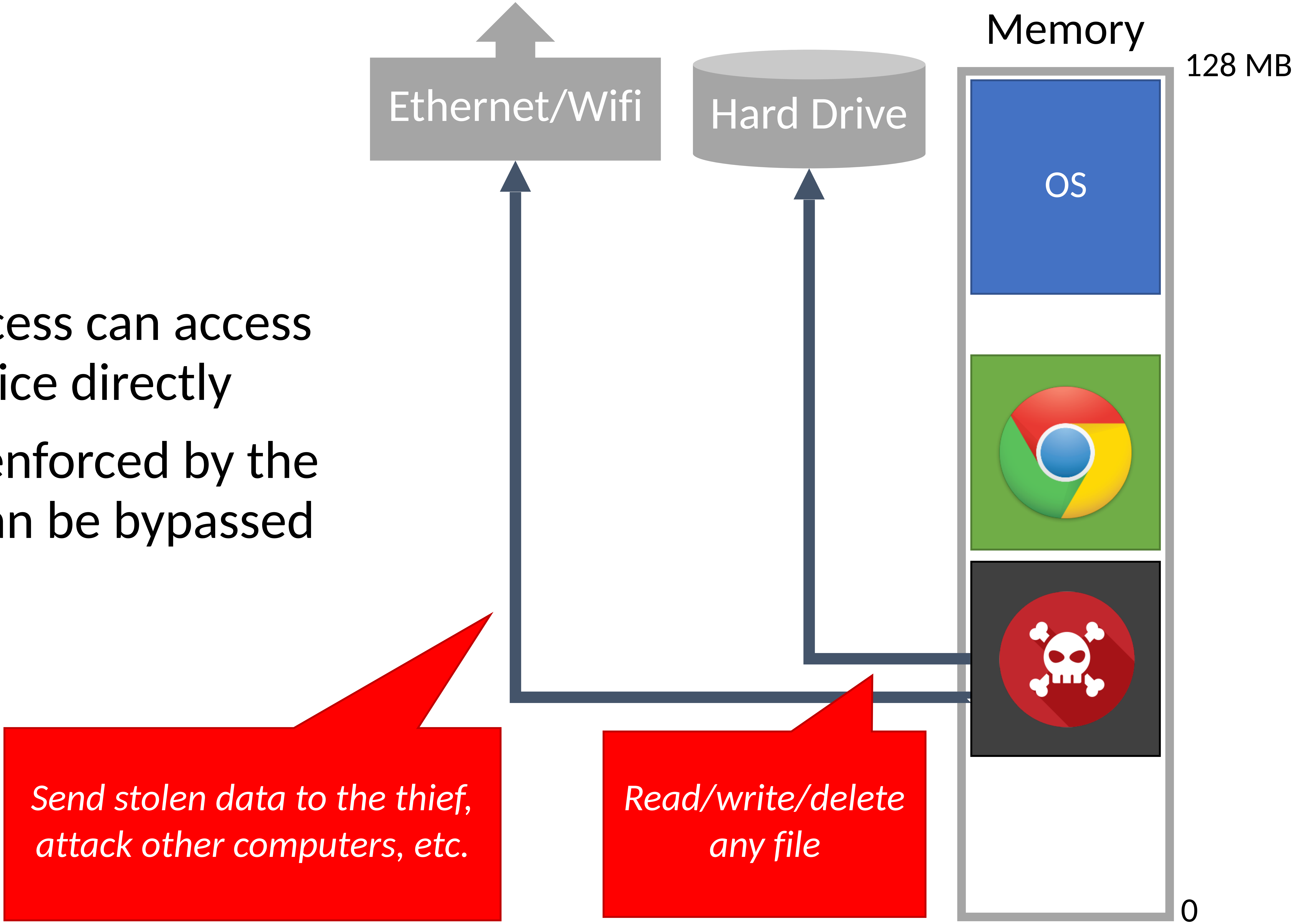

Review

Old systems did not protect memory or devices

- Any process could access any memory
- Any process could access any device

Problems

- No way to enforce access controls on users or devices
- Processes can steal from or destroy each other
- Processes can modify or destroy the OS

On old computers, systems security was literally impossible

ISOLATION

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ASUS

Towards Modern Architecture

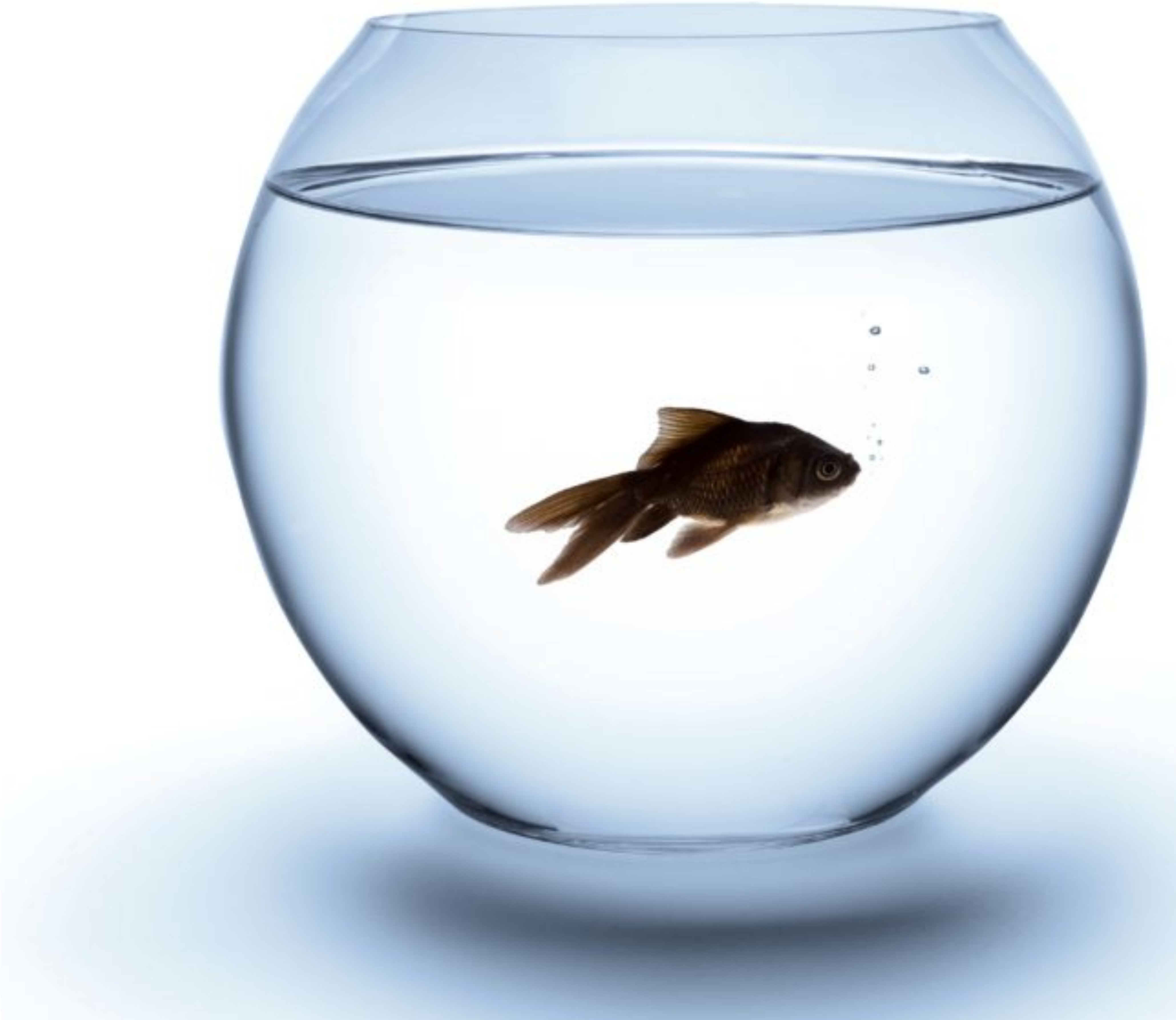
To achieve systems security, we need process isolation

- Processes cannot read/write memory arbitrarily
- Processes cannot access devices directly

How do we achieve this?

Hardware support for isolation

1. Protected mode execution (a.k.a. process rings)
2. Virtual memory



Protected Mode

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Most modern CPUs support protected mode

x86 CPUs support three rings with different privileges

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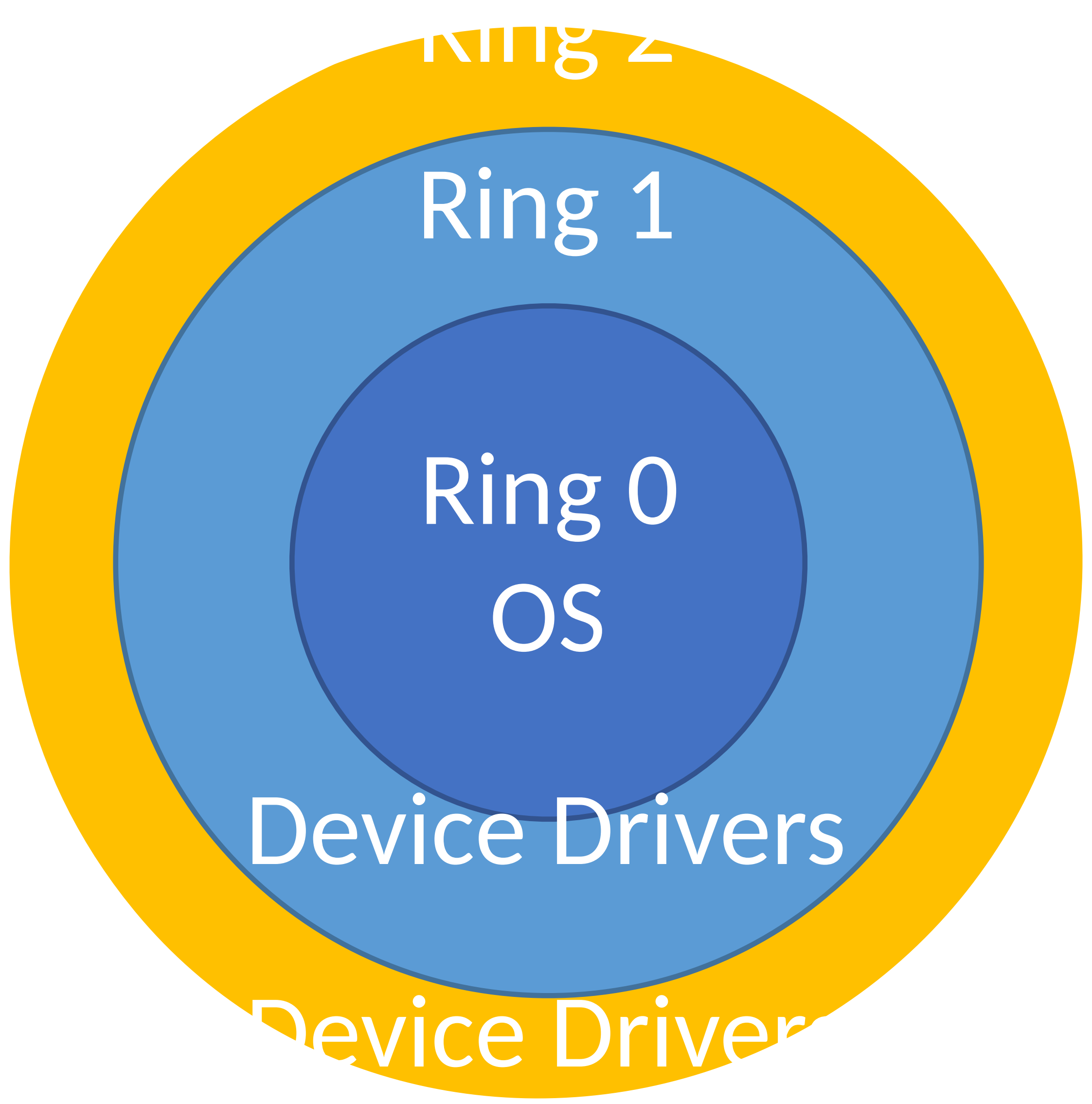
  - Code in these rings may directly access some devices
  - May not change the protection level of the CPU



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- Ring 3: userland
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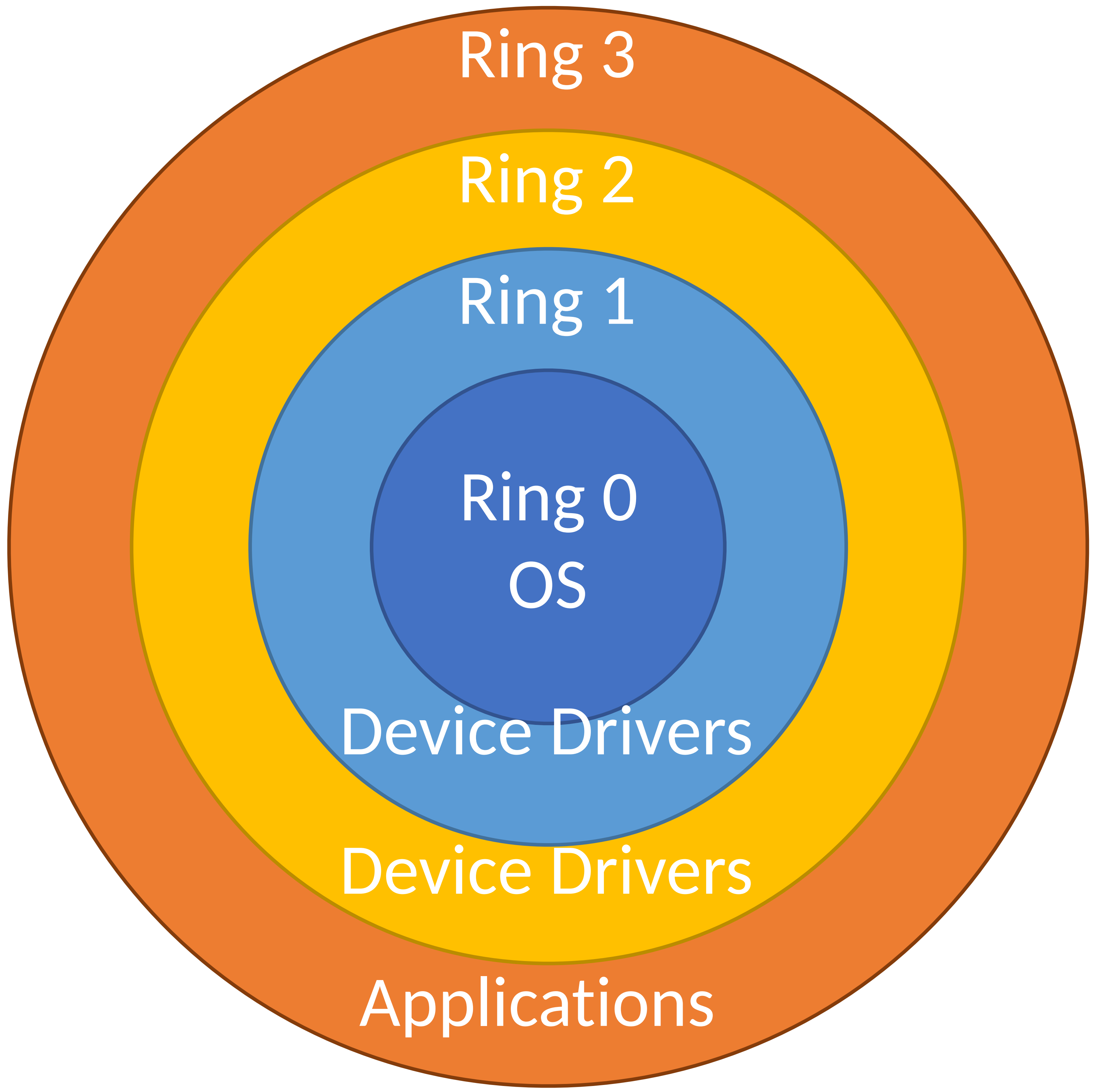

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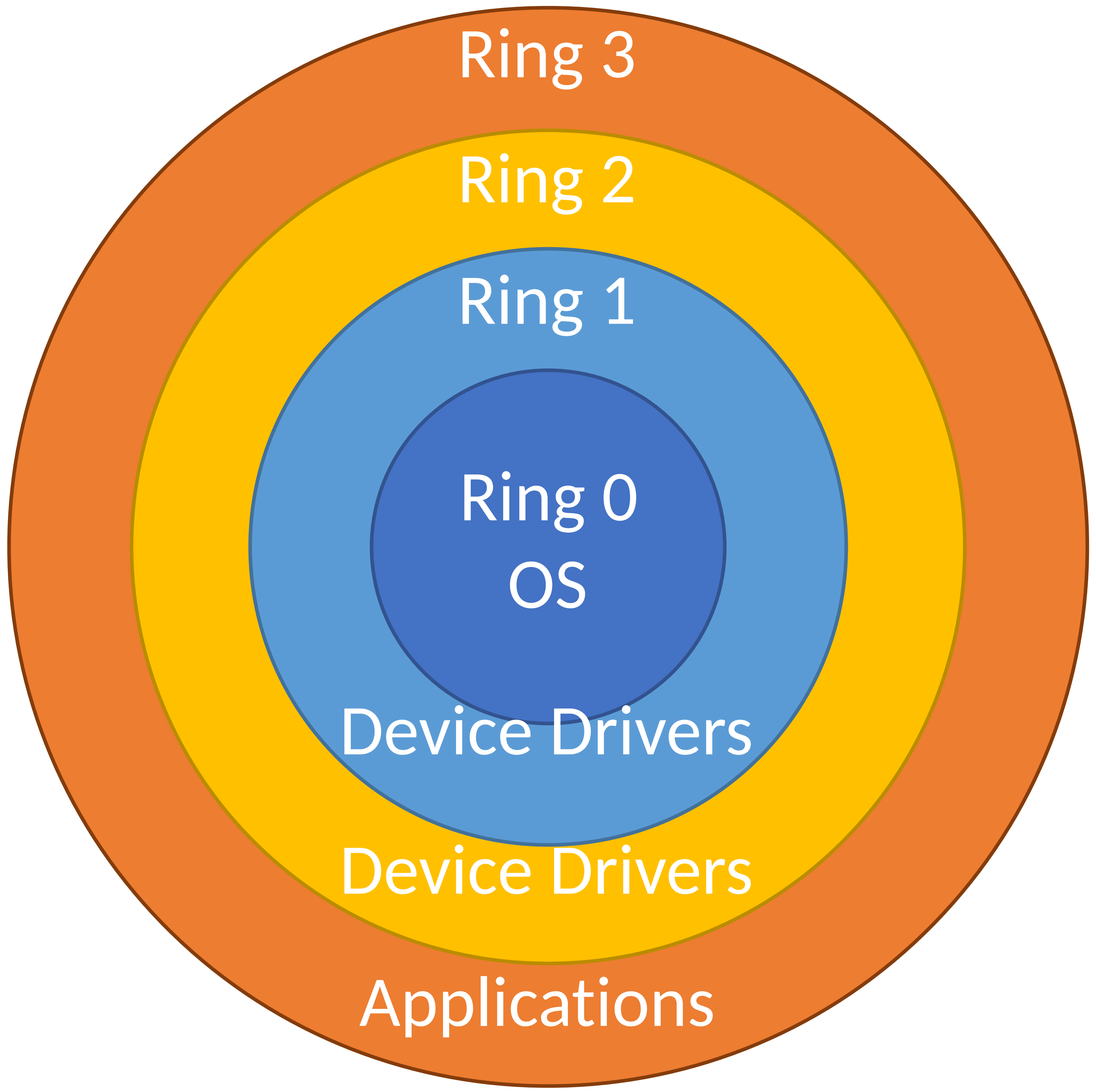
- Most OSes only use rings 0 and 3



Ring -1,-2,-3

“Google cited worries that the Intel ME (actually MINIX) code runs on their CPU's deepest access level — Ring "-3" — and also runs a web server component that allows anyone to remotely connect to remote computers, even when the main OS is turned off.”

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4. Shell gets executed, user may run programs
    - User processes are placed in Ring 3

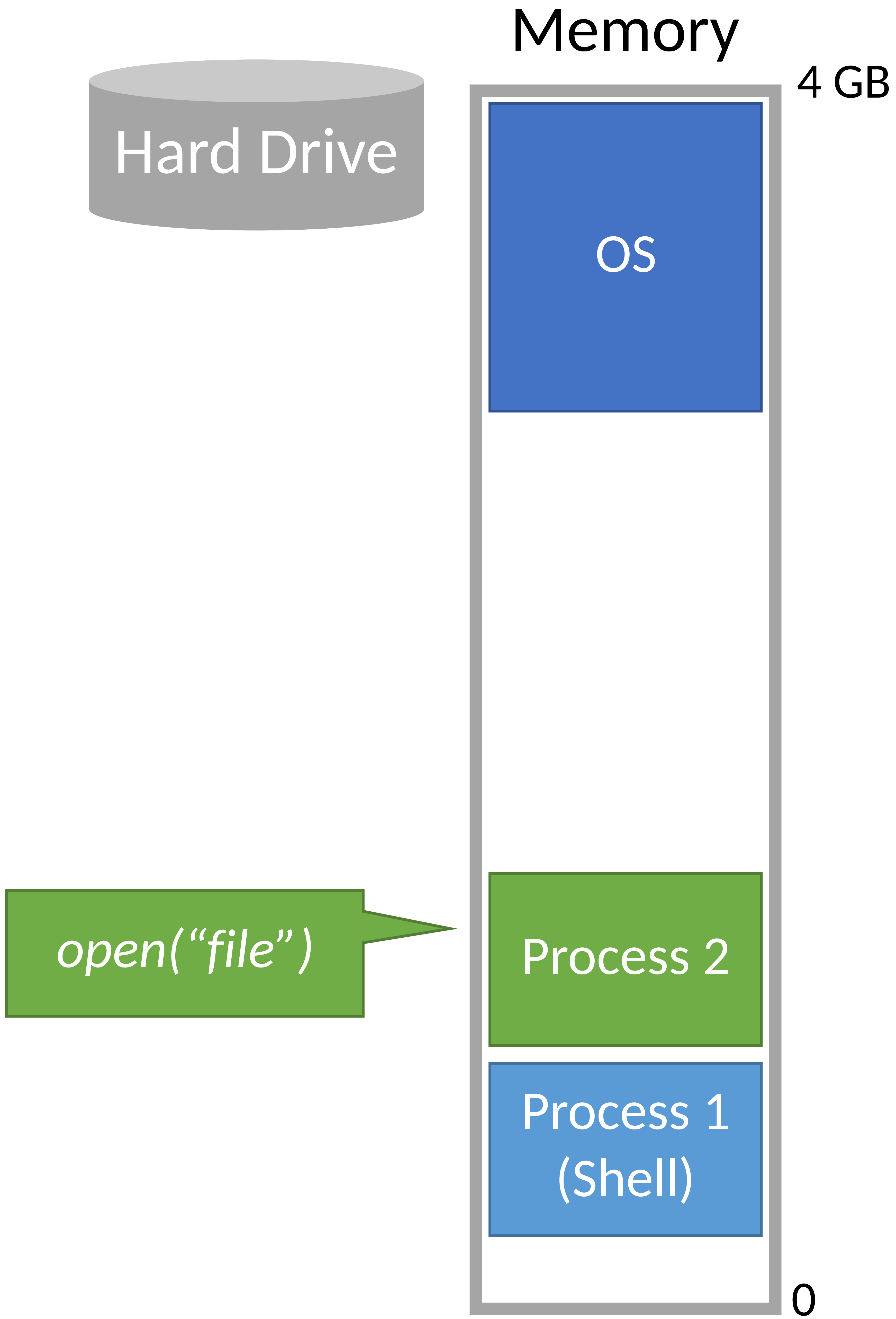
Restriction on Privileged Instructions

What CPU instructions are restricted in protected mode?

- Any instruction that modifies the CR0 register
  - Controls whether protected mode is enabled
- Any instruction that modifies the CR3 register
  - Controls the virtual memory configuration
  - More on this later…
- hlt – Halts the CPU
- sti/cli – enable and disable interrupts
- in/out – directly access hardware devices

If a Ring 3 process tries any of these things, it immediately crashes

How to change modes



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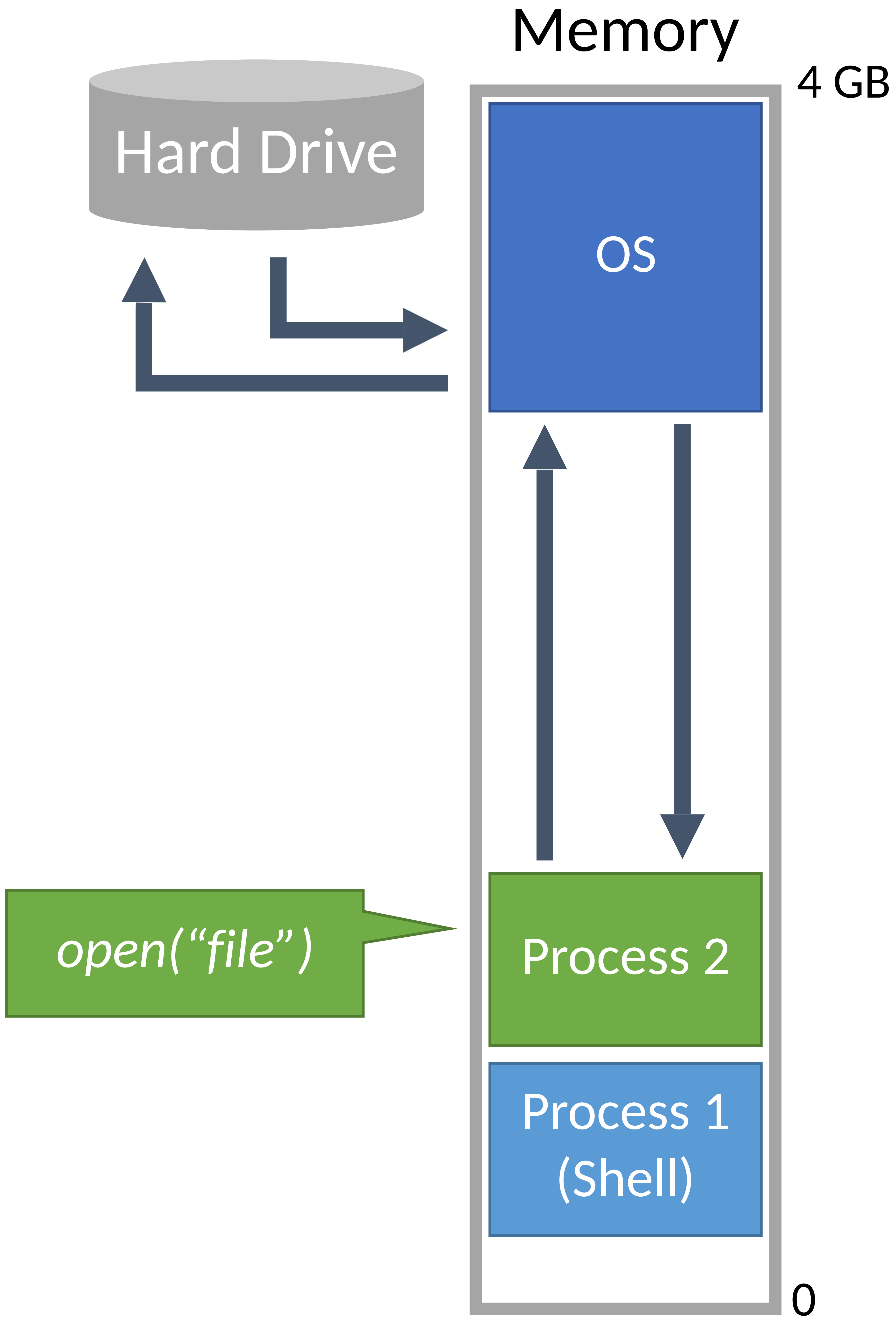

Changing Modes

Applications often need to access the OS APIs

- Writing files
- Displaying things on the screen
- Receiving data from the network
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But the OS is Ring 0, and processes are Ring 3

How do processes get access to the OS?

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How do processes get access to the OS?

- Invoke OS APIs with special assembly instructions
  - Interrupt: `int 0x80`
  - System call: `sysenter` or `syscall`
- `int`/`sysenter`/`syscall` cause a mode transfer from Ring 3 to Ring 0

Mode Transfer

Userland

1. Application executes trap (int) instruction
   - EIP, CS, and EFLAGS get pushed onto the stack
   - Mode switches from ring 3 to ring 0

Kernel Mode

Mode Transfer

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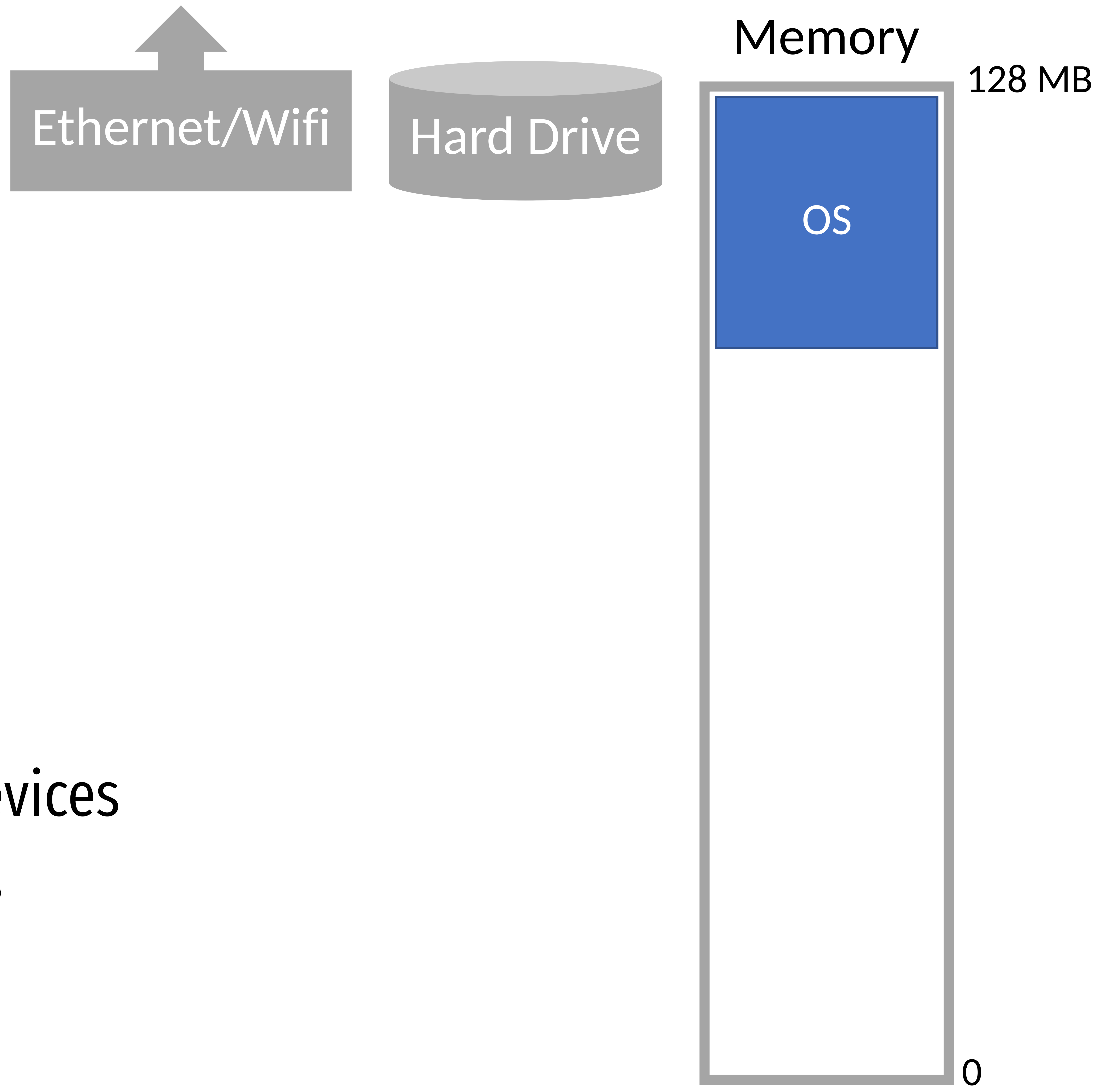
5. Place the return value in EAX
6. Use iret to return to the process
   - Switches back to the original mode (typically 3)

Protection in Action



Protected mode stops direct access to devices

All device access must go through the OS

OS will impose access control checks

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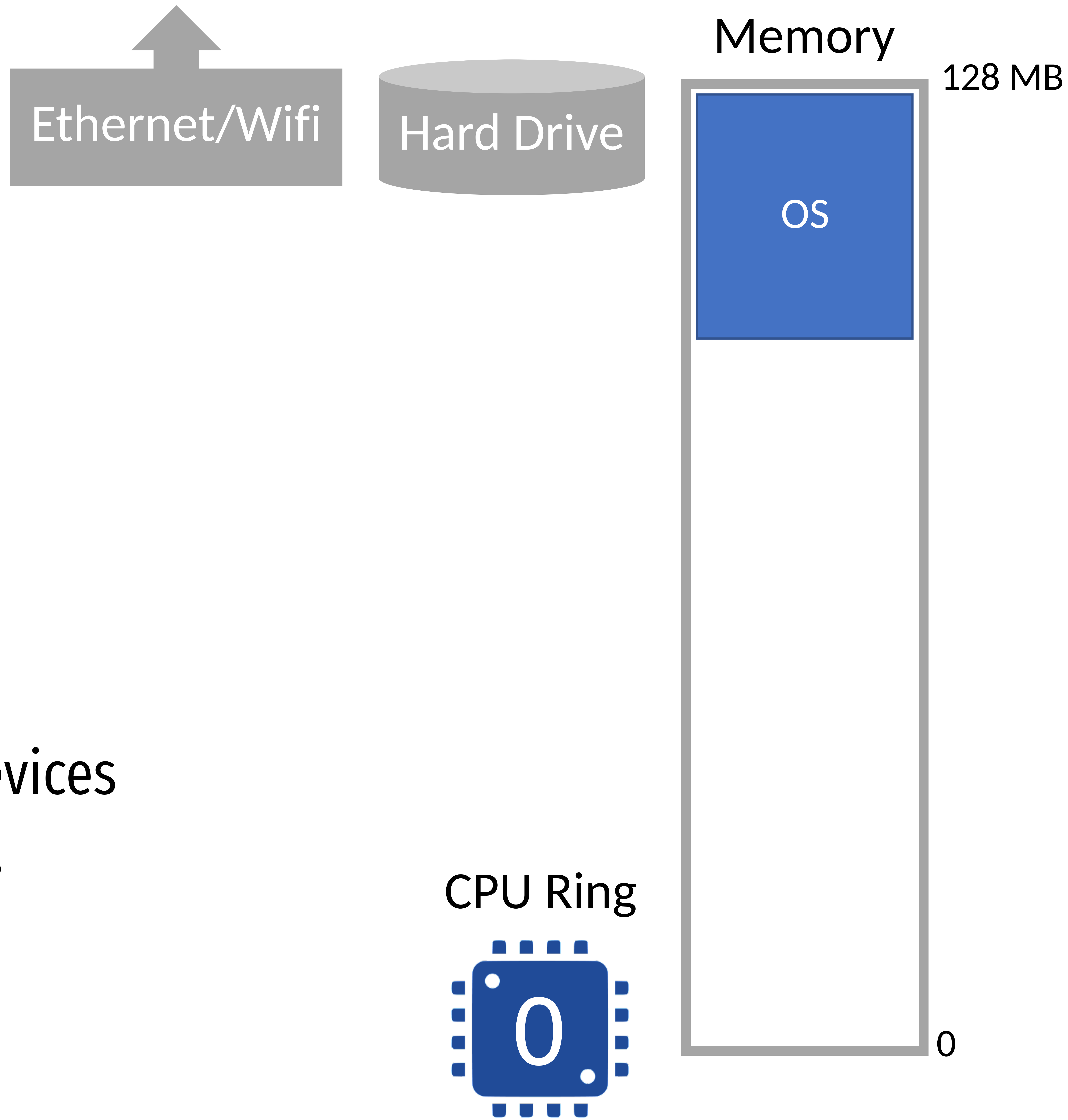

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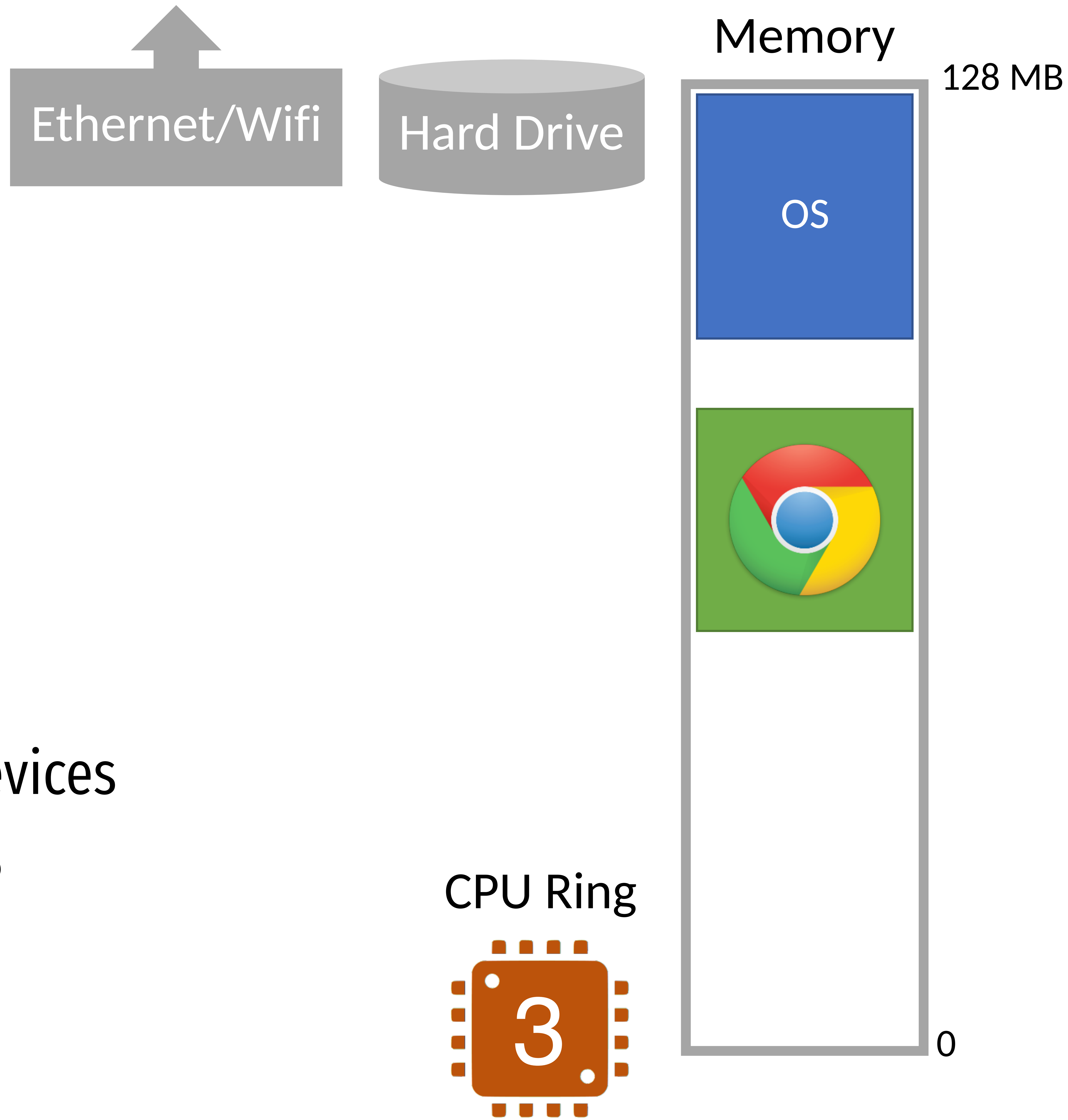

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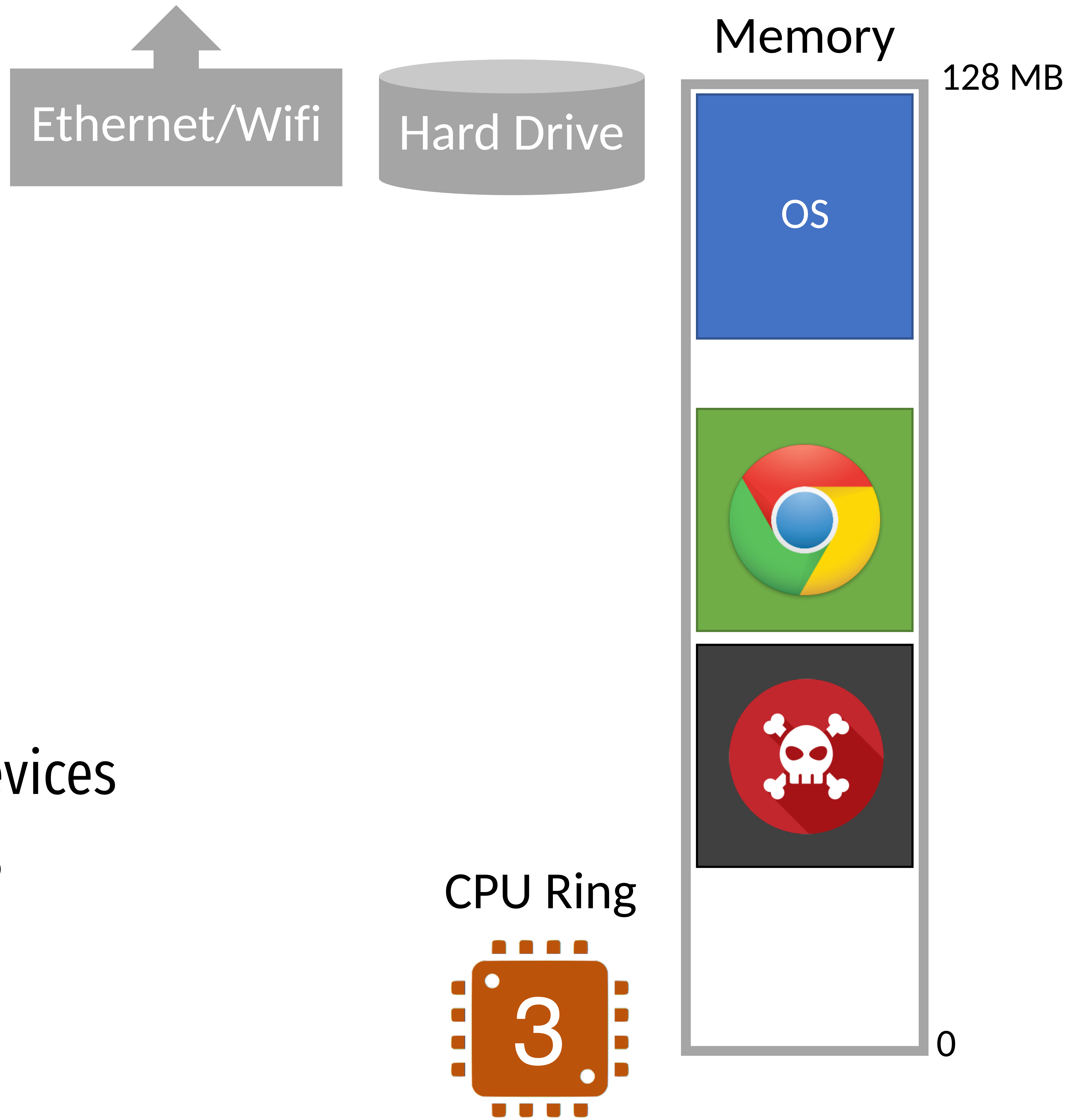
Protection in Action



Protected mode stops direct access to devices

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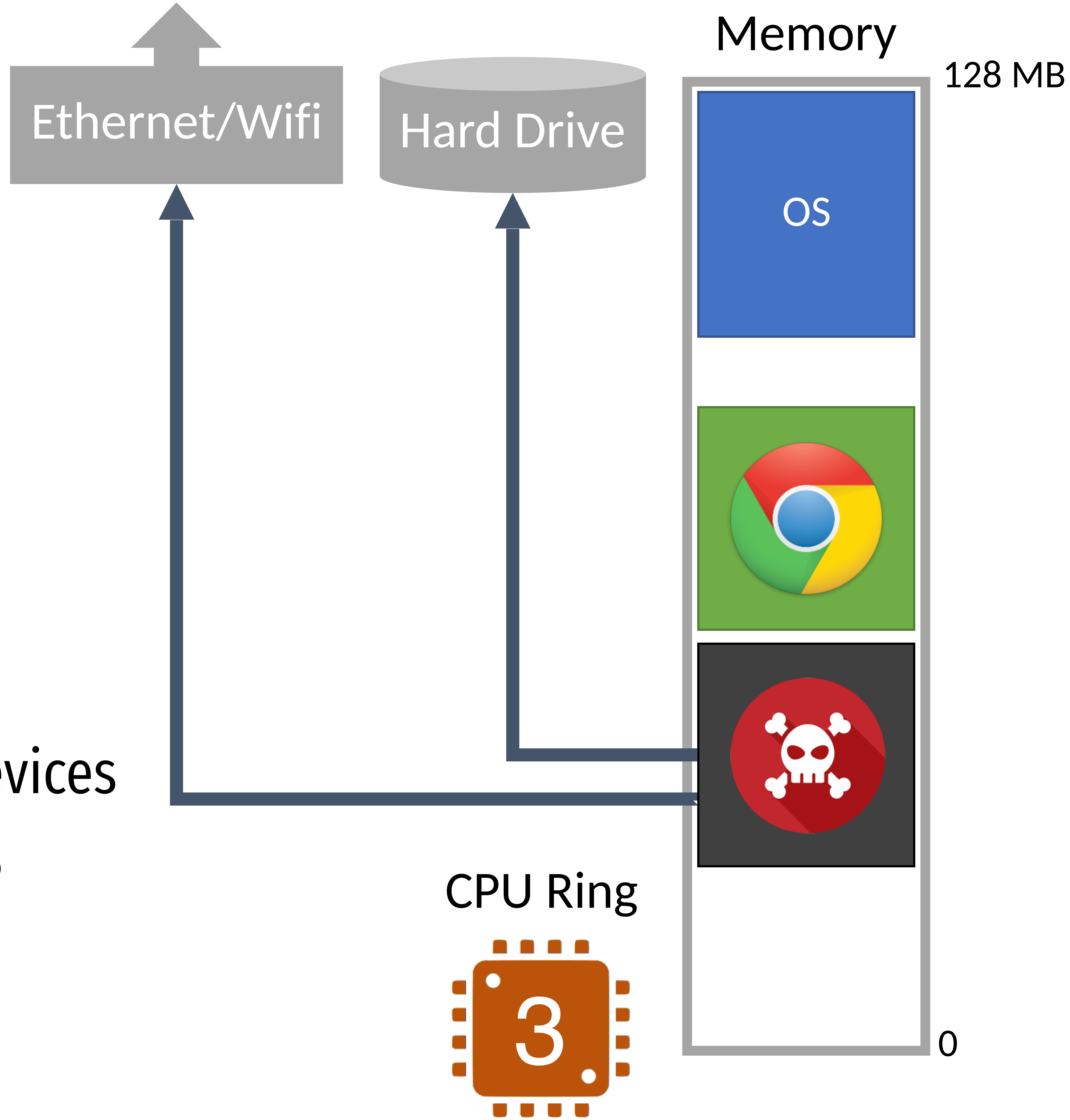
Protection in Action



Protected mode stops direct access to devices

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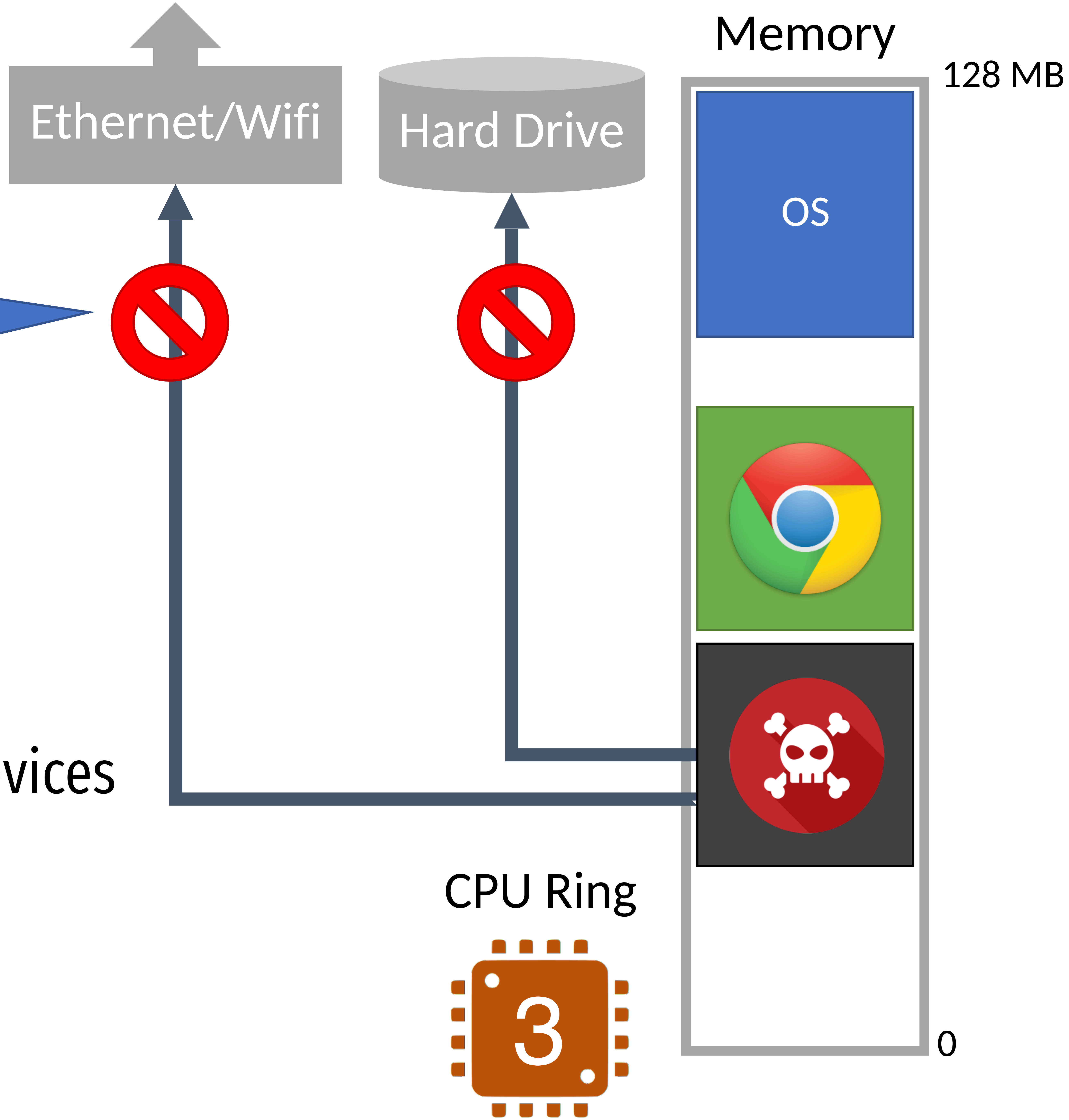
Protection in Action

Ring 3 = protected mode.
No direct device access



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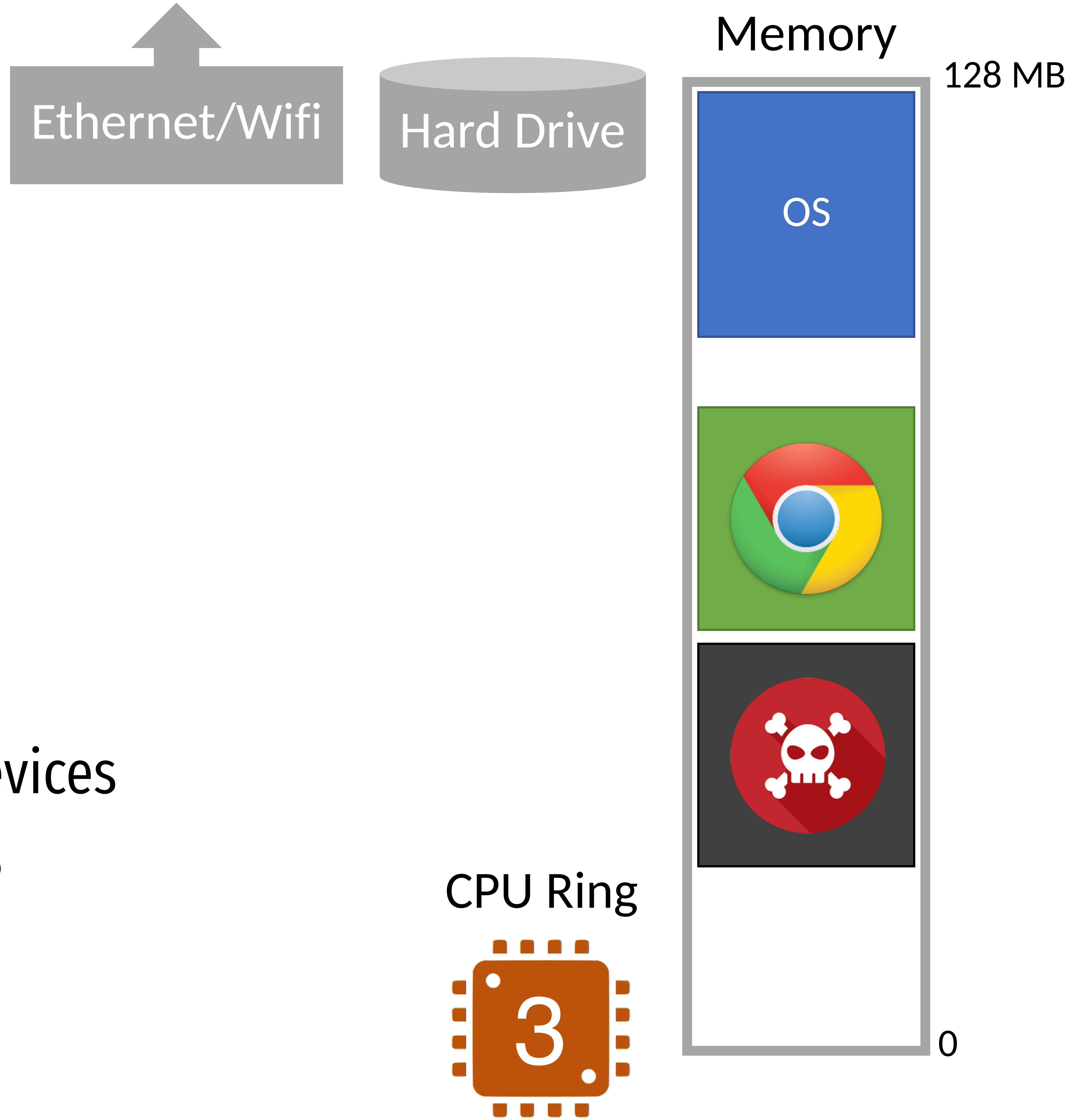

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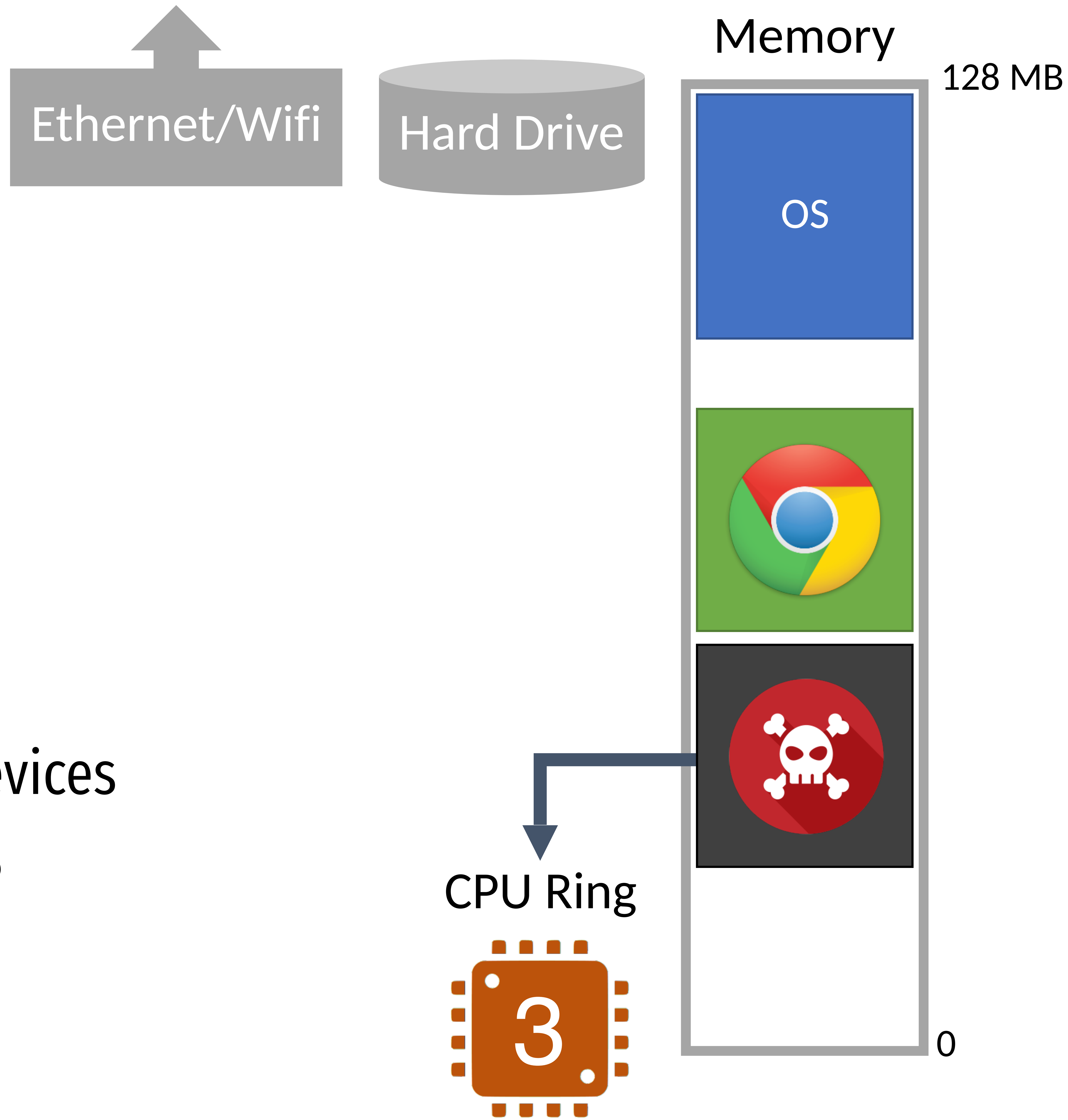

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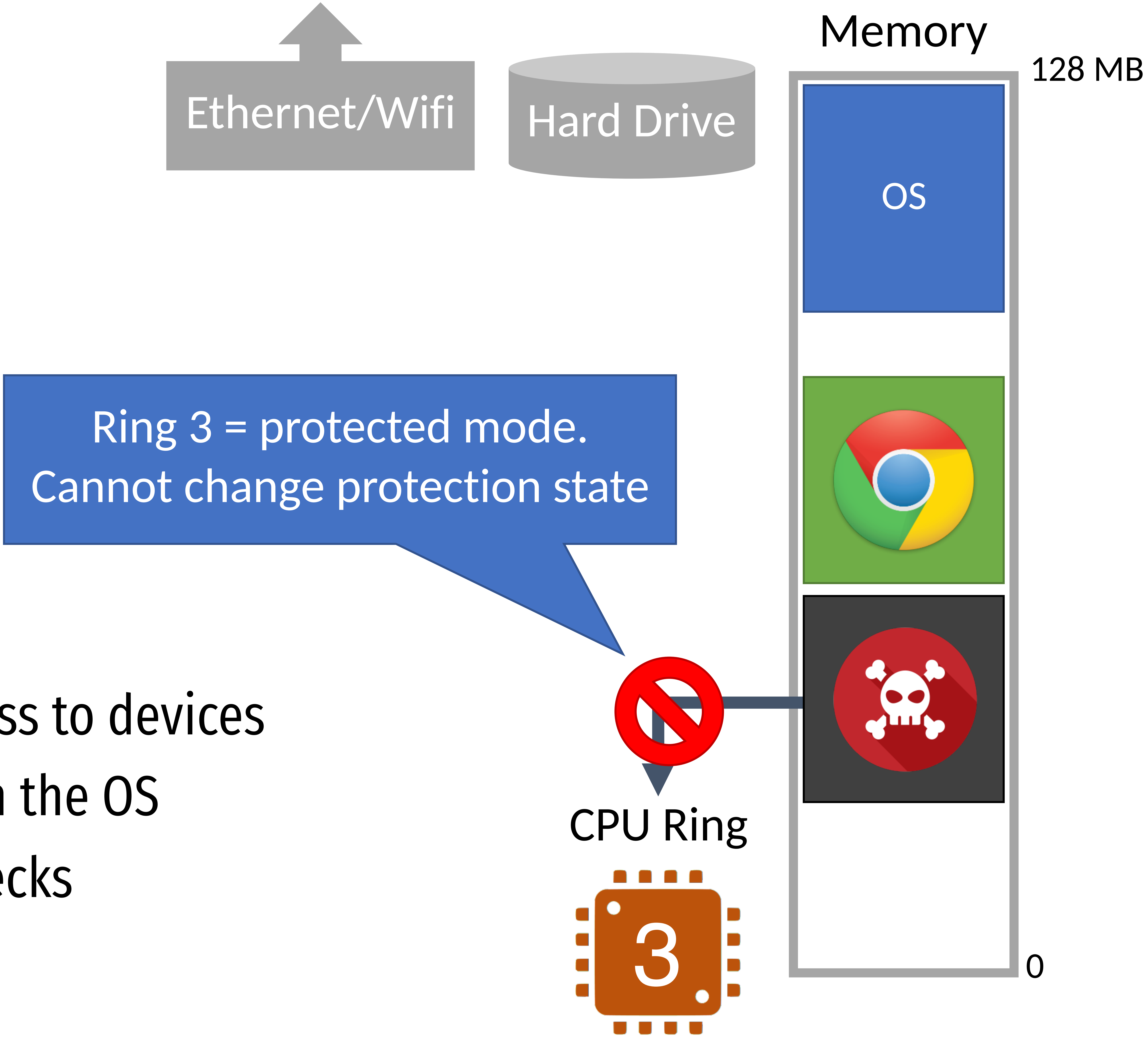

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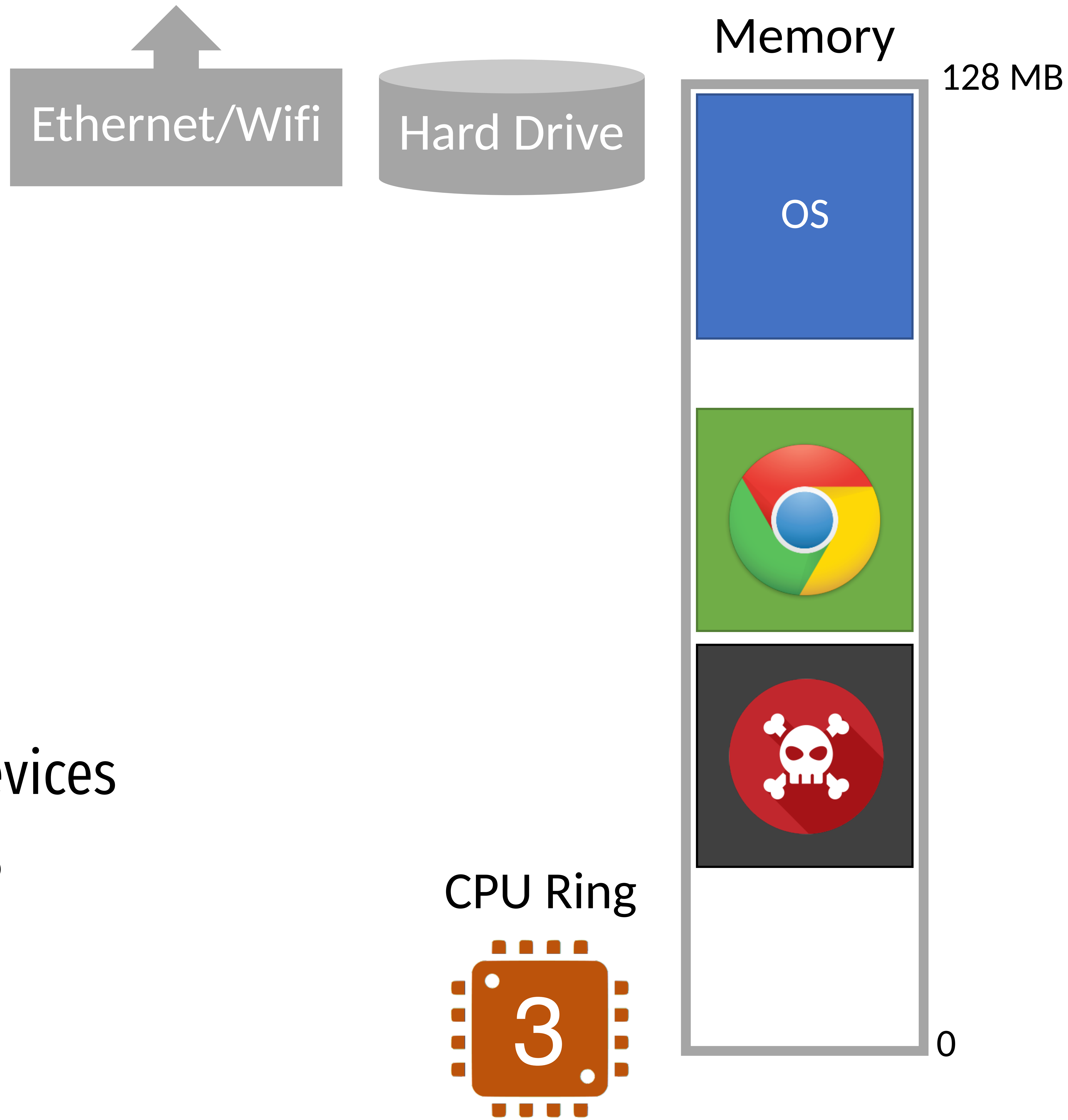

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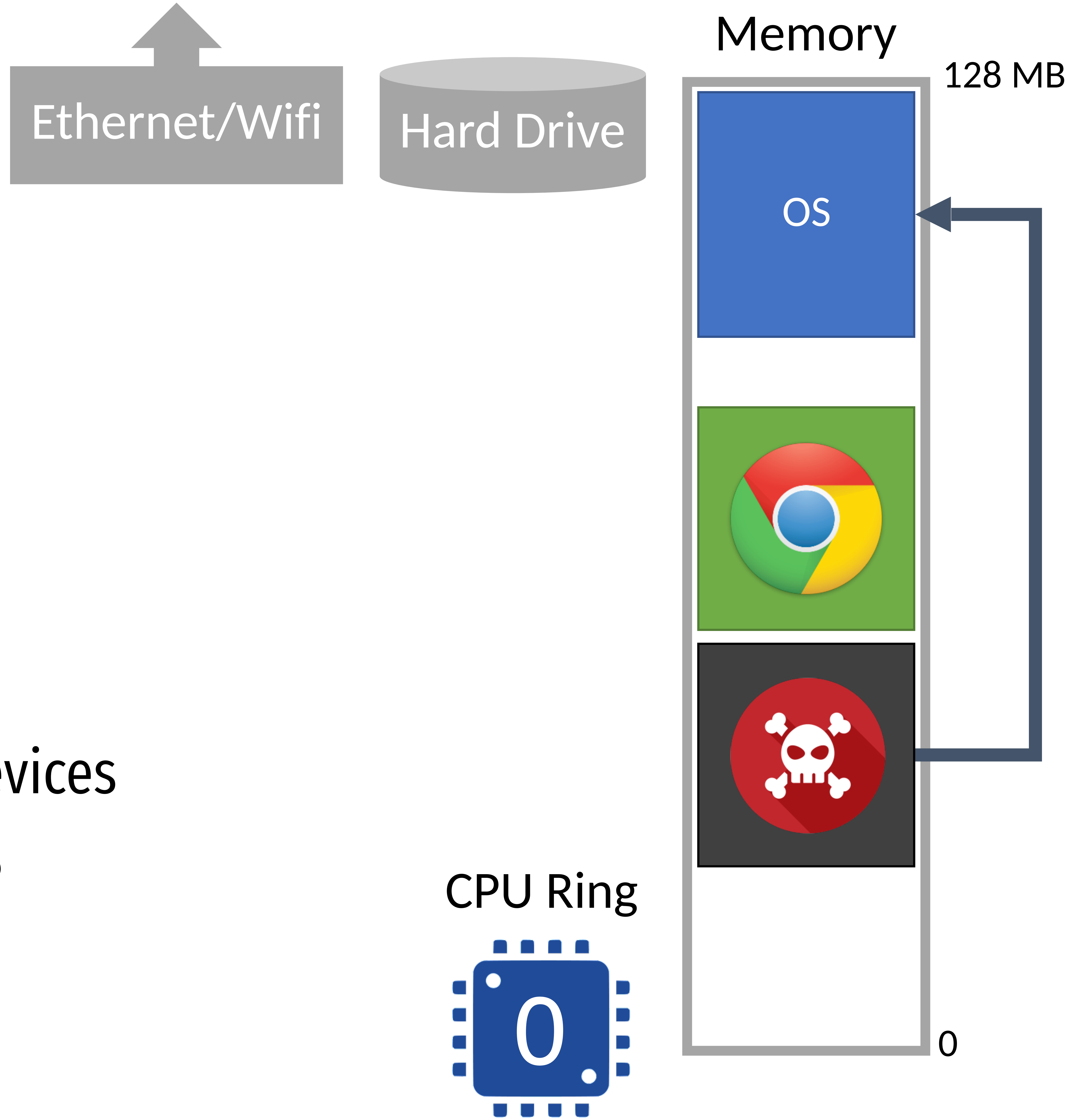

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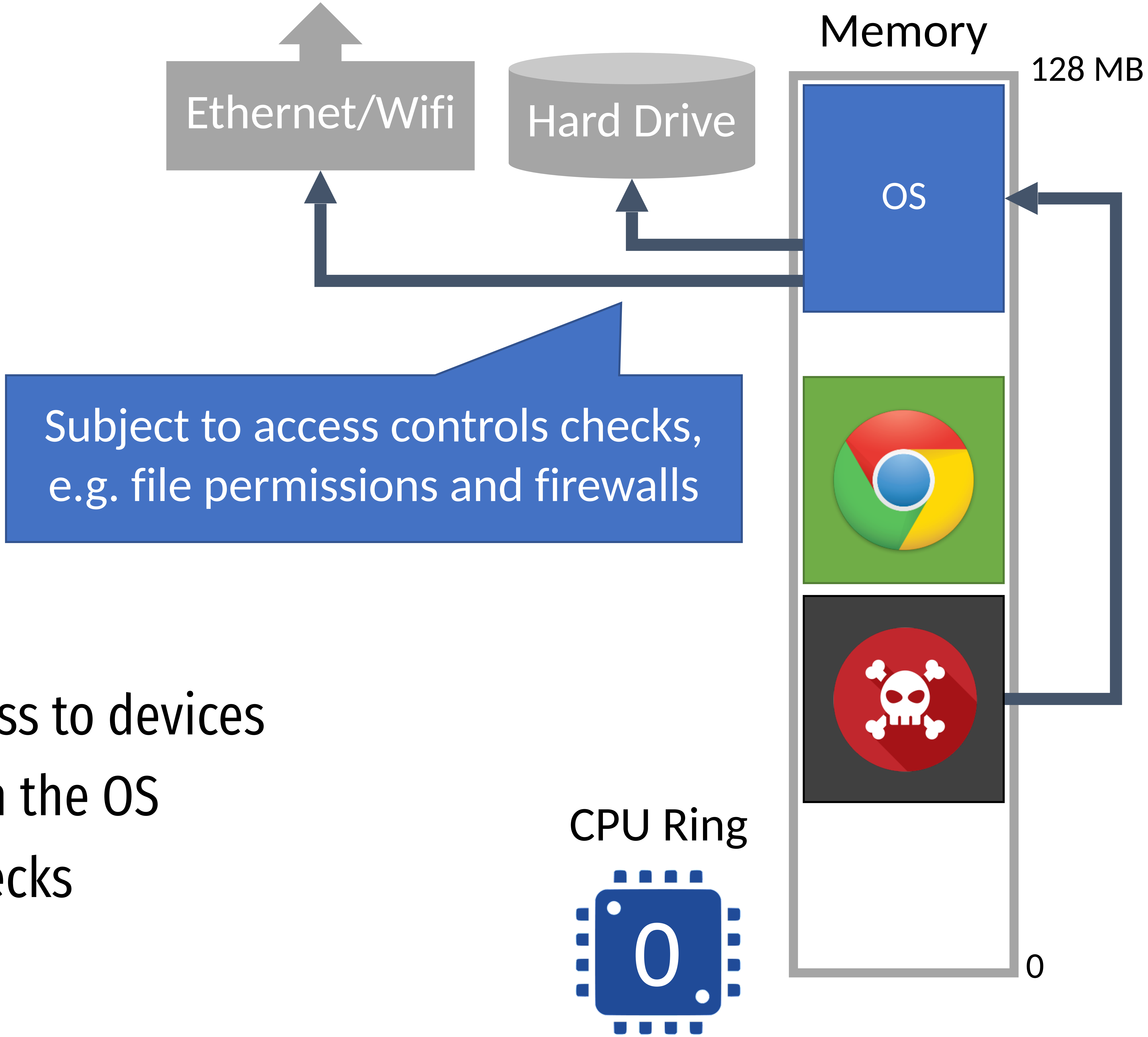

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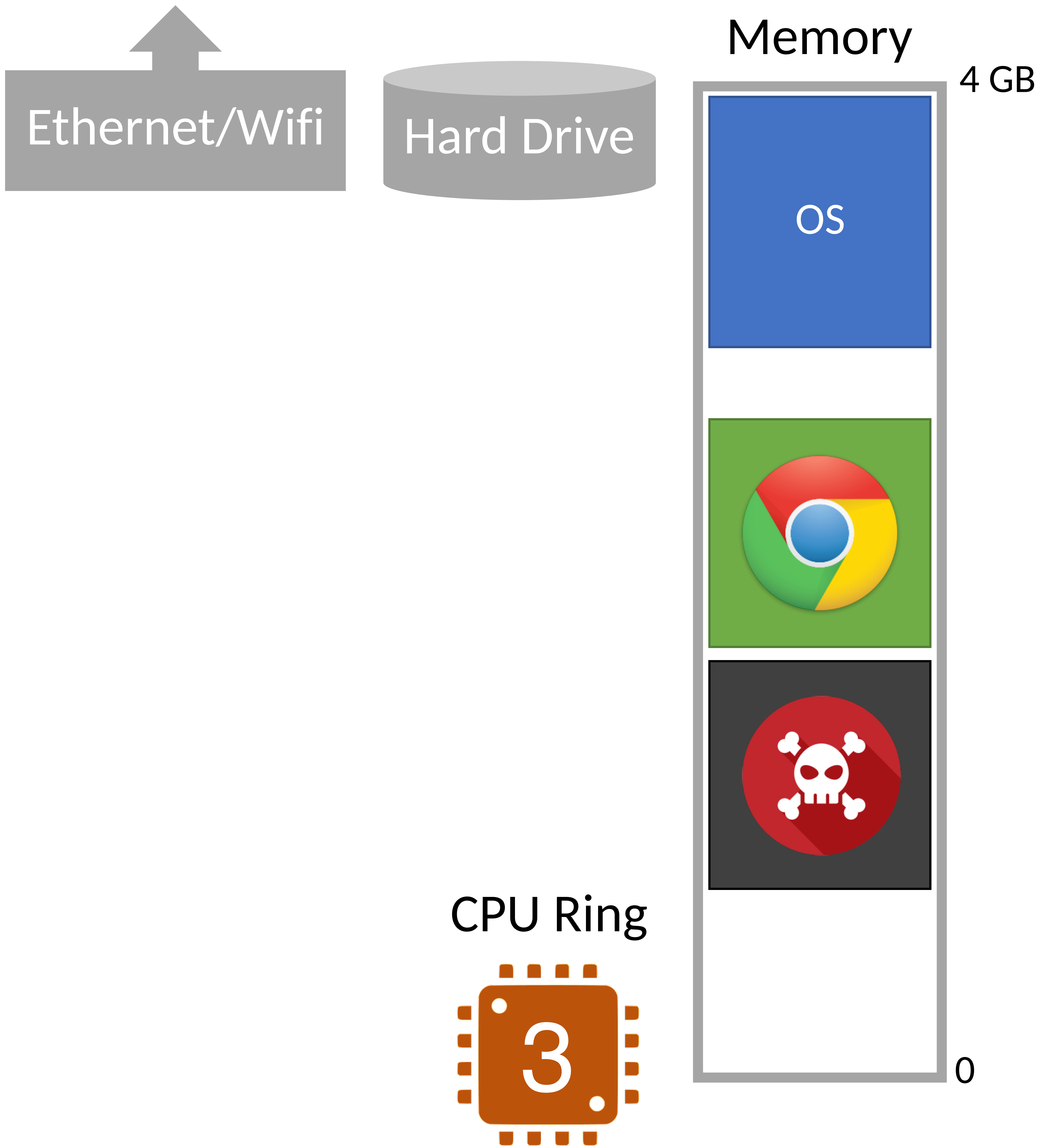
Virtual Memory

Status Check

At this point we have protected the devices attached to the system…

… But we have not protected memory



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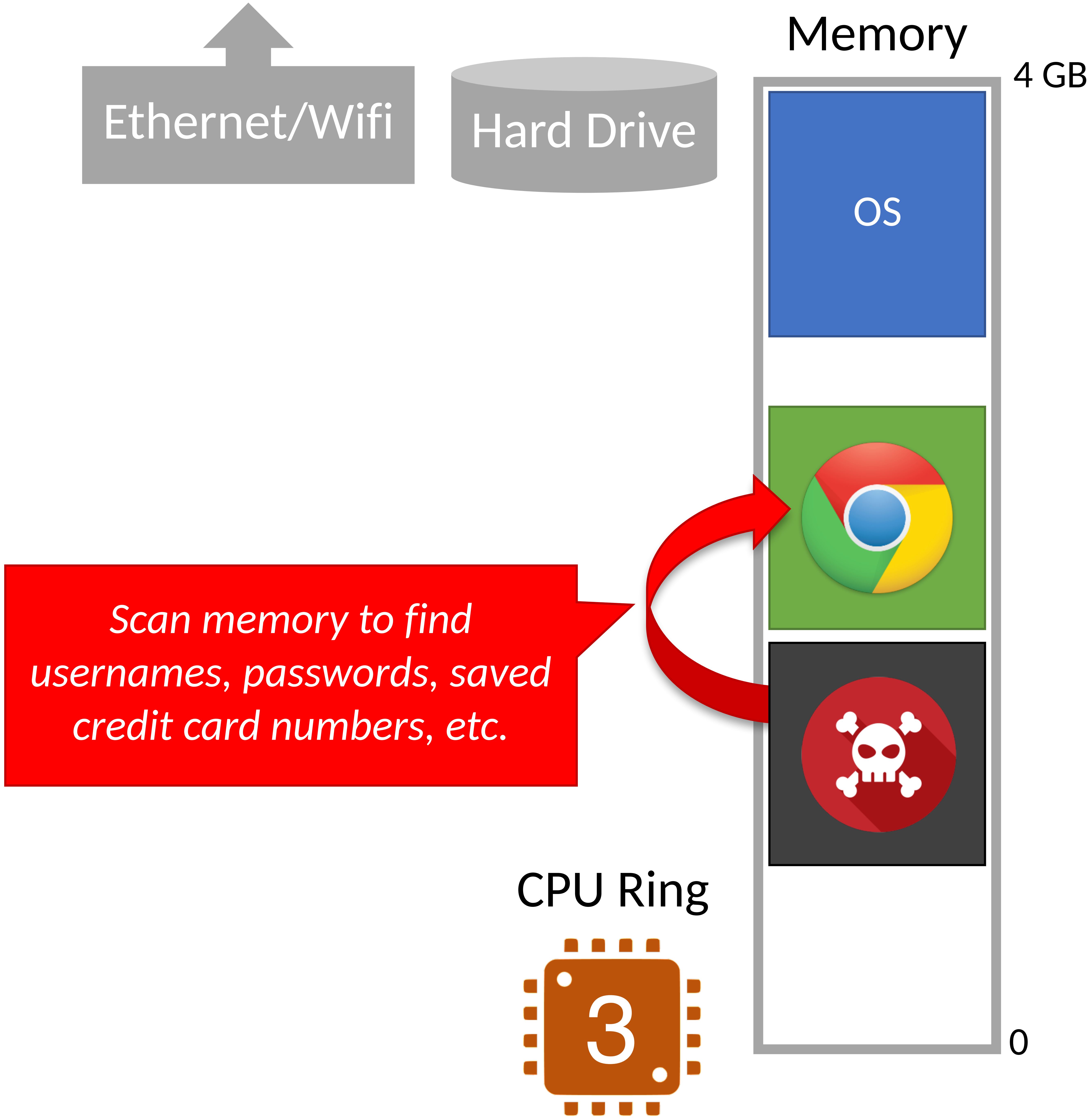

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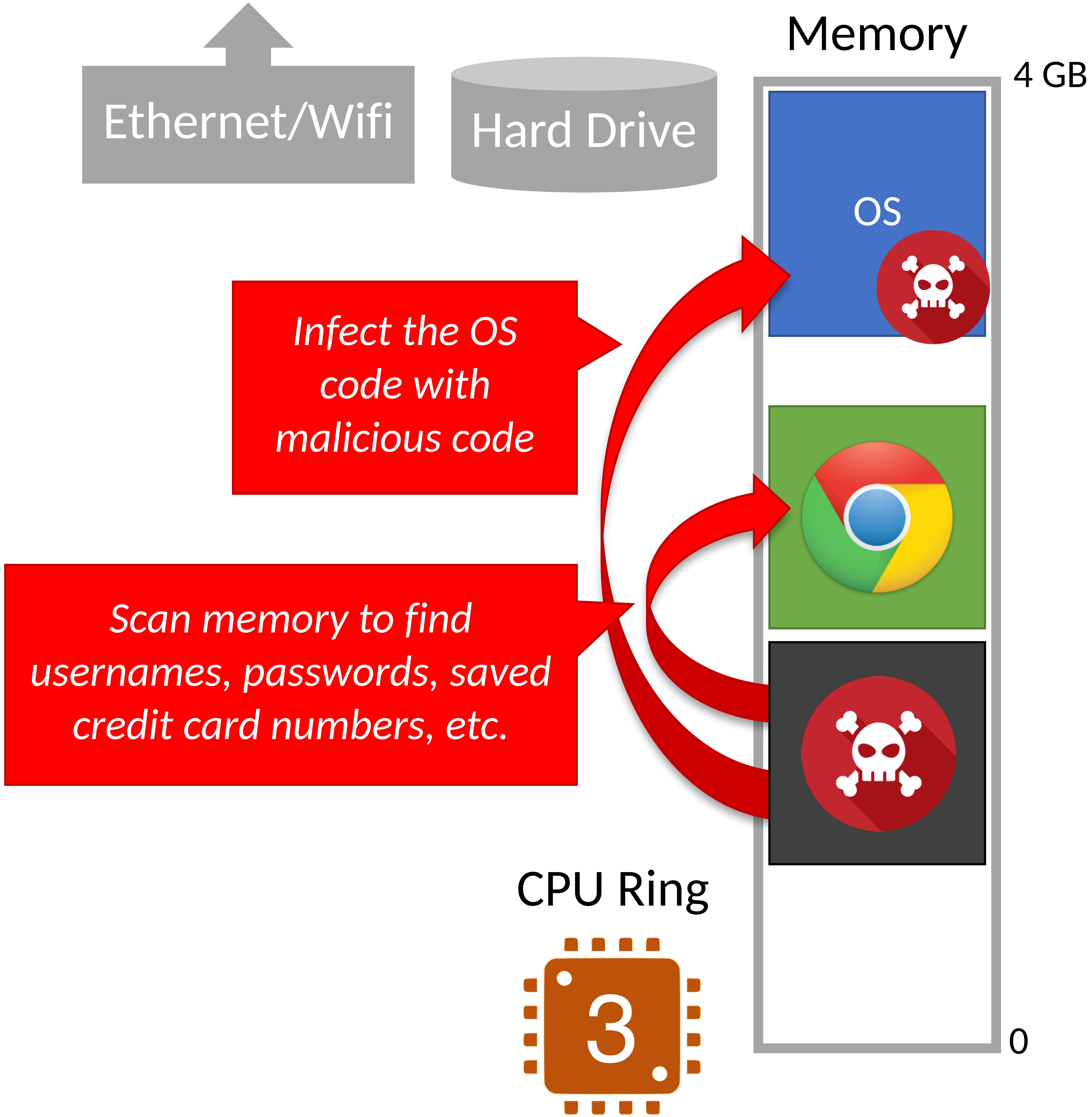

Memory Isolation and Virtual Memory

Modern CPUs support virtual memory

Creates the illusion that each process runs in its own, empty memory space

- Processes can not read/write memory used by other processes
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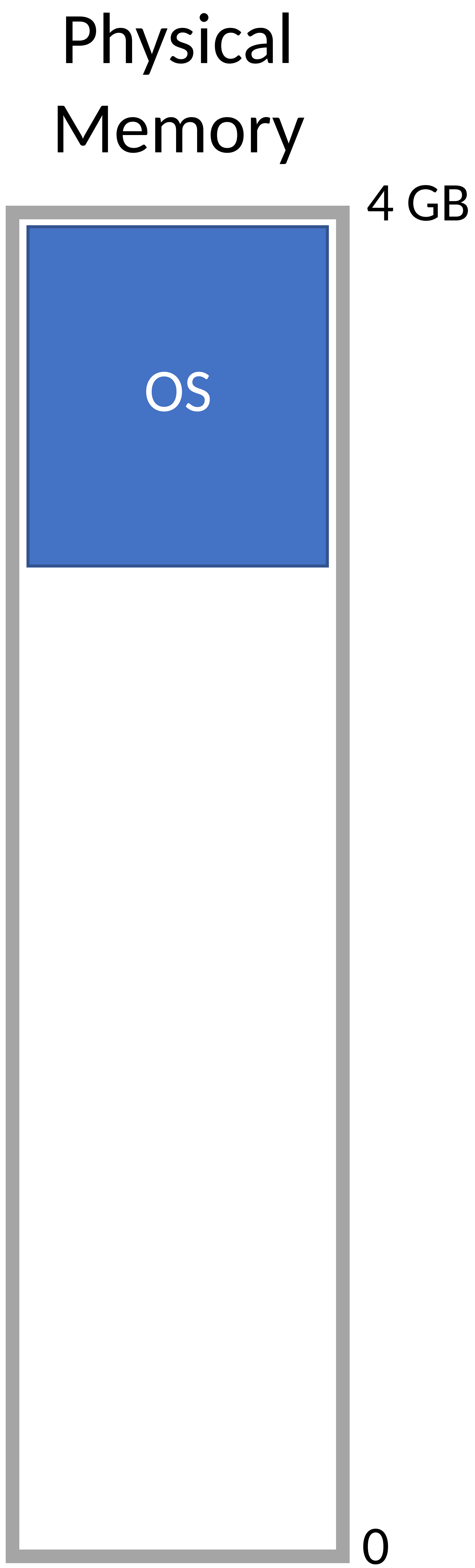
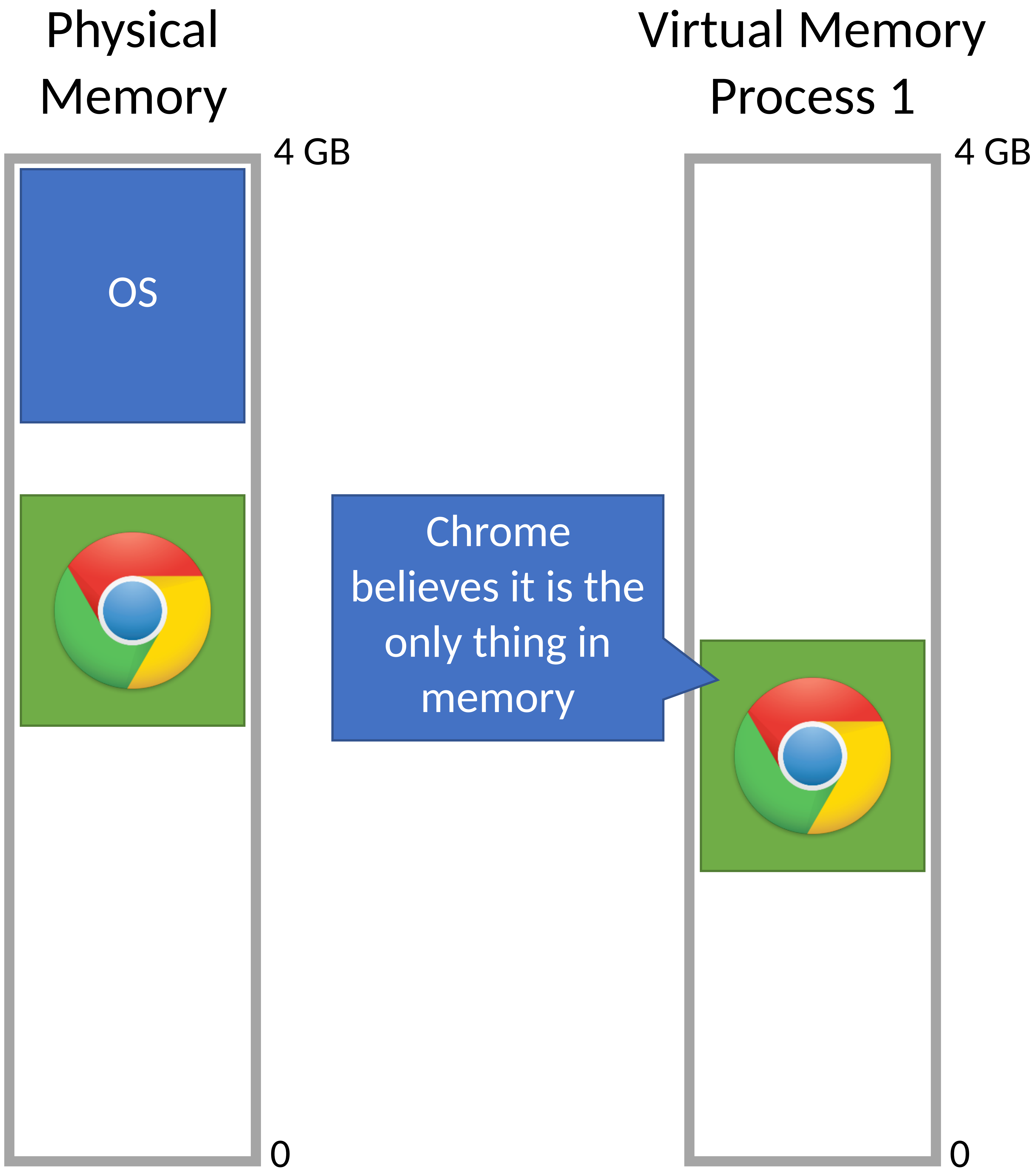
In later courses, you will learn how virtual memory is implemented

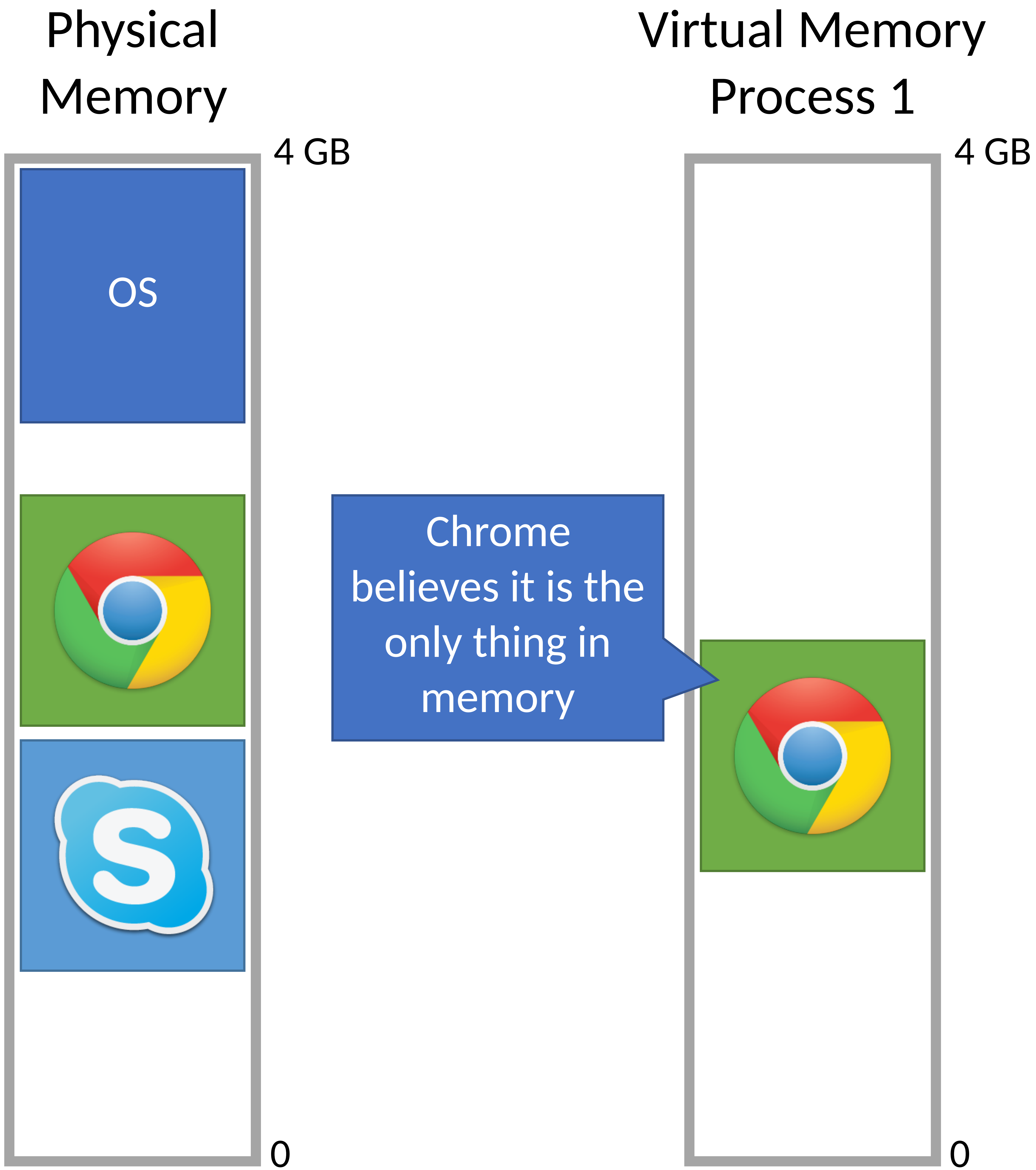
- Base and bound registers
- Segmentation
- Page tables

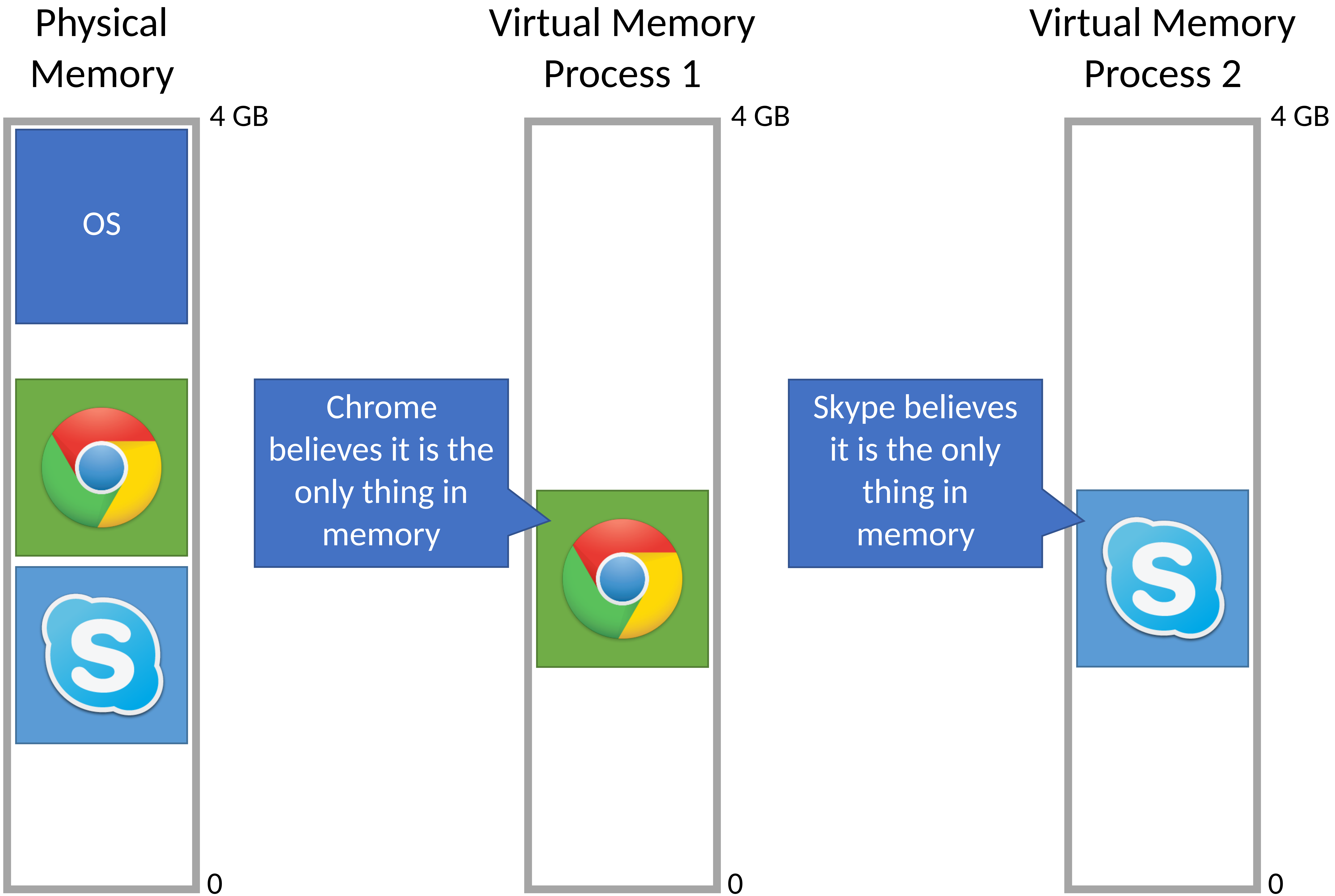
Today, we will do the cliffnotes version…

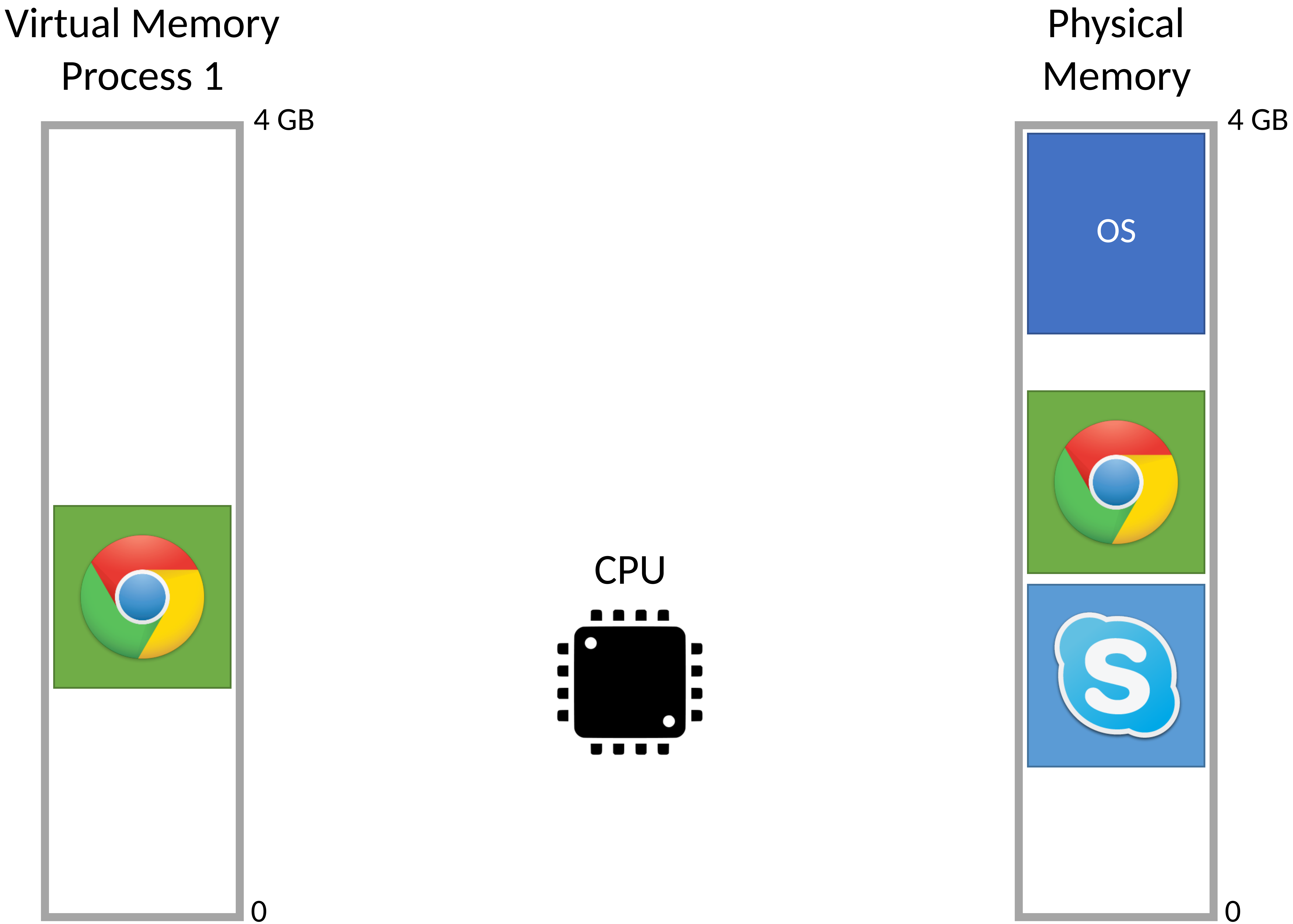

Physical
Memory
4 GB
OS
0

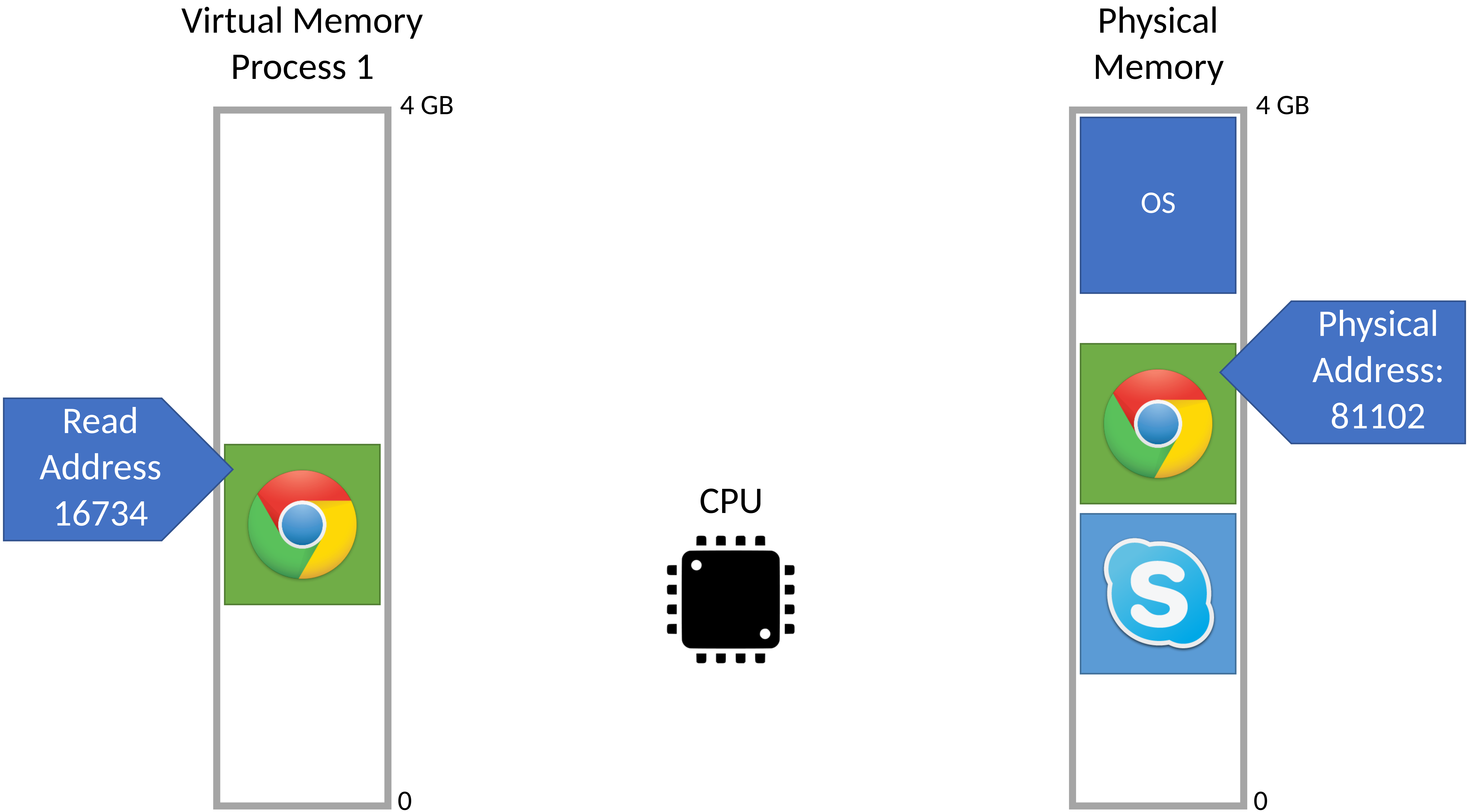

Physical
Memory
4 GB
OS
0

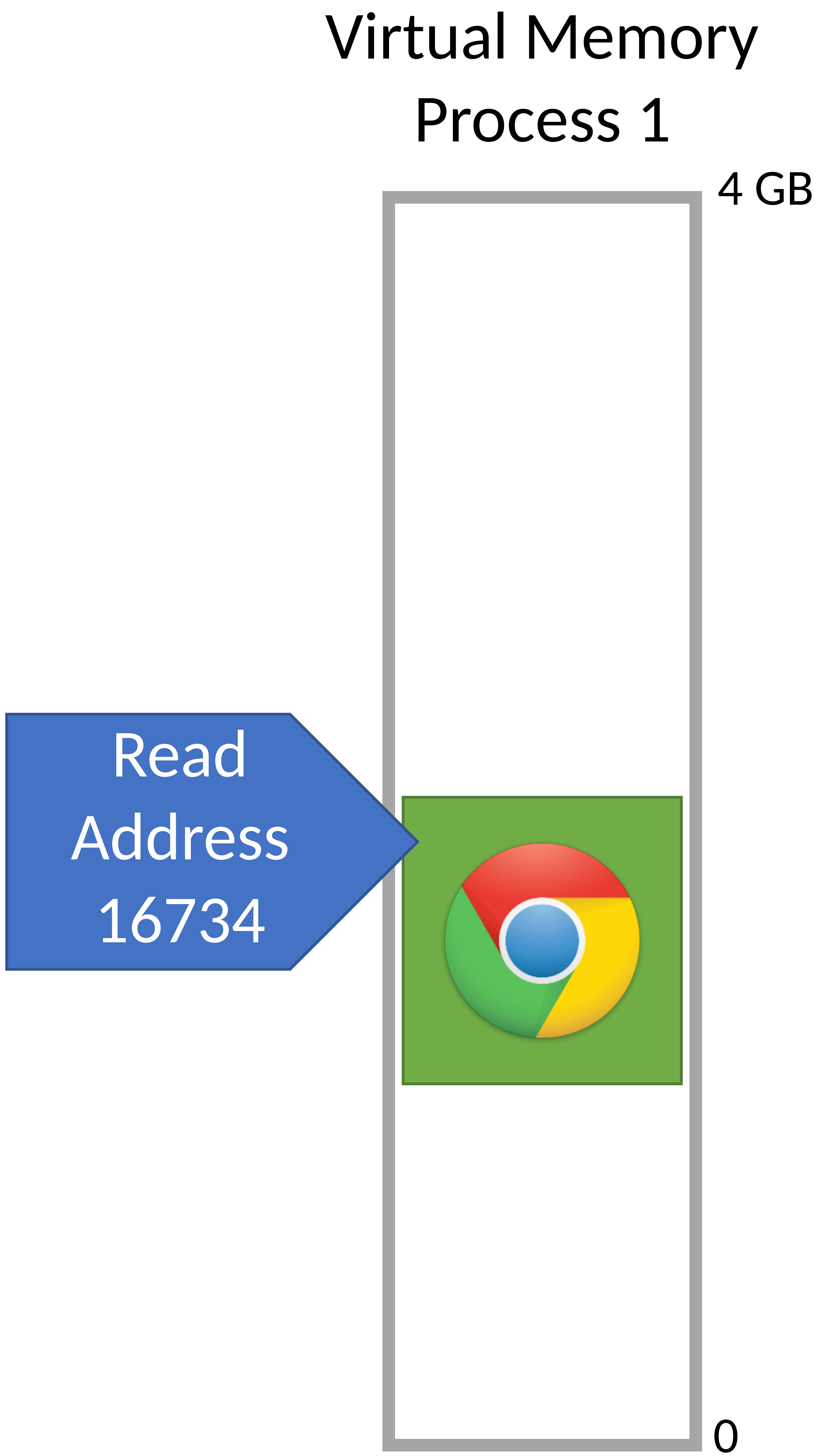

Physical
Memory
4 GB
OS
0
Chrome believes it is the only thing in memory
Virtual Memory
Process 1
4 GB
0


Physical Memory
Virtual Memory Process 1
4 GB
OS
0
Chrome believes it is the only thing in memory
4 GB
0


Physical Memory
Virtual Memory Process 1
Virtual Memory Process 2
4 GB
0
OS
Chrome believes it is the only thing in memory
Skype believes it is the only thing in memory
4 GB
0
4 GB
0

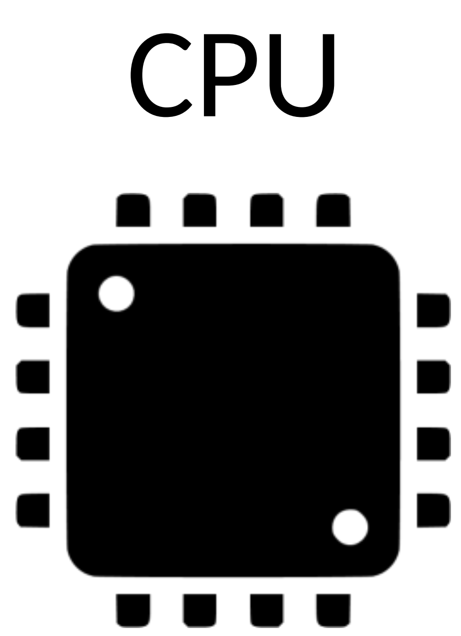

Virtual Memory
Process 1
4 GB
0
CPU
Physical
Memory
4 GB
OS
0

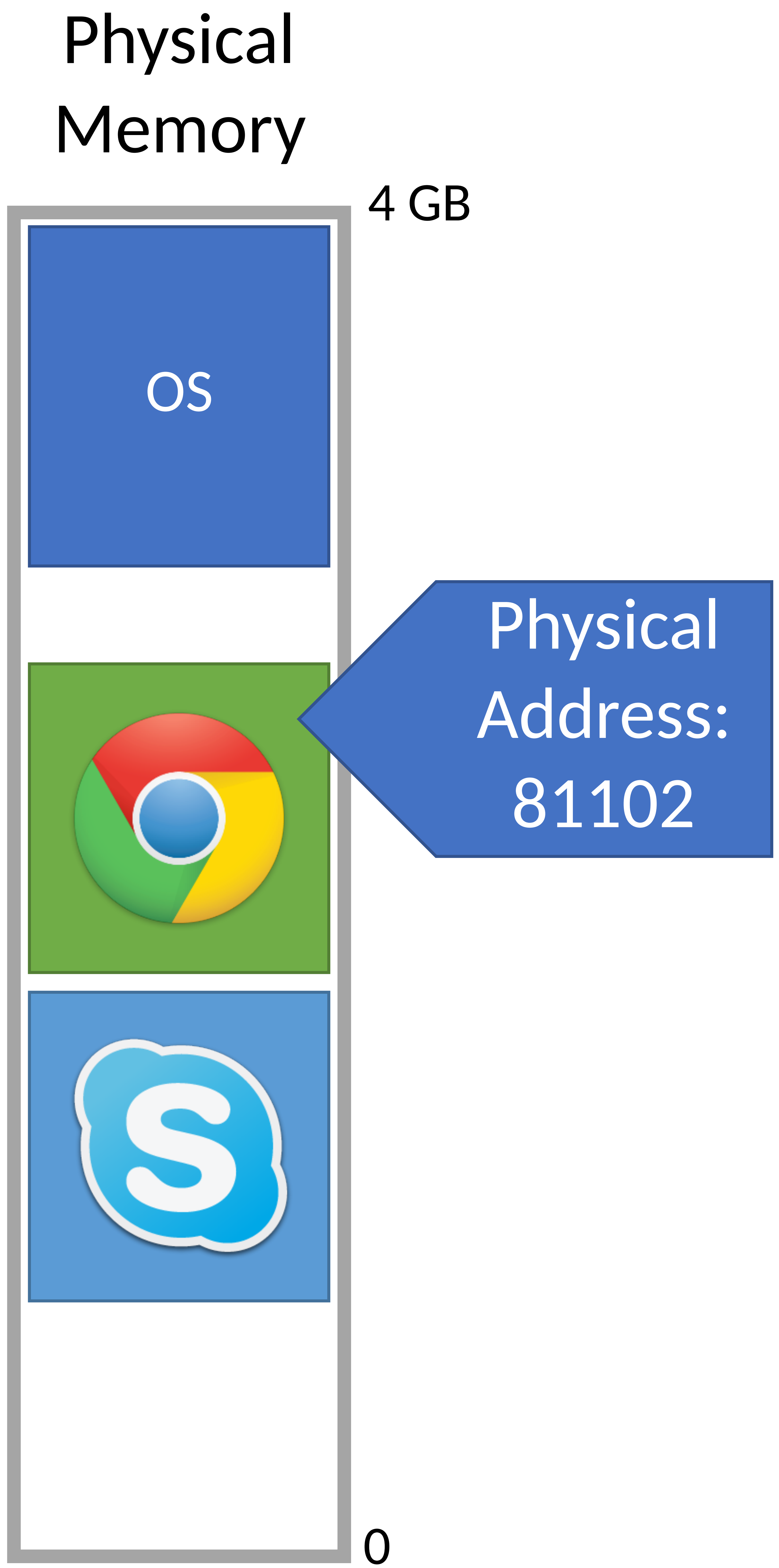

Virtual Memory
Process 1
4 GB
0
Read
Address
16734
CPU
Physical
Memory
4 GB
OS
Physical
Address:
81102
0



Page Table

Virtual Addr.	Physical Addr.
16732	81100
16734	81102
16736	93568
16738	93570



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Page Table
Virtual Addr.
Physical Addr.
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81100
16734
81102
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93568
16738
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CPU
Physical Memory
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OS
0
Physical Address: 81102

Virtual Memory Implementation

Each process has its own virtual memory space

- Each process has a page table that maps is virtual space into physical space
- CPU translates virtual address to physical addresses on-the-fly

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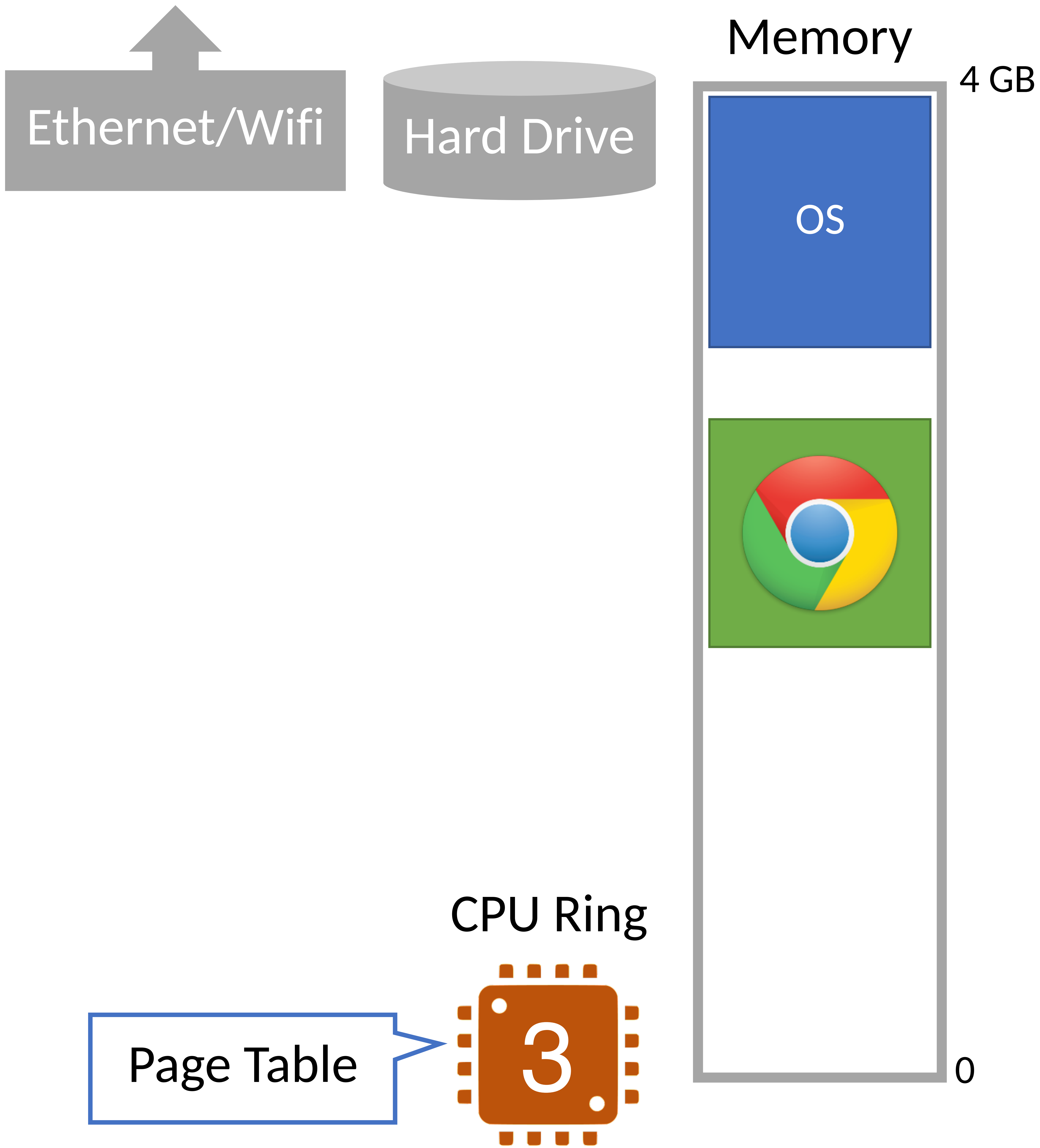
What happens if a process tries to read/write memory outside its page table?

- Segmentation Fault or Page Fault
- Process crashes
- In other words, no way to escape virtual memory

VM in Action

Processes can only read/ write within their own virtual memory

Processes cannot change their own page tables



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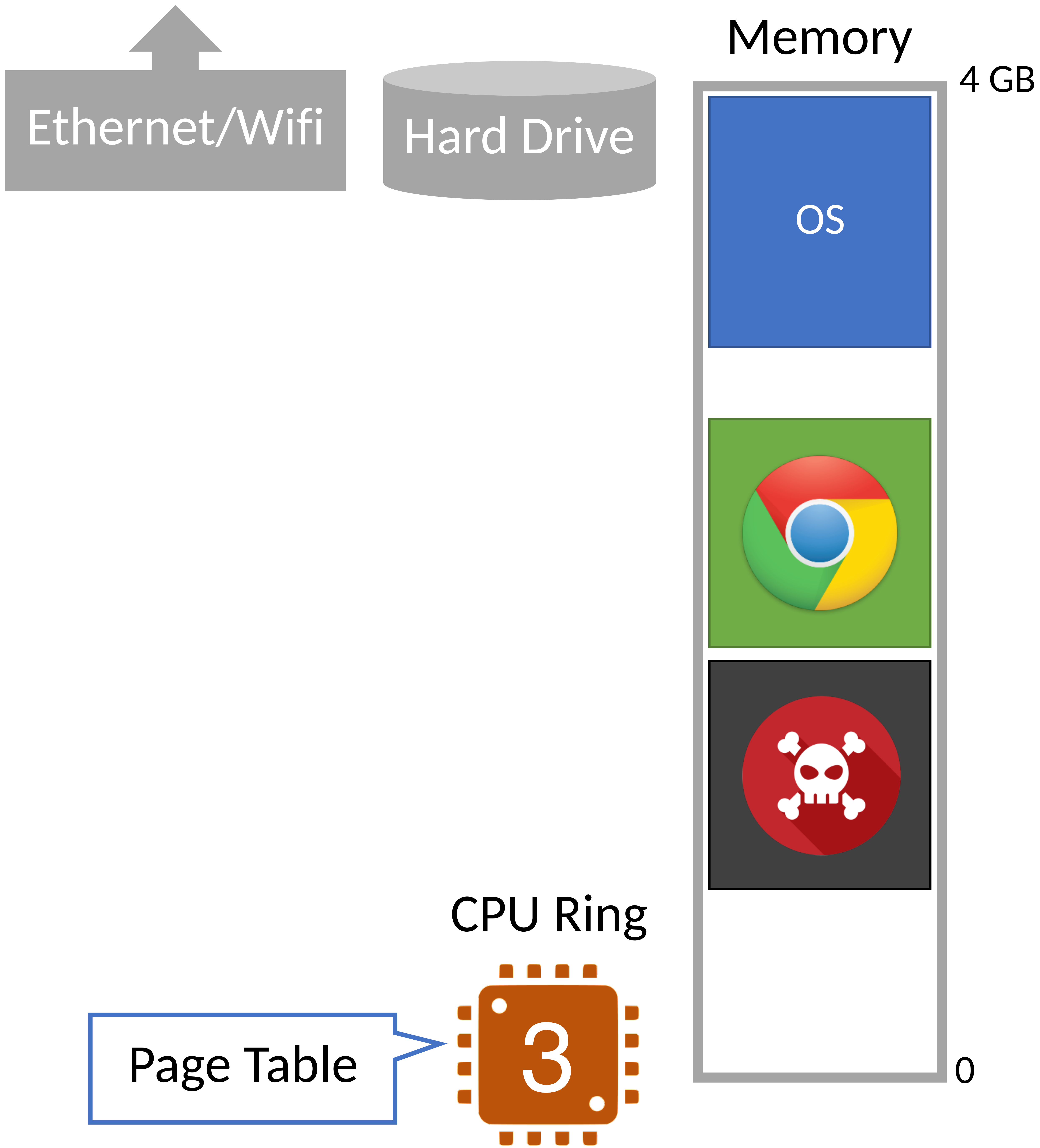

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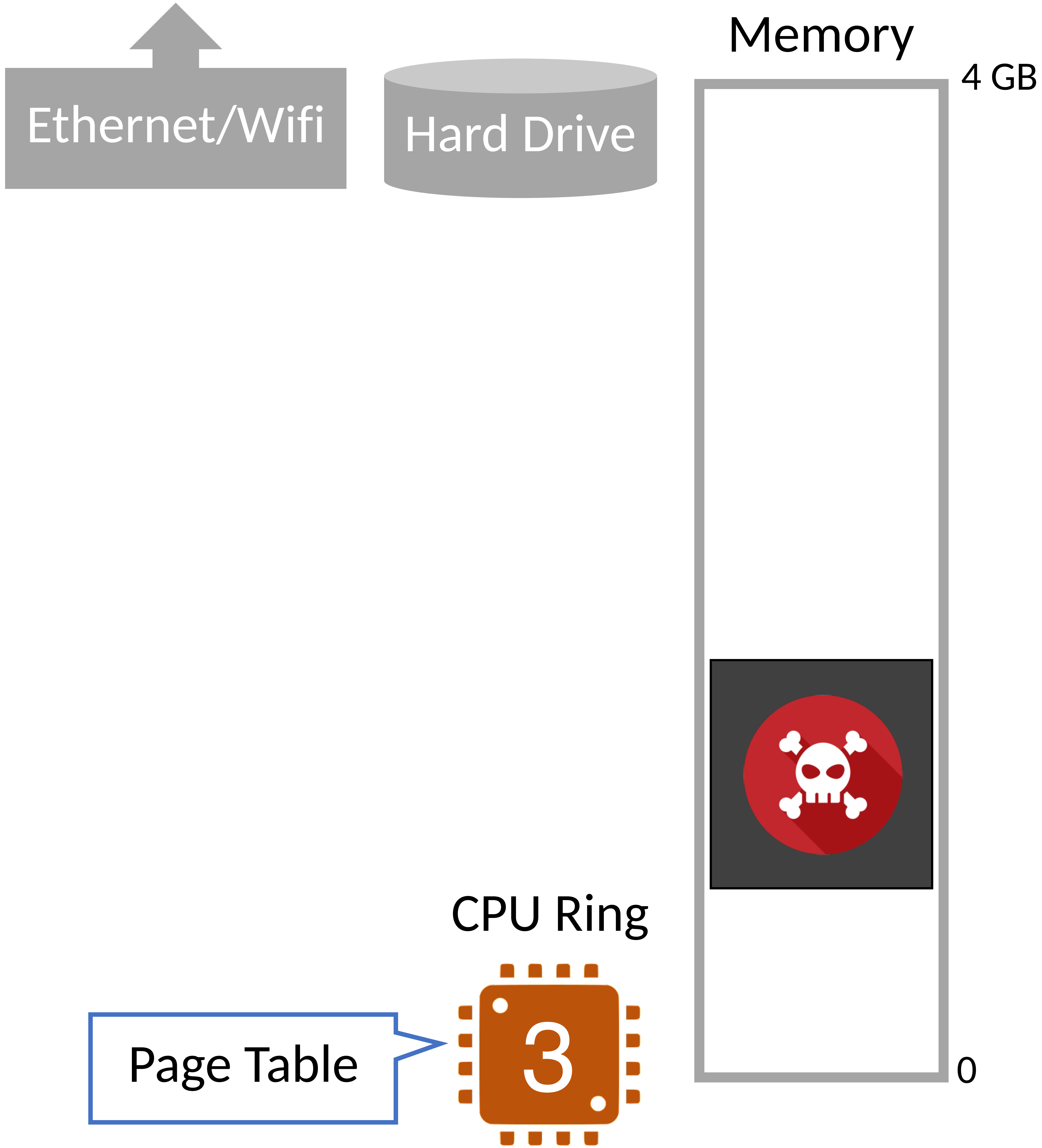

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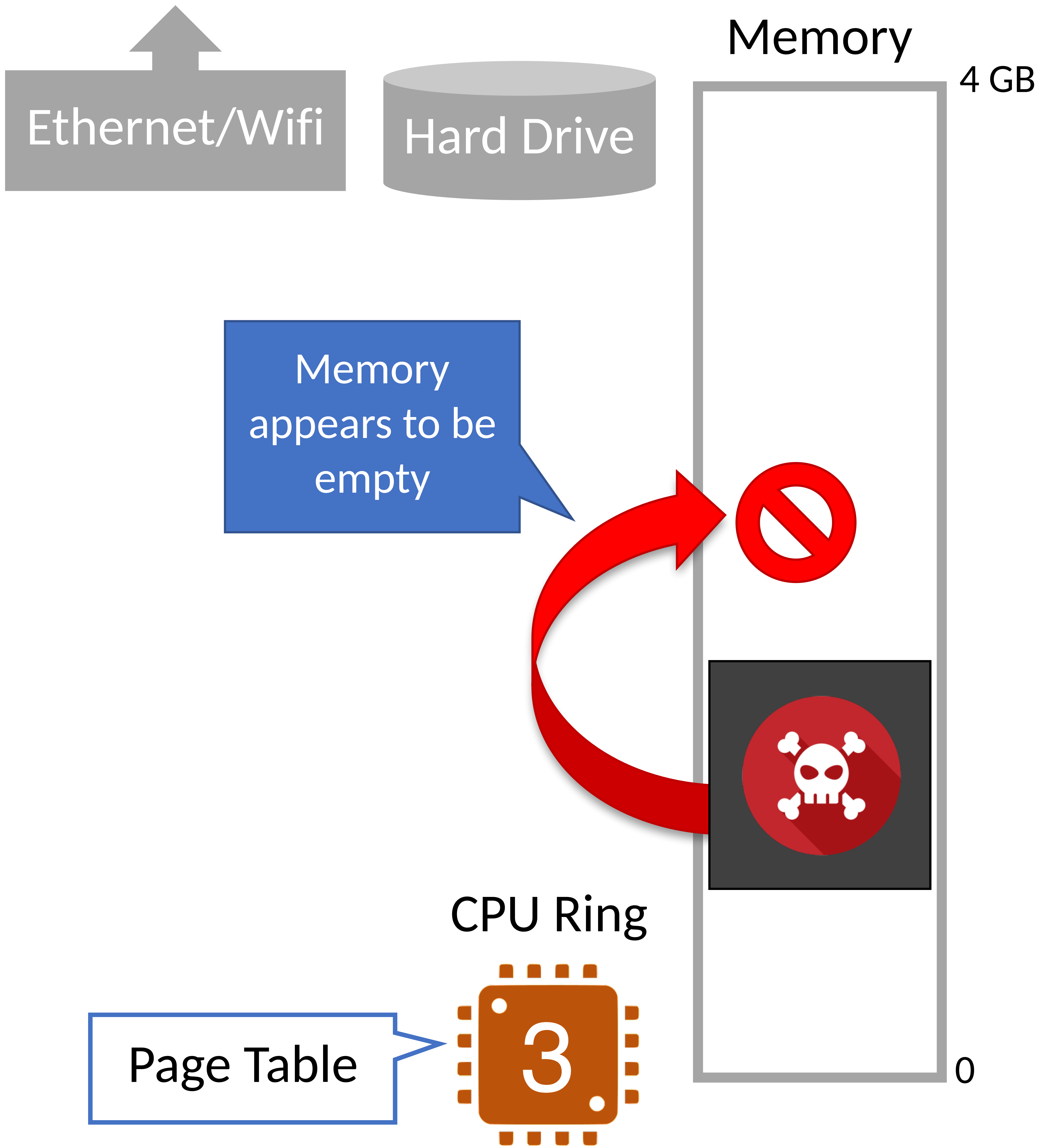

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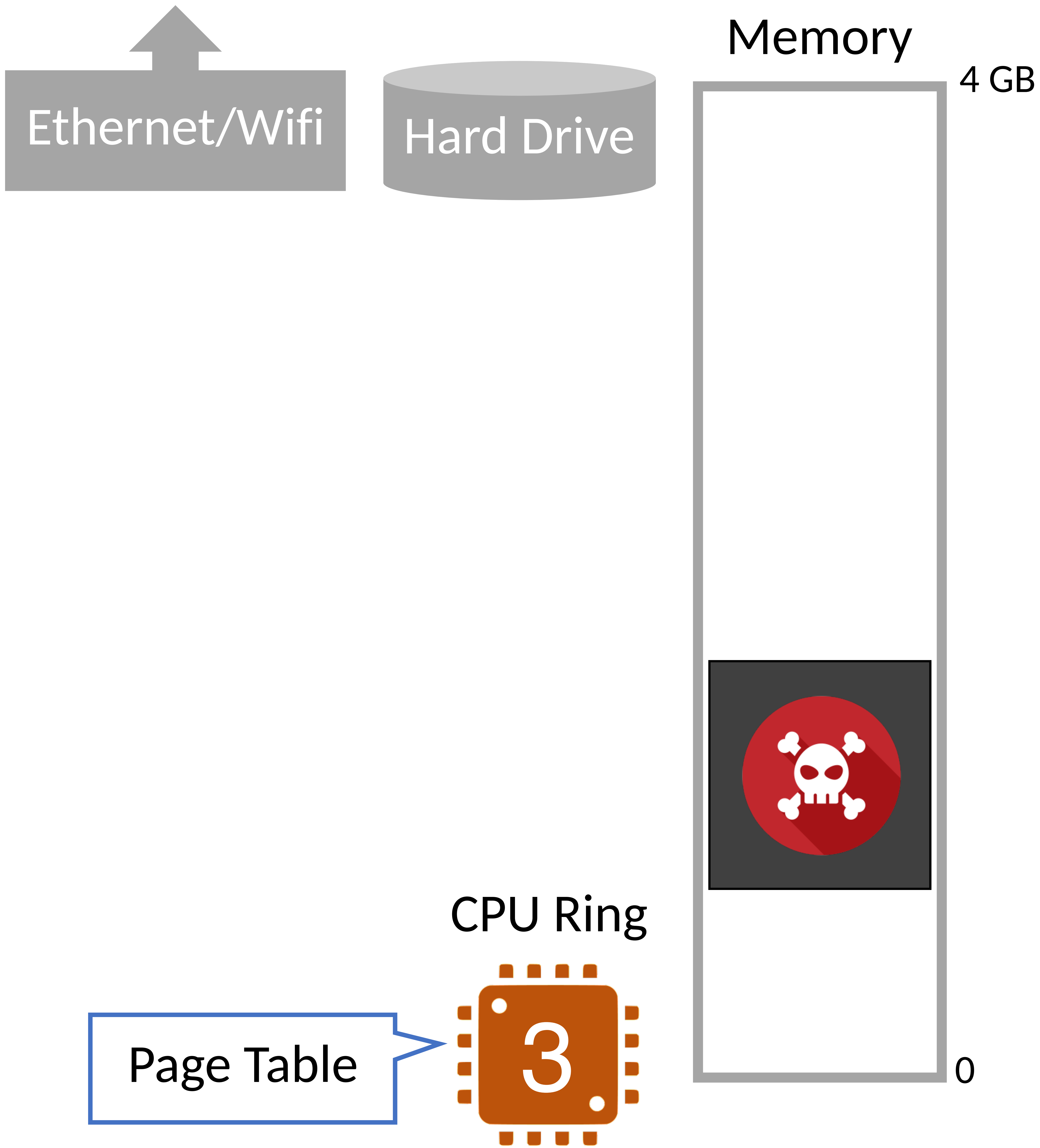

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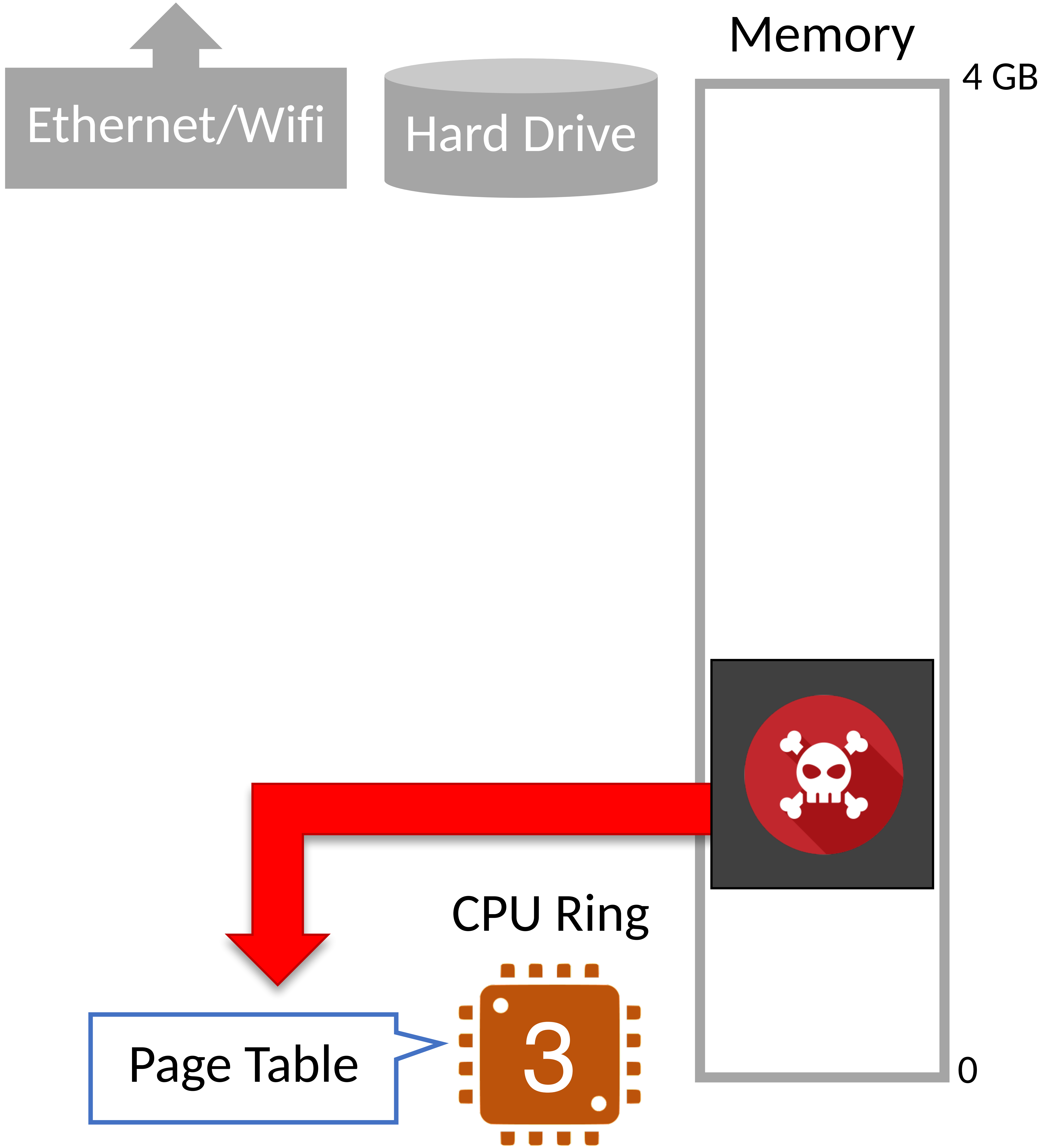

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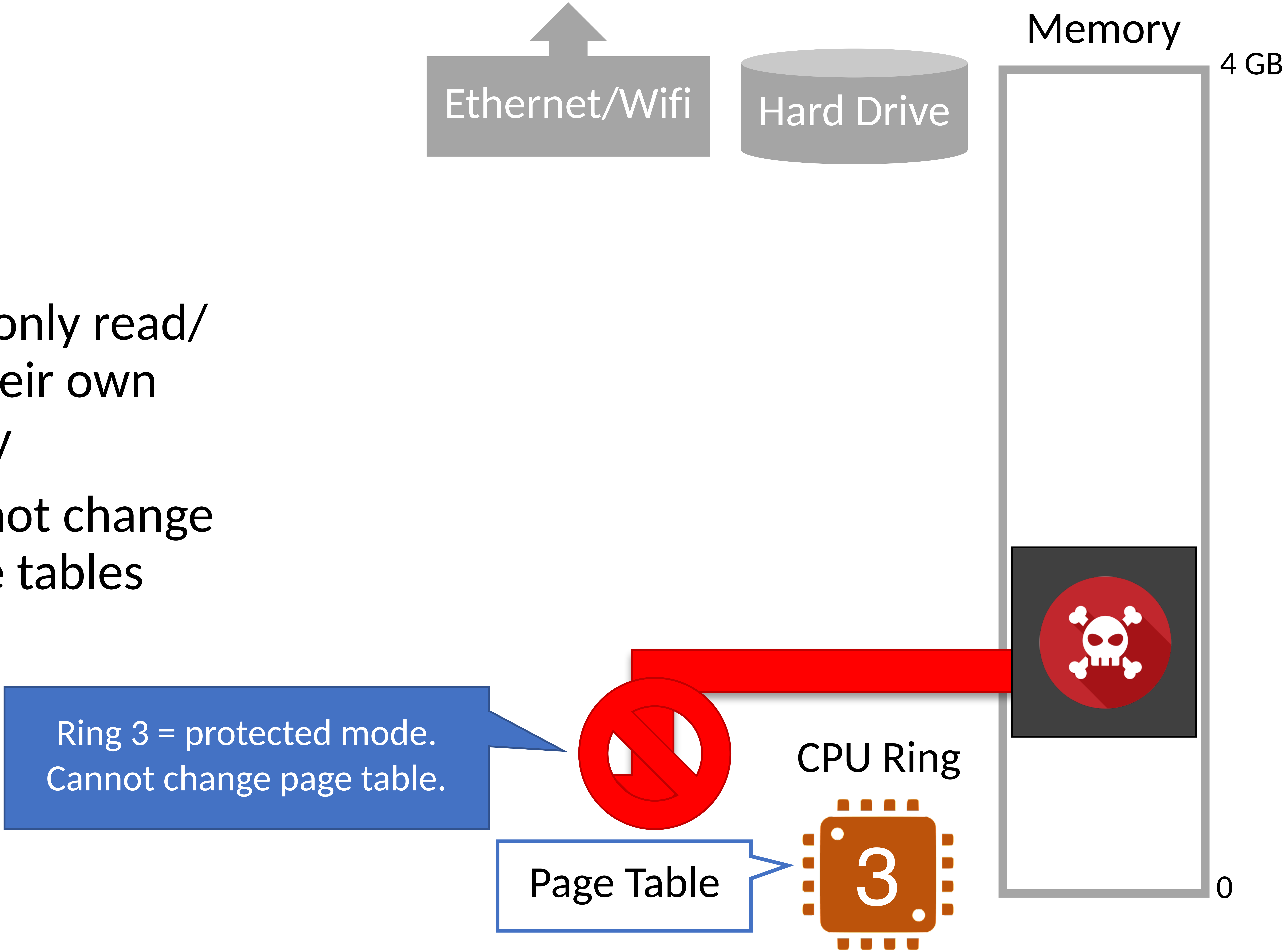


Threat Model
Intro to System Architecture
Hardware Support for Isolation
Examples
Principles

Review

At this point, we have achieved process isolation

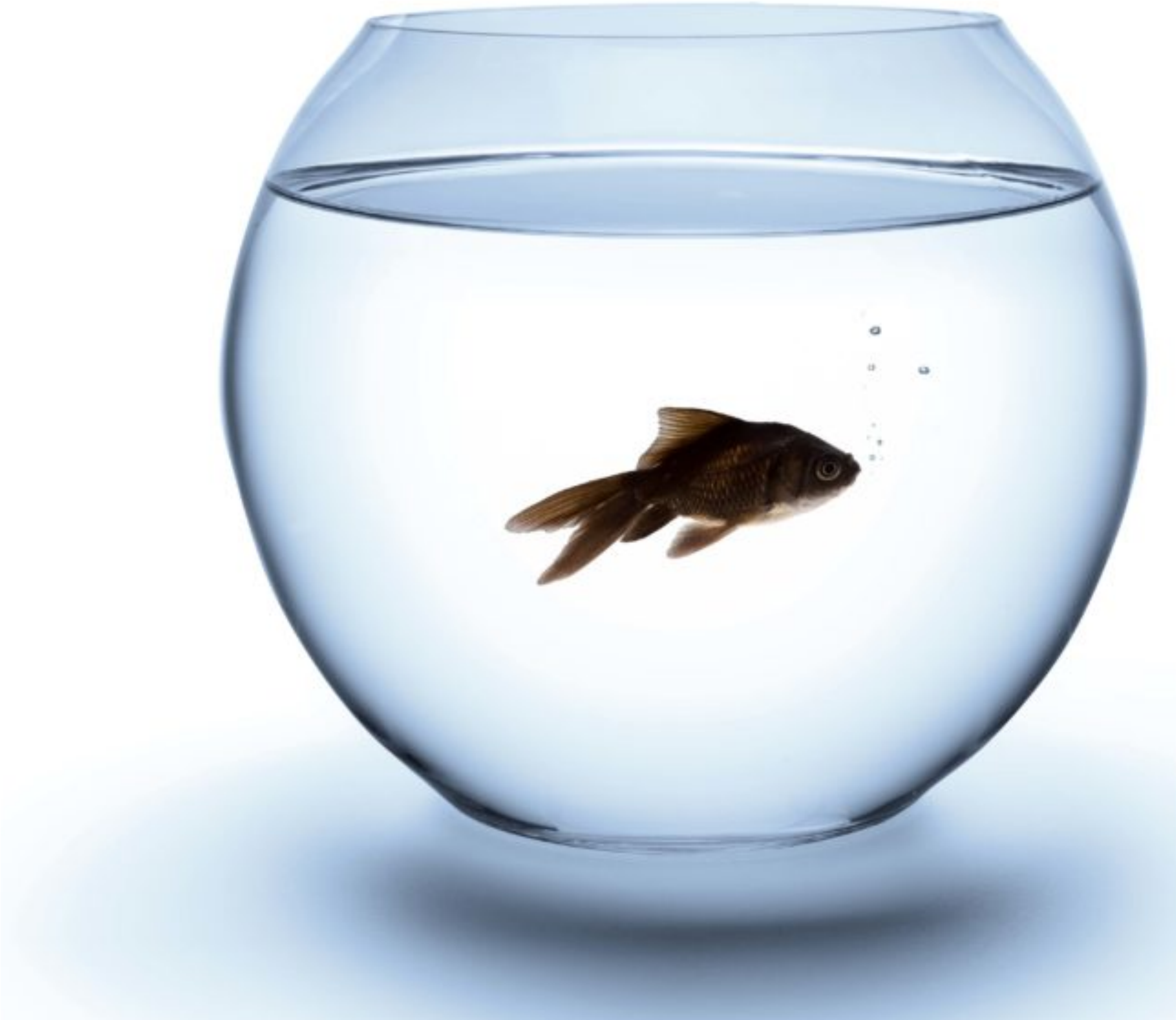
- Protected mode execution prevents direct device access
- Virtual memory prevents direct memory access

Requires CPU support

- All moderns CPUs support these techniques

Requires OS support

- All moderns OS support these techniques
- OS controls process rings and page tables



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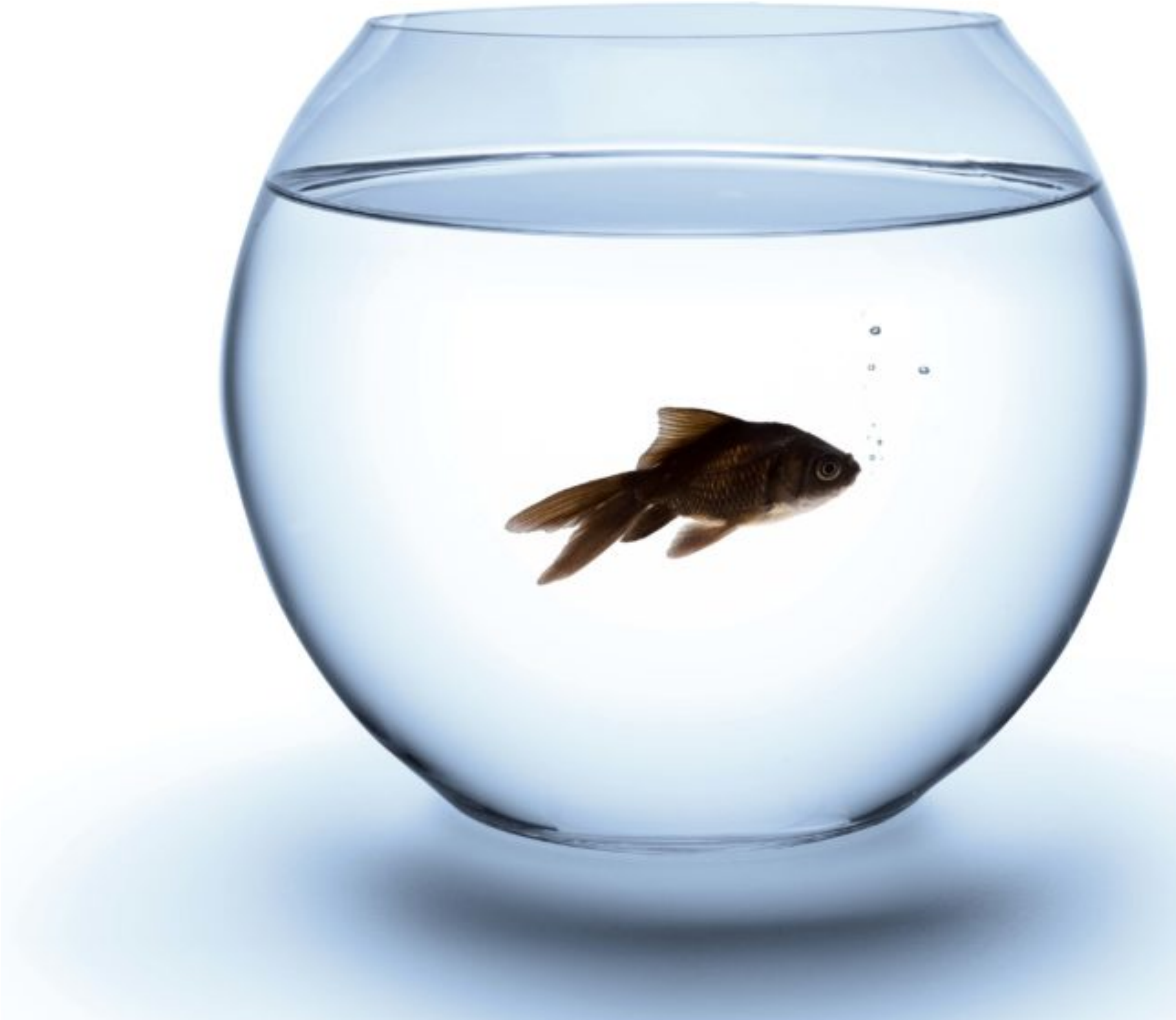
Warning: bugs in the OS may compromise process isolation



Towards Secure Systems

Now that we have process isolation, we can build more complex security features

File Access Control

Anti-virus

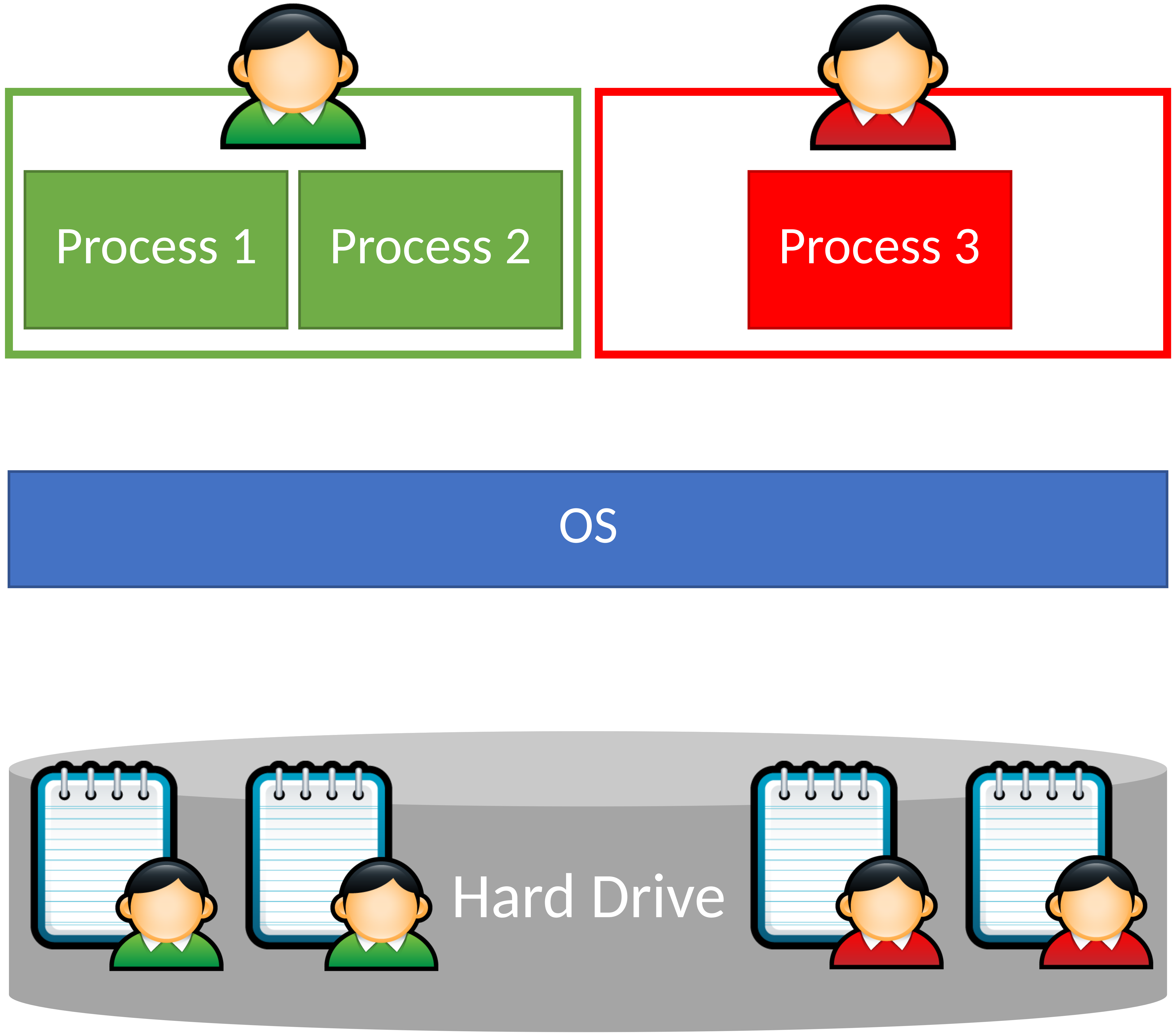
Firewall

Secure Logging

File Access Control

All disk access is mediated by the OS

OS enforces access controls



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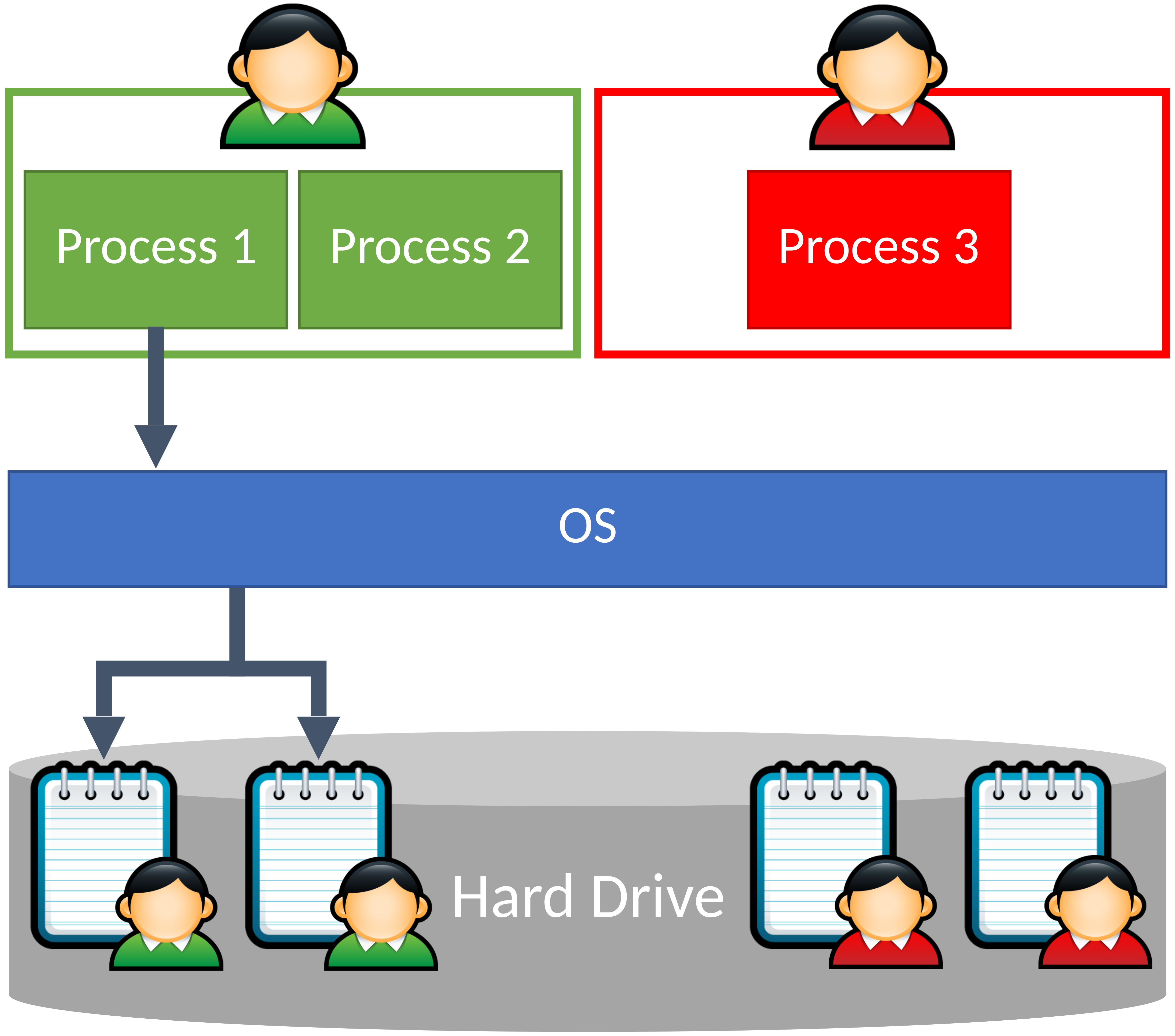

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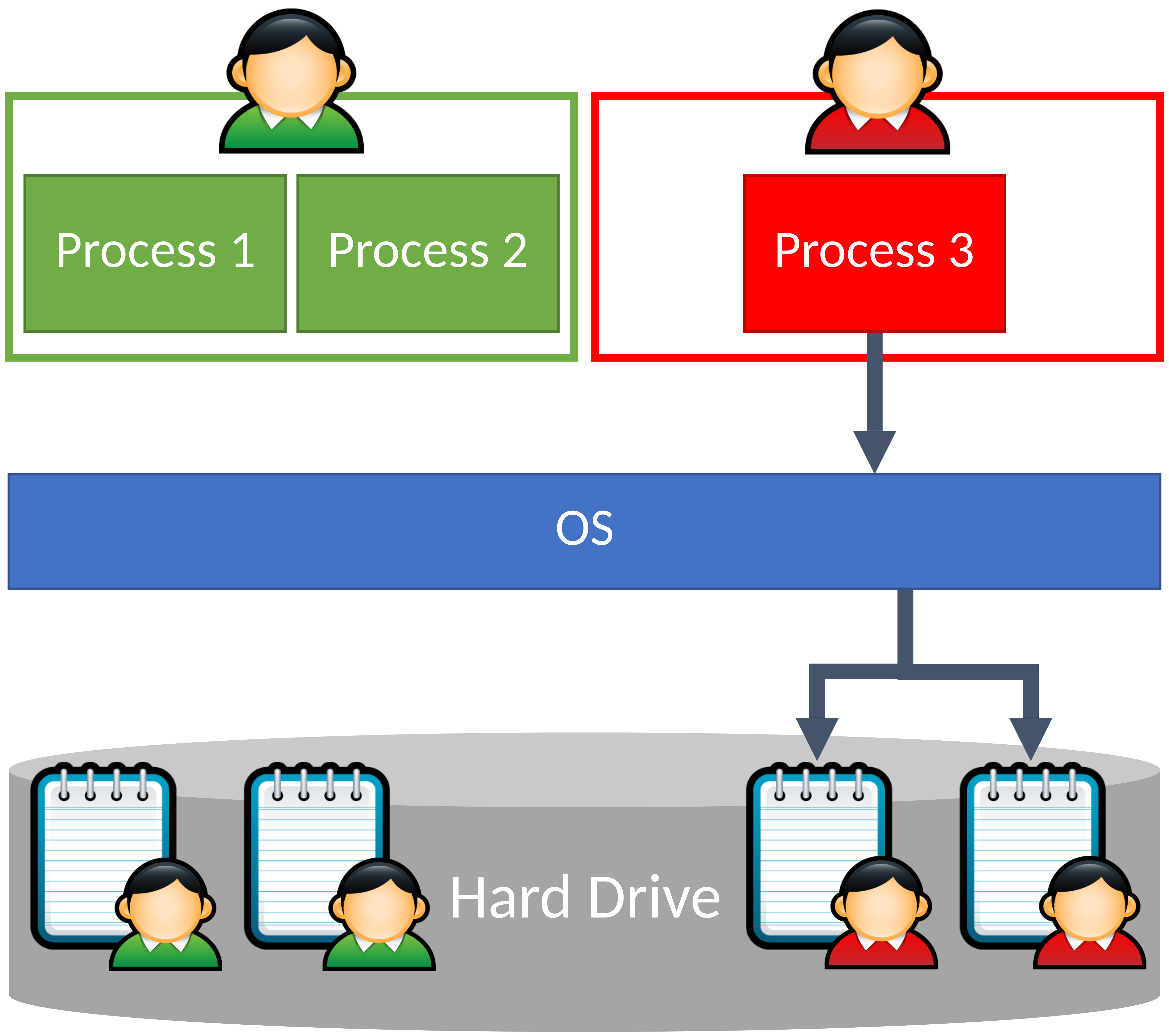

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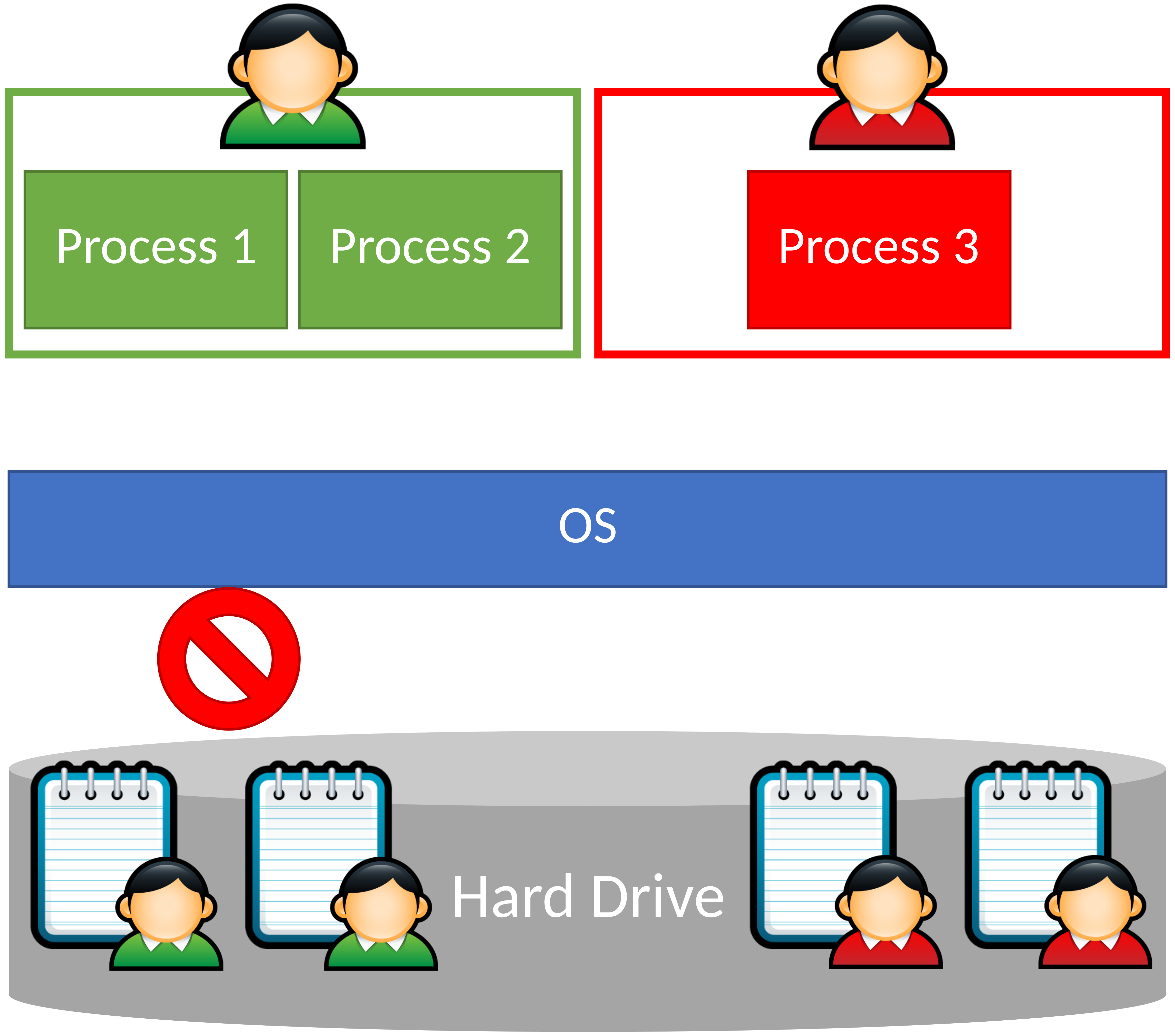
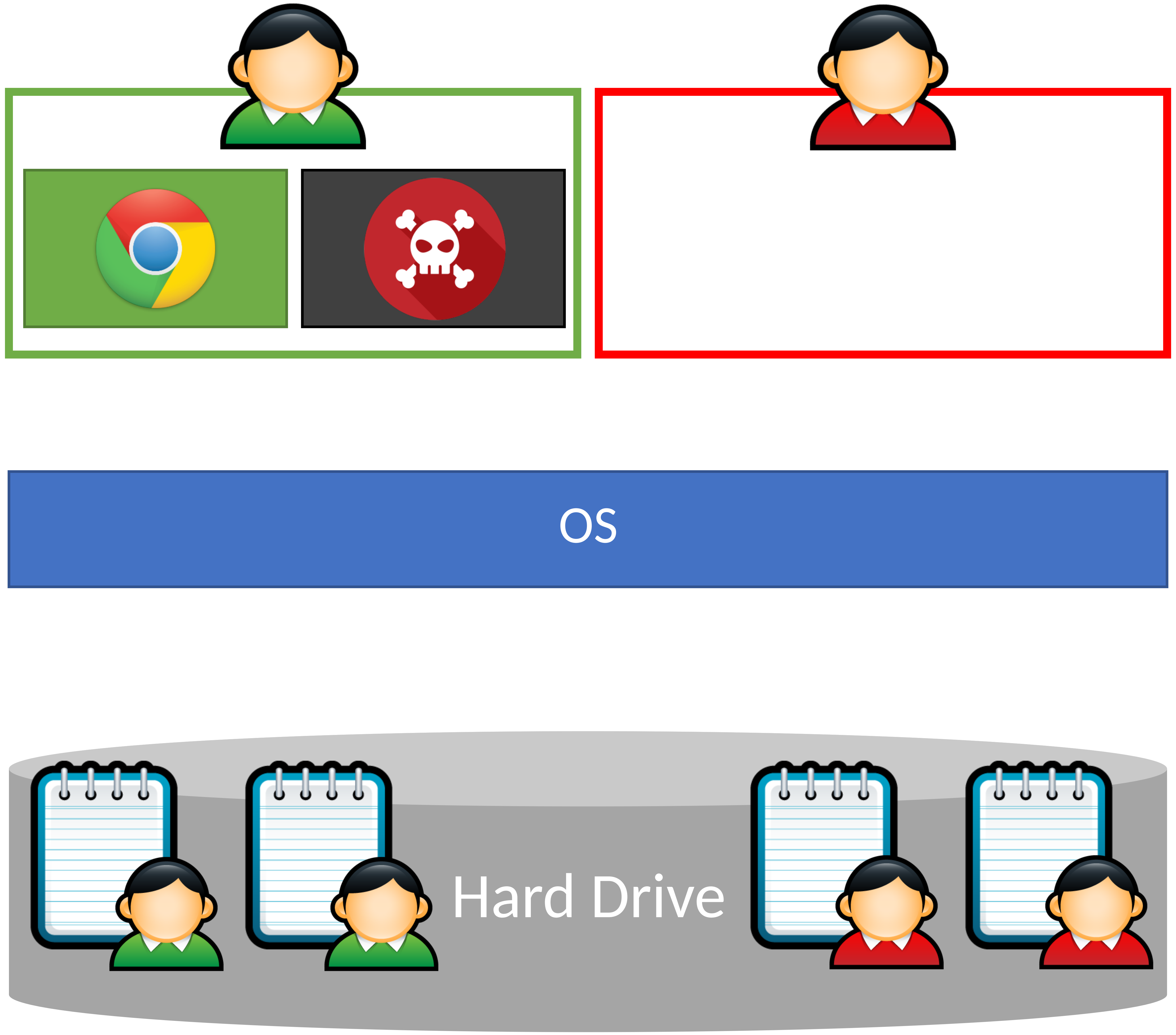


Limitations

Malware can still cause damage

Discretionary access control means that isolation is incomplete



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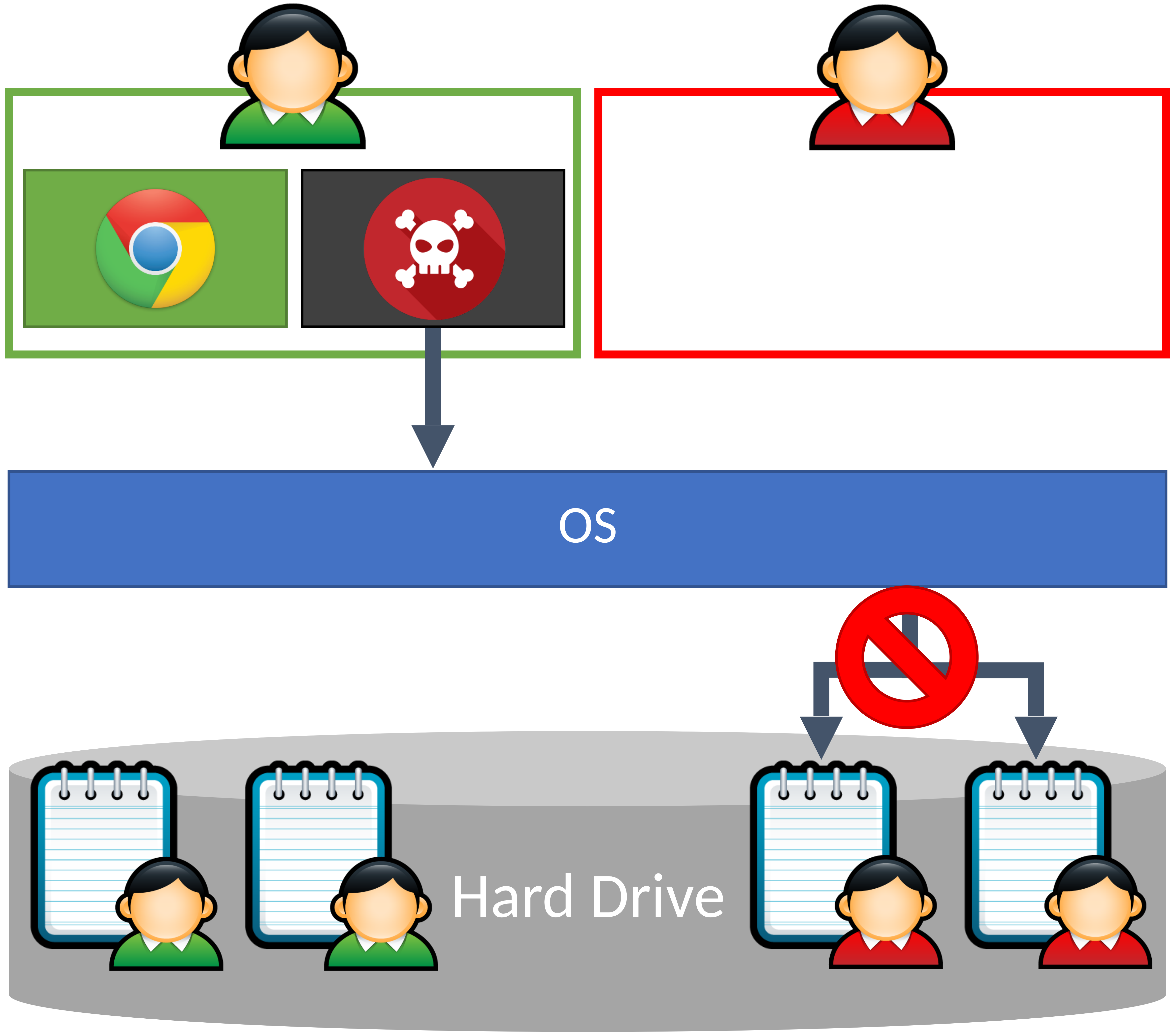

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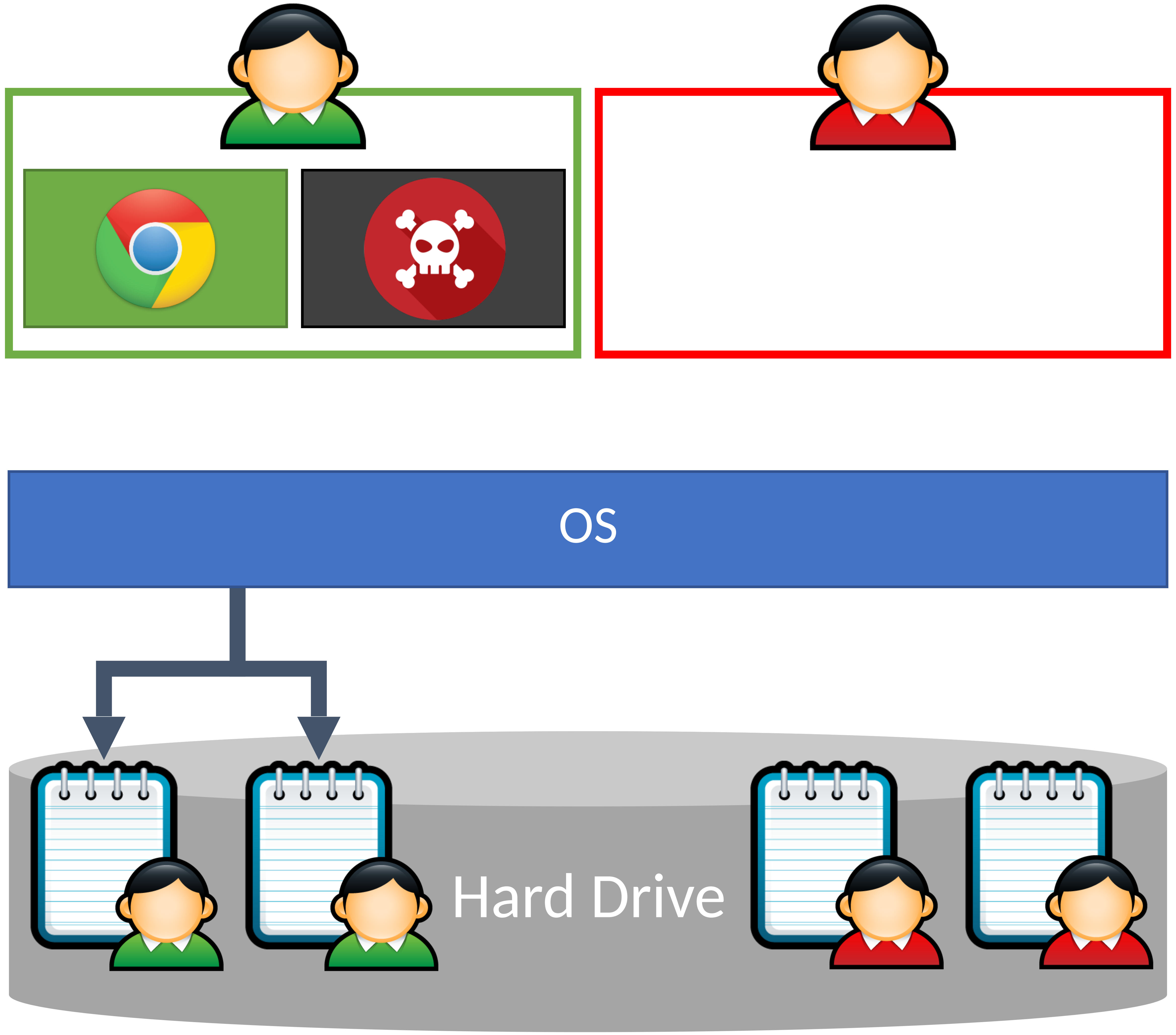


Anti-virus

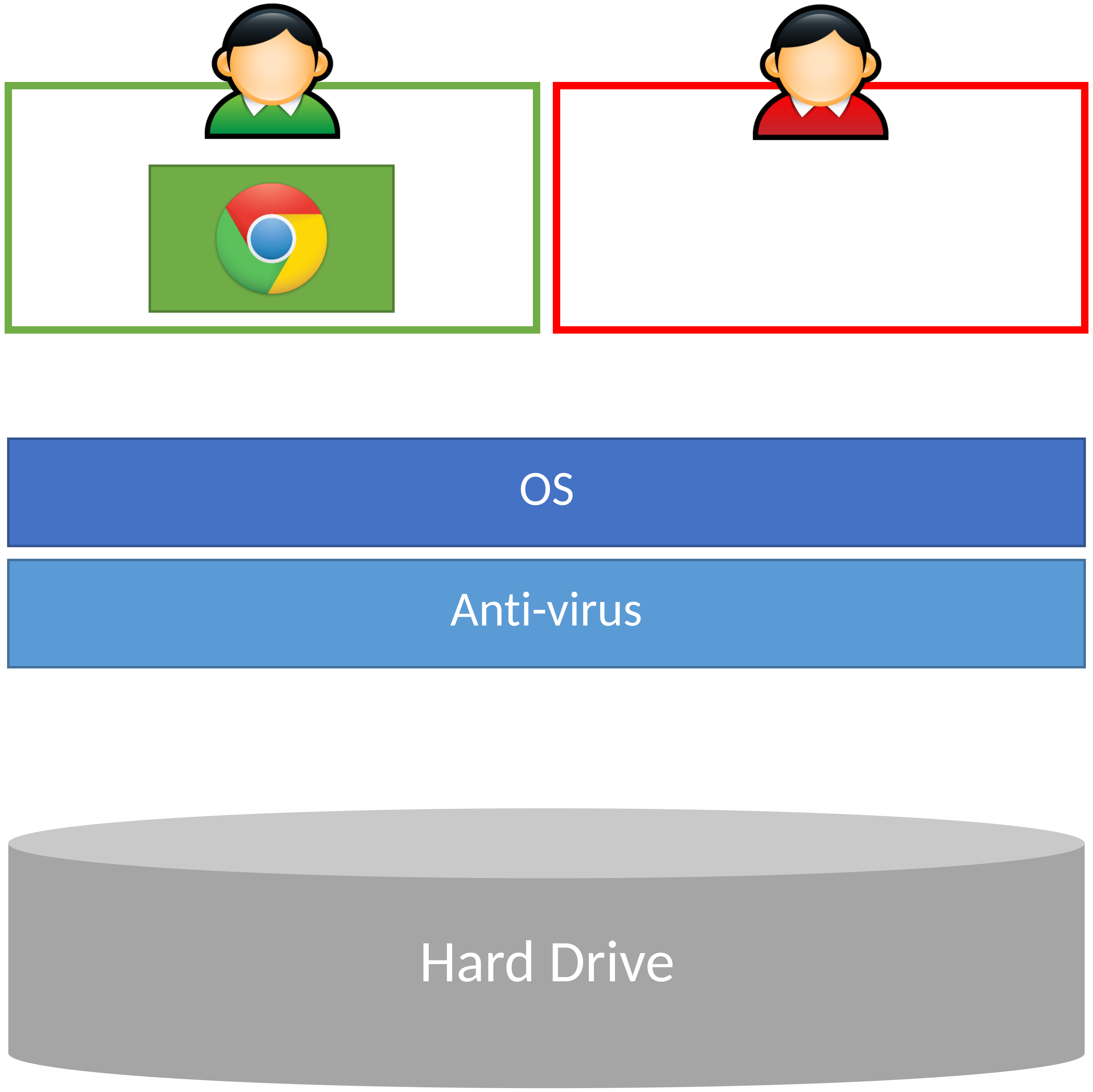
Anti-virus process is privileged

- Often runs in Ring 0

Scans all files looking for signatures

- Each signature uniquely identifies a piece of malware

Files scanned on creation and access



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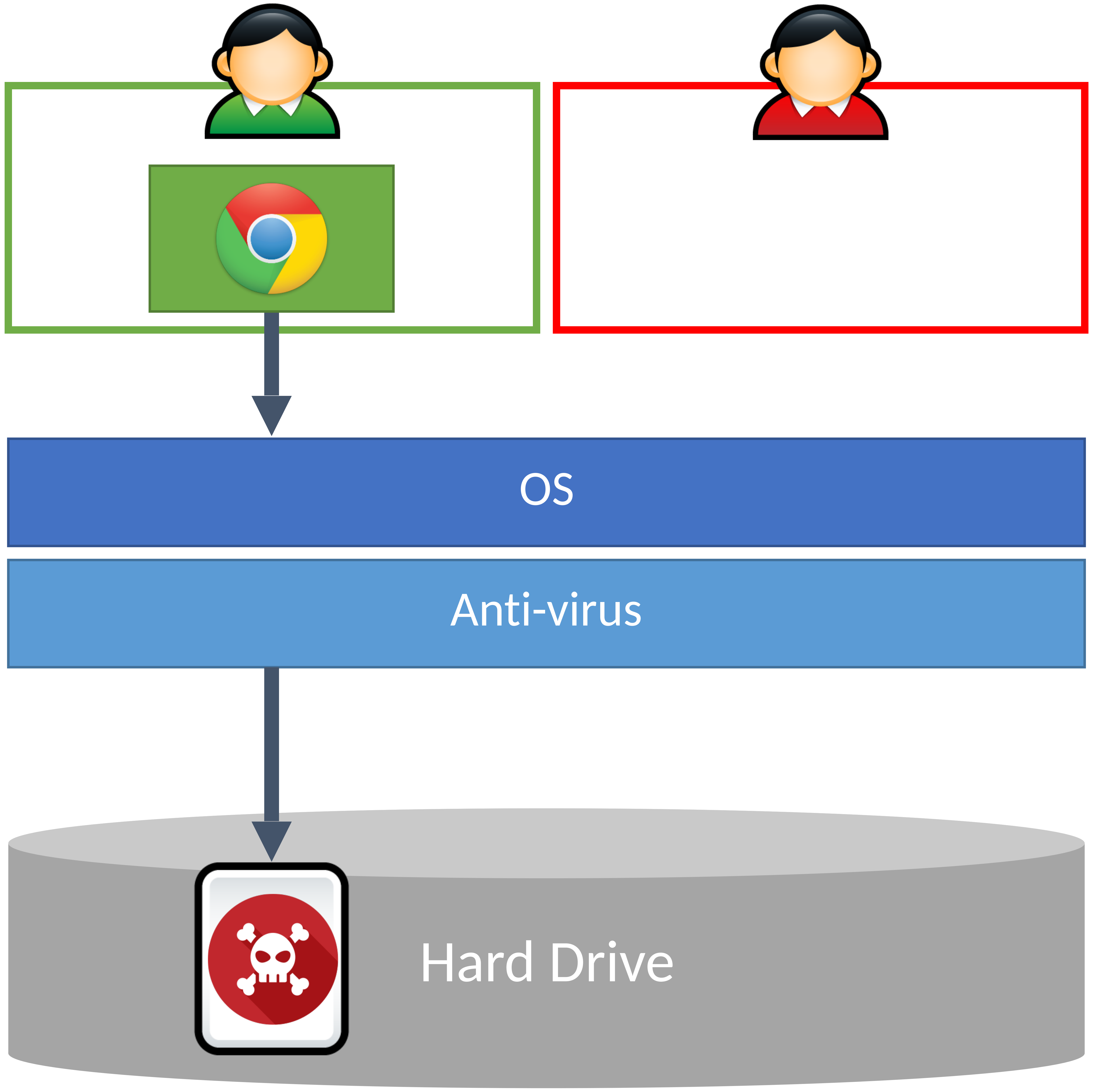

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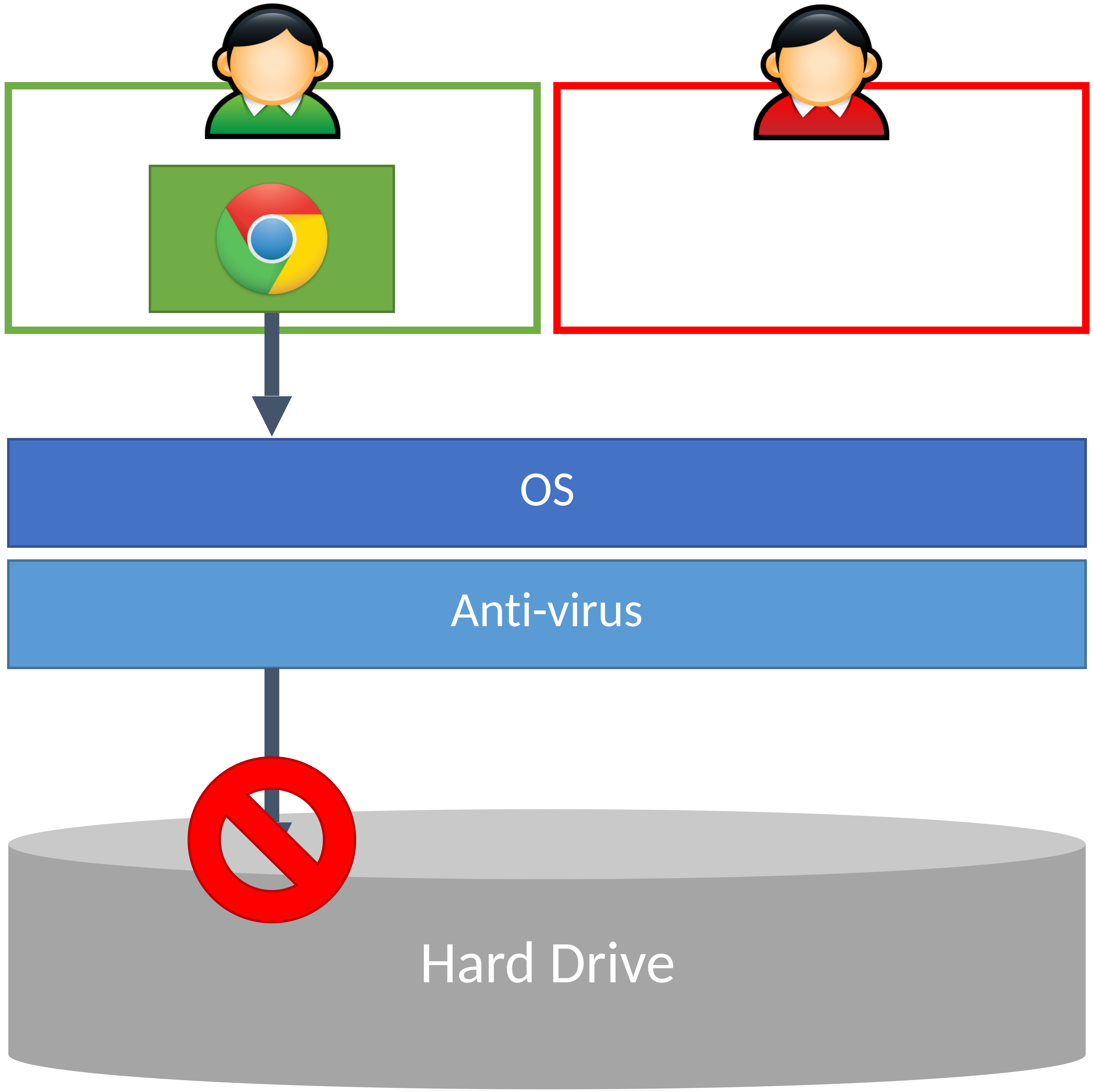

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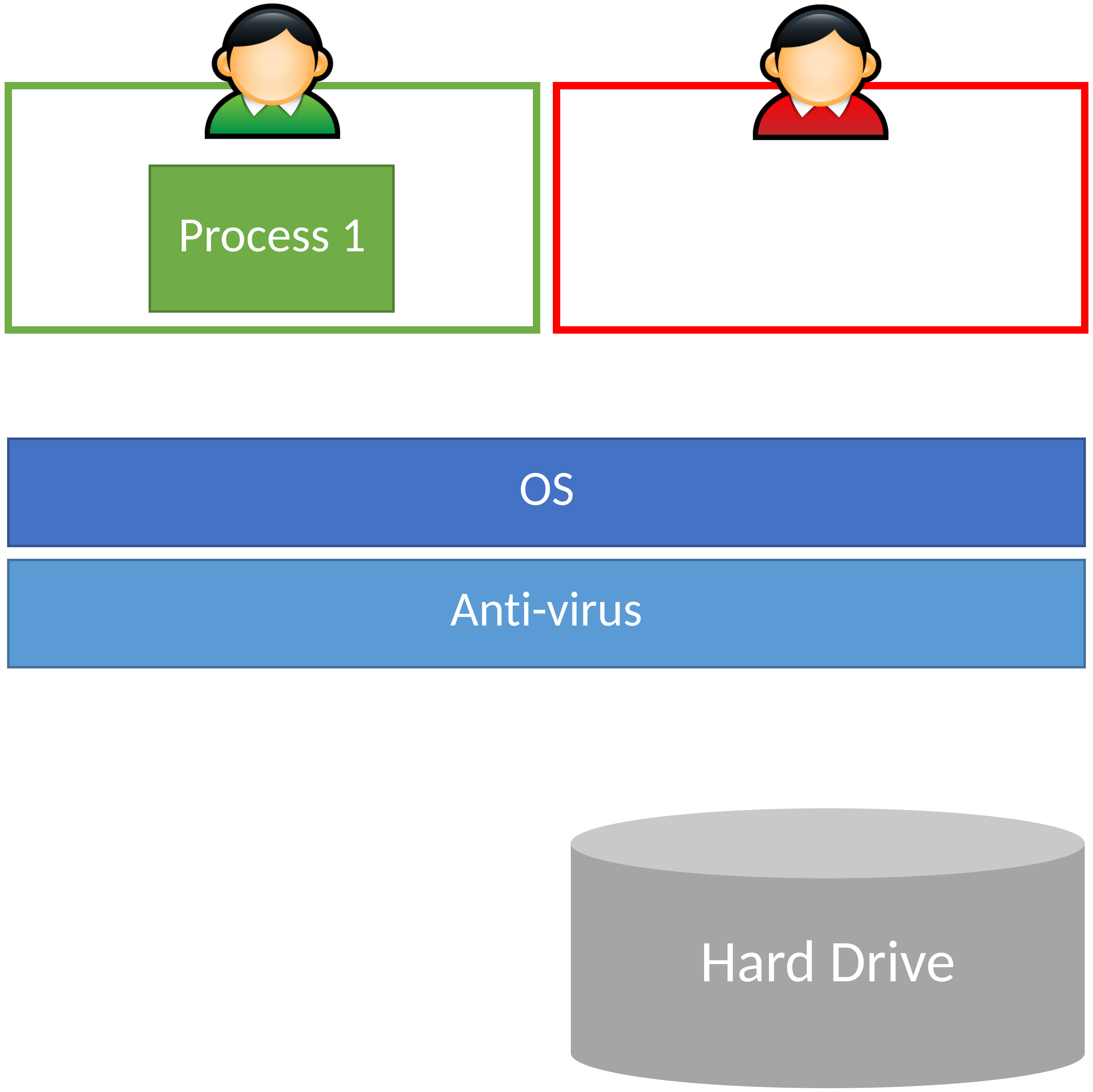

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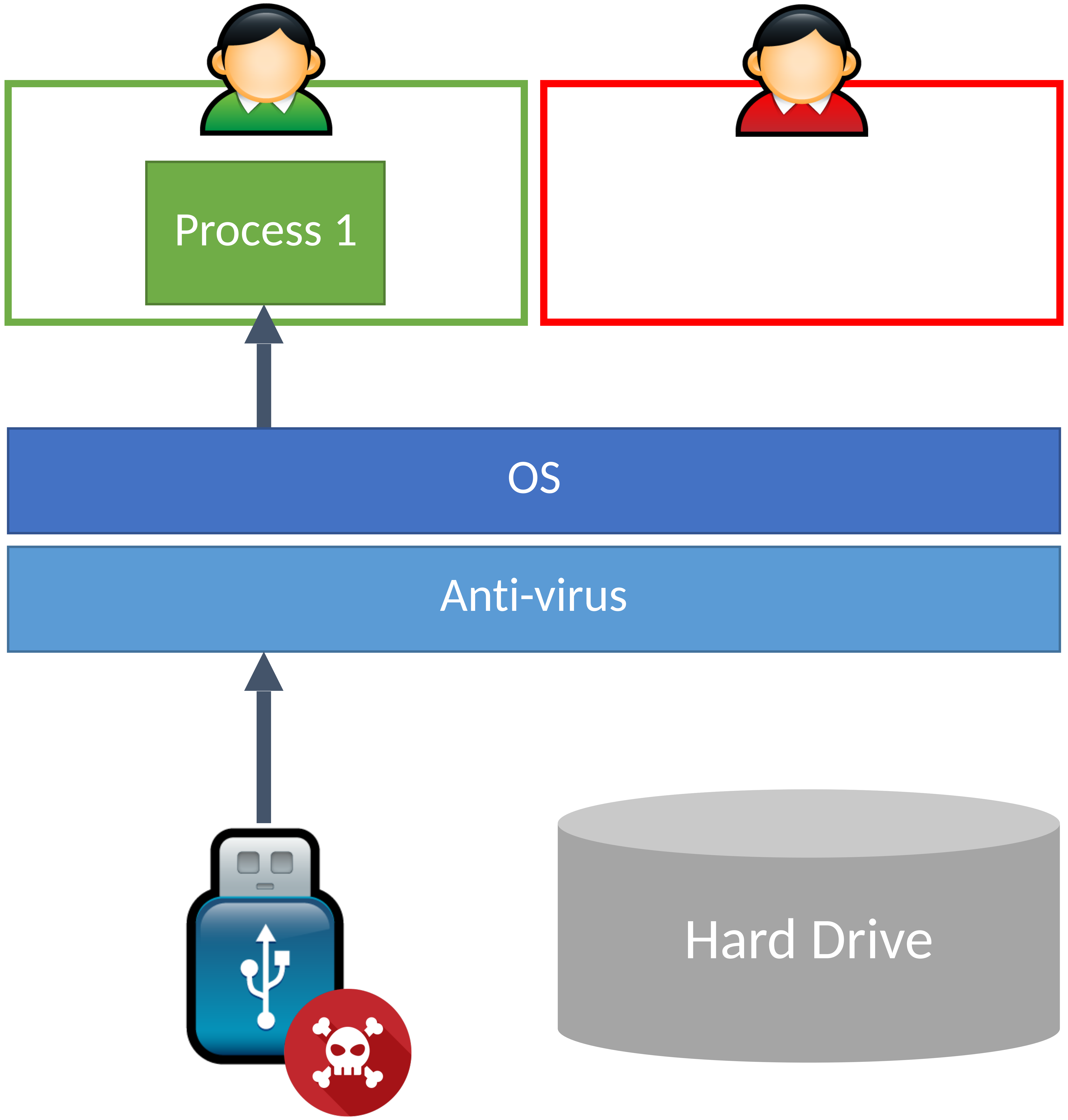

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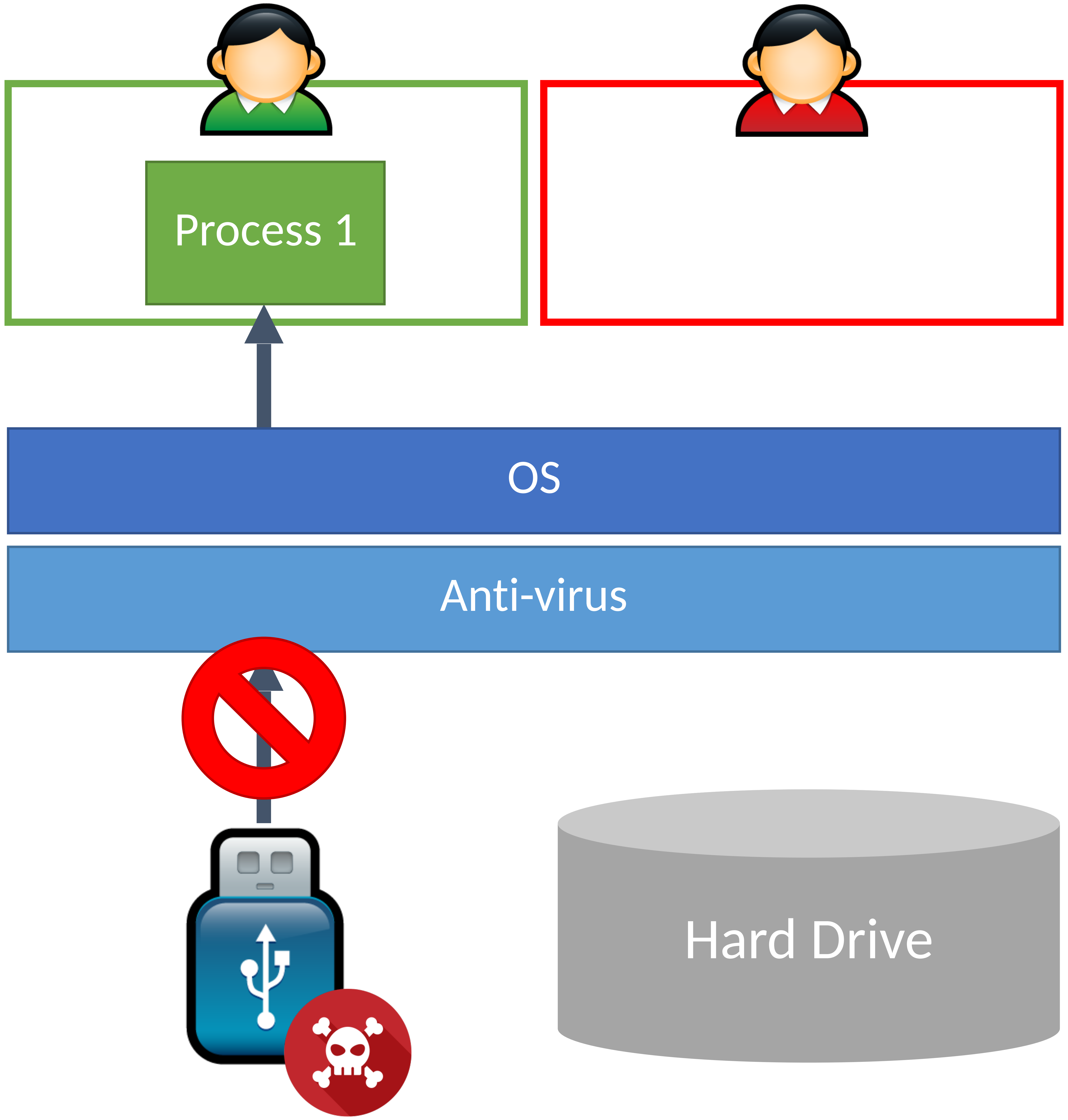

Signature-based Detection

Key idea: identify invariants that correspond to malicious code or data

Example – anti-virus signatures

- List of code snippets that are unique to known malware

Problems with signatures

Signature-based Detection

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Example – anti-virus signatures

- List of code snippets that are unique to known malware

Problems with signatures

- Must be updated frequently
- May cause false positives
  - Accidental overlaps with good programs and benign network traffic

Avast Malware Signature Update Breaks Installed Programs

Users of the free version of Avast antivirus unscathed

May 7, 2015 13:55 GMT · By Ionut Ilascu · Share:

A bad virus definition update from Avast released on Wednesday caused a lot of trouble, as it mistook various components in legitimate programs installed on the machine for malware.

The list of valid software affected by the signature update includes Firefox, iTunes, NVIDIA drivers, Google Chrome, Adobe Flash Player, Skype, Opera, TeamViewer, ATI drivers, as well as products from Corel and components of Microsoft Office.

Avoiding Anti-virus

Malware authors go to great length to avoid detection by AV

Polymorphism

- Viral code mutates after every infection

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```
b = a + 10
```

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```
b = a + 10        b = a + 5 + 5     b = (2 * a + 20) / 2
```

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Polymorphism

- Viral code mutates after every infection

```
b = a + 10        b = a + 5 + 5      b = (2 * a + 20) / 2
```

Packing

- Malware code is encrypted, key is changed every infection
- Decryption code is vulnerable to signature construction
- Polymorphism may be used to mutate the decryption code

Firewall

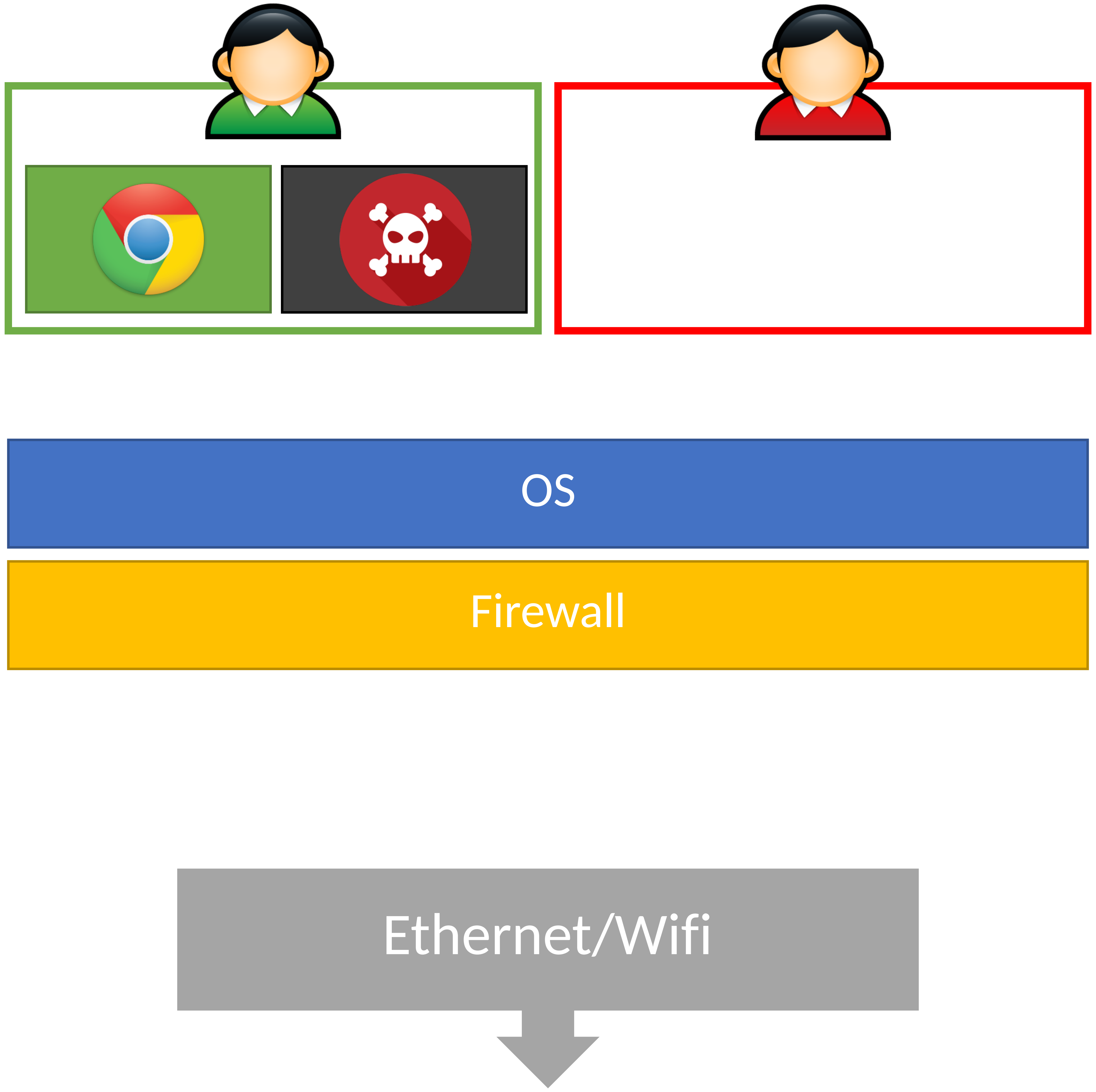
Firewall process is privileged

- Often runs in Ring 0

Selectively blocks network traffic

- By process
- By port
- By IP address
- By packet content

Inspects outgoing and incoming network traffic



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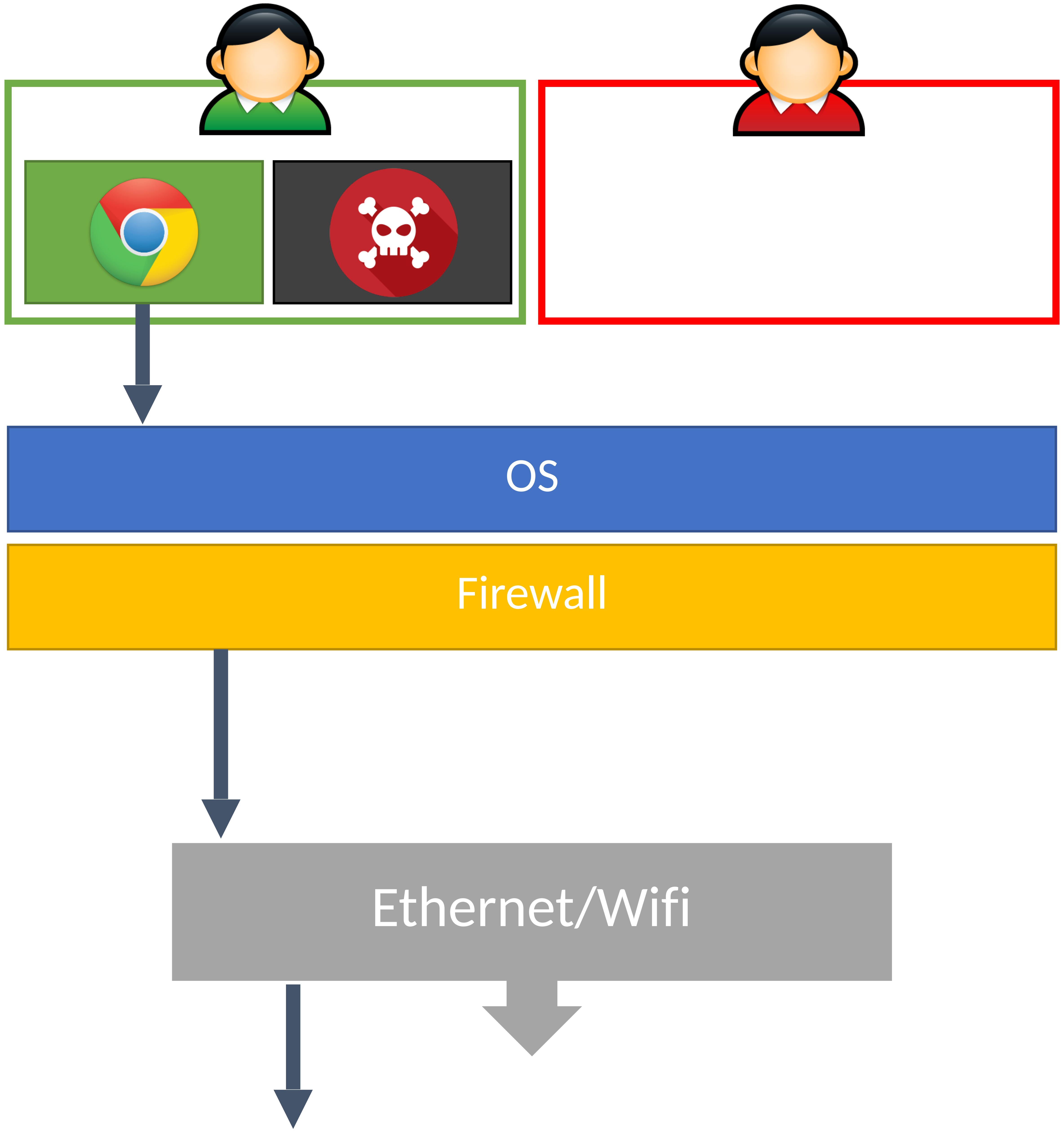

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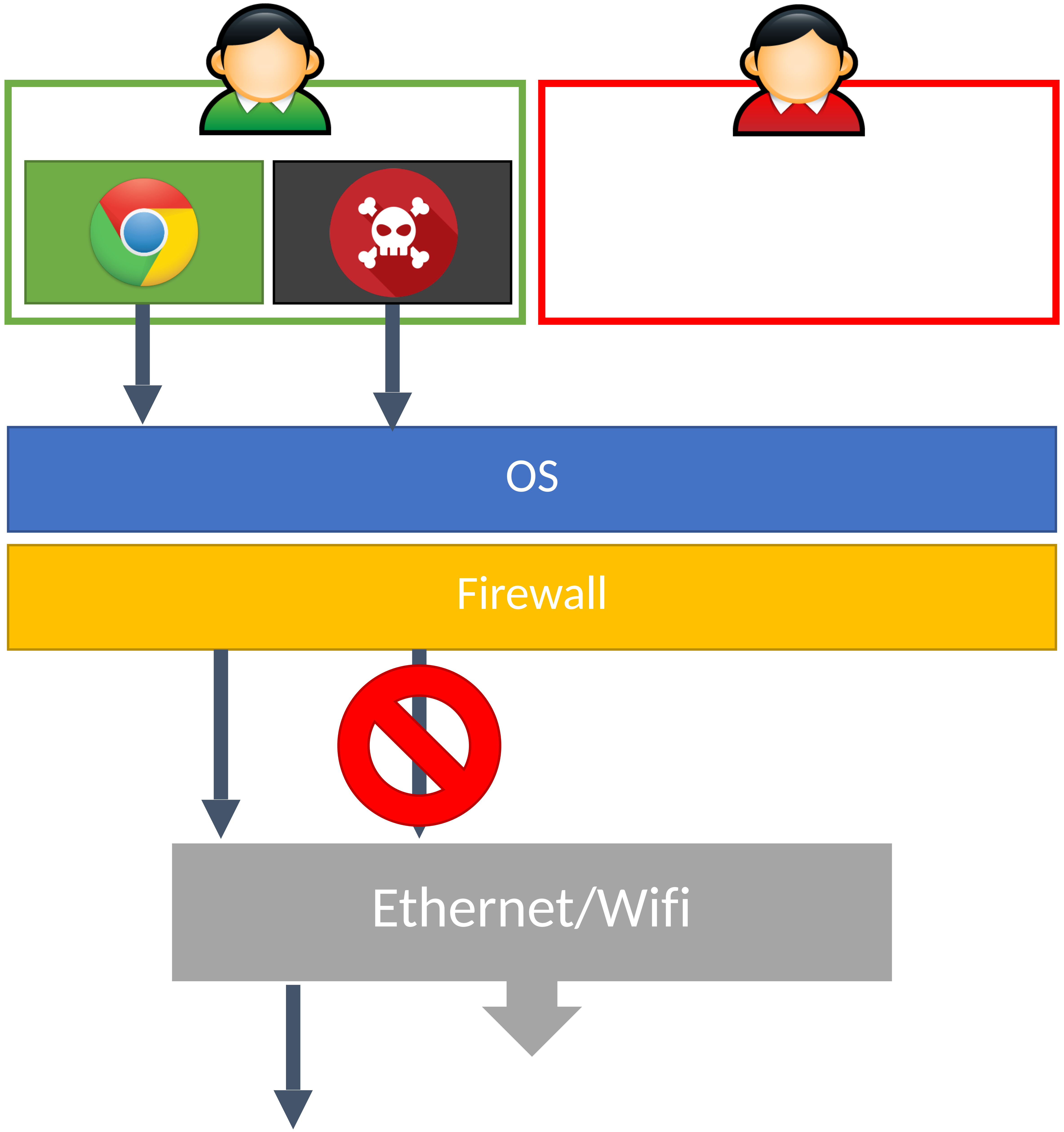

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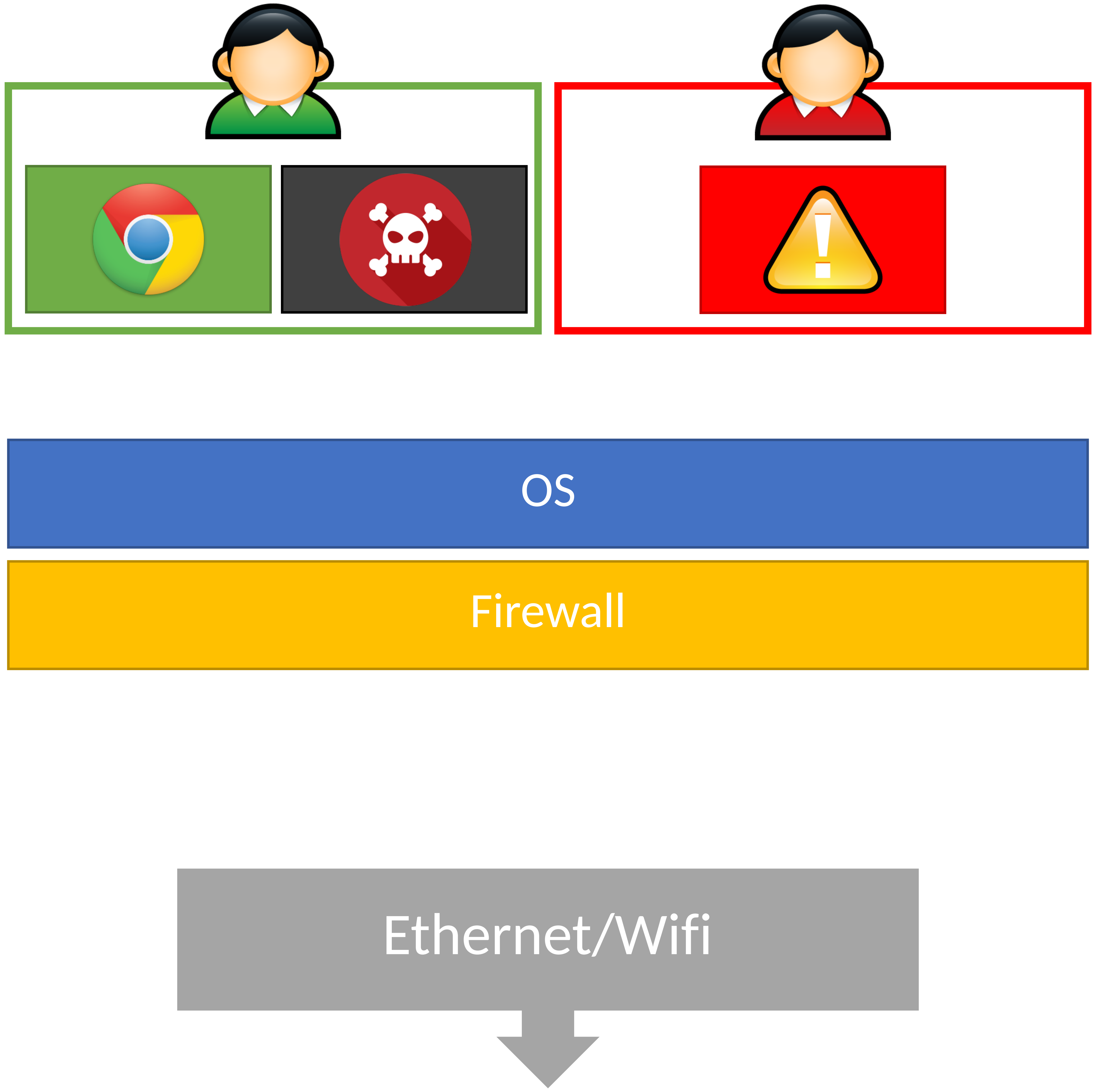

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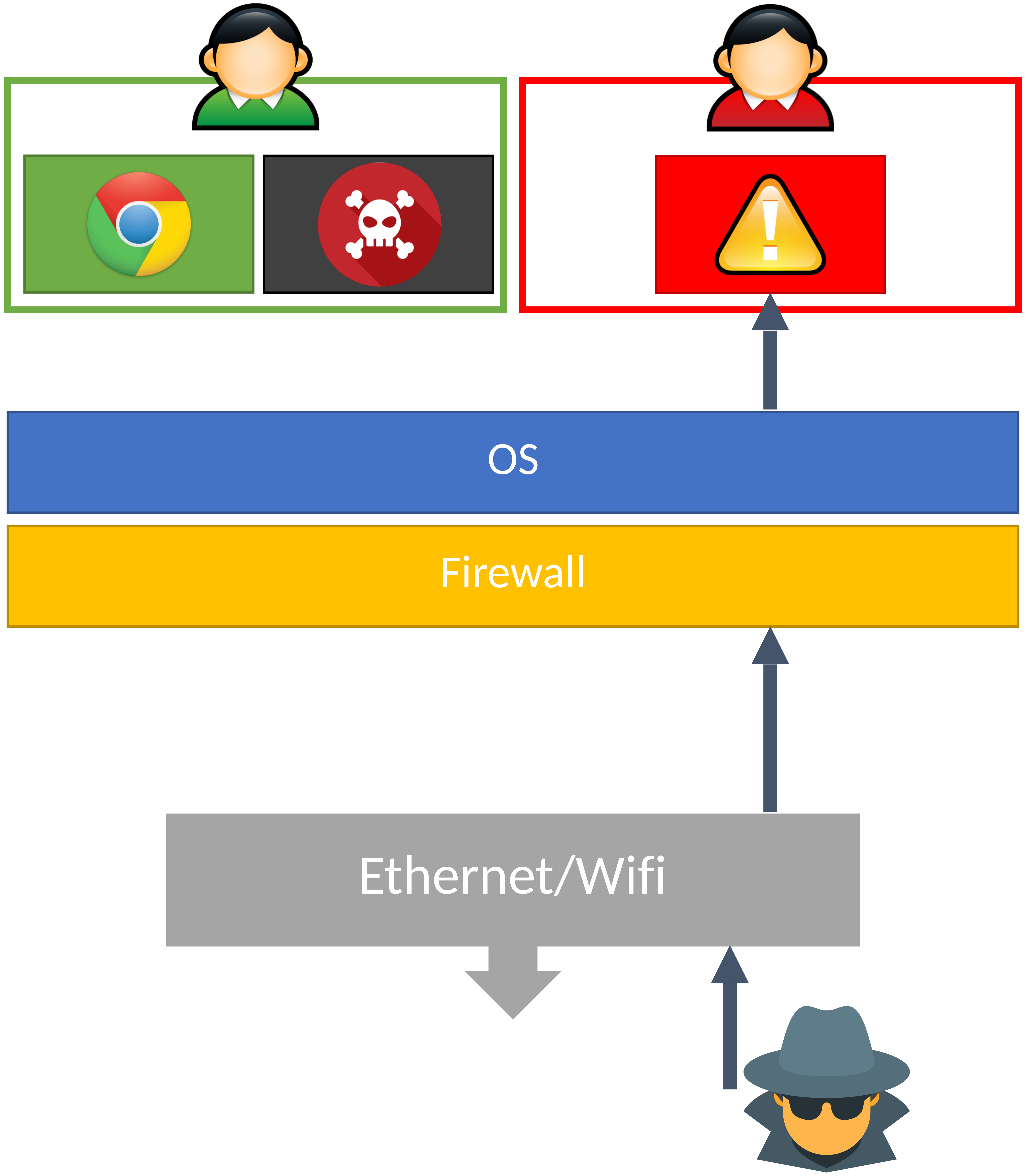

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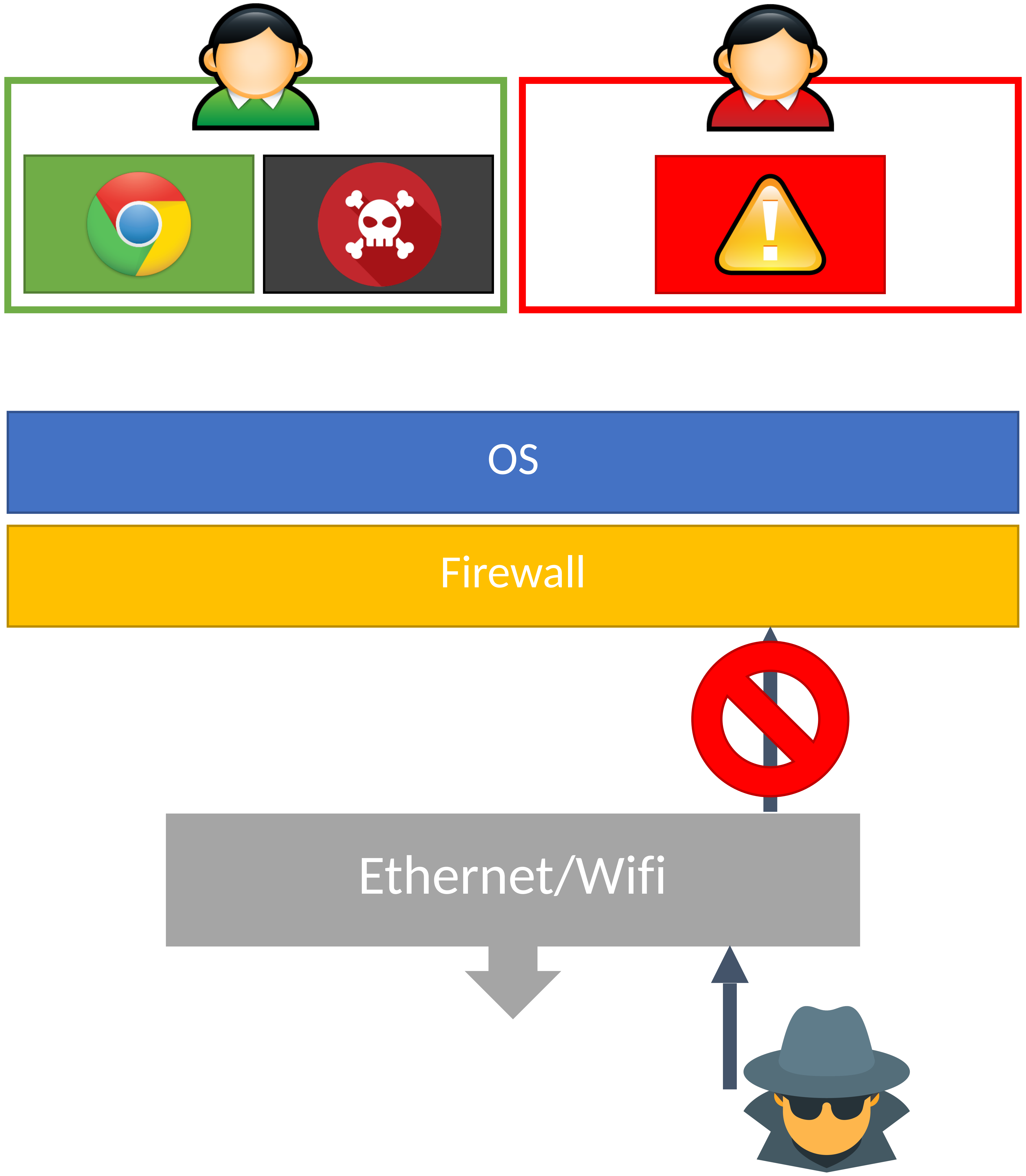


Network Intrusion Detection Systems

NIDS for short

Snort

- Open source intrusion prevention system capable of real-time traffic analysis and packet logging
- Identifies malicious network traffic using signatures

Bro

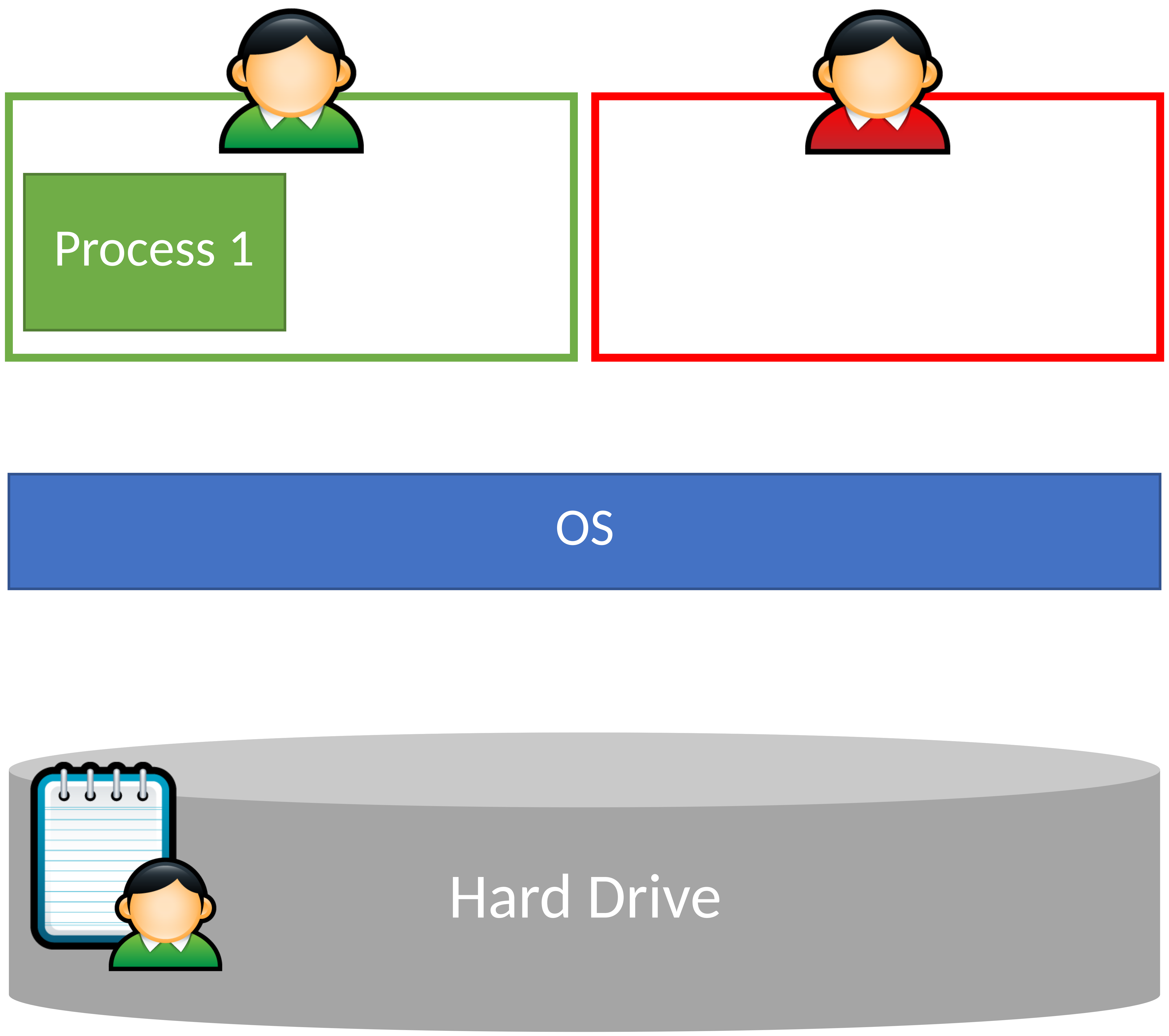
- Open source network monitoring, analysis, and logging framework
- Can be used to implement signature based detection
- Capable of more complex analysis

Insecure Logging

Suppose Process 1 writes information to a log file

Malware can still destroy the log

- Add or remove entries
- Add fake entries
- Delete the whole log



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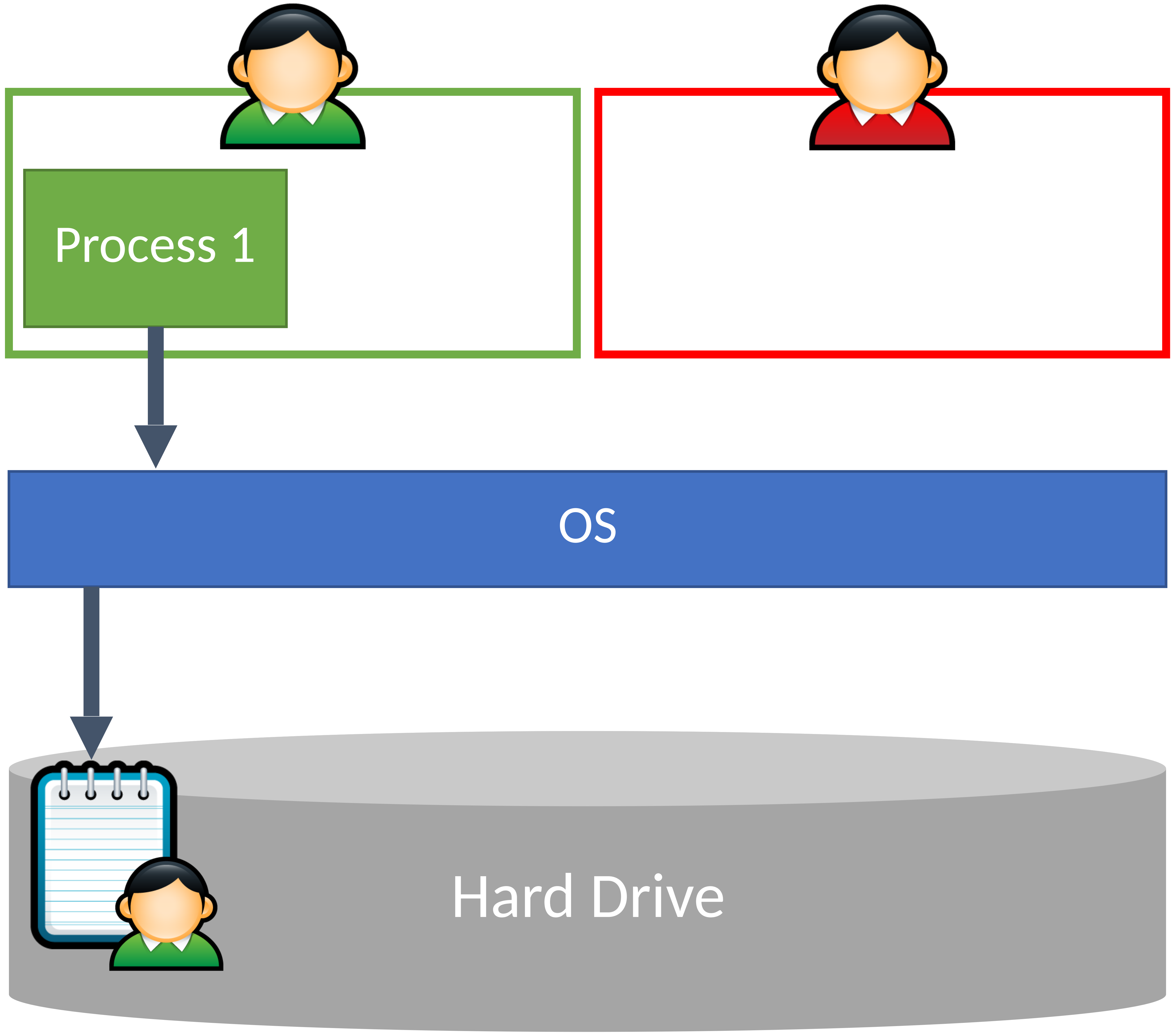

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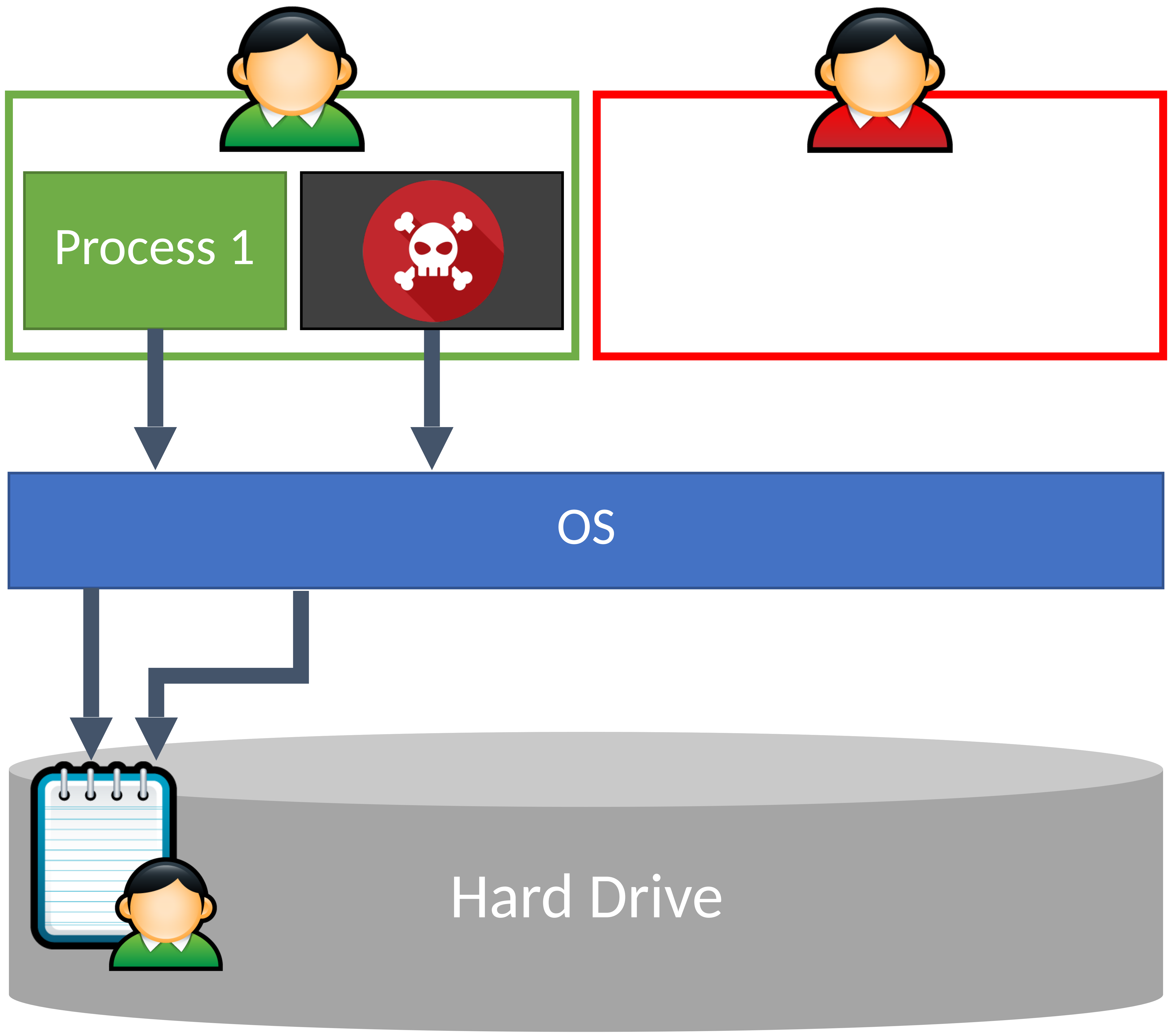

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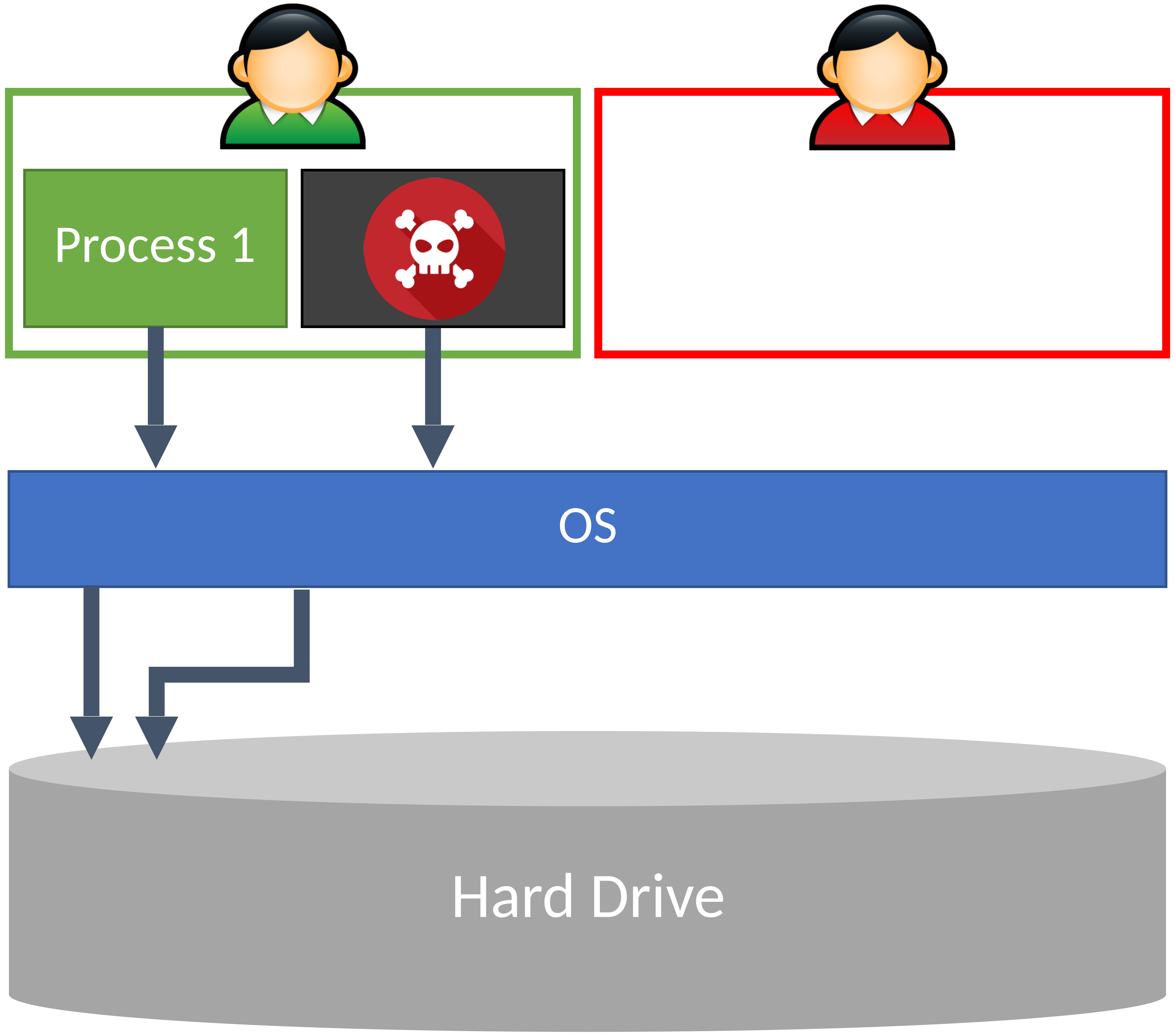
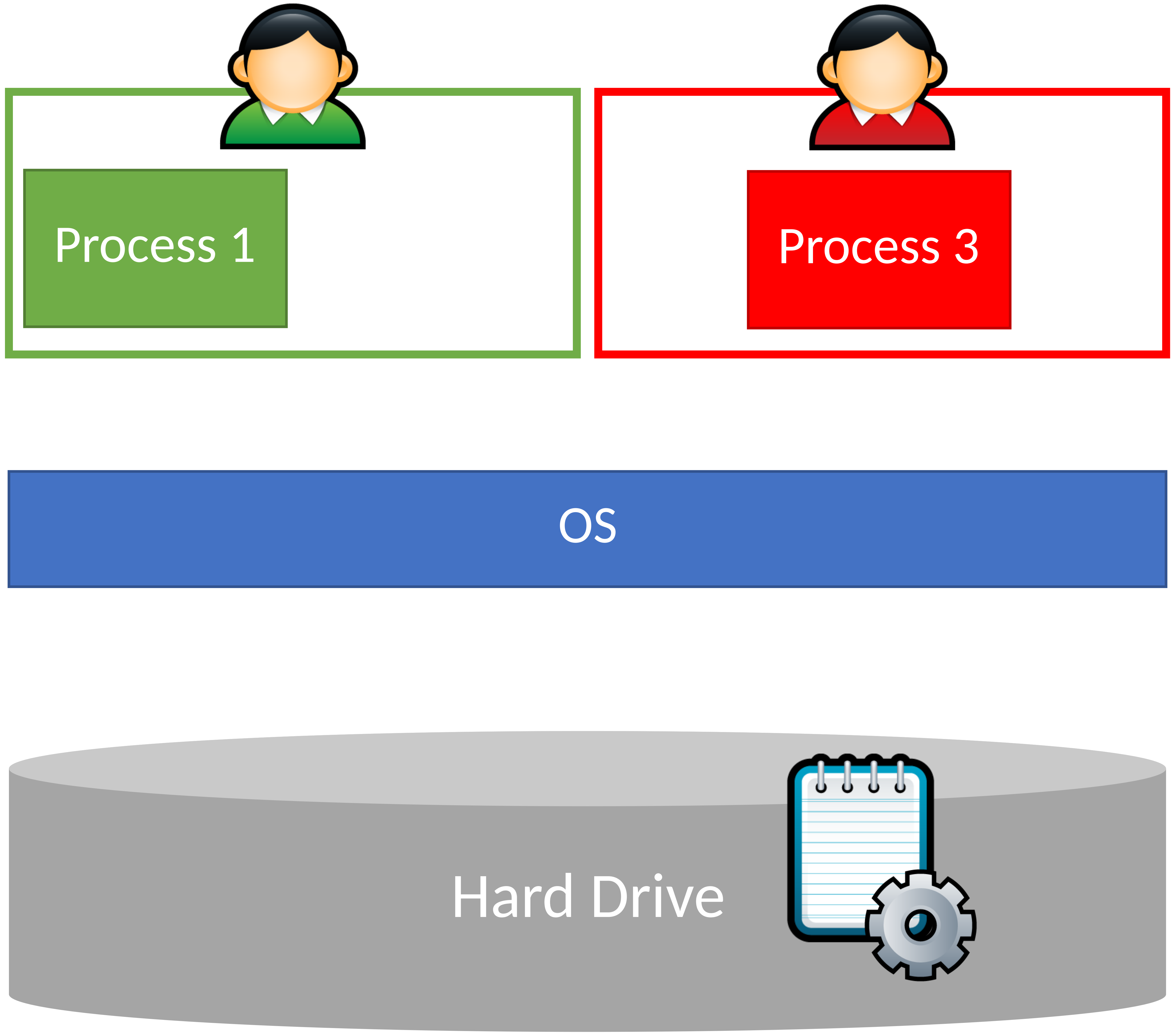


Secure Logging

OS maintains a system log

Processes may write entries to the log using an OS API

Processes may not delete entries or the log



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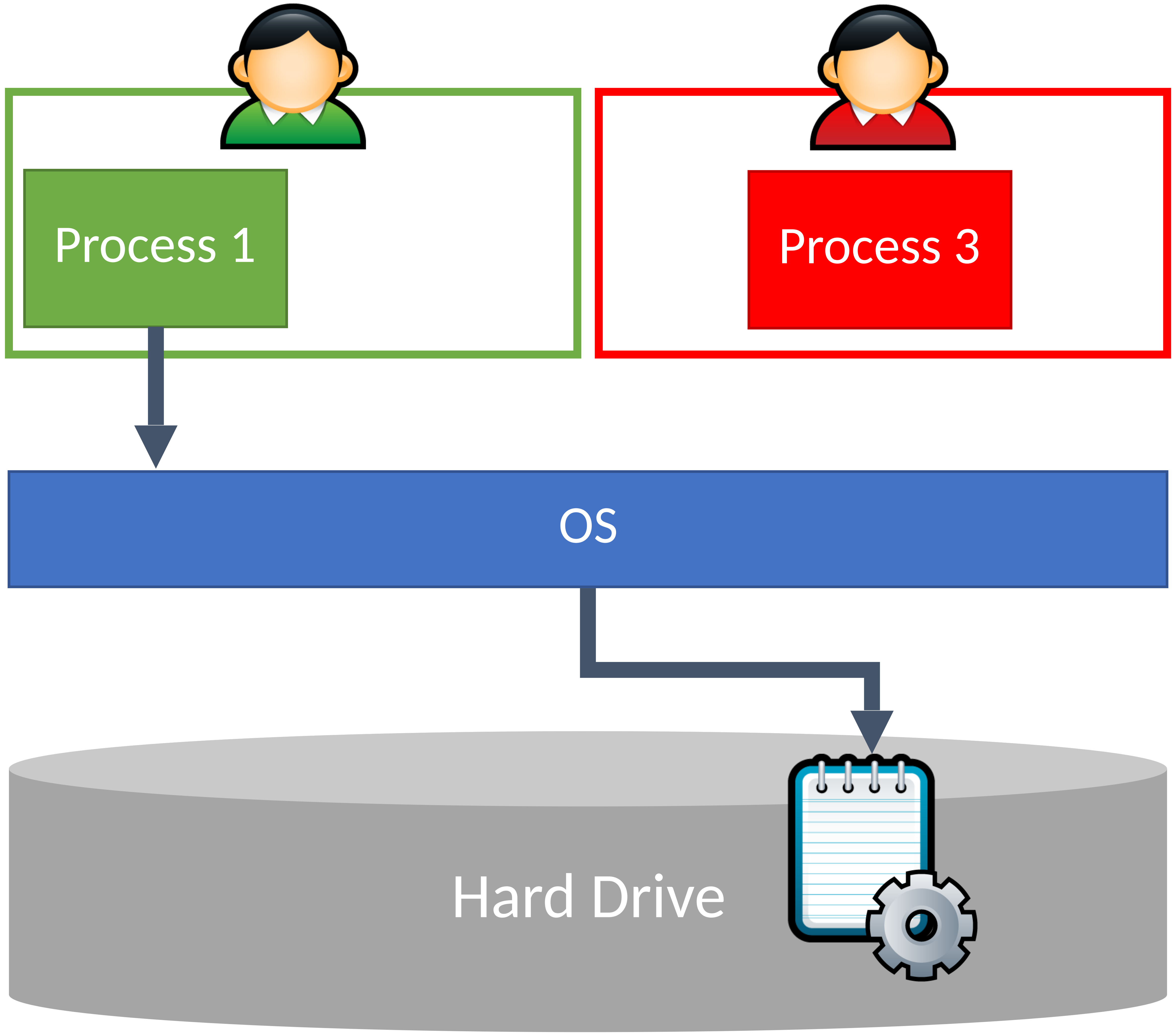

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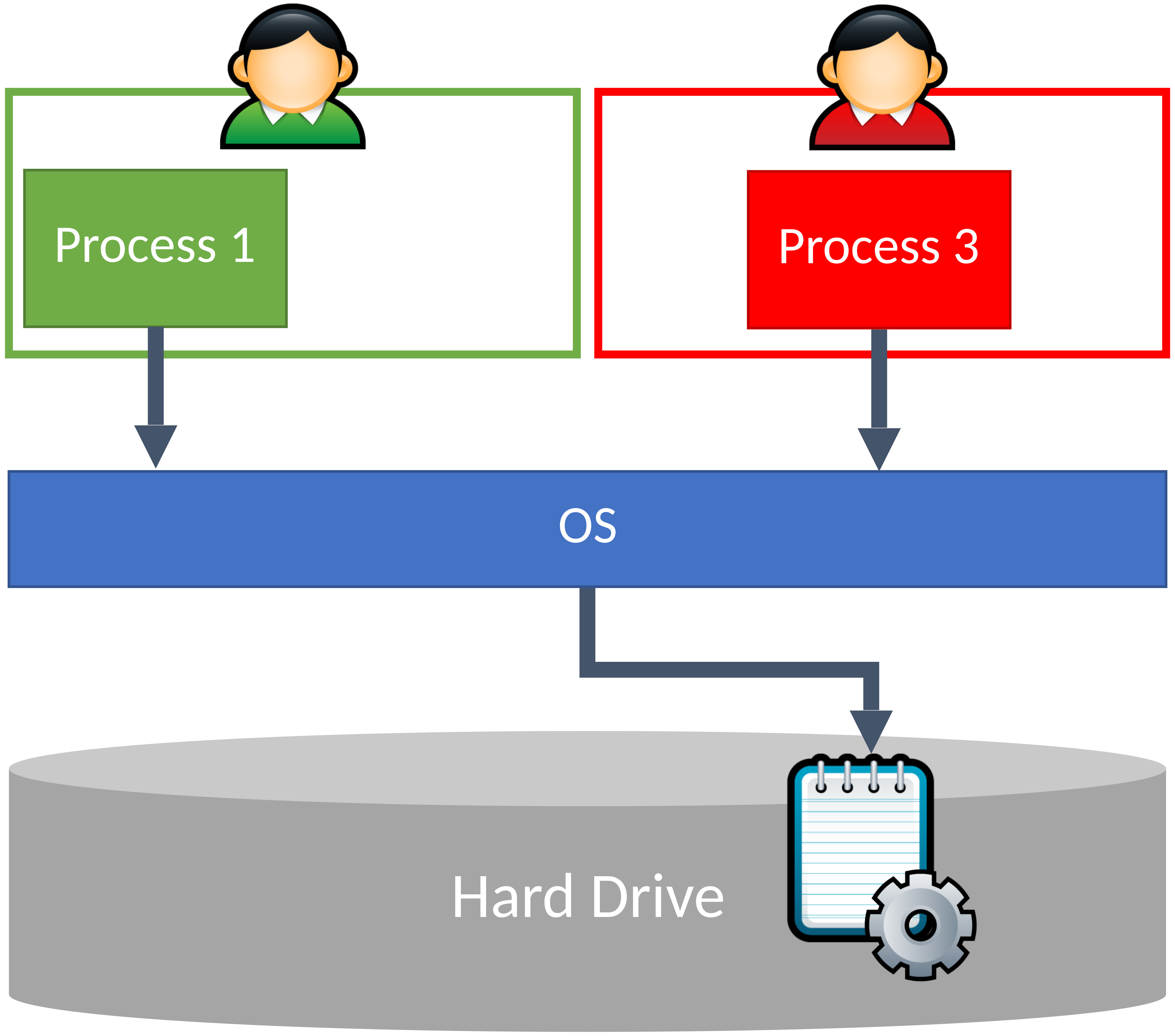

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