

Introduction

COL331/COL633

Abhilash Jindal

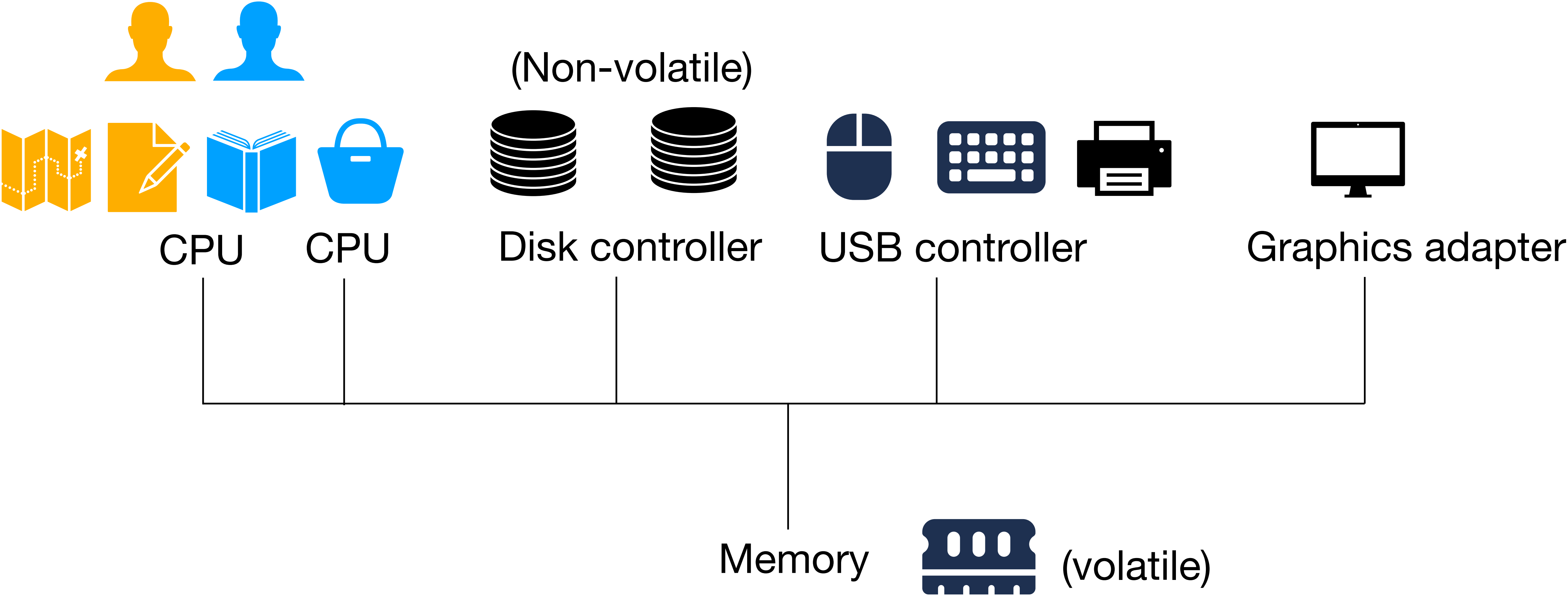
Reference. OSTEP book: Chapter 2

Administrivia

- <http://abhilash-jindal.com/teaching/2023-2-col-331/>
- Grading criteria, TAs, late policy, audit criteria, quizzes, labs, project, piazza link
- Piazza access code: col331col633

Why does OS matter to a computer?

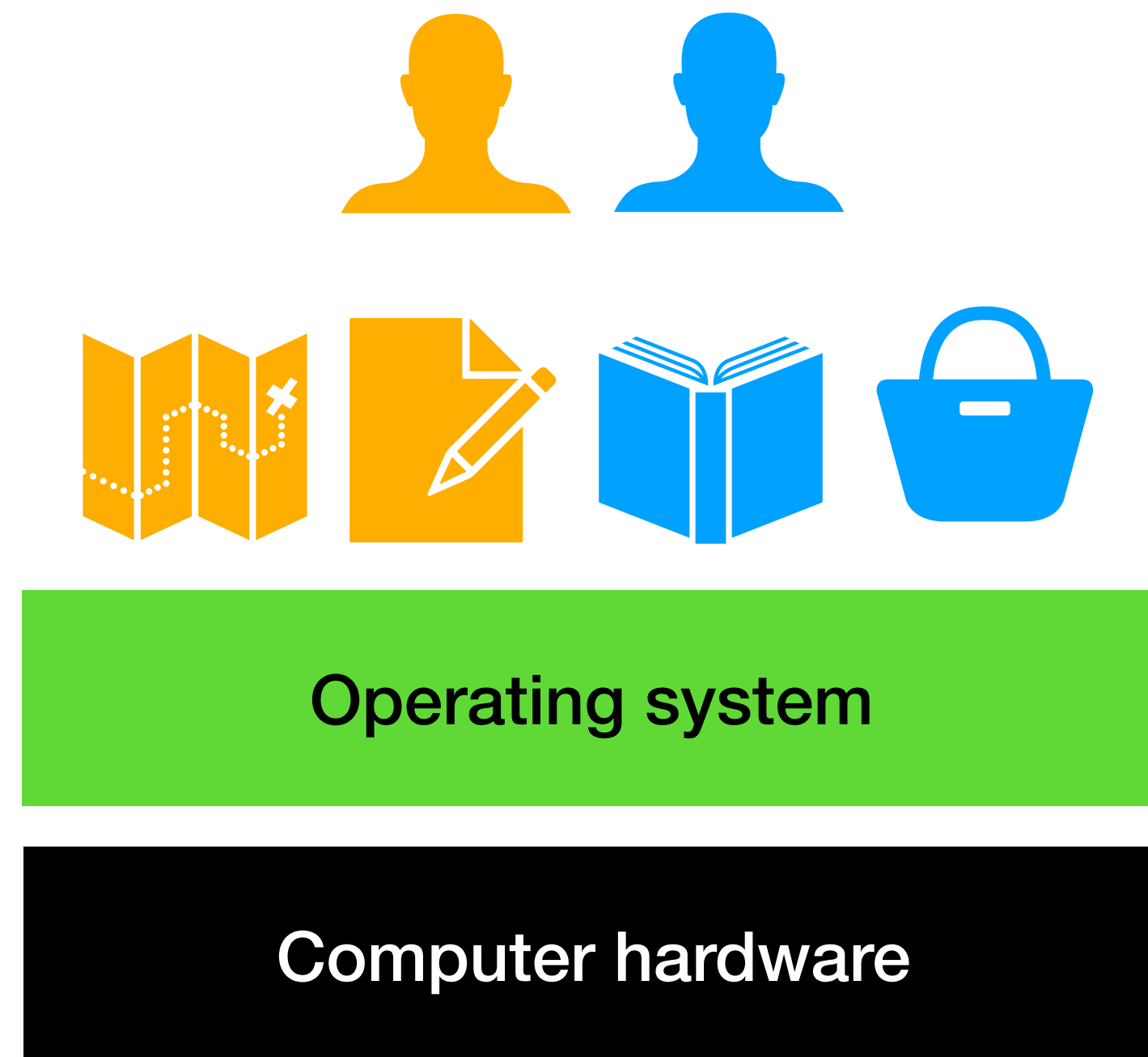
Computer organization



Purpose of an OS

- **Resource management**
- Provide higher-level services
- Protection and isolation

Purpose of OS: Resource management



- Example: `cpu.c`
- Give the illusion of more CPUs than there are
- Multiplex the hardware

Calculator analogy: Computing long sum



20
10
30
50
30
10
20
10

- 2 0 = (move pointer to 10)
- + 1 0 = (move pointer to 30)
- + 3 0 = (move pointer to 50)
- + 5 0 = (move pointer to 30)
- + 3 0 = (move pointer to 10)
- + 1 0 = (move pointer to 20)
- + 2 0 = (move pointer to 10)

Sharing the calculator



20
10
30
50
30
10
20
10



10
70
20
40
20
10
50
10

Sharing the calculator



20
10
30
50
30
10
20
10



10
70
20
40
20
10
50
10

- Steps to share the calculator:
 - $20 + 10 = 30 + 30 = 60$
 - Write 60 in notebook, remember that we were done till 30, give calculator
 - $10 + 70 = 80$
 - Write 80 in notebook, remember that we were done till 70, give the calculator back

Remember whatever is on the screen and give calculator?



20
10
30
50
30
10
20
10



10
70
20
40
20
10
50
10

- 2 0 = (move pointer to 10)
- + 1 0 = (move pointer to 30)
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Remember whatever is on the screen and give calculator?



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- + 2 0 = (move pointer to 10)

Can I give calculator here?

“Save 1 and remember pointer to be at 10”

Remember whatever is on the screen and give calculator?



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10
30
50
30
10
20
10



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70
20
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10
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10

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- + 3 0 = (move pointer to 10)
- + 1 0 = (move pointer to 20)
- + 2 0 = (move pointer to 10)

Can I give calculator here?

“Save 1 and remember pointer to be at 10”

No! Sum would be wrong!

“+ xx = (move pointer)” has to be atomic

Resource manager: multiplexing CPU

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- OS switches CPU between processes in the same manner as our calculator example

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 - Fairness: One banker got more calculator time than others

Resource manager: multiplexing CPU

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 - Fairness: One banker got more calculator time than others
 - Often need to break away from fairness. Game should get more CPU time than Dropbox to provide good user experience

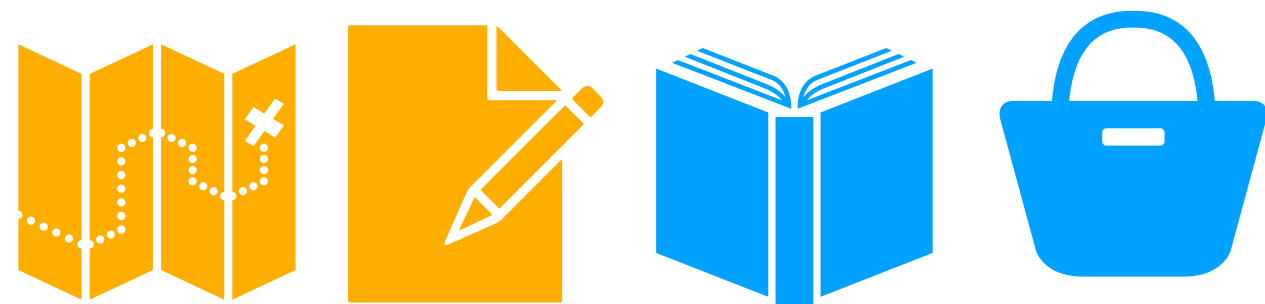
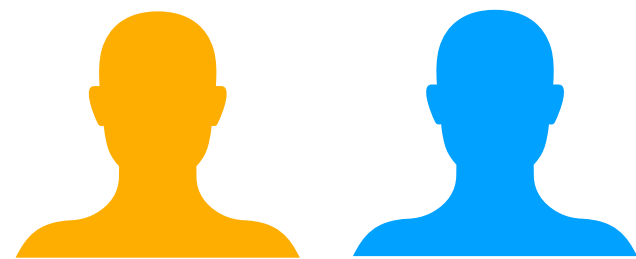
Resource manager: multiplexing CPU

- CPU is also executing one instruction after another and incrementing “instruction pointer”
- OS switches CPU between processes in the same manner as our calculator example
- What should happen when multiple processes want to run simultaneously?
 - Fairness: One banker got more calculator time than others
 - Often need to break away from fairness. Game should get more CPU time than Dropbox to provide good user experience
 - Starvation freedom: When there are multiple bankers, one banker never got the calculator

Purpose of OS: Resource manager

Different approaches to memory management:

- Segment different memory portions to different processes
- Multiplex memory pages across processes



Operating system

Computer hardware

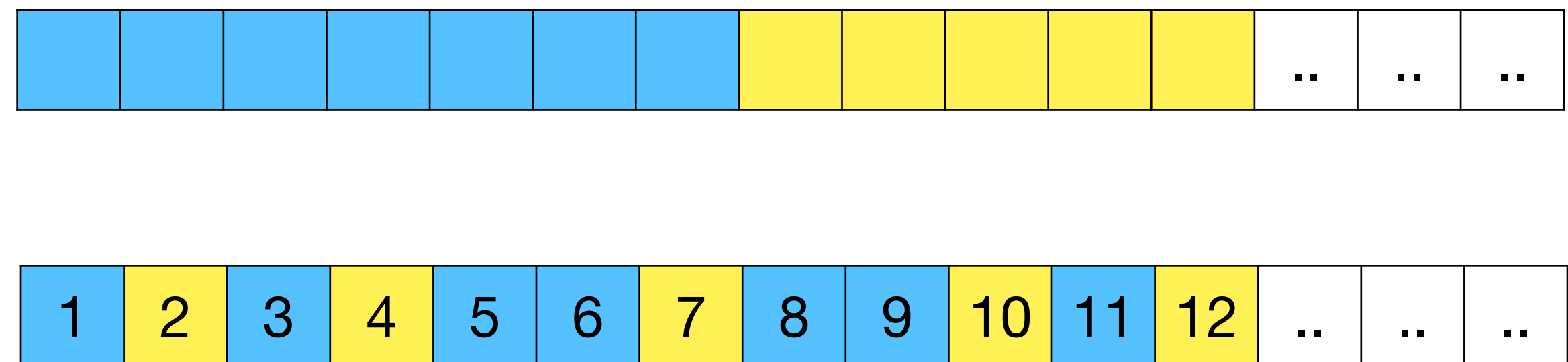
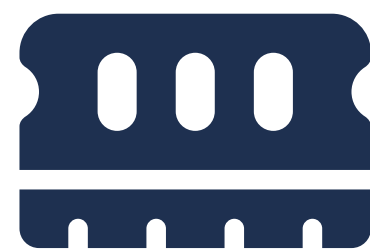


Or



Memory management

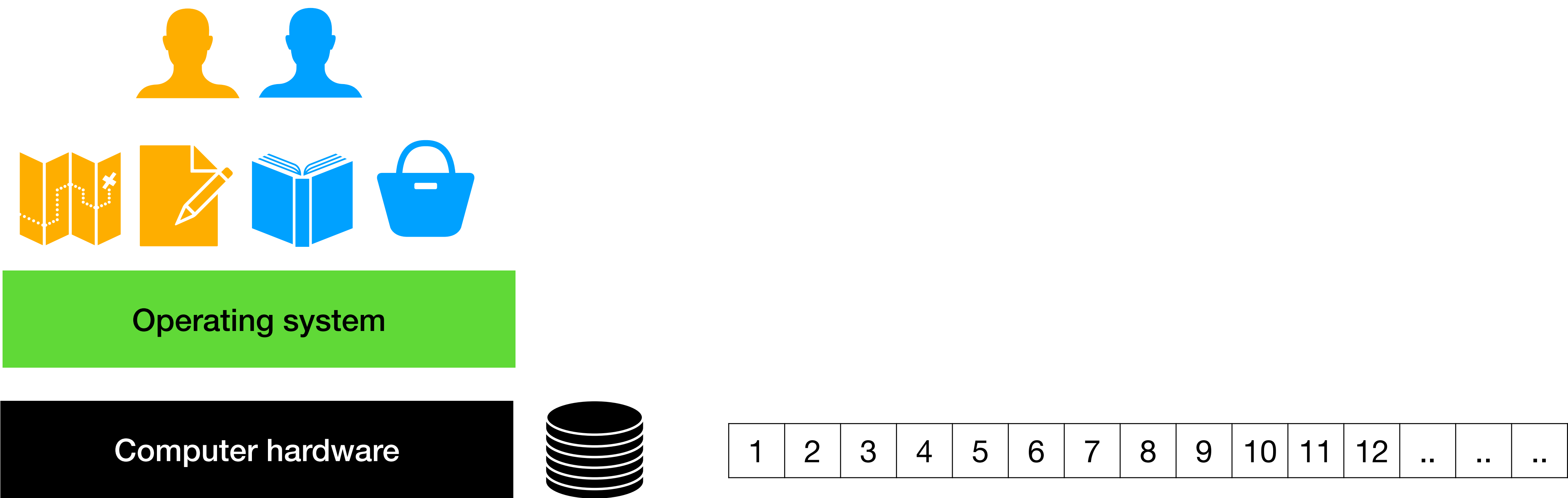
- Segmentation is cheap to implement
- But not flexible. What if a process needs more memory than what OS gave?
- Paging is complicated to implement
- Highly flexible



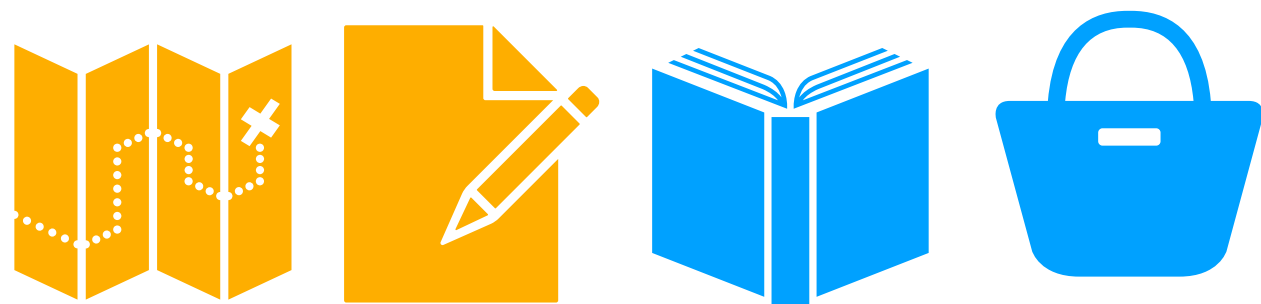
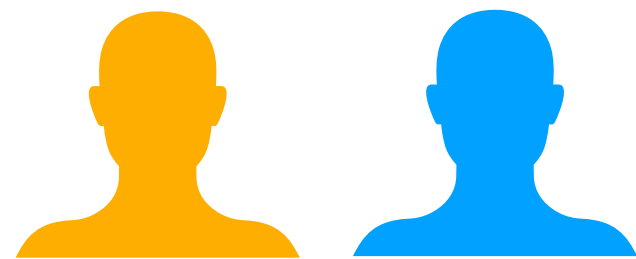
Purpose of an OS

- Resource management
- **Provide higher-level services**
- Protection and isolation

Purpose of OS: Provide higher-level services

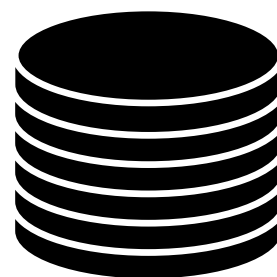


Purpose of OS: Provide higher-level services



Operating system

Computer hardware

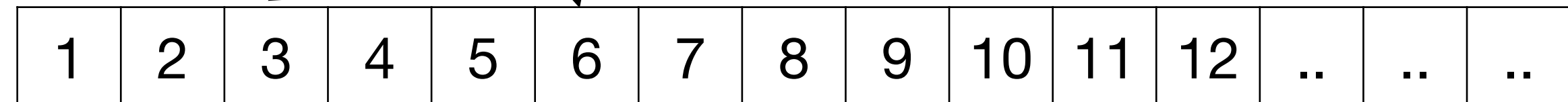


Example: io.c

Disk interface: List of blocks

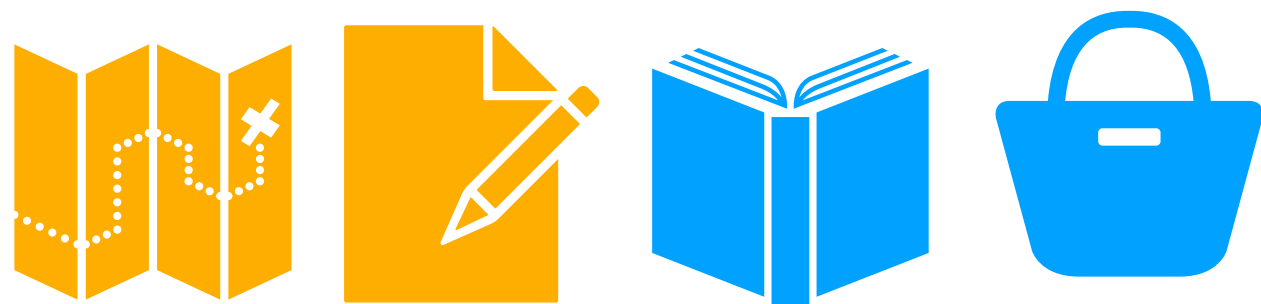
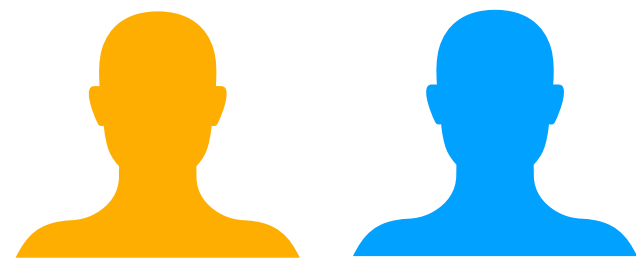
File system OS interface: Folders and files

```
int fd = open("/tmp/file", O_WRONLY | O_CREAT);  
int rc = write(fd, "hello world\n", 13);  
close(fd);
```



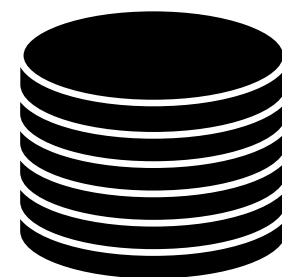
Why file system?

Why not just multiplex disk blocks like memory?



Operating system

Computer hardware

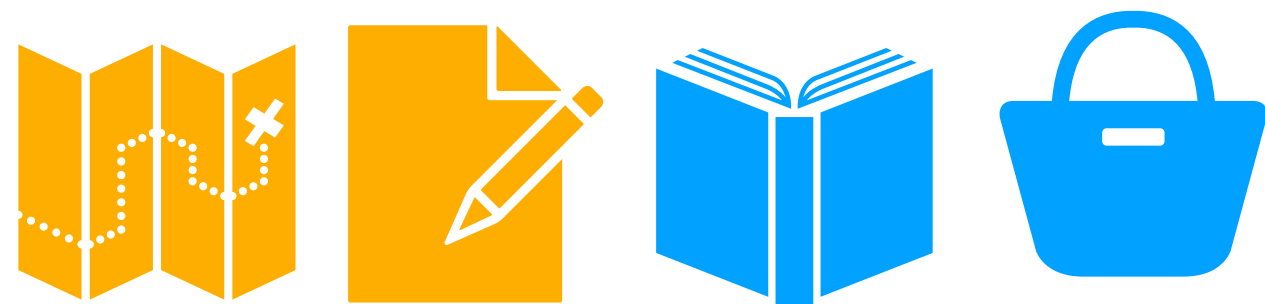
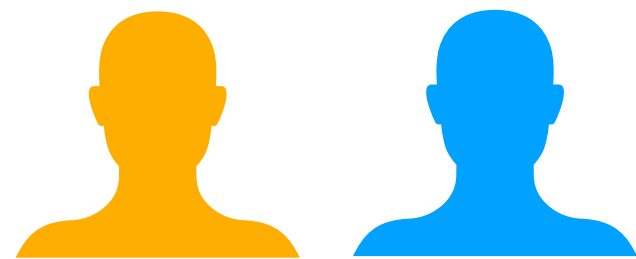


1	2	3	4	5	6	7	8	9	10	11	12
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Why file system?

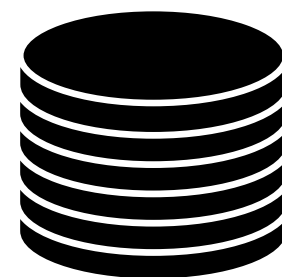
Why not just multiplex disk blocks like memory?

- Disk blocks live after programs exits, computer restarts



Operating system

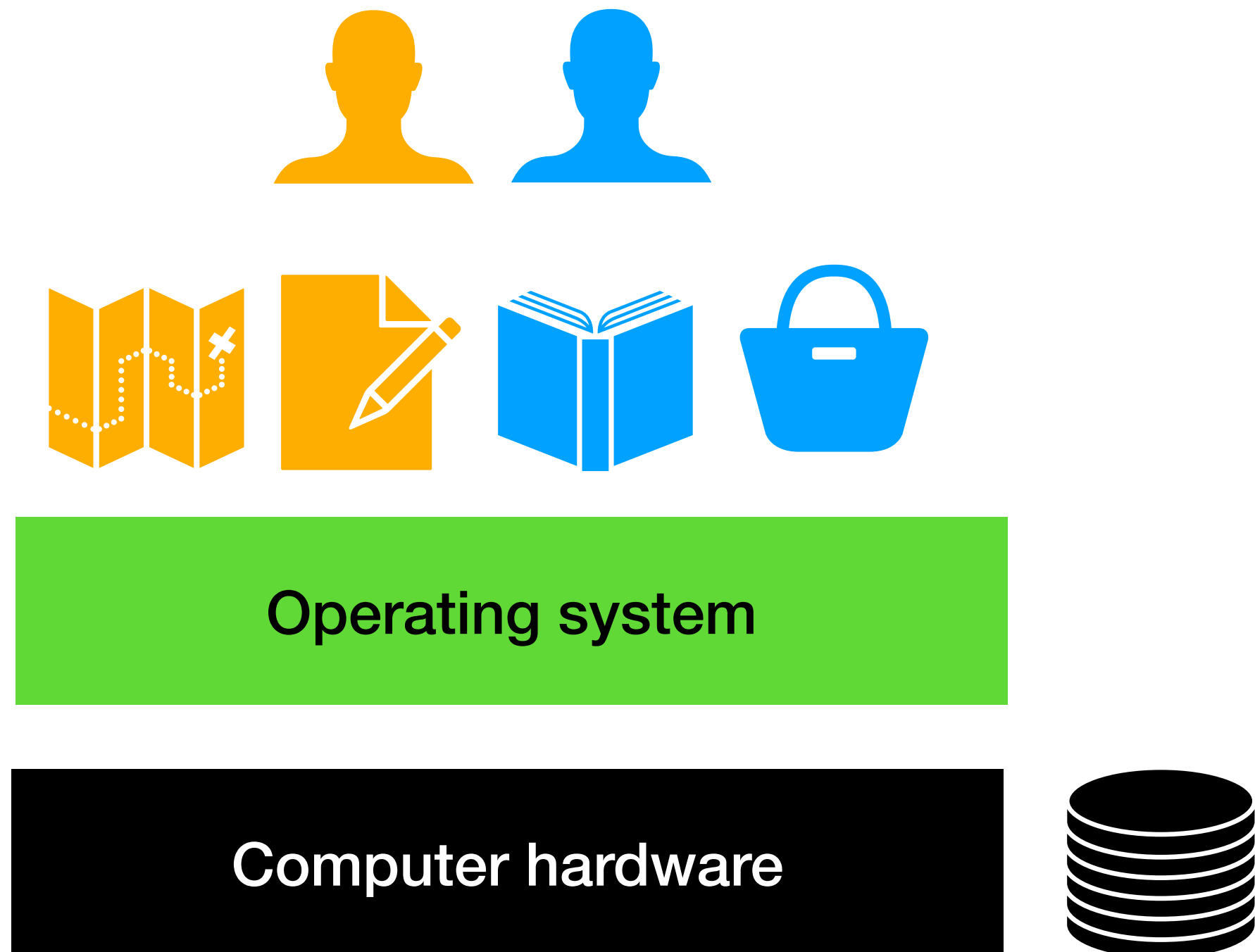
Computer hardware



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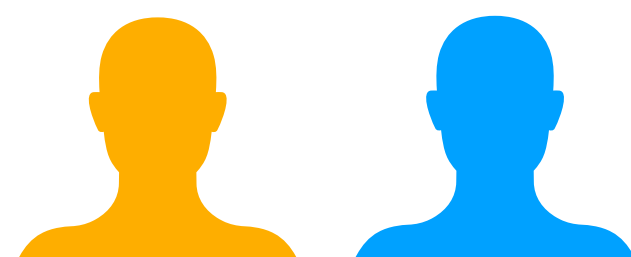
Why not just multiplex disk blocks like memory?



- Disk blocks live after programs exits, computer restarts
- Different programs read / write same file
 - vim writes io.c
 - gcc reads io.c, write io
 - We finally run io

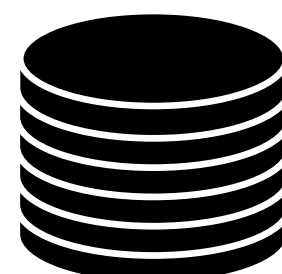
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Higher level services provide portability



Operating system

Computer hardware

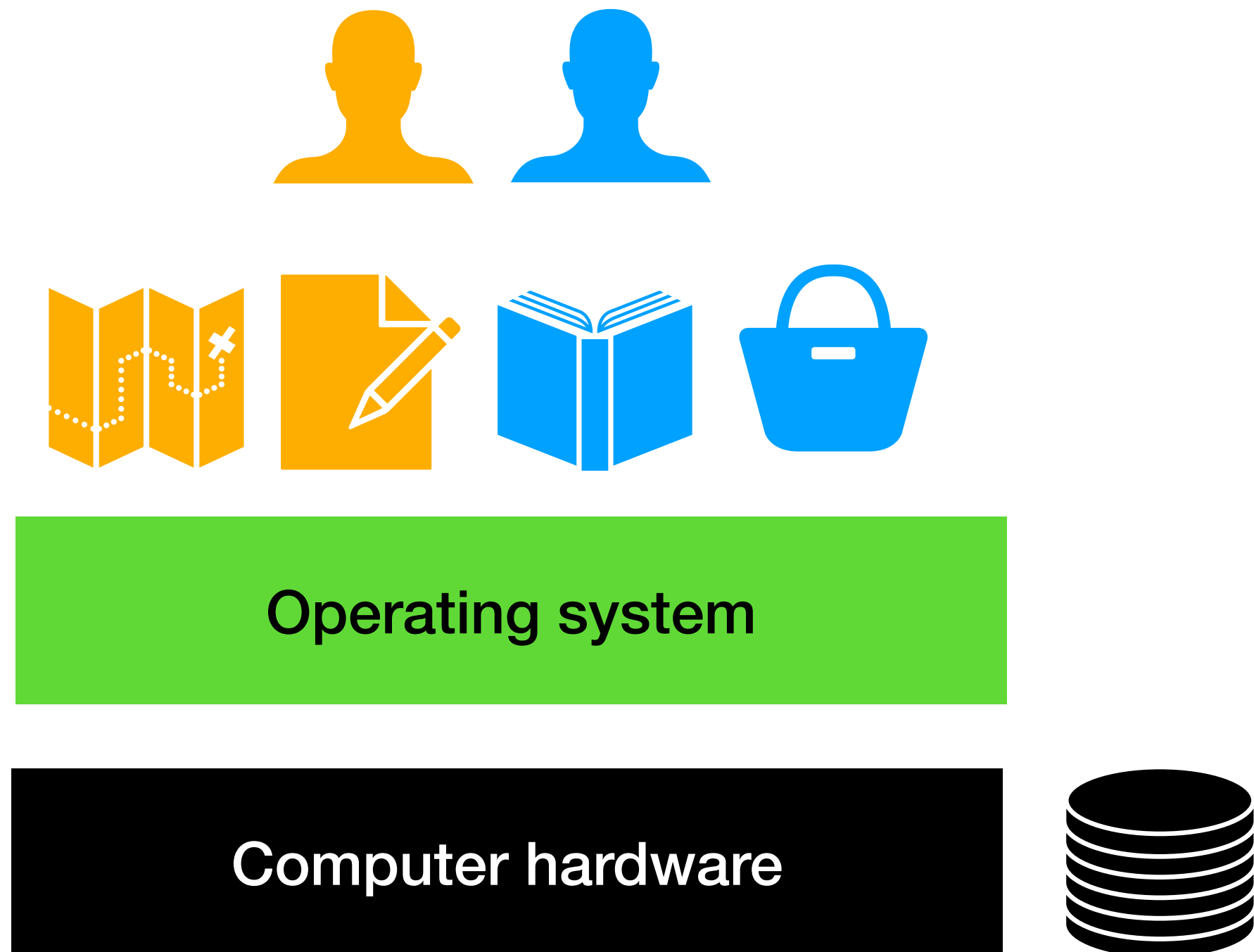


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Higher level services provide portability

- Abstract away hardware details

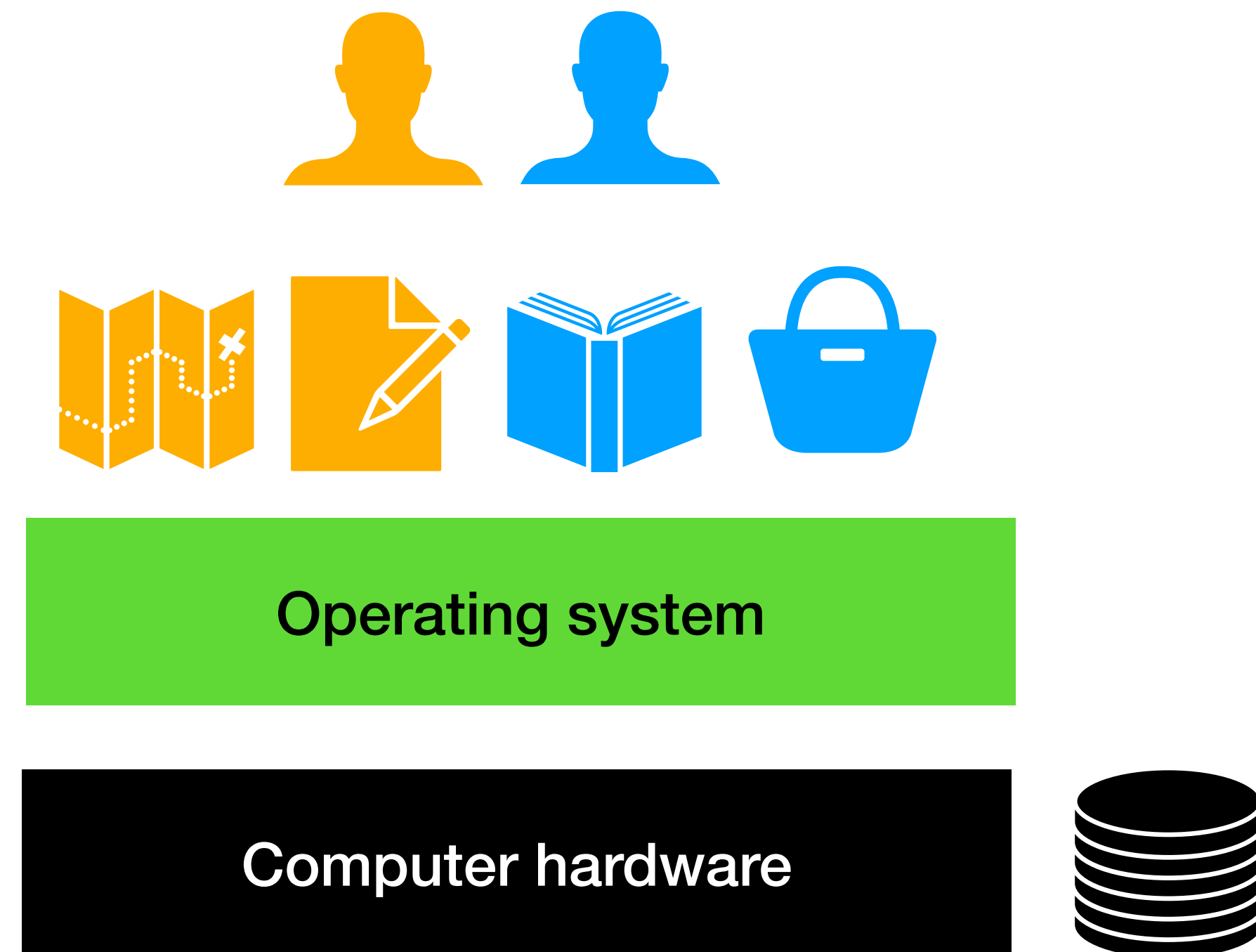


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Higher level services provide portability

- Abstract away hardware details
- Programs need not be rewritten when moving from hard-disk drive to solid state drive



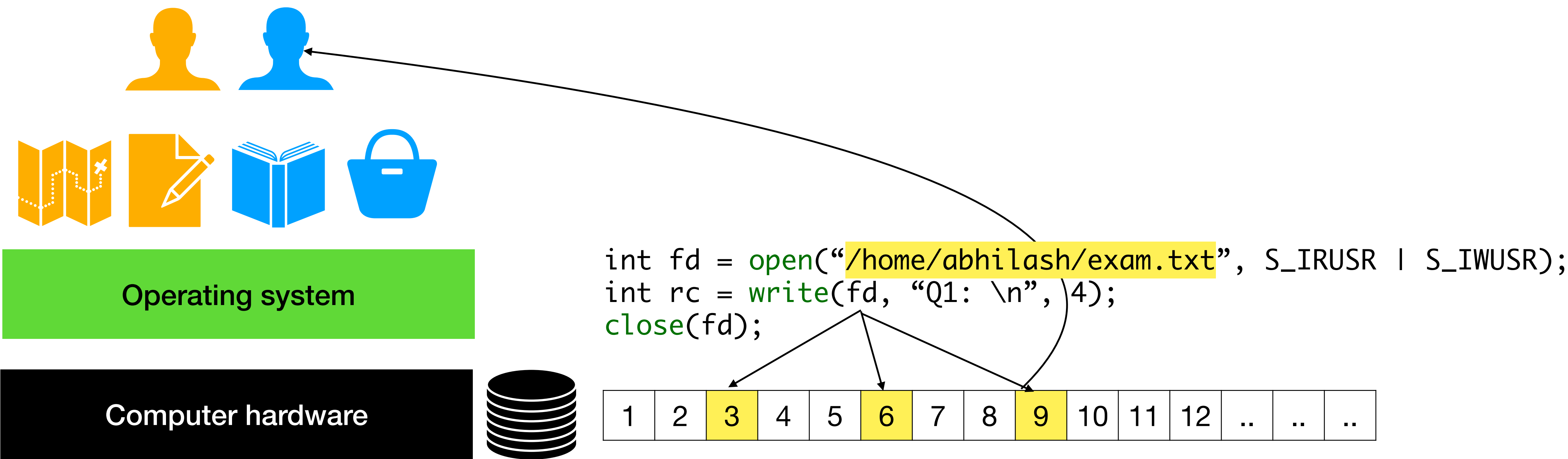
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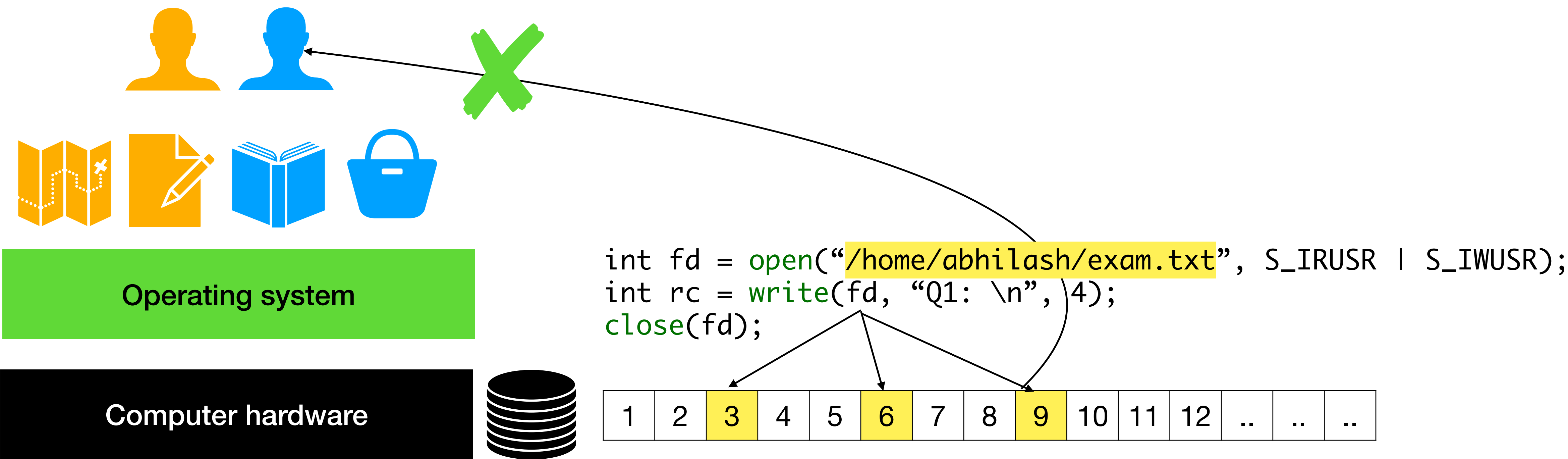
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- Provide higher-level services
- **Protection and isolation**

Purpose of OS: Protection

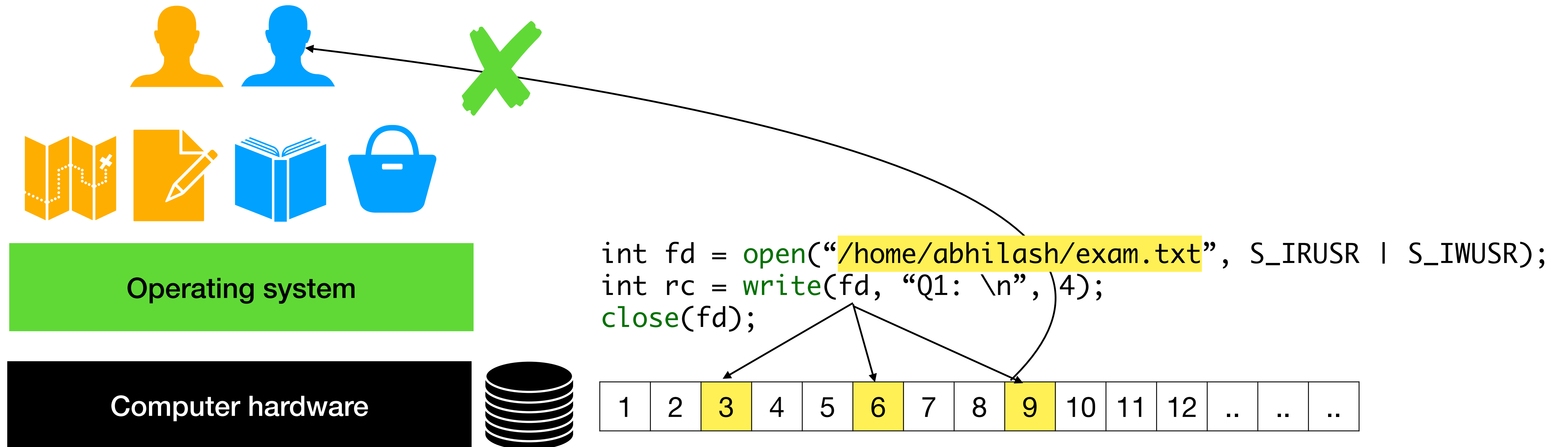


Purpose of OS: Protection



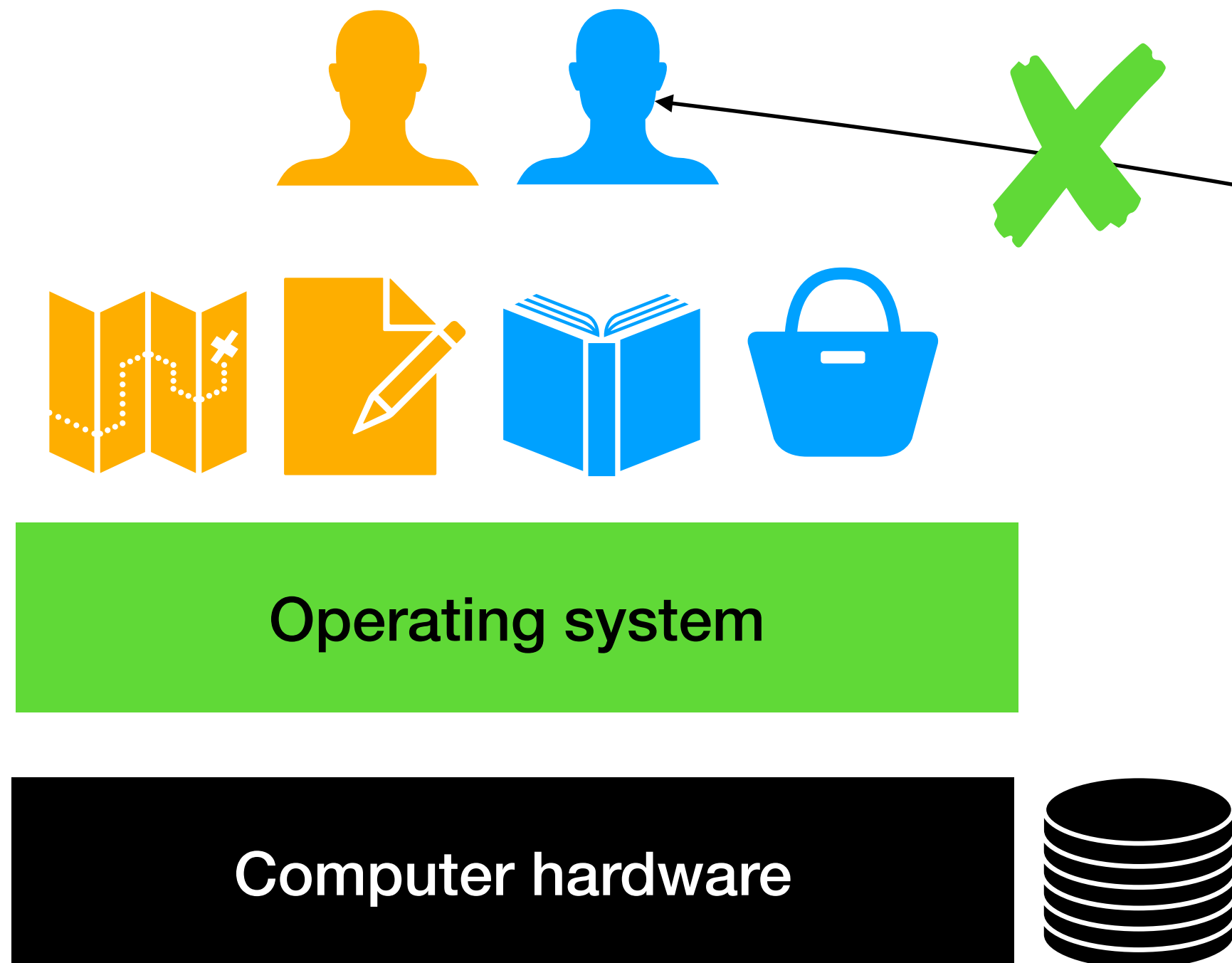
Purpose of OS: Protection

- S_IRUSR | S_IWUSR: File can only be rw by user



Purpose of OS: Protection

- S_IRUSR | S_IWUSR: File can only be rw by user
- Disallow inappropriate accesses. Example: users reading each other's files

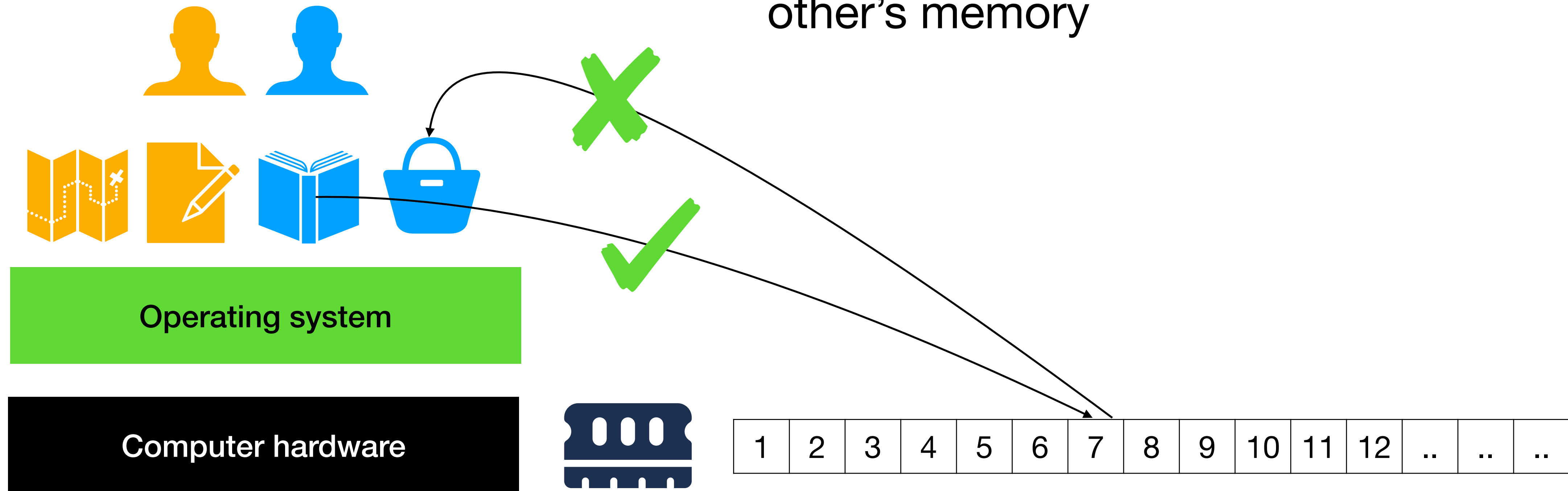


```
int fd = open("/home/abhilash/exam.txt", S_IRUSR | S_IWUSR);  
int rc = write(fd, "Q1: \n", 4);  
close(fd);
```

1	2	3	4	5	6	7	8	9	10	11	12
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----

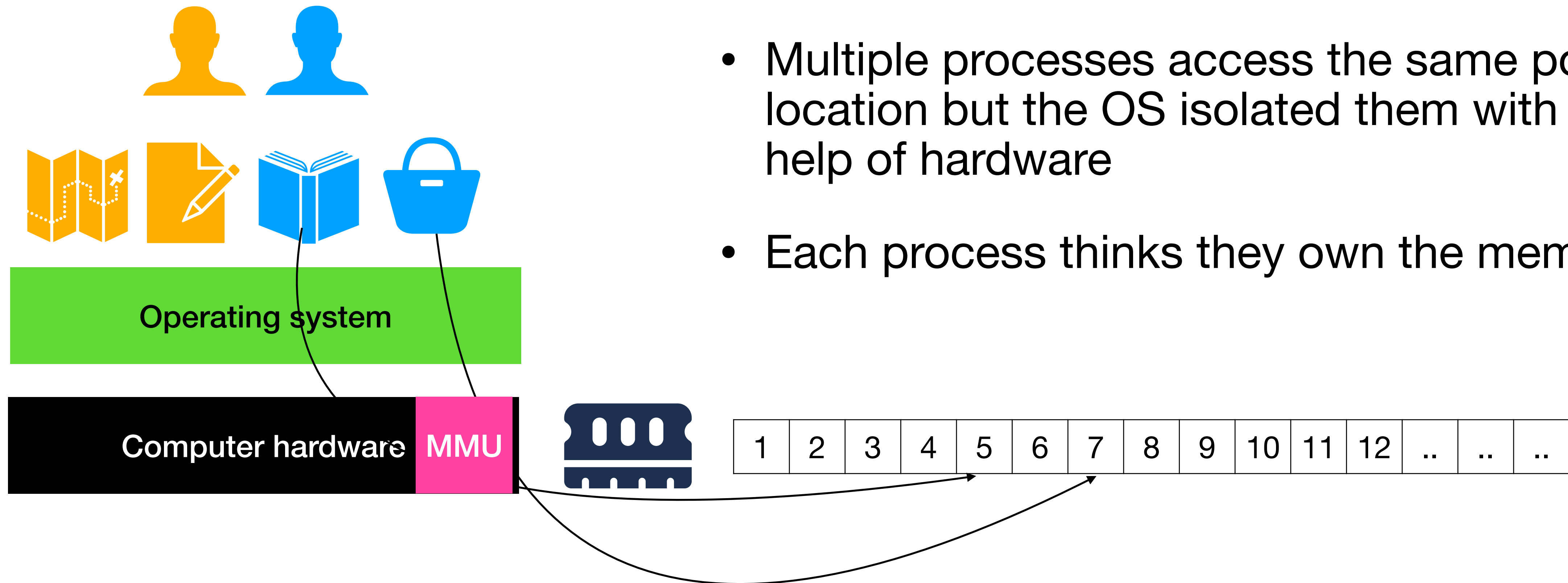
Purpose of OS: Protection

- Disallow inappropriate accesses.
Example: processes reading each other's memory



Purpose of OS: Isolation

- Example: mem.c
- Multiple processes access the same pointer location but the OS isolated them with the help of hardware
- Each process thinks they own the memory



Course structure: OS in action

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 - Shell: Pipes, IO redirection
 - Parallelism: Enable more CPUs, revisit locks

Data races due to concurrency

Thread 1	Thread 2
Read counter = 0	
Write counter = 1	
	Read counter = 1
	Writer counter = 2
Read counter = 2	
	Read counter = 2
	Writer counter = 3
Writer counter = 3	

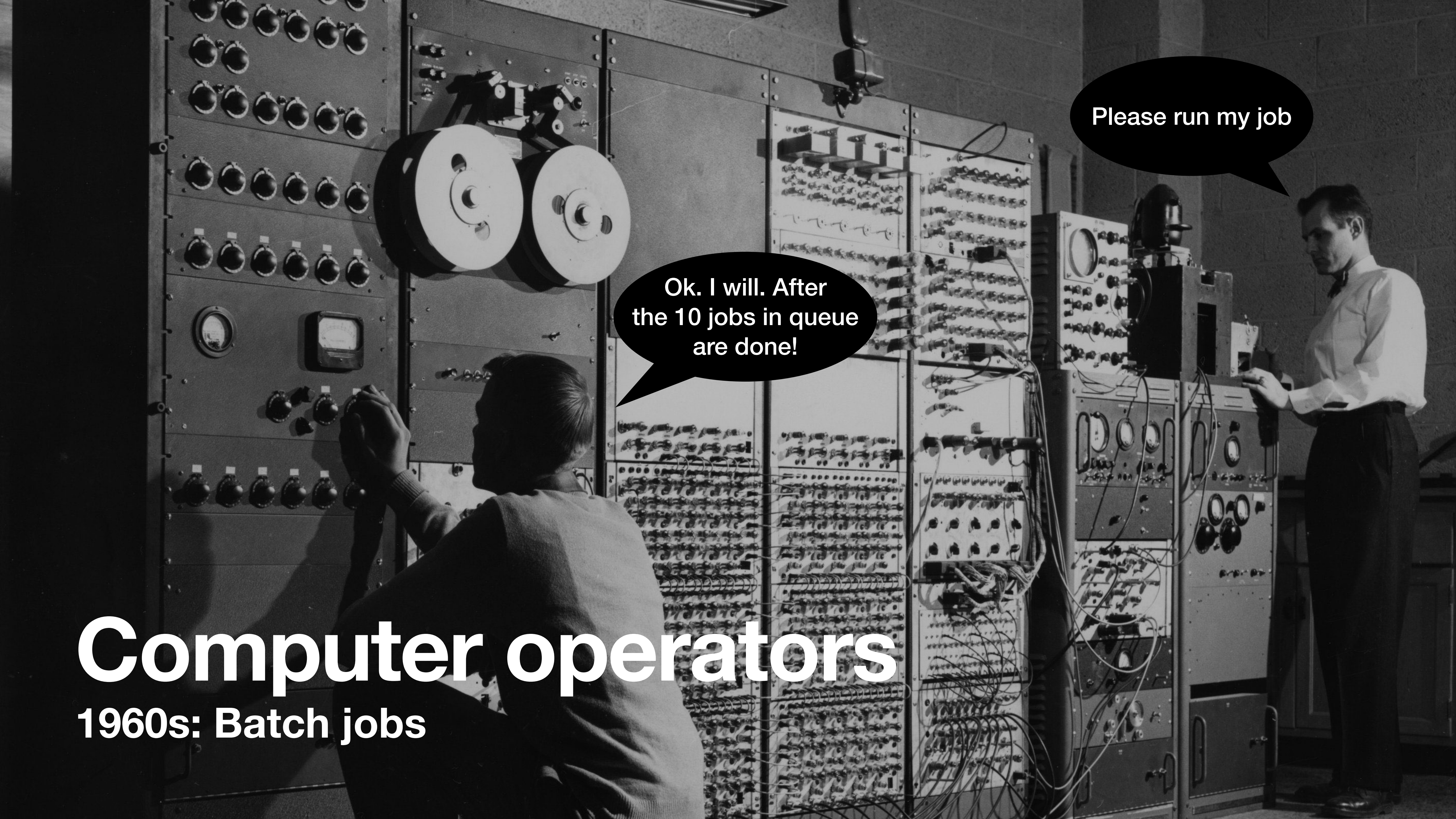
Data races due to concurrency

`./threads 100000`

Thread 1	Thread 2
Read counter = 0	
Write counter = 1	
	Read counter = 1
	Writer counter = 2
Read counter = 2	
	Read counter = 2
	Writer counter = 3
Writer counter = 3	

**Why should I learn OS in 2024?
Isn't it a solved problem?**

We have indeed made good progress ..



Please run my job

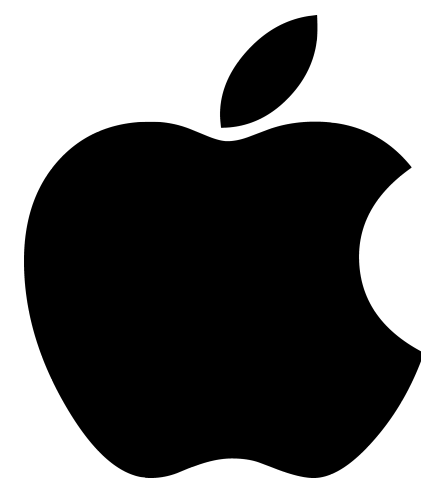
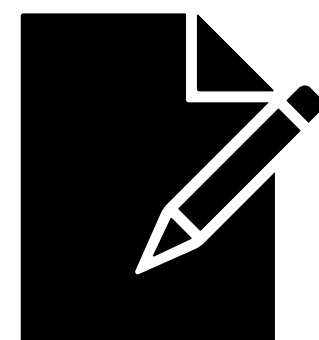
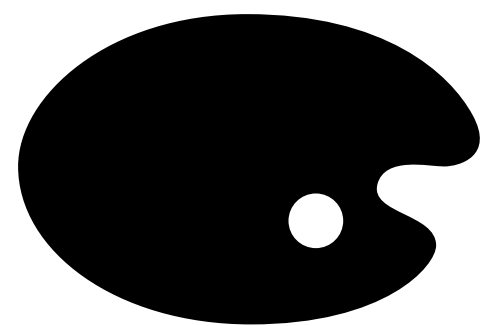
Ok. I will. After
the 10 jobs in queue
are done!

Computer operators

1960s: Batch jobs

Personal computers

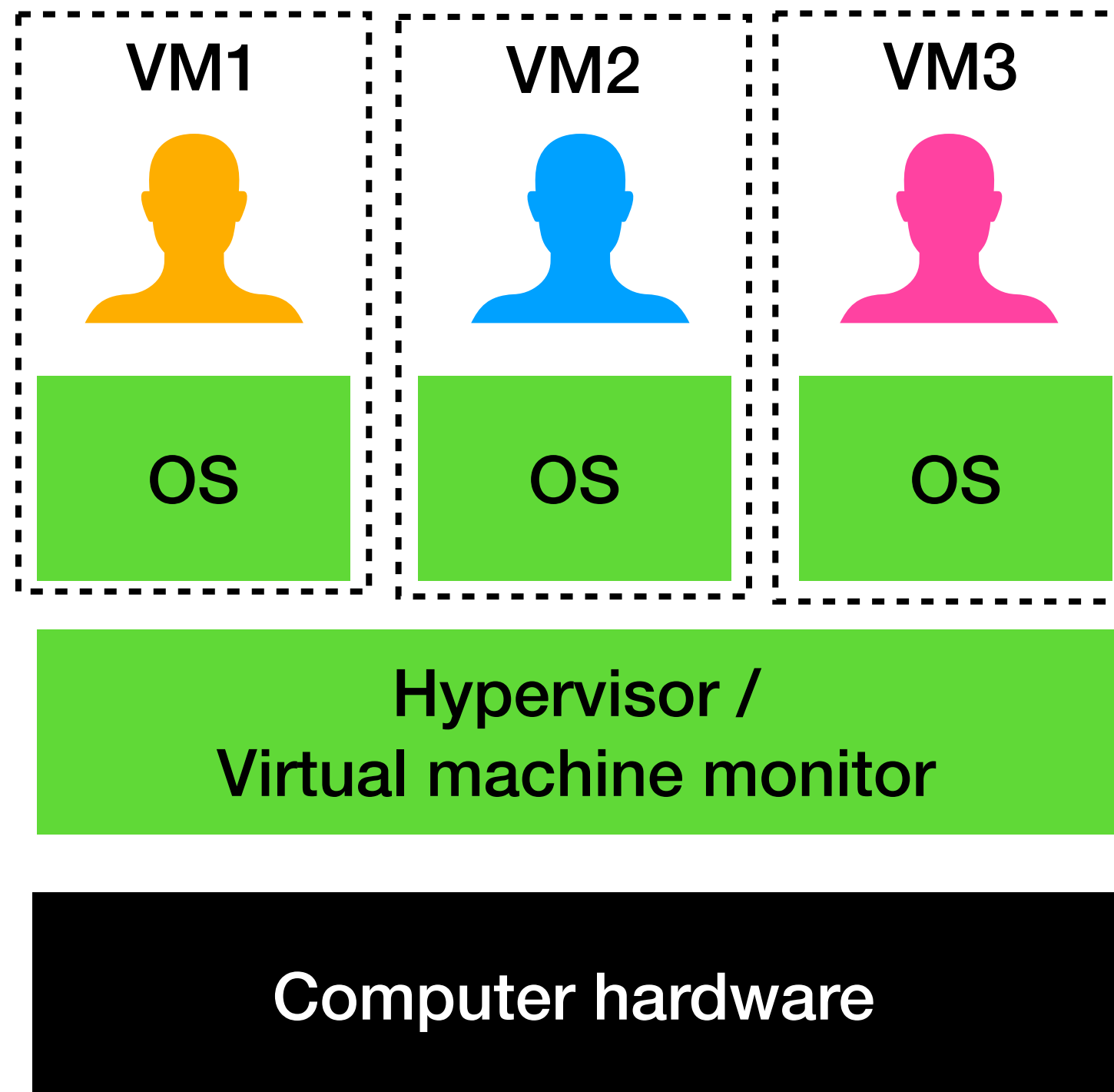
1980s: Interactive jobs!



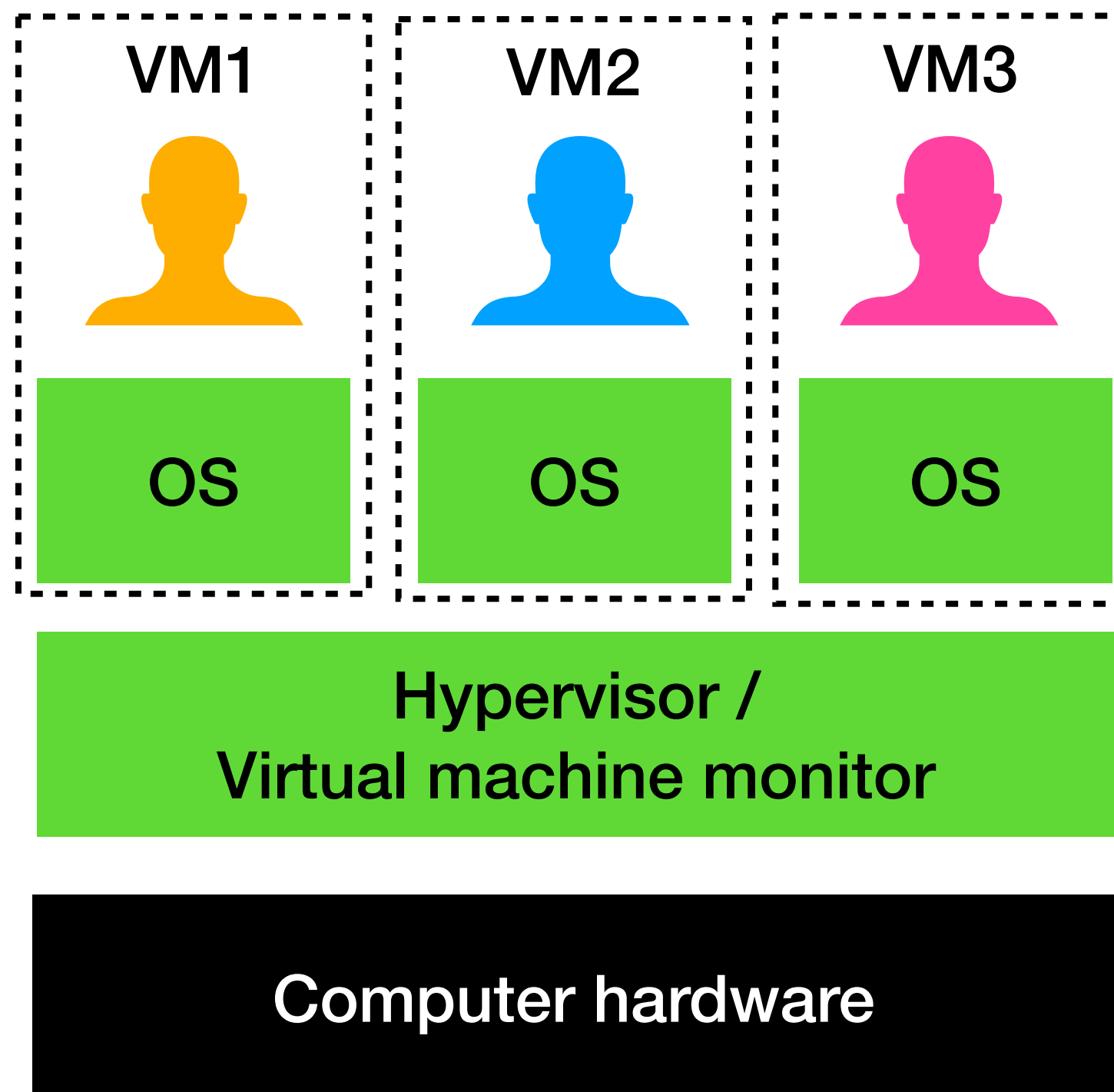
UNIX®



2000s: Cloud

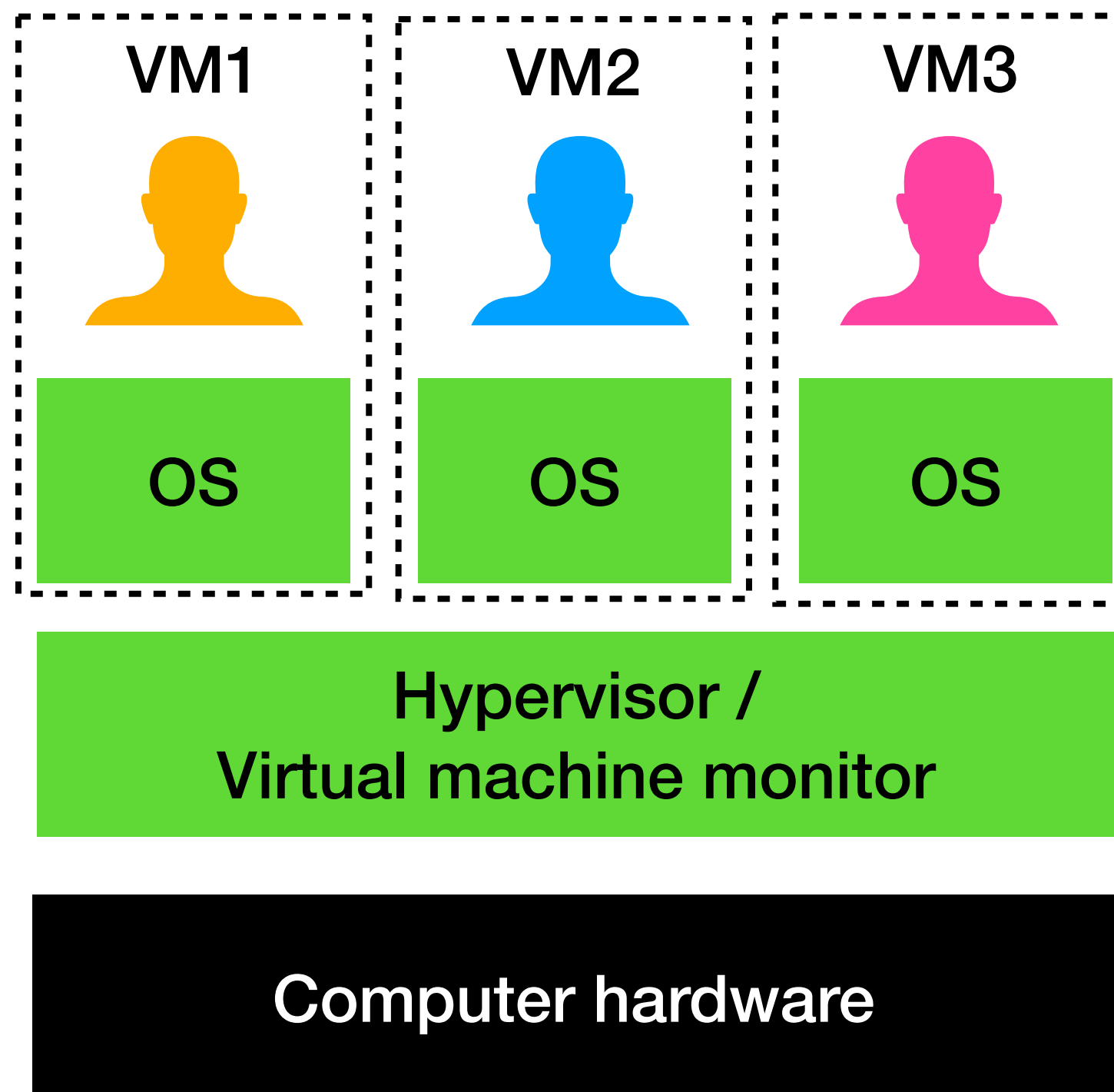


2000s: Cloud



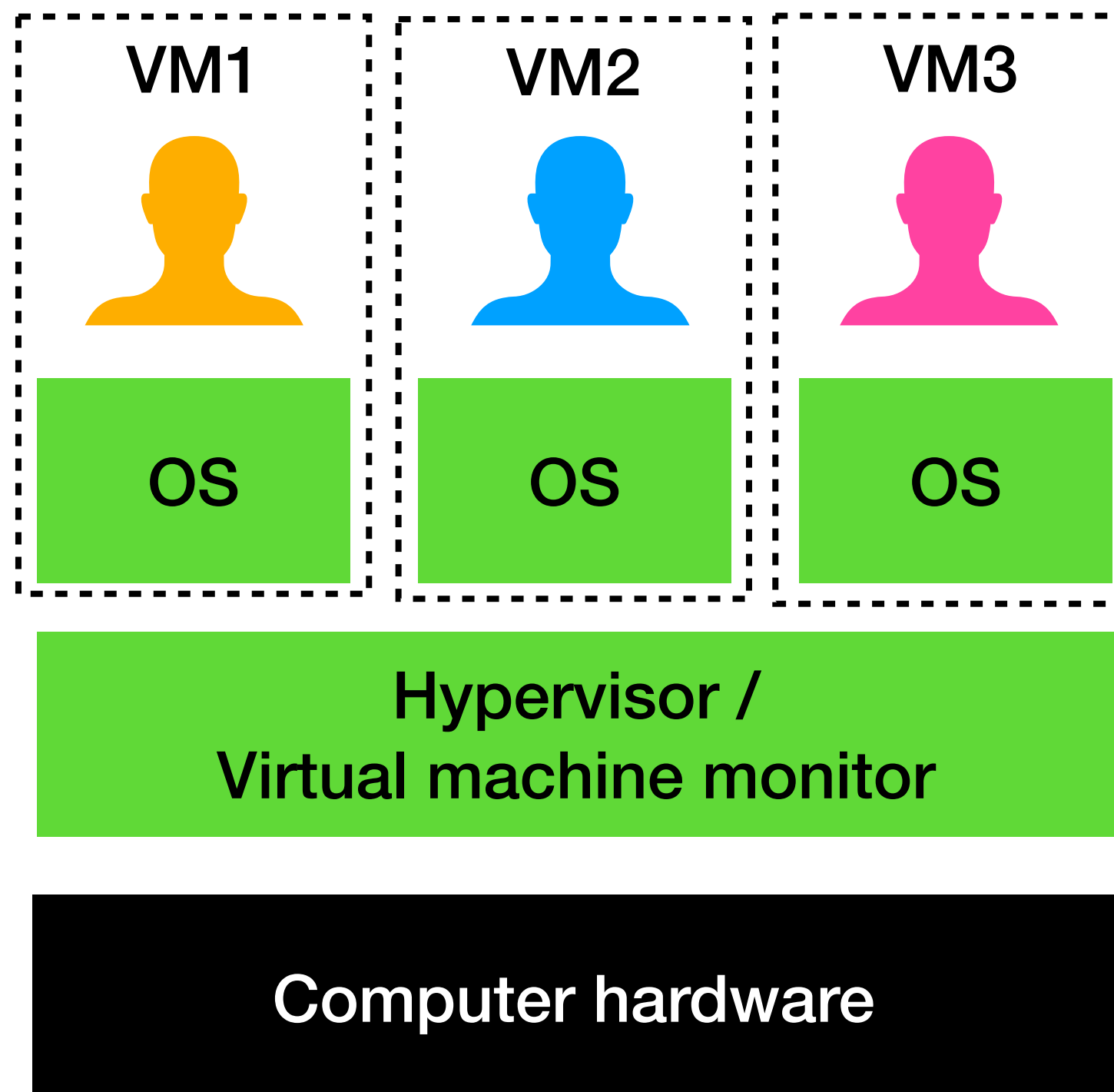
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2000s: Cloud



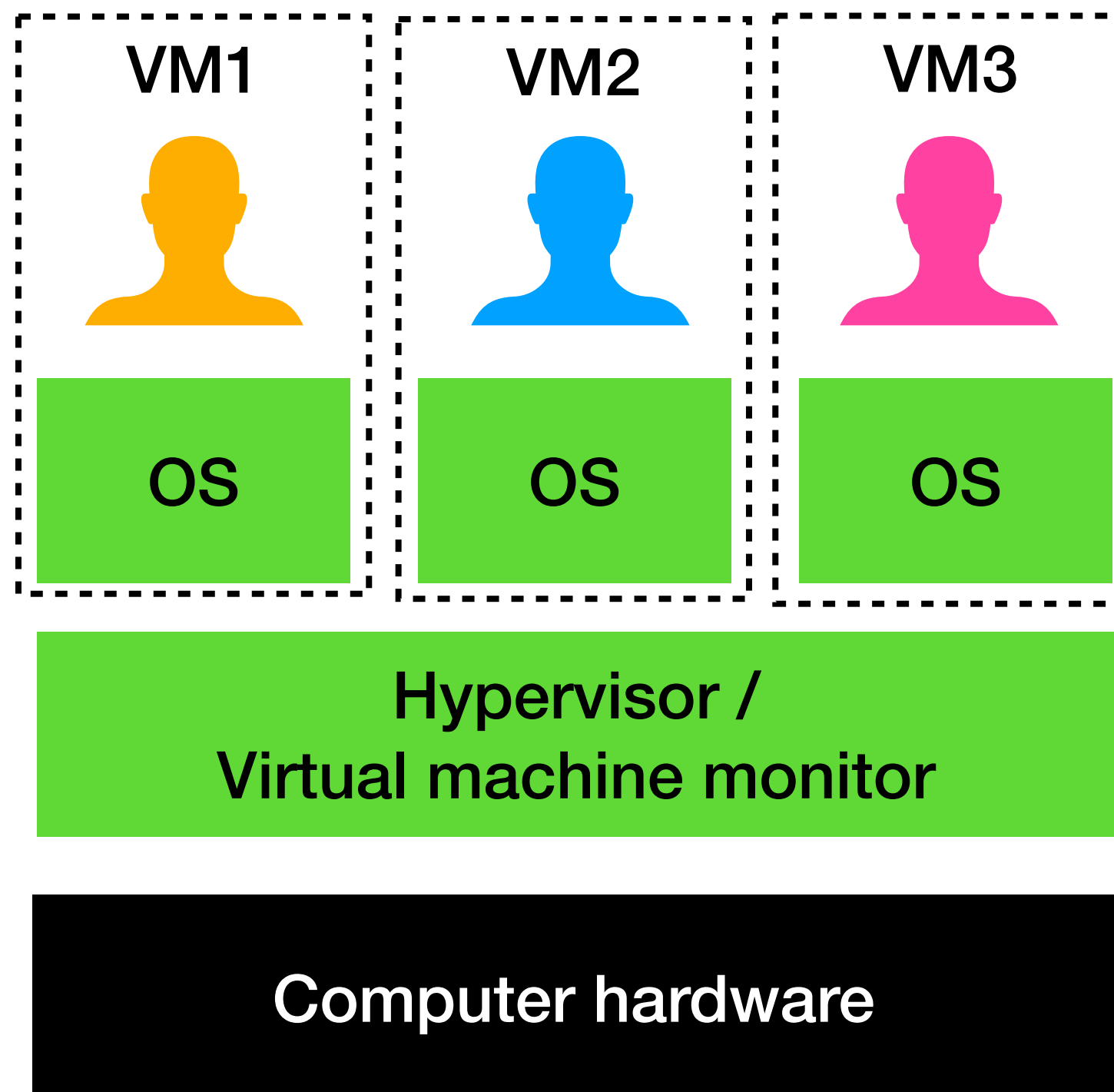
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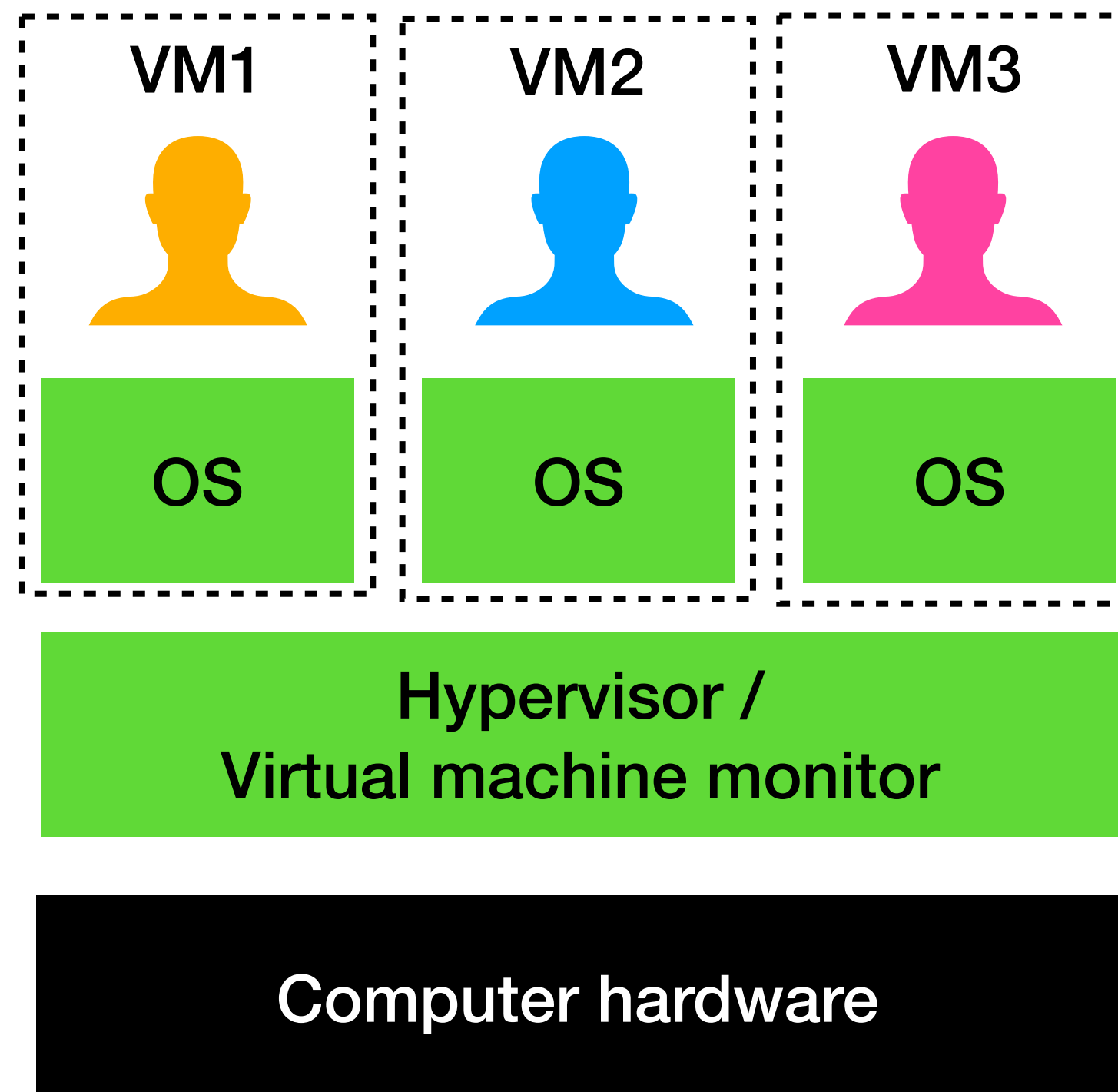
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- Cloud: I can rent *virtual machines* so I don't have to buy and manage servers.
- Hypervisor provides facilities to operating systems that OS provides to processes
 - multiplexes hardware among OS
 - protects and isolates OS from each other
- Hypervisors fundamentally enabled cloud computing

2000s: Smartphones



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- New kinds of higher-level services: localisation, cellular, accelerometer, touch interface, etc.



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- Resource constraints: Power management, UI system, etc.



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- Even higher-level services: voice recognition, augmented reality, etc.



2000s: Smartphones

- New kinds of higher-level services: localisation, cellular, accelerometer, touch interface, etc.
- Resource constraints: Power management, UI system, etc.
- Even higher-level services: voice recognition, augmented reality, etc.
- Increased security concerns because of increase in sensitive data with rise of mobile banking, UPI etc. and because of moving devices





2000s: Cyber-physical systems

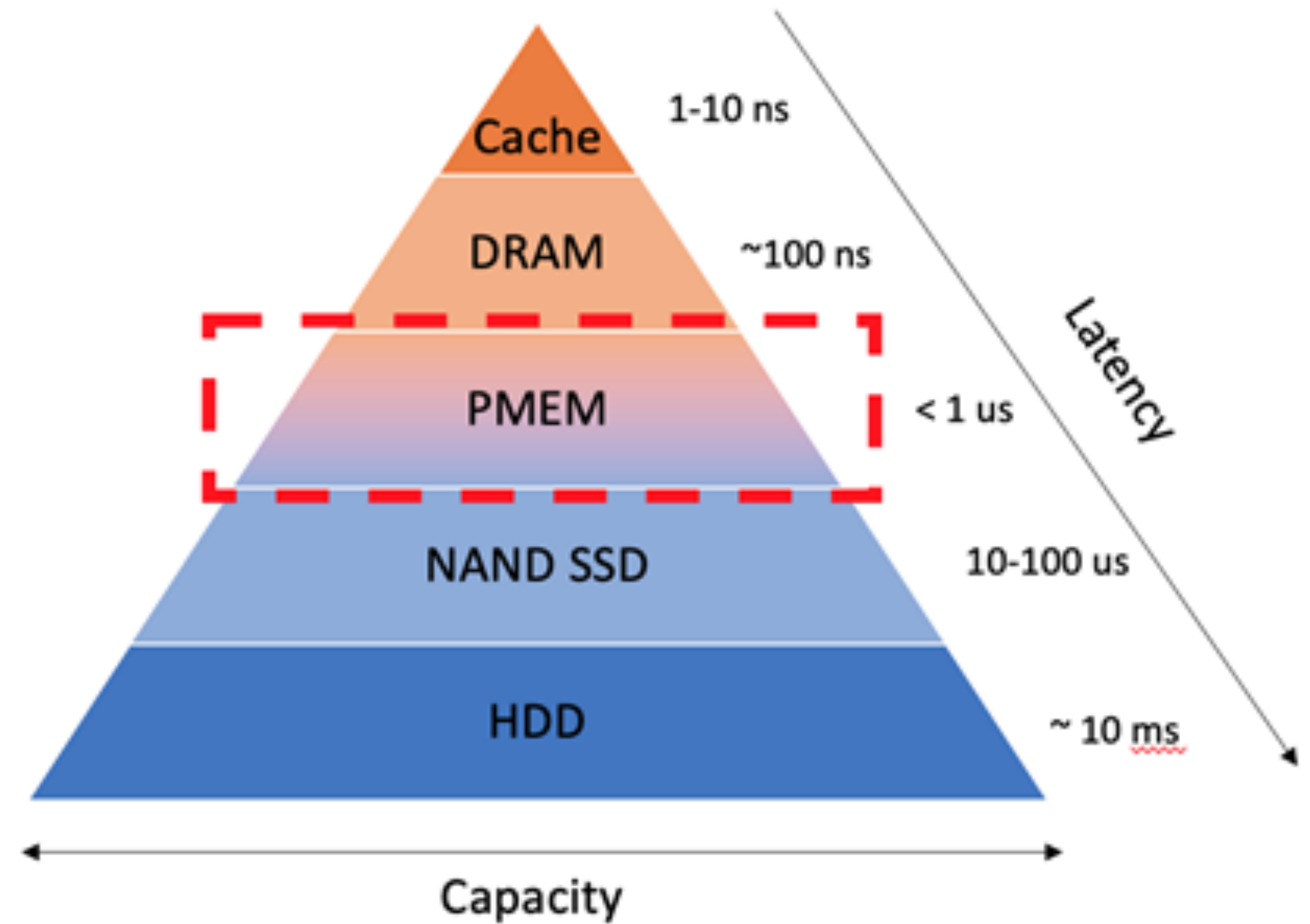
OS must not crash! Formally verified OS. Example: seL4

Typical progression of systems research

- Systems optimise for the “common case”
 - If common case changes, we need to rethink OS design
- Macro examples
 - Personal computers: batch jobs to interactive jobs
 - Smartphones: resource constraints, new sensors
 - Cyber physical systems: risk of human life

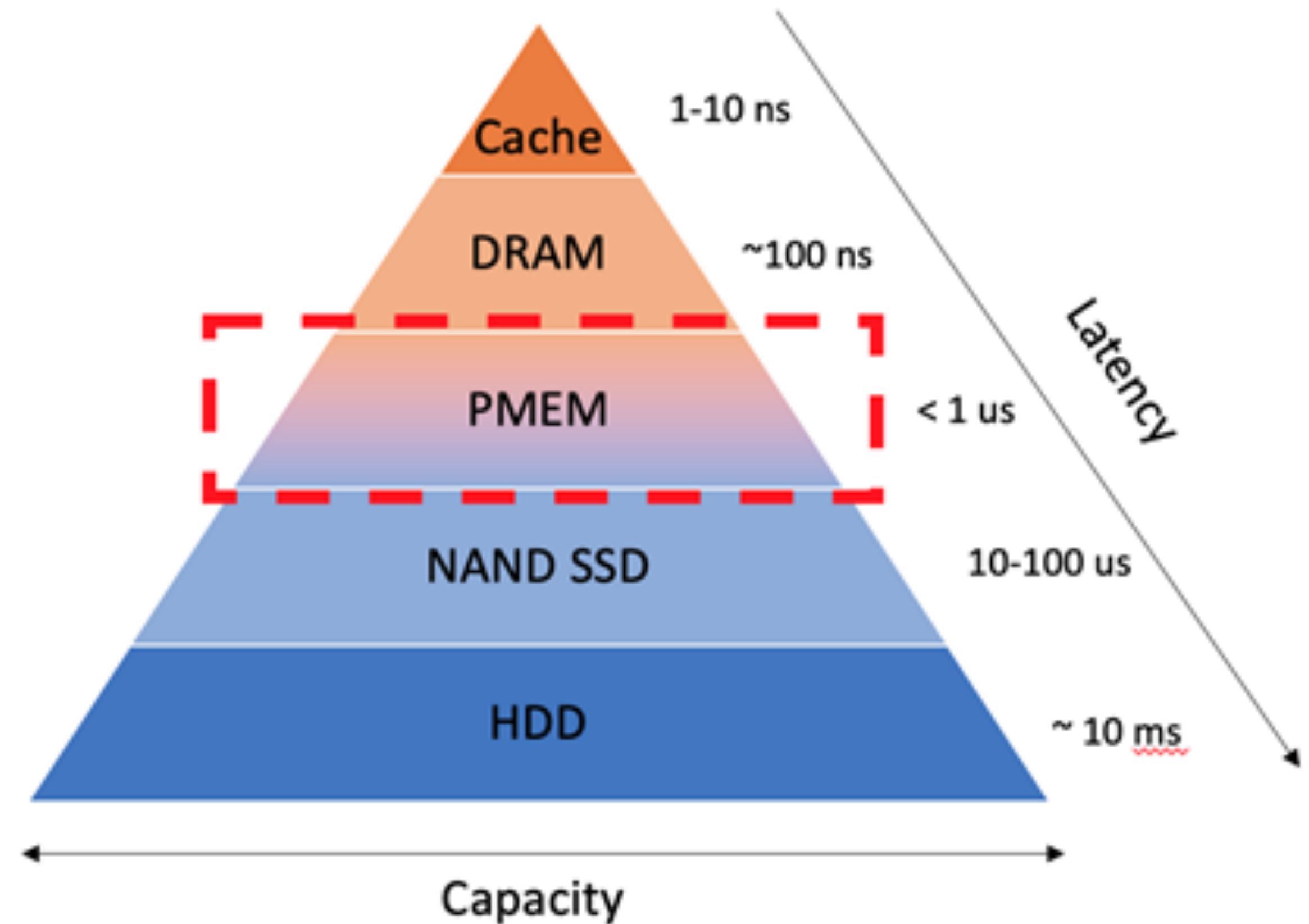
Users
Applications
Libraries
Operating systems
Hardware

More trends: persistent memory



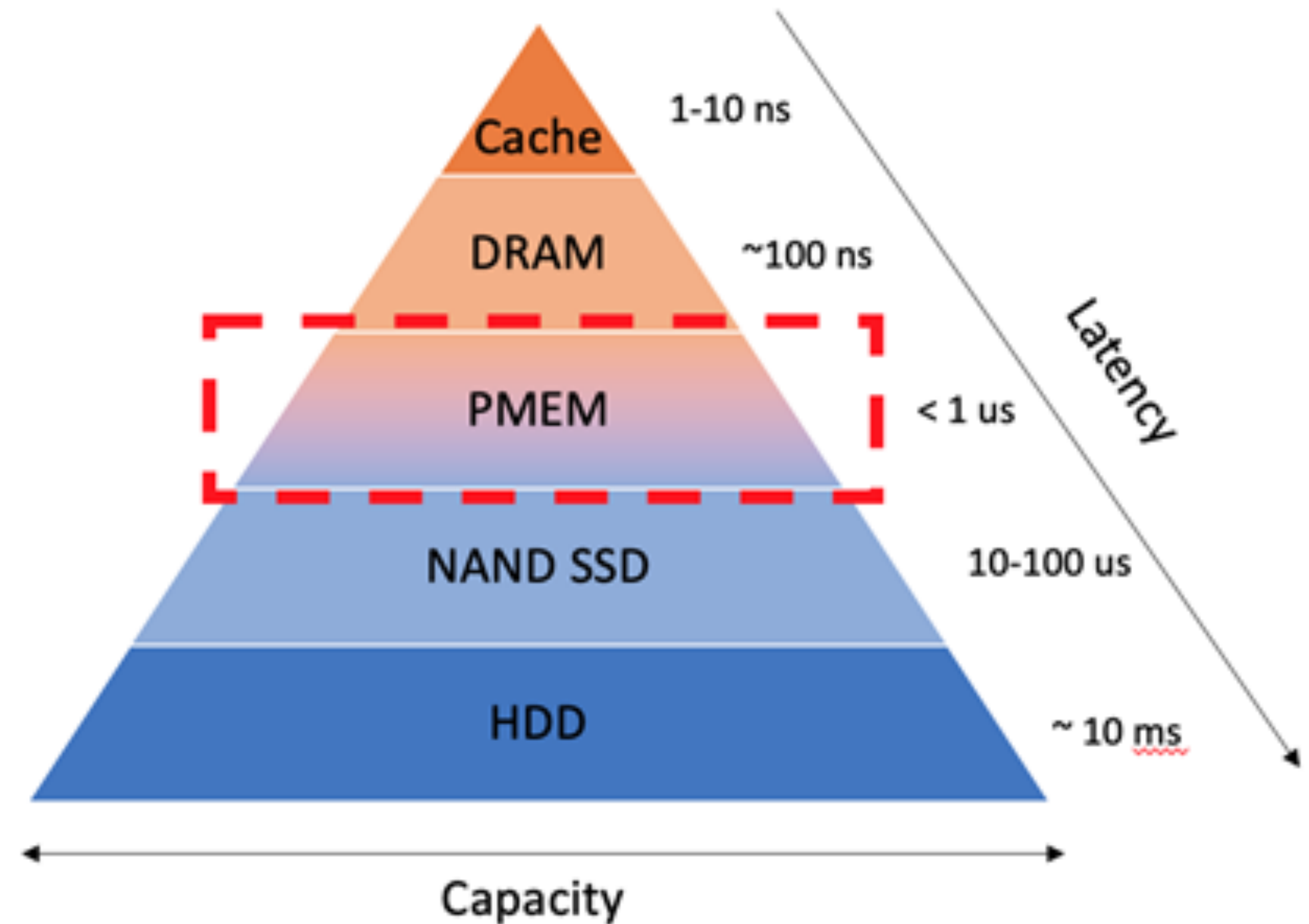
More trends: persistent memory

- Memory: volatile but fast



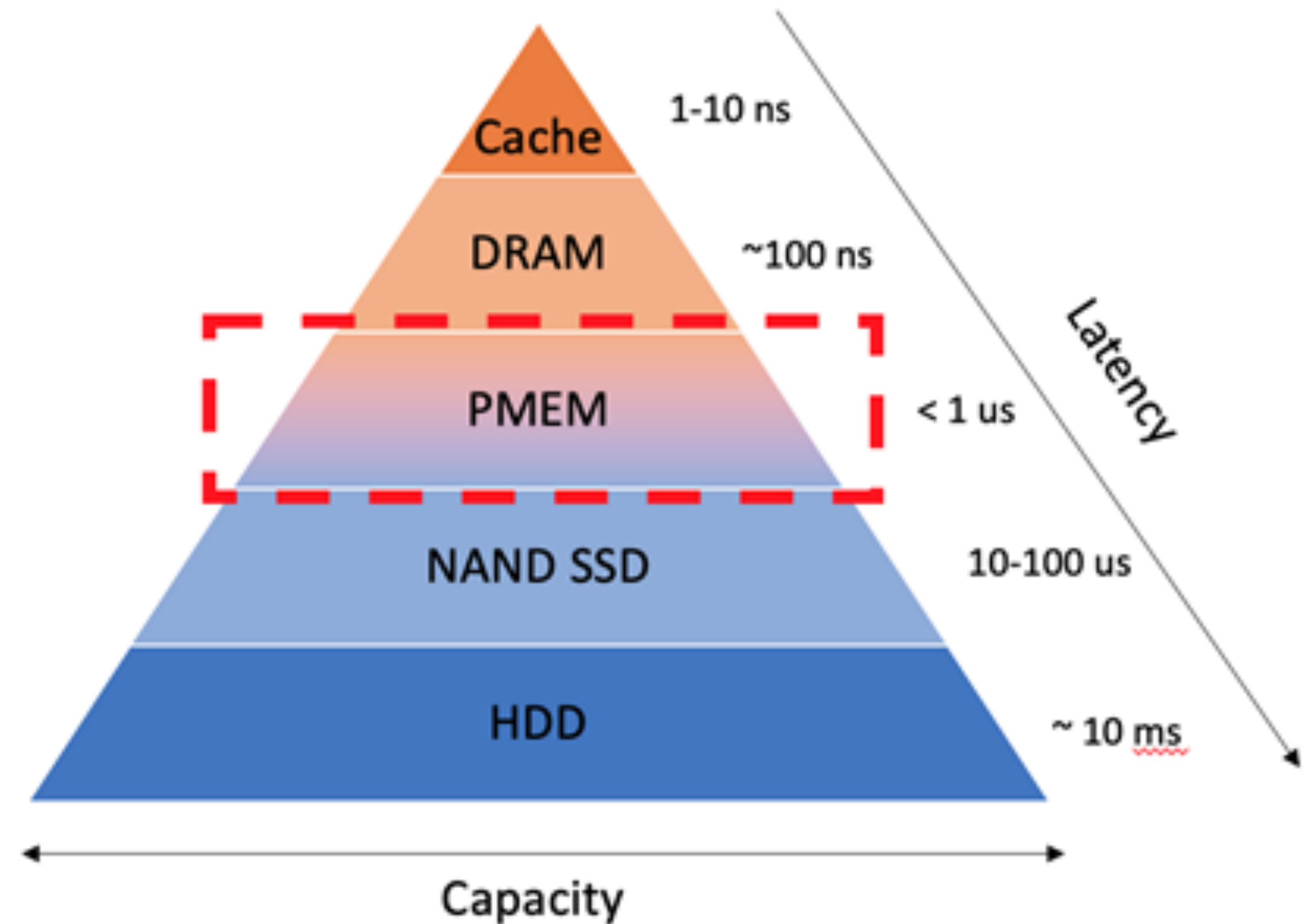
More trends: persistent memory

- Memory: volatile but fast
- Disk: persistent but large



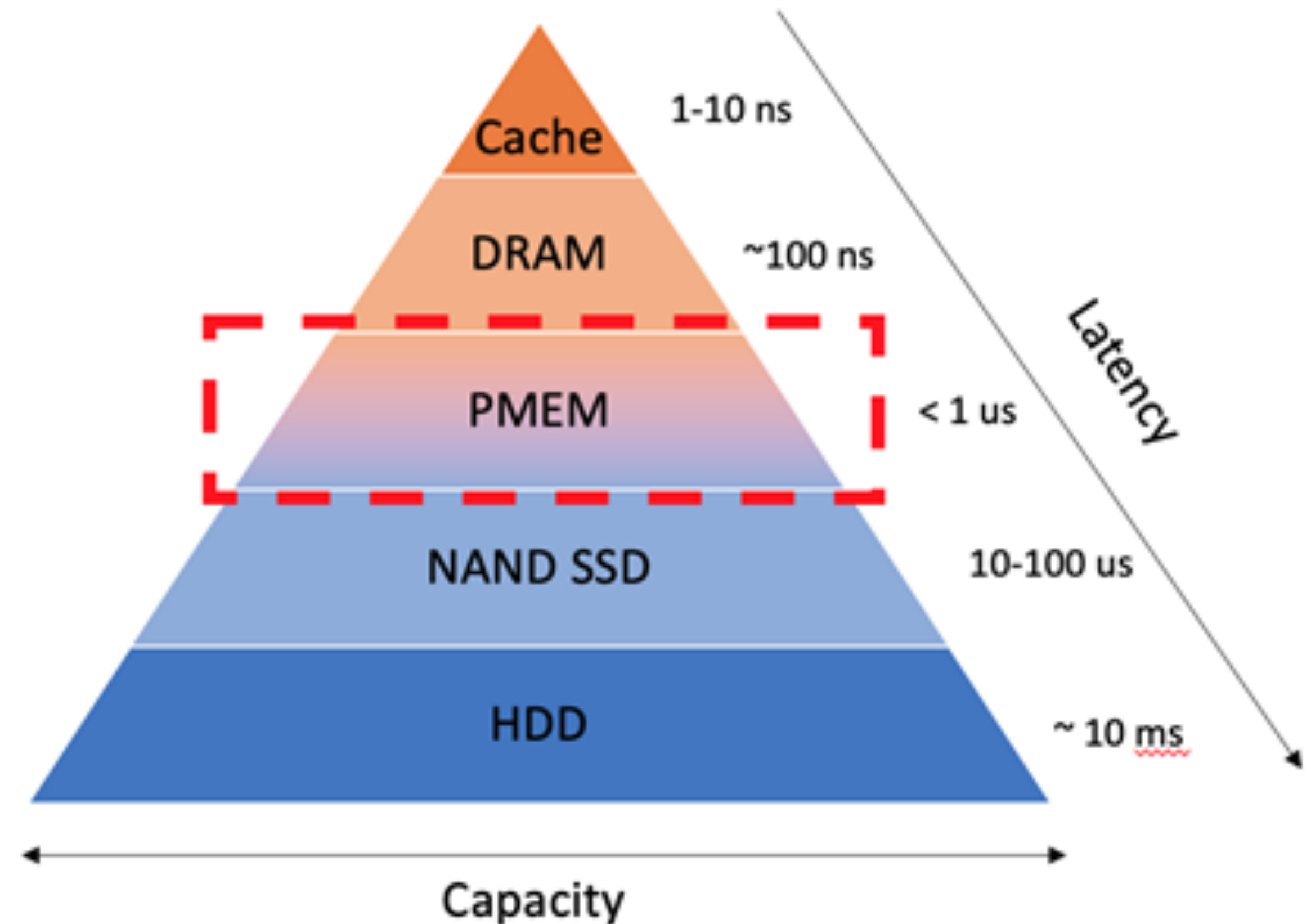
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- Memory: volatile but fast
- Disk: persistent but large
- PMEM: persistent and fast!



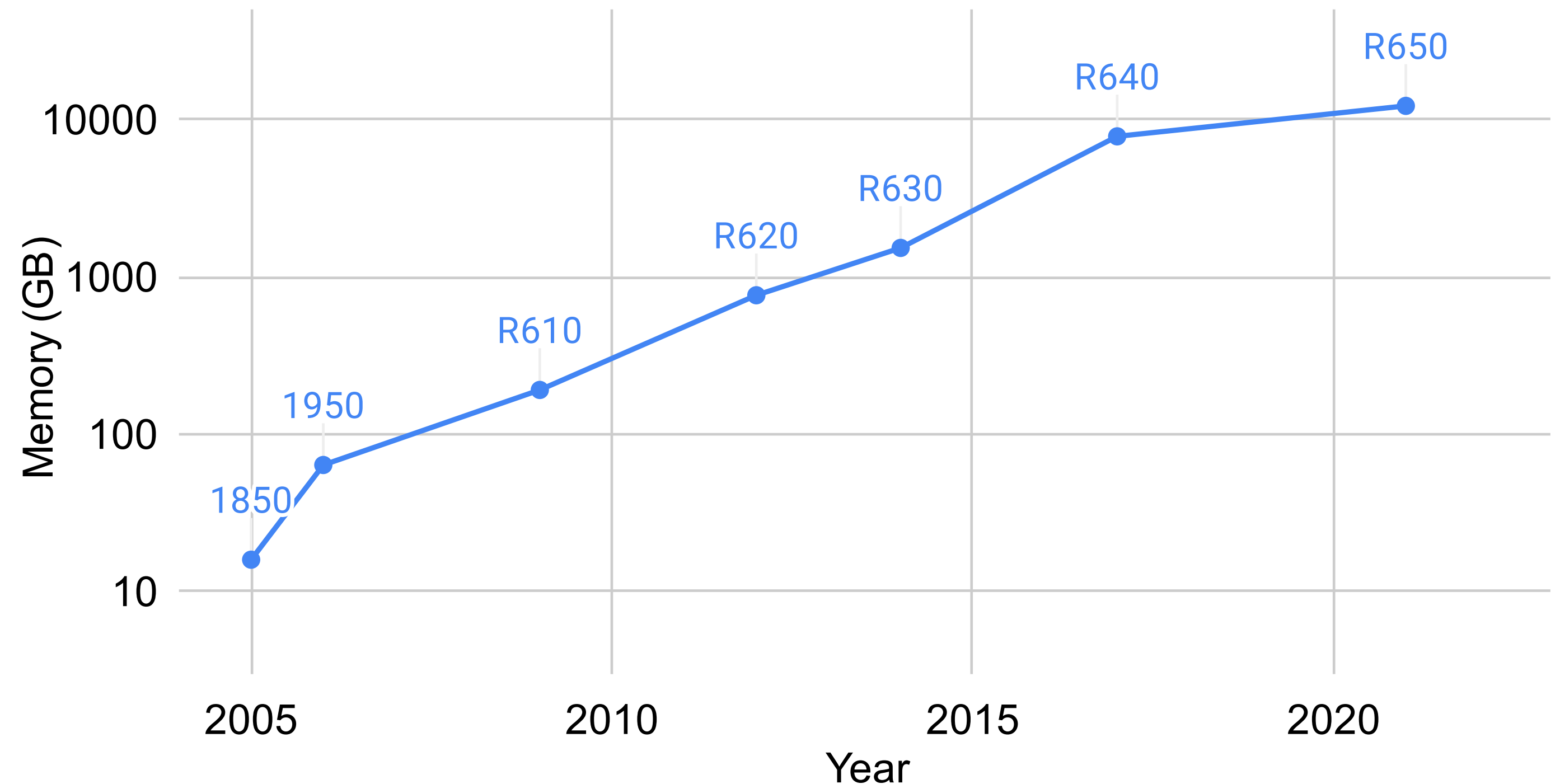
More trends: persistent memory

- Memory: volatile but fast
- Disk: persistent but large
- PMEM: persistent and fast!
 - PMEM aware file systems



More trends: big memory

- OS were designed when memory was scarce: few KBs
- You can now buy a server with 12TB of DRAM!
- Transparent huge pages

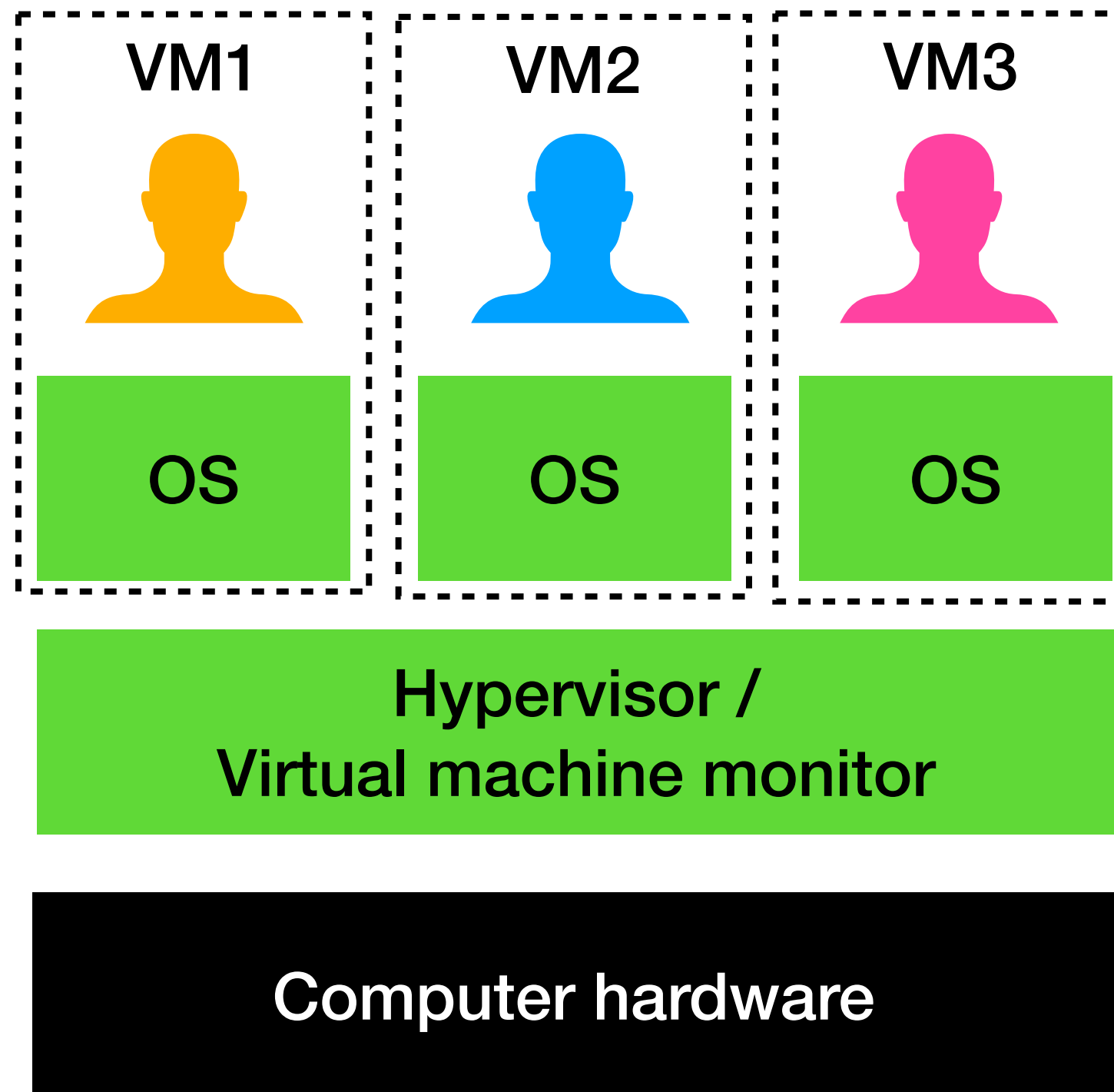


More trends: fast networks

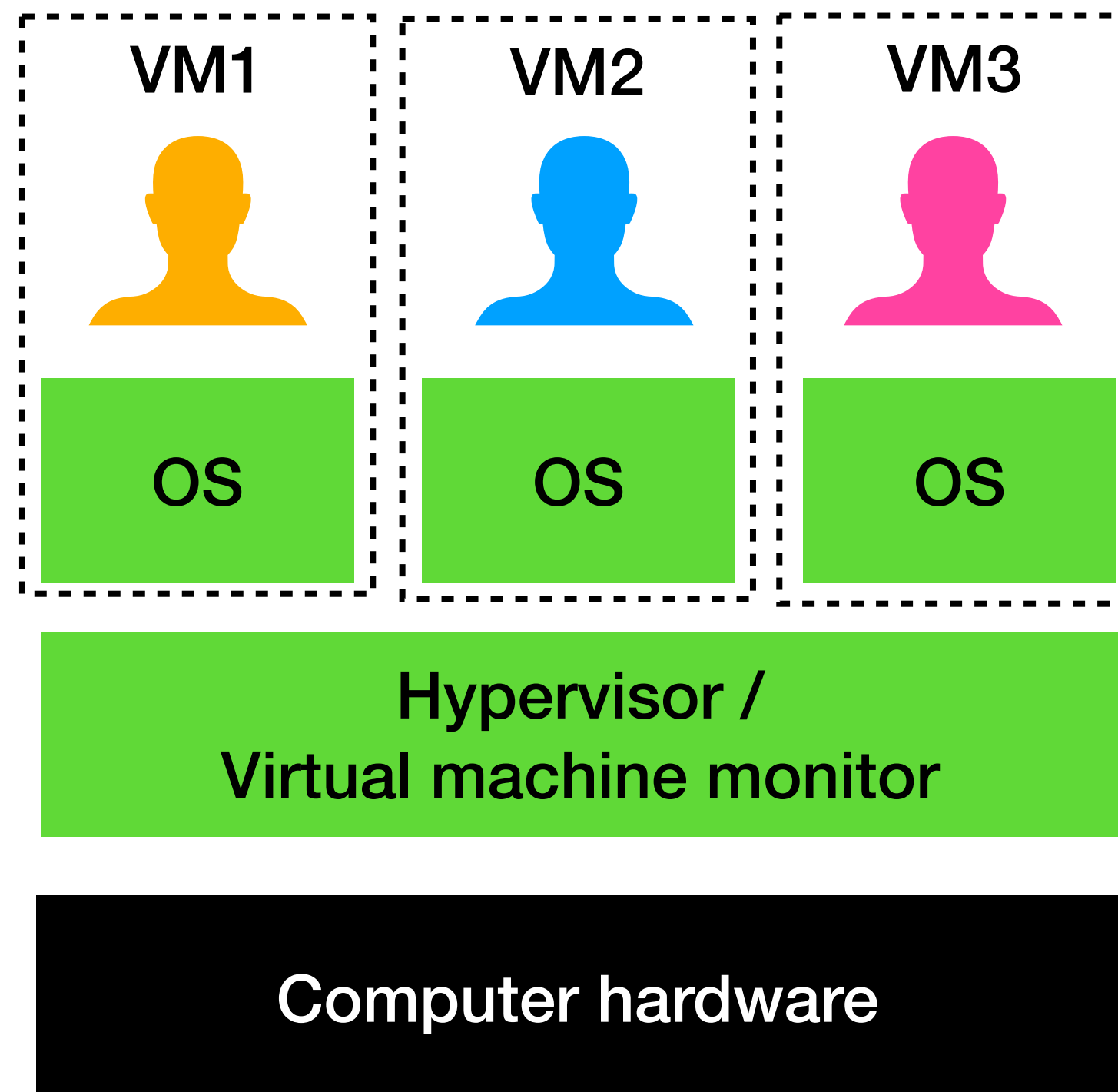
- OS typically assumed network is *much slower* than DRAM
 - Far memory

2020s	Latency	Bandwidth
DRAM	15ns	400 GBps
Ethernet	500ns	50 GBps

Rise of Unikernels

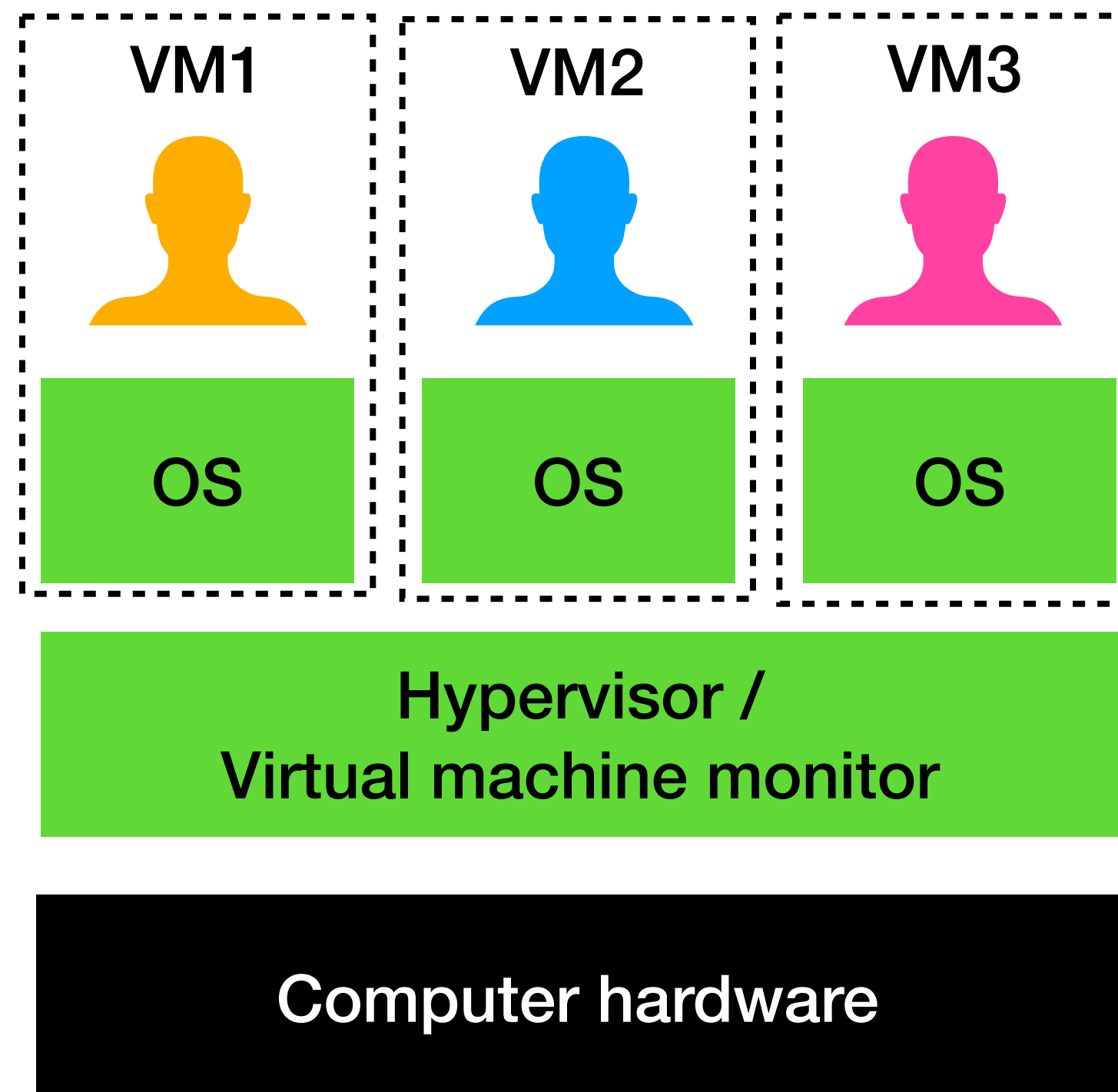


Rise of Unikernels



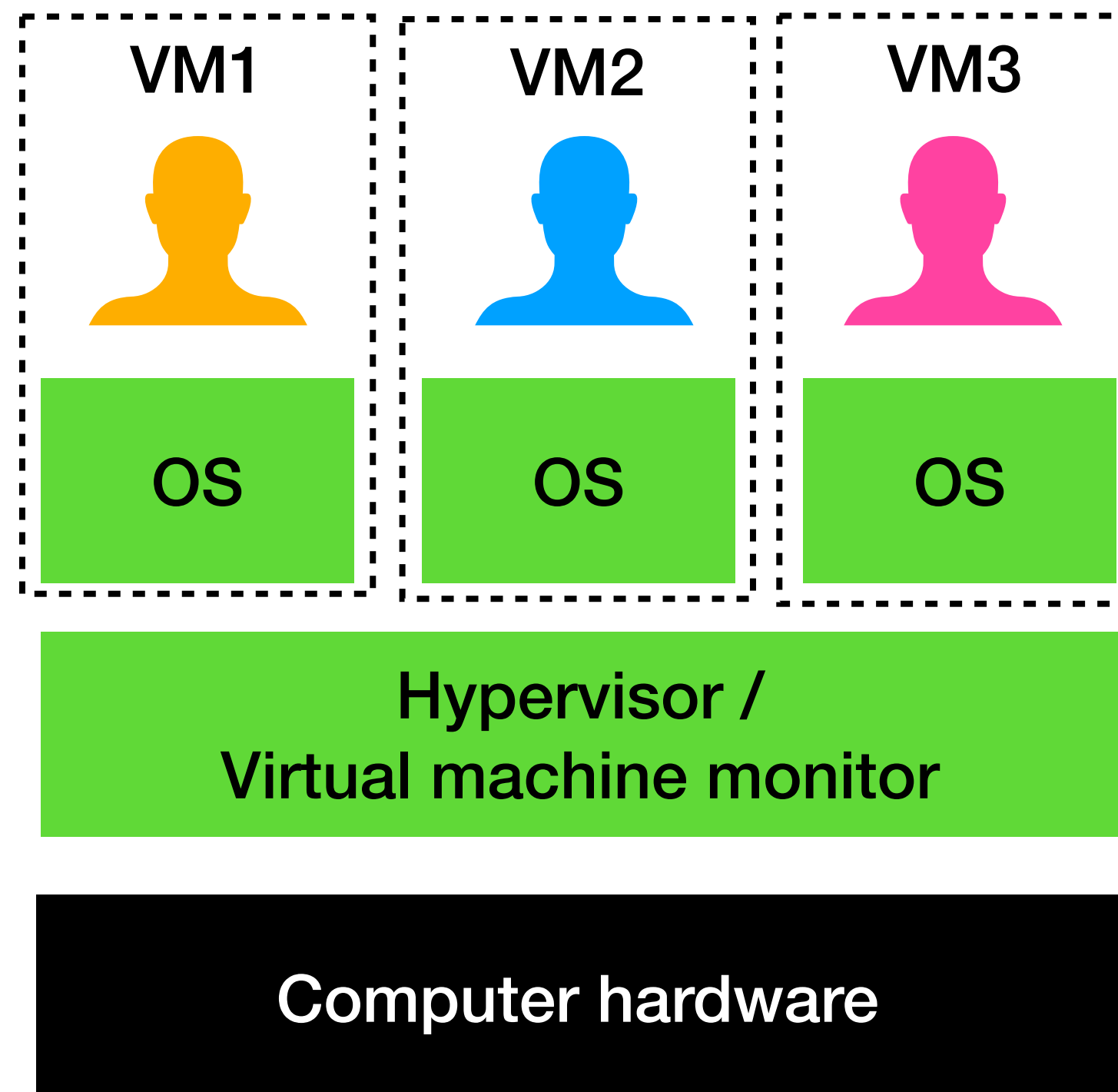
- OS optimises for common behaviours across all applications

Rise of Unikernels



- OS optimises for common behaviours across all applications
- Each OS is now running only single application

Rise of Unikernels



- OS optimises for common behaviours across all applications
- Each OS is now running only single application
- Unikernels optimise only for a single application

Why should I care about learning OS?

If I don't want to do systems research

- OS is ultimately a study of abstraction. Absorb all the complexity away from the developer / the user.
- Principles are useful when designing any large-scale system