

Systems and Networking I

Applied Computer Science and Artificial Intelligence
2024-2025



SAPIENZA
UNIVERSITÀ DI ROMA

Gabriele Tolomei

Dipartimento di Informatica
Sapienza Università di Roma

tolomei@di.uniroma1.it

Useful Information

Class schedule

- **Tuesday:** 5 p.m. – 7 p.m.
- **Wednesday:** 4 p.m. – 7 p.m.

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- **email:** tolomei@di.uniroma1.it
- **website:** <https://github.com/gtolomei/systems-and-networking>
- **moodle:** <https://elearning.uniroma1.it/course/view.php?id=18520>

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Office hours

- Arranged via email
- **in-person** or **remotely**
- **Room 106**, 1st floor Building "E" ([map](#))

Class Material

- Released on the class website
- Suggested books (though not mandatory!):
 - "*Operating System Concepts*" Ninth Edition – Silberschatz, Galvin, Gagne
 - "*Modern Operating Systems*" Fourth Edition – Tanenbaum, Bos
 - "*Operating Systems: Three Easy Pieces*" – Remzi and Andrea Arpaci-Dusseau [[available online](#)]
- Any additional resource available on the Web!

Moodle

- Provides native support for:
 - Sharing news and messages (forum)
 - Additional class material (e.g., exercises)
 - Exam simulations (e.g., quizzes)
 - ...

Remember to enroll in the course from the
[moodle web page](#)!

Exam

- Moodle Quiz:

- 20 multiple-answer questions (max. 45 minutes)
- Marks: +3 (correct answer), 0 (no answer), -1 (wrong answer)
 - score $\leq 14/30 \rightarrow \text{FAIL}$
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- Oral Session:

- Questions and exercises on the subjects covered during the whole semester

Outline of the Course

- Part I: Introduction

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- Part II: Process Management

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- Part VI: File System
- Part VII: Advanced Topics

Part I: Introduction

Language and Naming Conventions

- OS → Operating System
- HW → Hardware
- SW → Software
- VM → Virtual Machine
- ...
- Other shortcuts/acronyms may appear here and there without notice! Please, ask if anything is not clear!

What is an Operating System?

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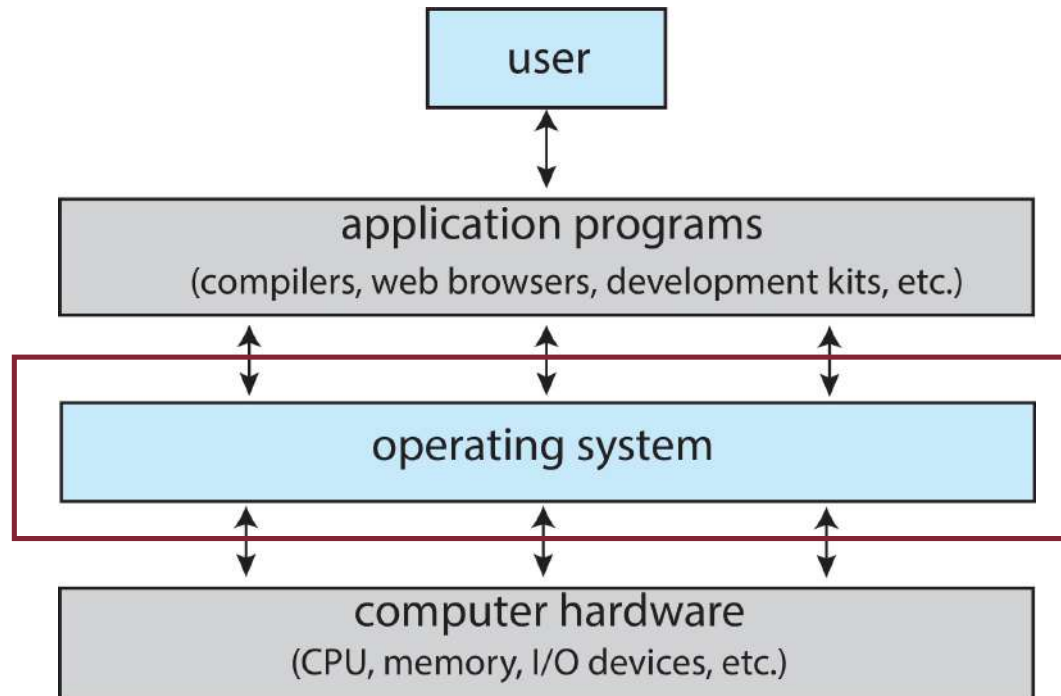
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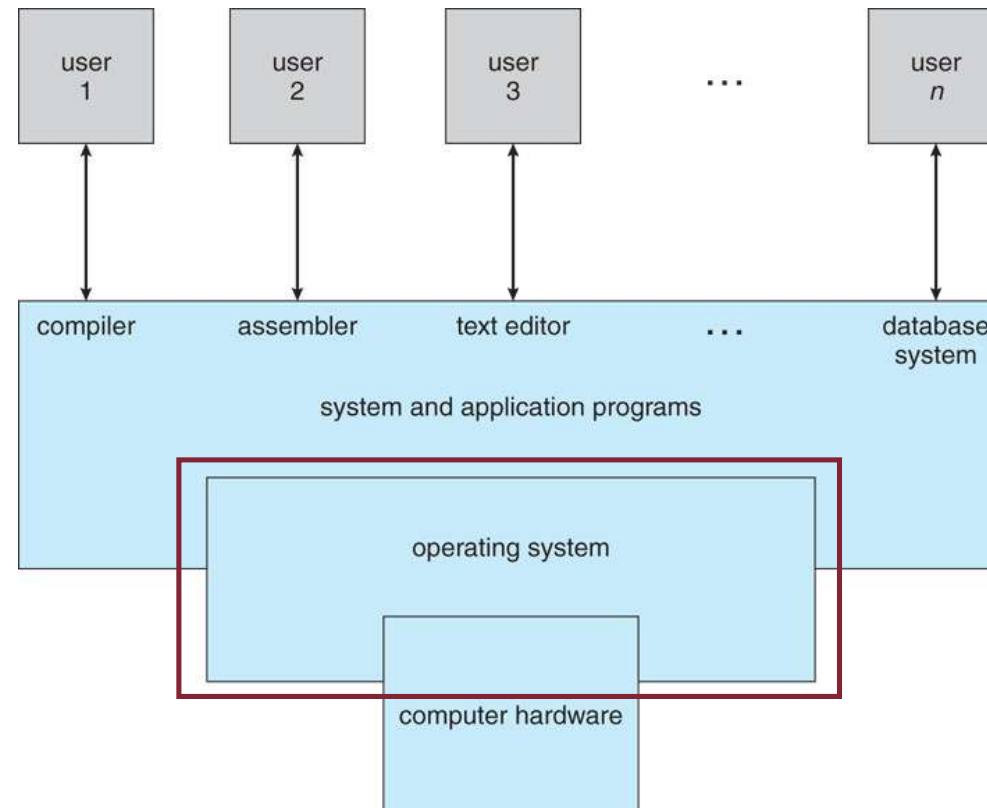
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- However, the definition below is quite appropriate:

Implementation of a virtual machine that is (hopefully) easier to program than bare hardware

Computer System Overview



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- It is a **system design** choice to decide what to include in the OS
- Different systems may have different requirements:
 - general-purpose, real-time, mobile, etc.
- Typically, we distinguish between:
 - **kernel** → the "core" of the OS (always up and running)
 - **system programs** → everything else which is still part of the OS

OS Wears Many Hats

- Referee (Resource Manager)
 - Manages shared physical resources: CPUs, memory, I/O, etc.



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 - Manages shared physical resources: CPUs, memory, I/O, etc.
 - To achieve **fairness** and **efficiency**



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 - Virtualize any physical resource



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 - To give applications/users the **illusion of infinite resources** available



OS Wears Many Hats

- Glue (HW/SW Interface)
 - Provides a set of **common services** (APIs) to separate HW from SW



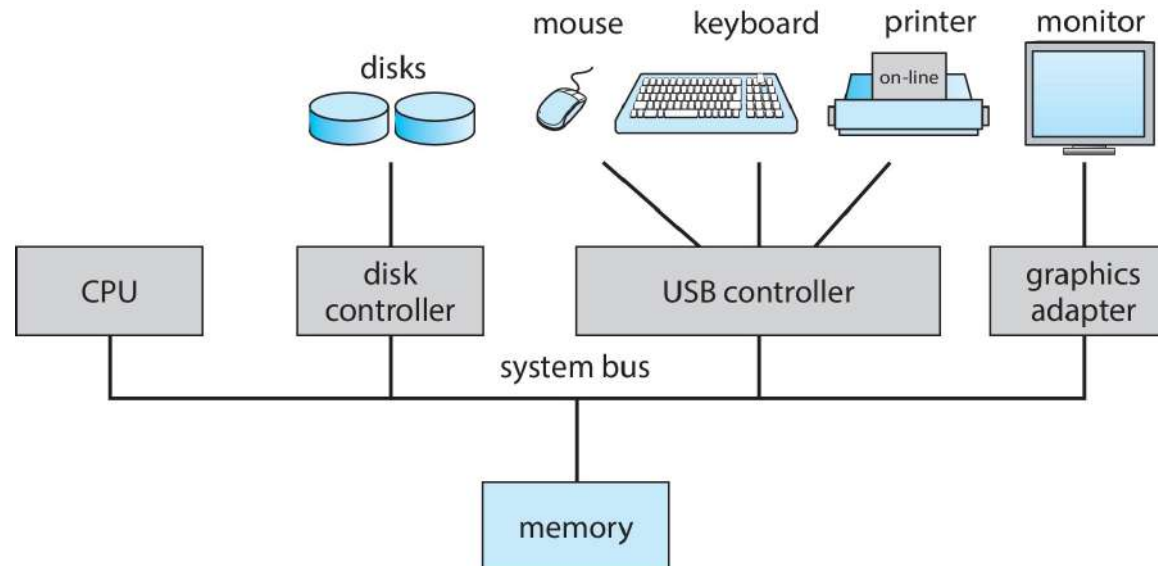
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- Glue (HW/SW Interface)
 - Provides a set of **common services** (APIs) to separate HW from SW
 - To allow applications/users to interact with the system **without talking directly to the HW**

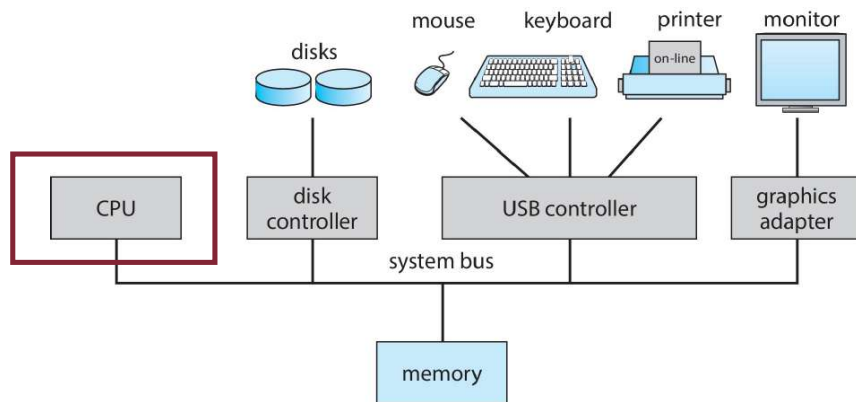


Computer System Organization

High-Level View of a Computer



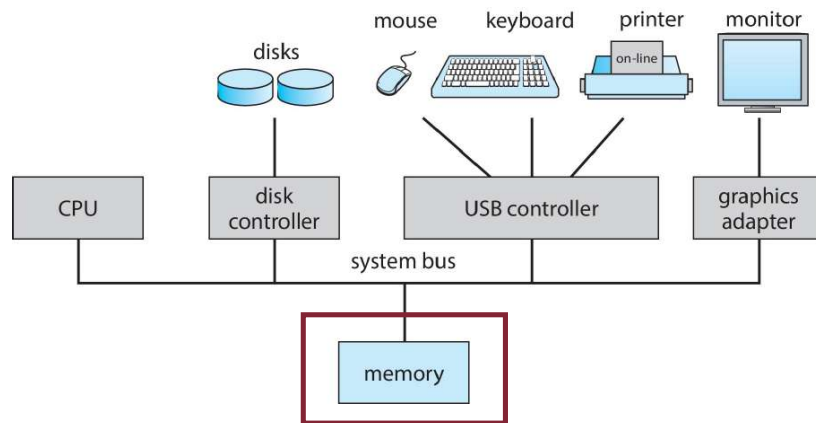
High-Level View of a Computer



CPU

- The processor that performs the actual computation
- Multiple cores are now common in modern architectures

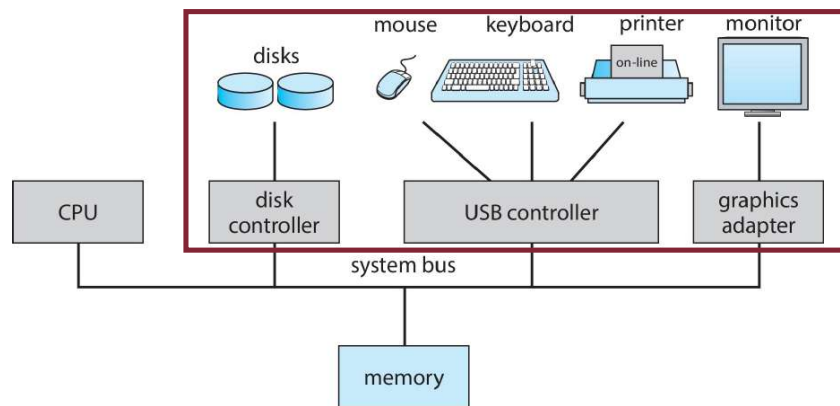
High-Level View of a Computer



Main Memory

- Stores data and instructions used by the CPU
- Shared between CPU and I/O

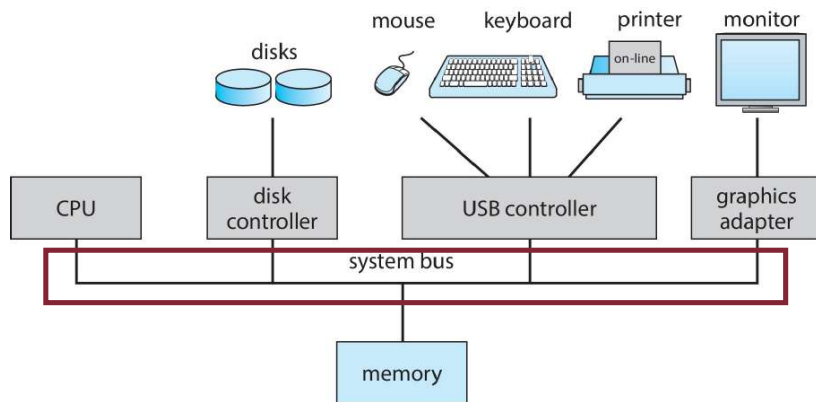
High-Level View of a Computer



I/O devices

- terminal, keyboard, disks, etc.
- Associated with specific device controllers

High-Level View of a Computer



System Bus

- Communication medium between CPU, memory, and peripherals

Computer Architecture Model

- Conceptually, the same architectural model for many computing devices:
 - PCs/laptops
 - High-end servers
 - Smartphones/Tablets
 - etc.

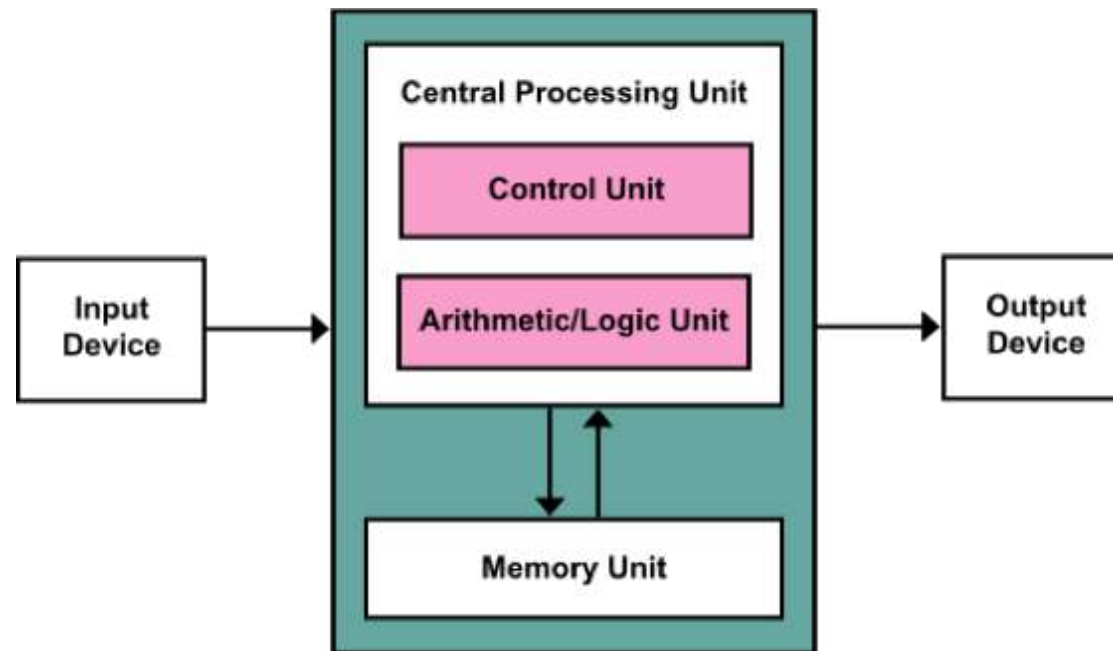
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- Based on **stored-program** concept (as opposed to fixed-program)

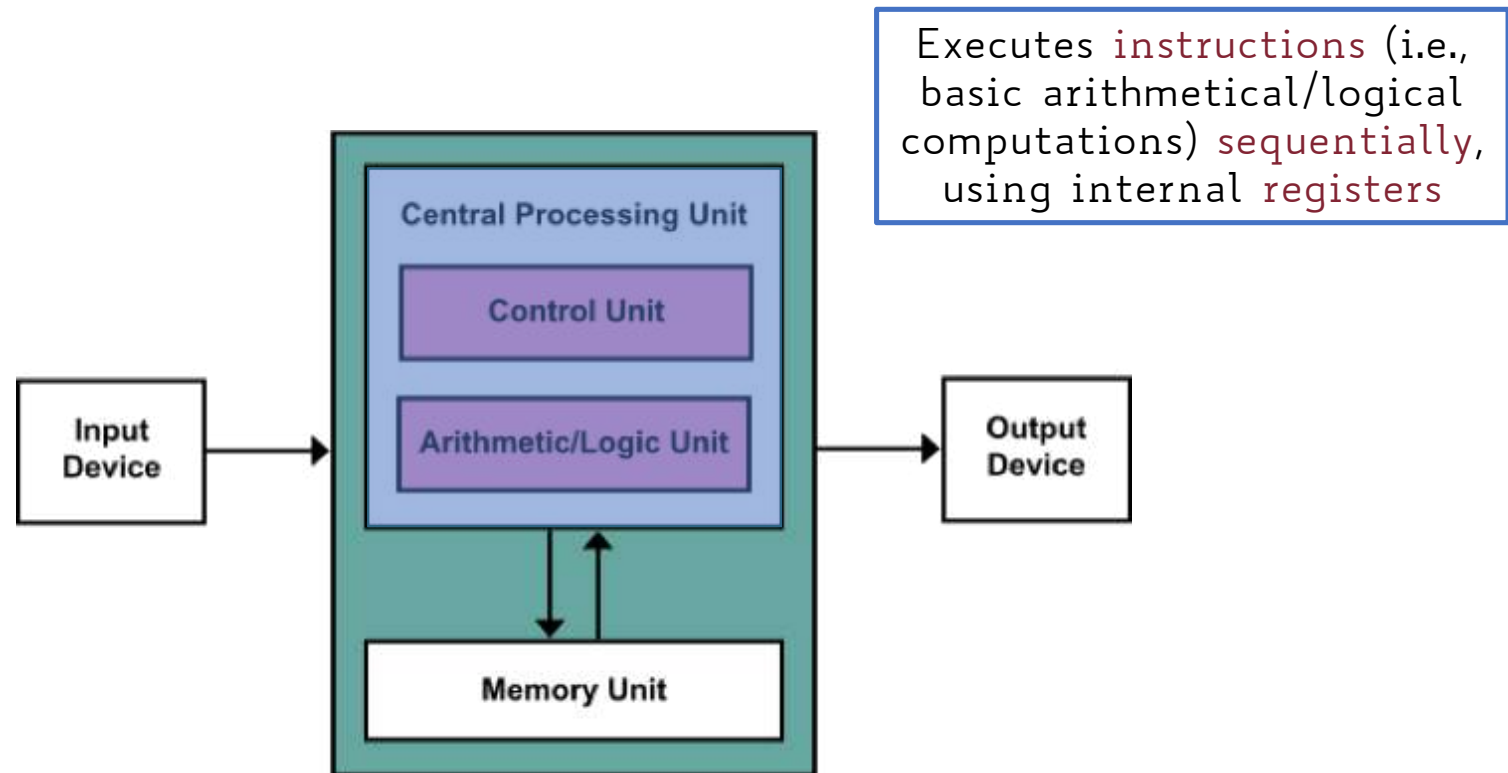


John von Neumann

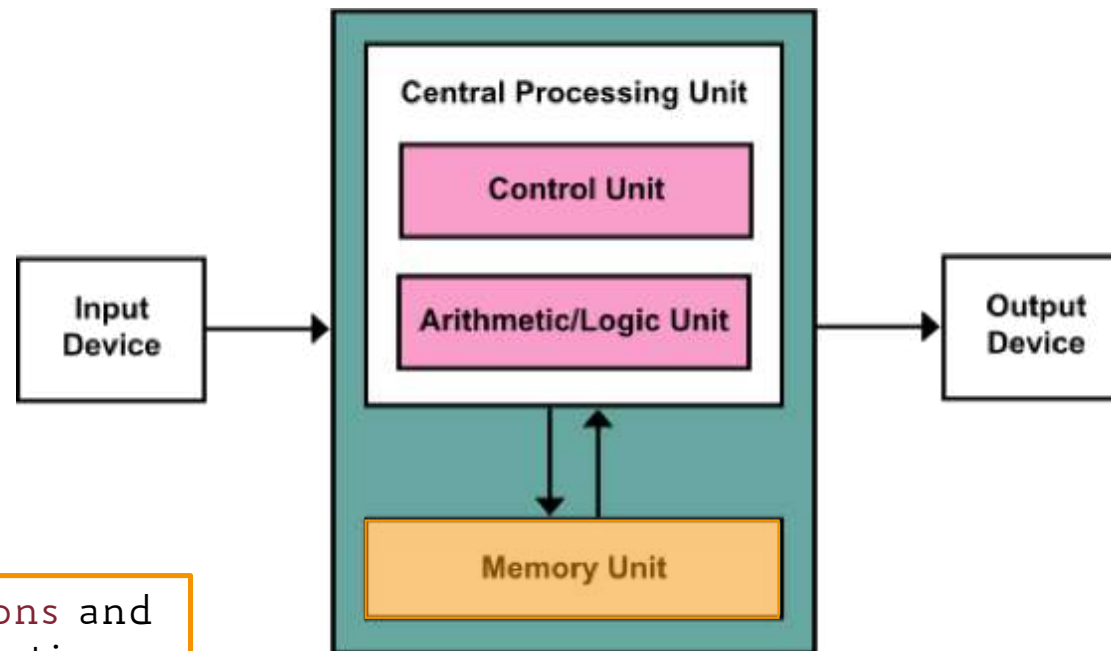
von Neumann Architecture



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Contains **instructions** and **data** (which instructions operate on)

Central Processing Unit (CPU)

Instruction Cycle: Fetch-Decode-Execute

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 - **Execute:** runs the actual decoded instruction

Machine Language

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 - A single bit is the smallest unit of (digital) information
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- A **word** is the unit of data the CPU can directly operate on
 - today ranging from 32 to 64 bits

A Side Note on Units

Prefixes for multiples of bits (bit) or bytes (B)					
Decimal			Binary		
Value		SI	Value	IEC	JEDEC
1000	10^3	k kilo	1024	2^{10} Ki kibi	K kilo
1000^2	10^6	M mega	1024^2	2^{20} Mi mebi	M mega
1000^3	10^9	G giga	1024^3	2^{30} Gi gibi	G giga
1000^4	10^{12}	T tera	1024^4	2^{40} Ti tebi	–
1000^5	10^{15}	P peta	1024^5	2^{50} Pi pebi	–
1000^6	10^{18}	E exa	1024^6	2^{60} Ei exbi	–
1000^7	10^{21}	Z zetta	1024^7	2^{70} Zi zebi	–
1000^8	10^{24}	Y yotta	1024^8	2^{80} Yi yobi	–

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- An **abstraction** of the underlying physical (hardware) architecture (e.g., x86, ARM, SPARC, MIPS, etc.)

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- Special-purpose (x86):
 - `esp` → Stack pointer for top address of the stack
 - `ebp` → Stack base pointer for the address of the current stack frame
 - `eip` → Instruction pointer, holds the program counter (i.e., the address of next instruction)

Single- vs. Multi-Processor

Single-Processor Systems

- One main CPU for executing programs
- Other dedicated processors that do not run programs (e.g., disk controllers, GPUs, etc.)

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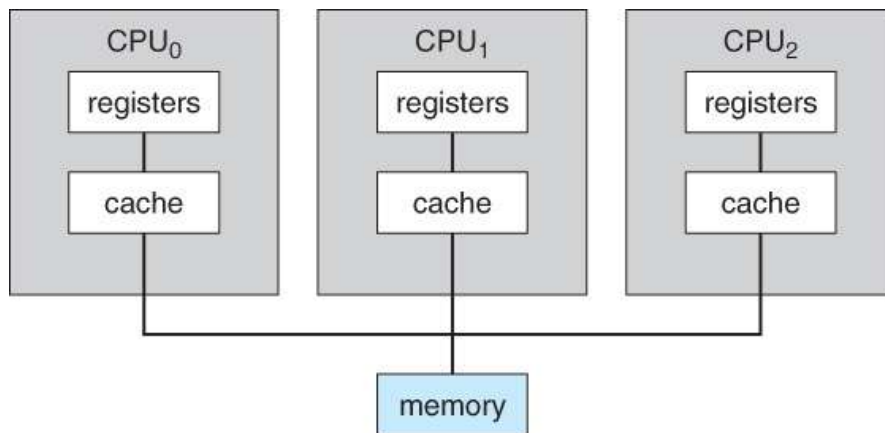
Our main focus!

Multi-Processor Systems

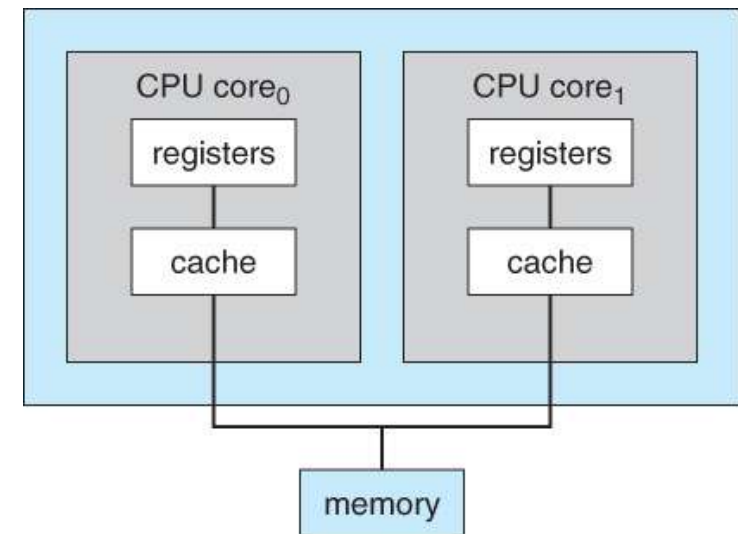
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Multi-Processor Systems: Examples

Symmetric Multiprocessing Architecture

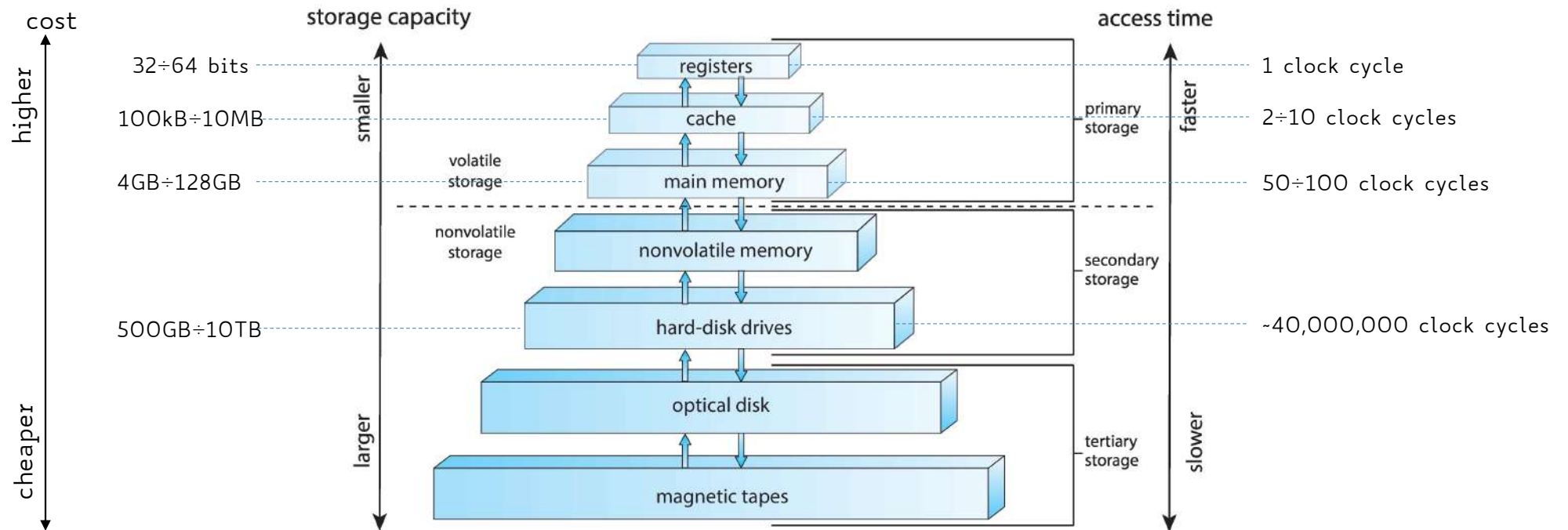


Multicore Architecture

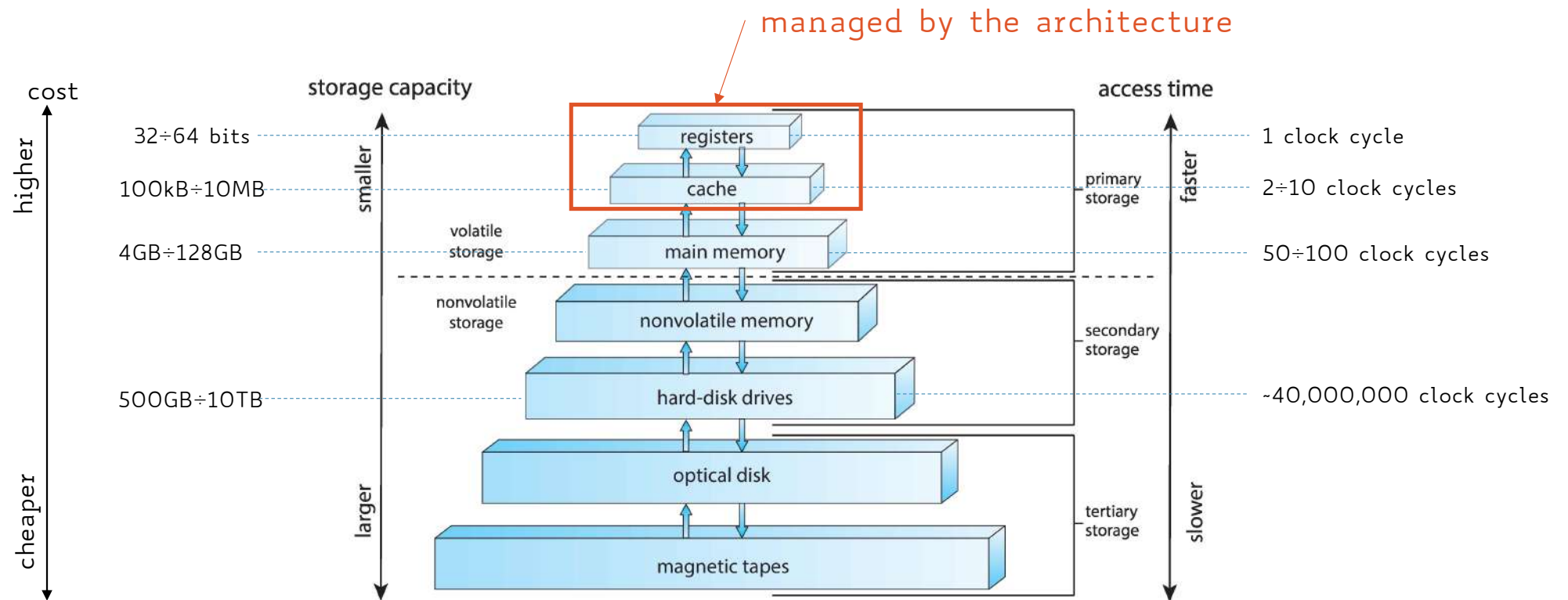


Memory

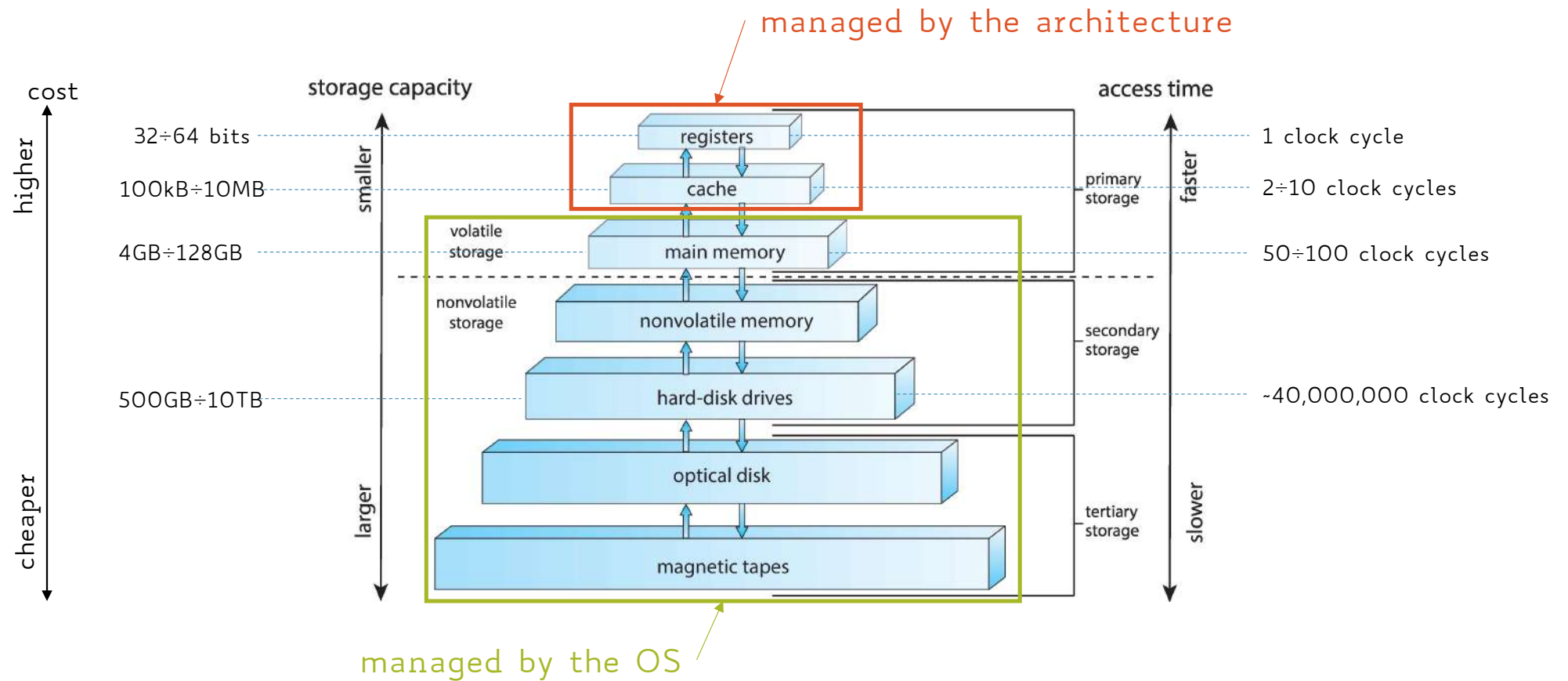
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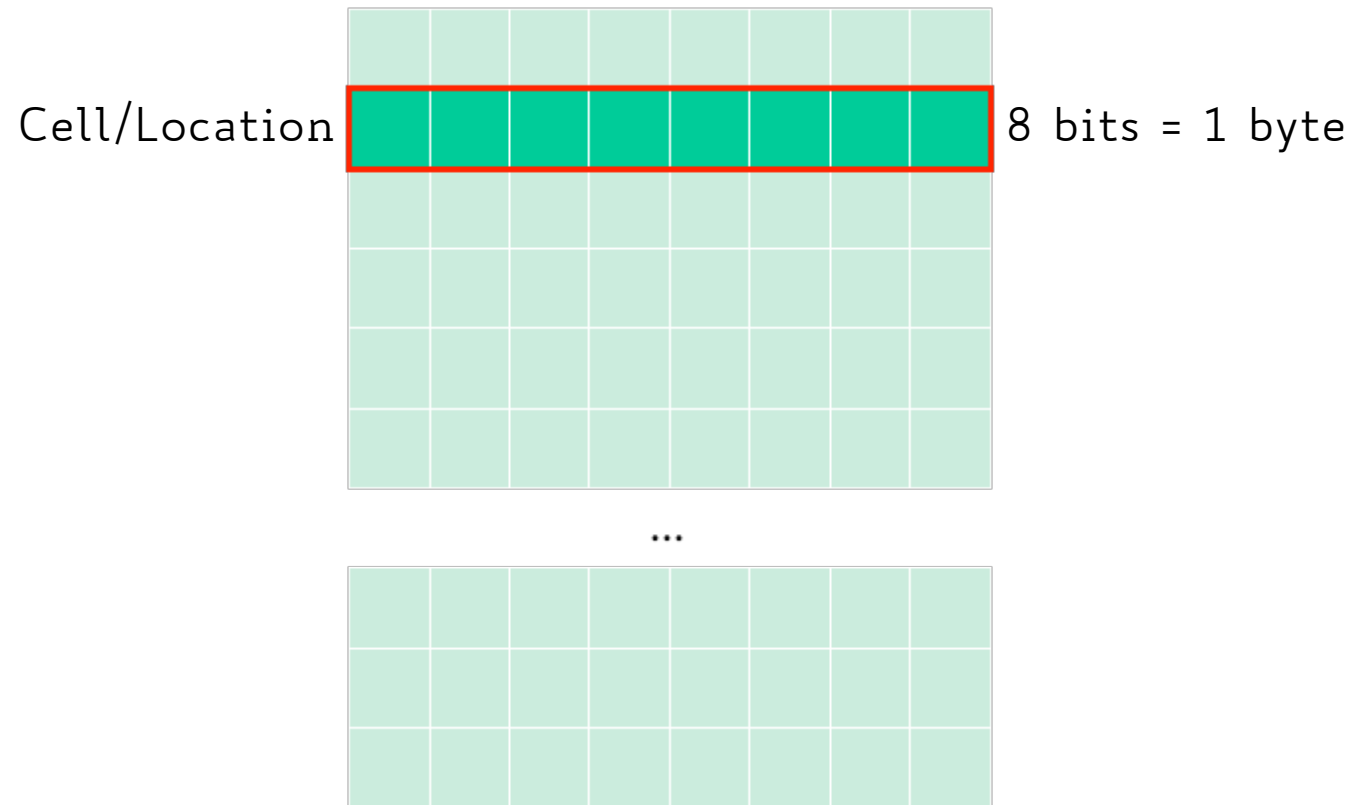
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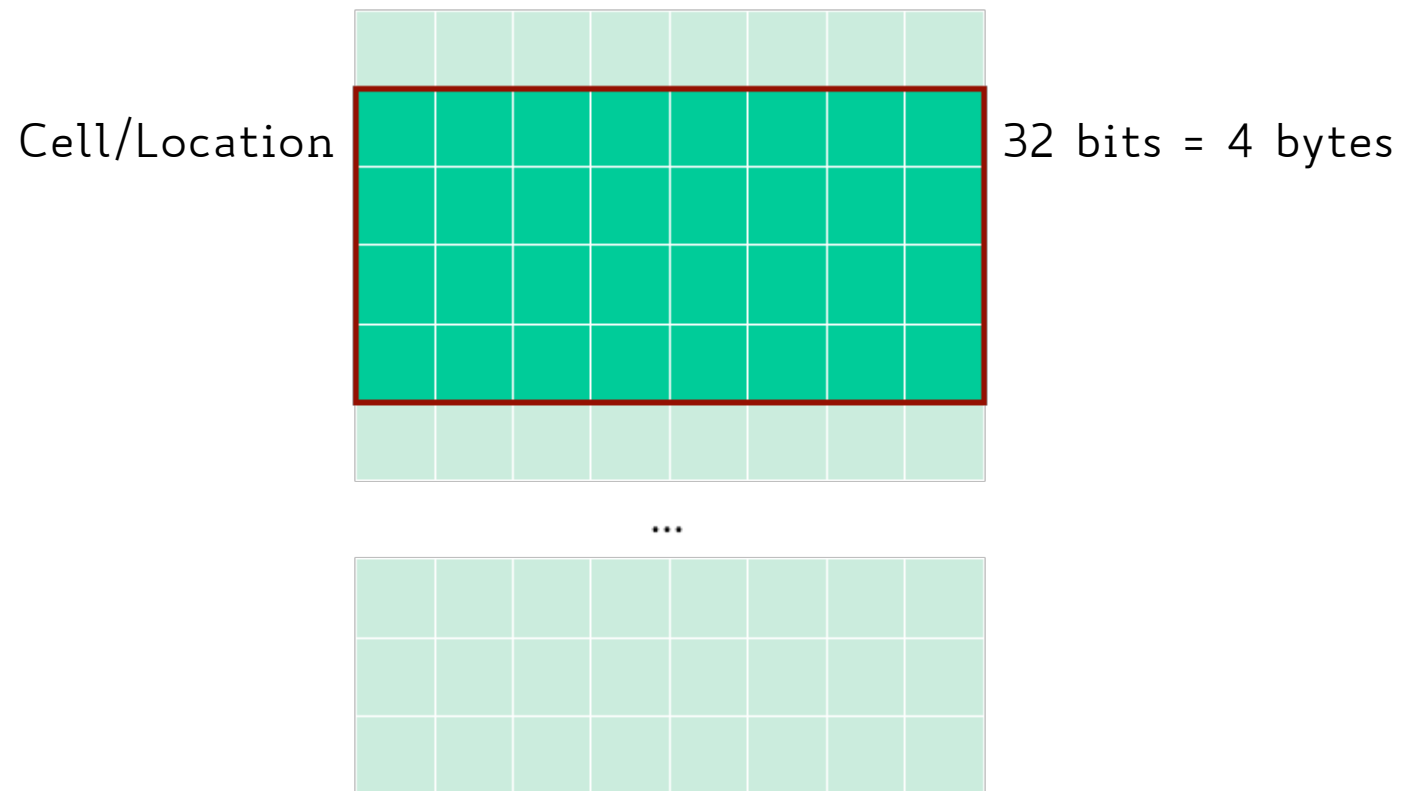
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- The smallest addressable unit is usually 1 byte

Memory Cell (1)



Memory Cell (2)



Memory Address (Single Byte)

00000000							
00000001							
00000010							
00000011							
00000100							
00000101							
...							
00100010							
00100011							
00100100							

Computer Buses

System Bus

- Initially, a single bus to handle all the traffic

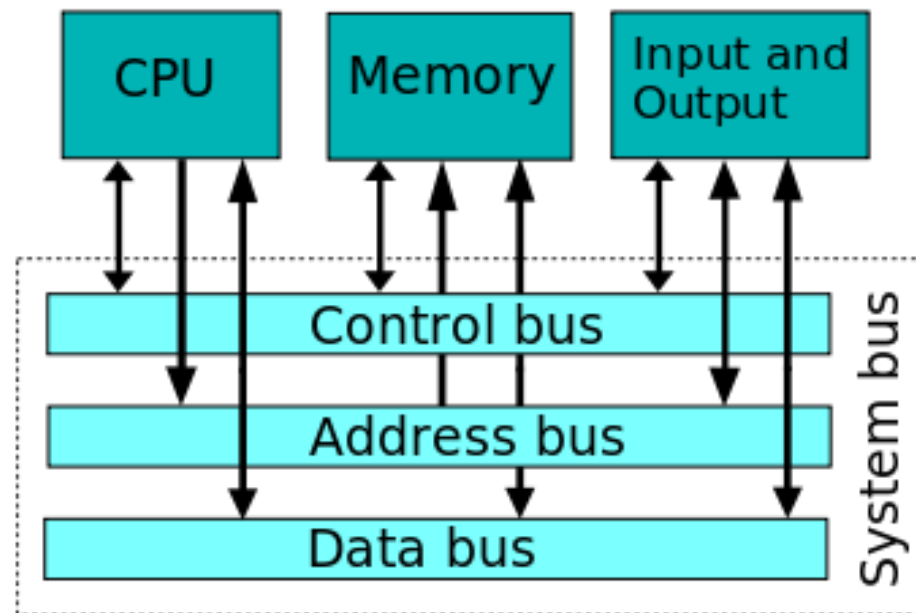
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- More dedicated buses have been added to manage CPU-to-memory and I/O traffic
 - PCI, SATA, USB, etc.

System Bus



I/O Devices

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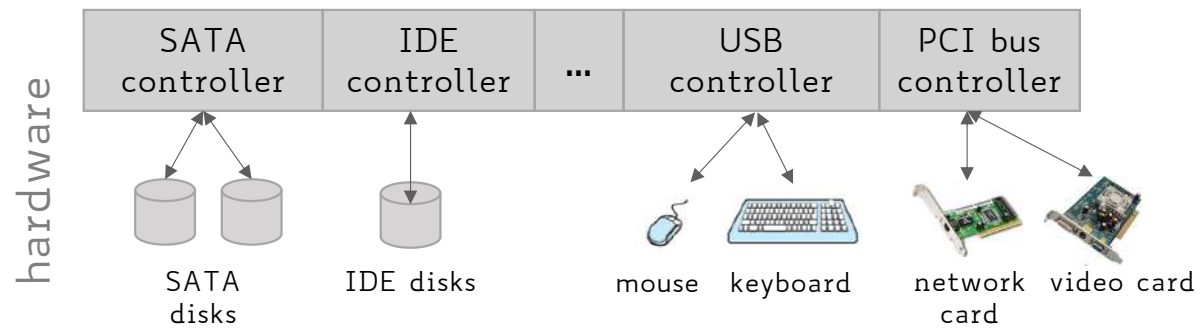
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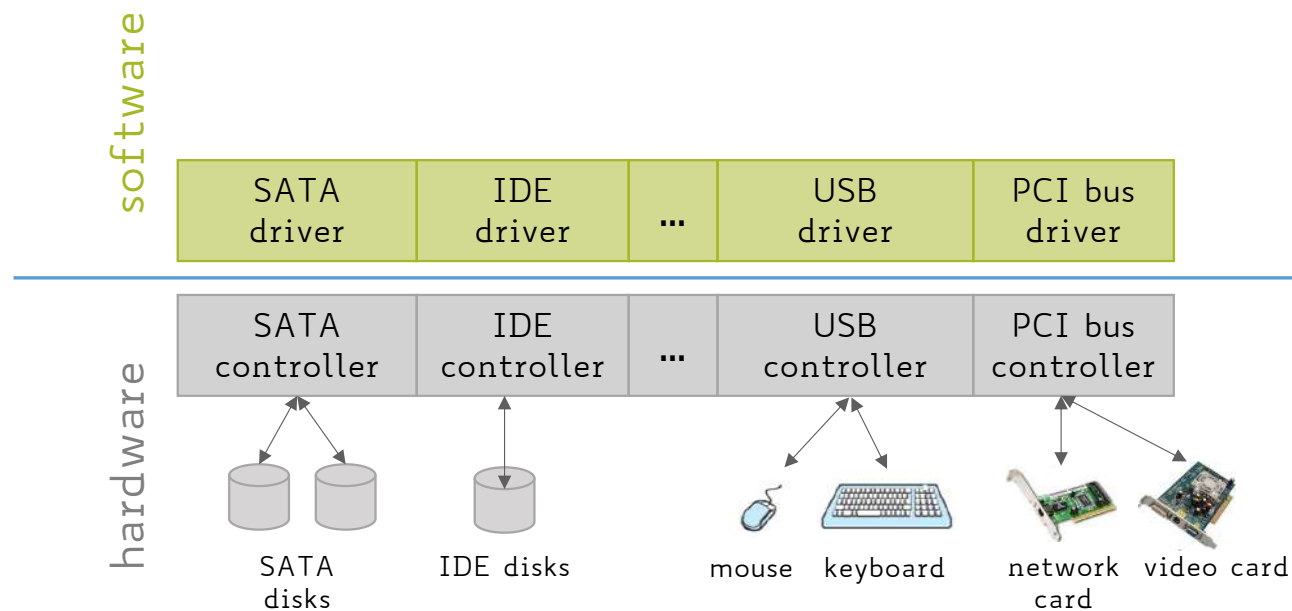
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- OS talks to a device controller using a specific **device driver**

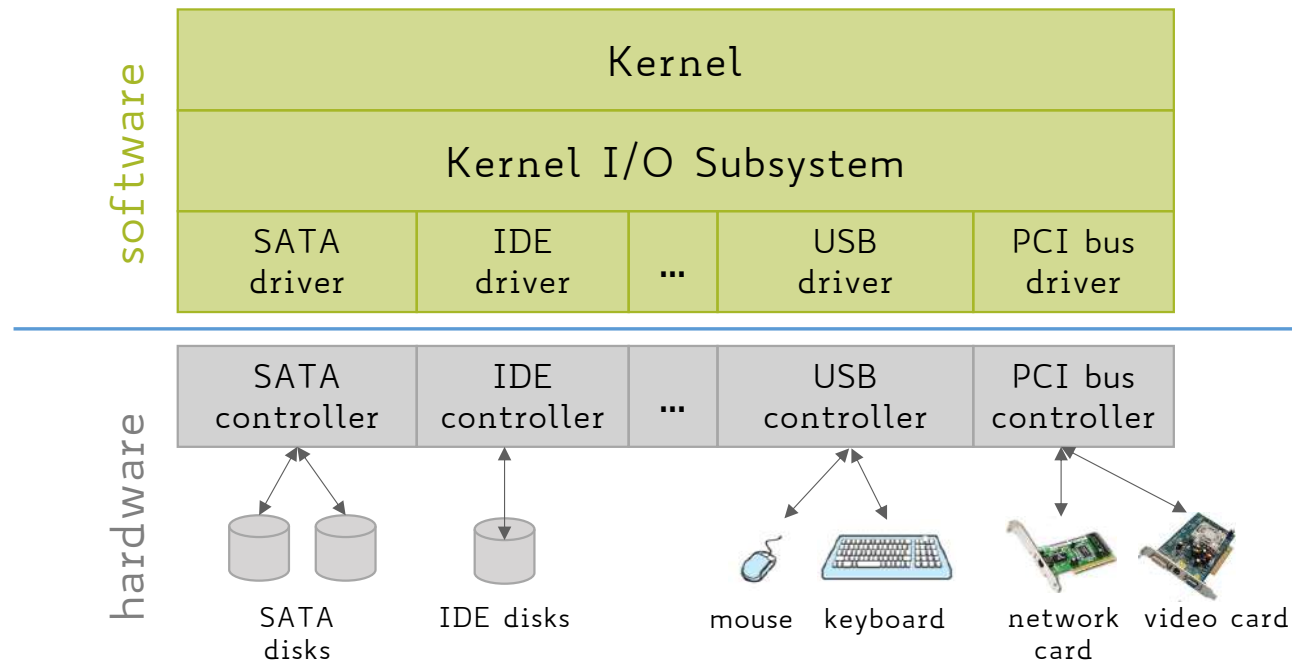
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Device Controllers

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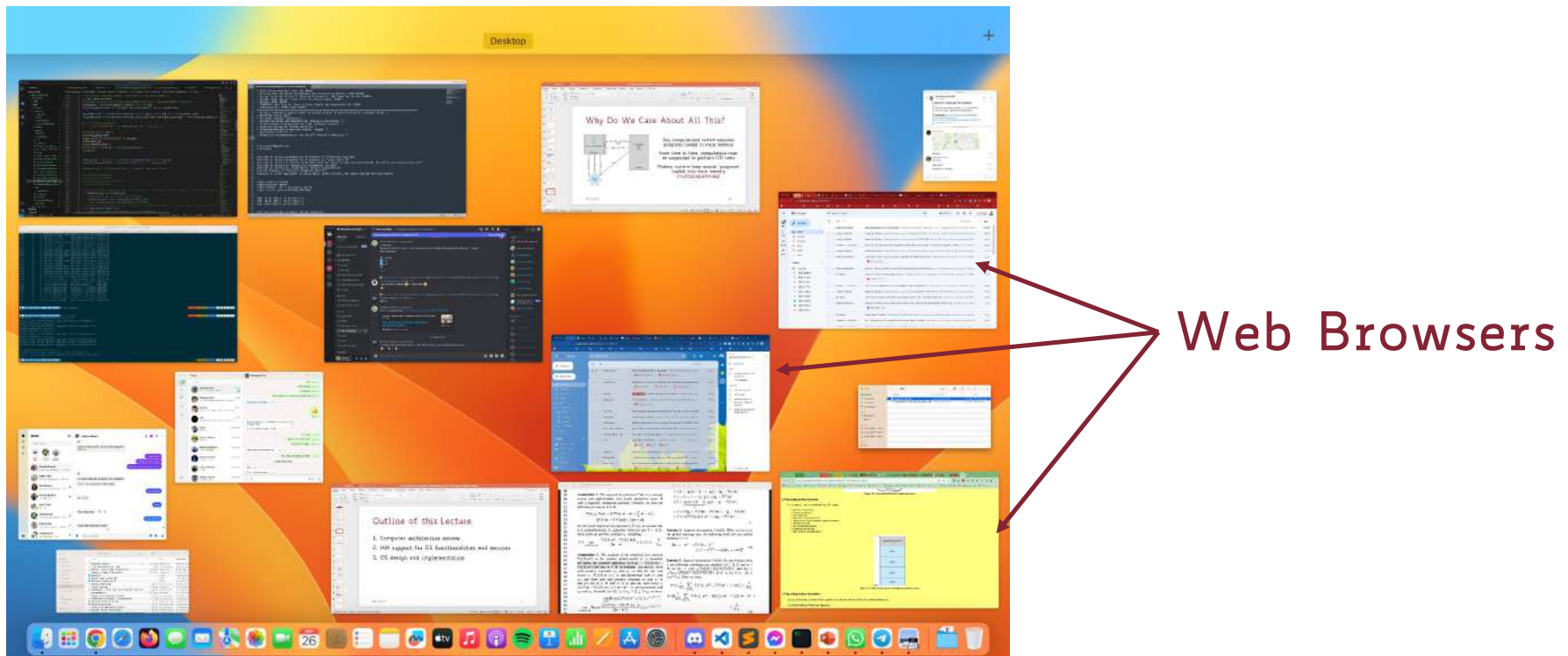
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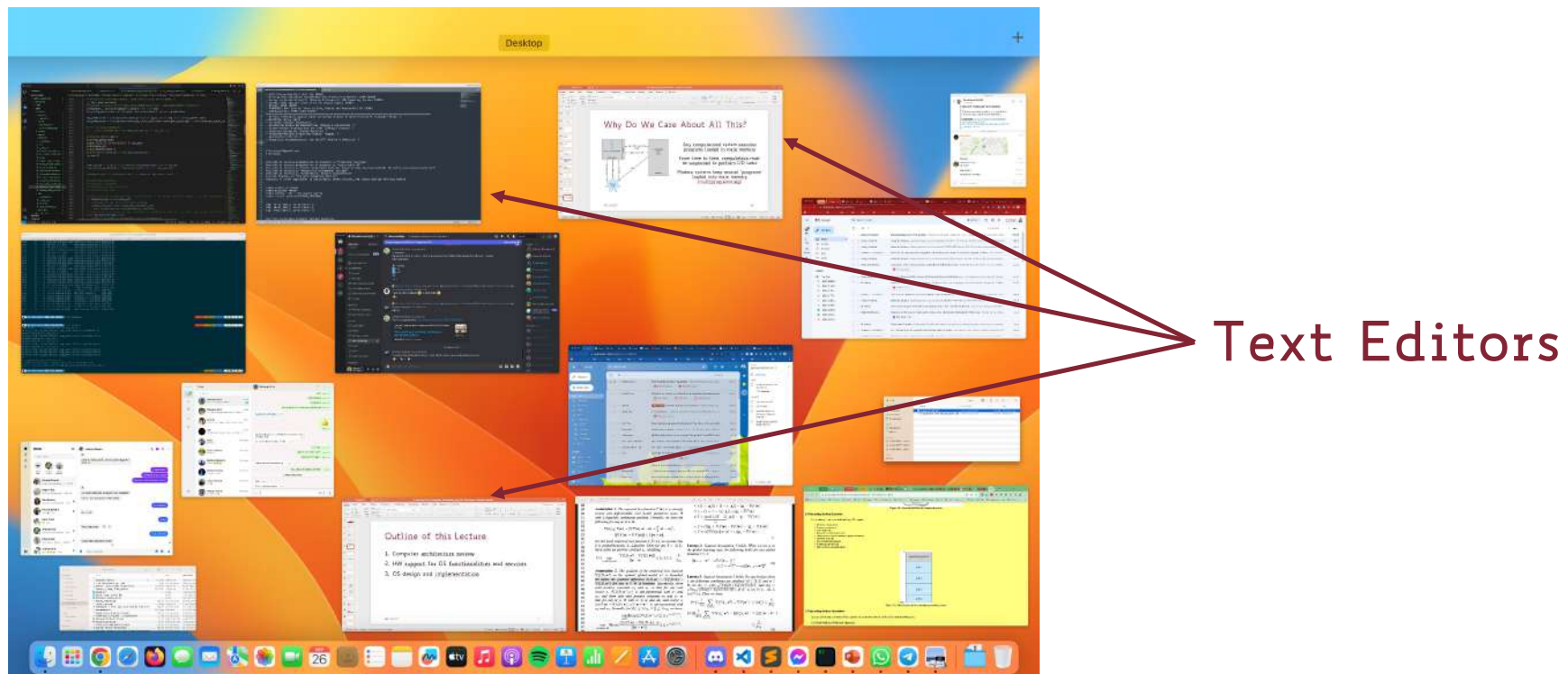
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 - **Data registers** → used to read data from or send data to the I/O device

Modern Computer Systems

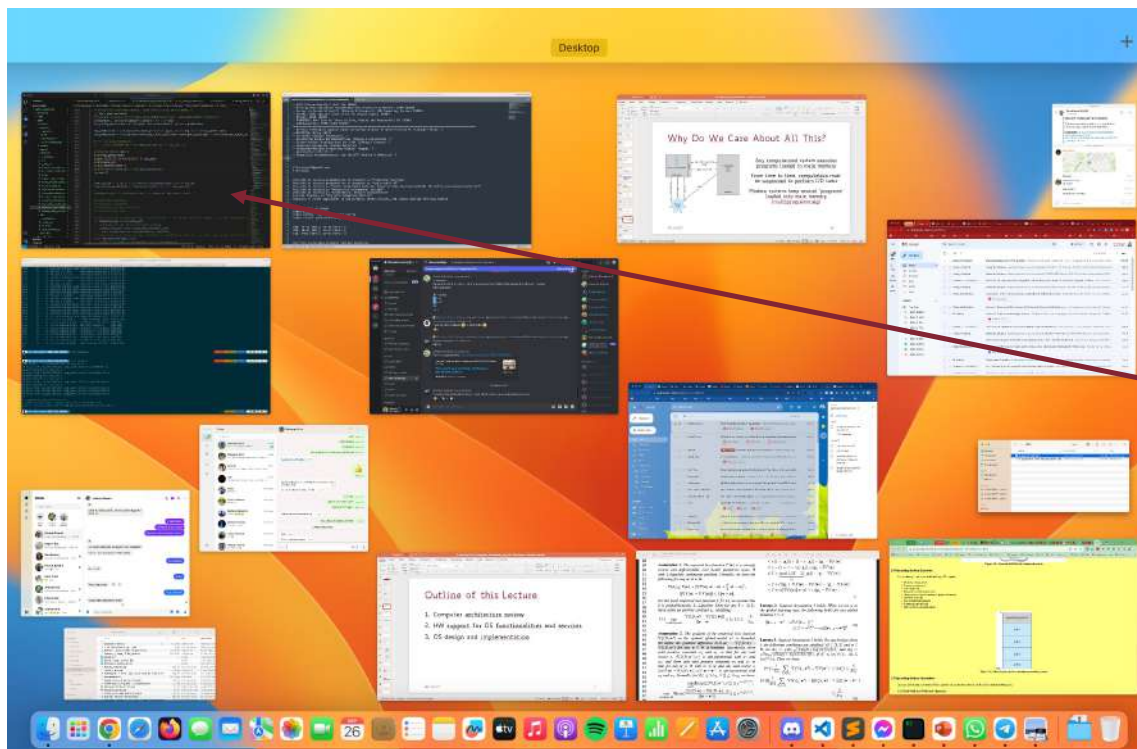
Many User Applications Running



Many User Applications Running

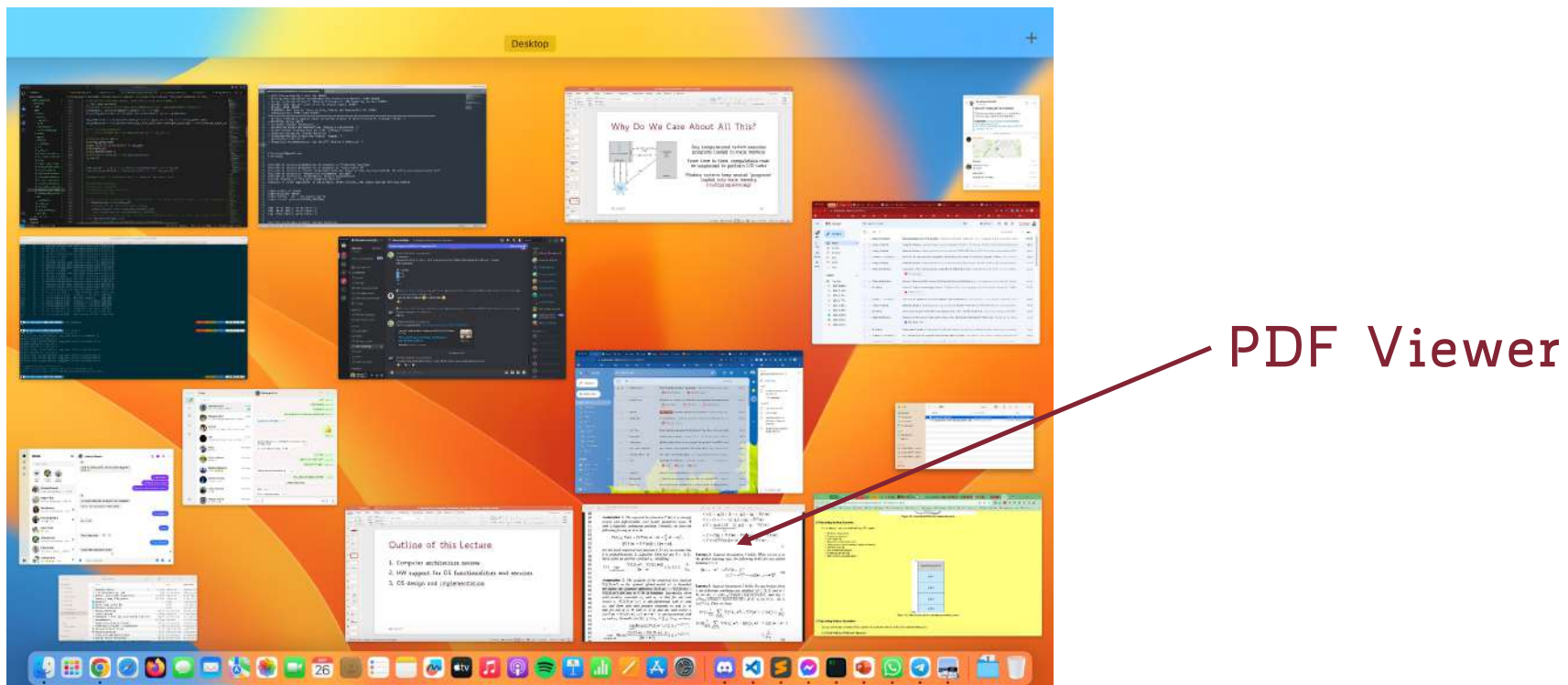


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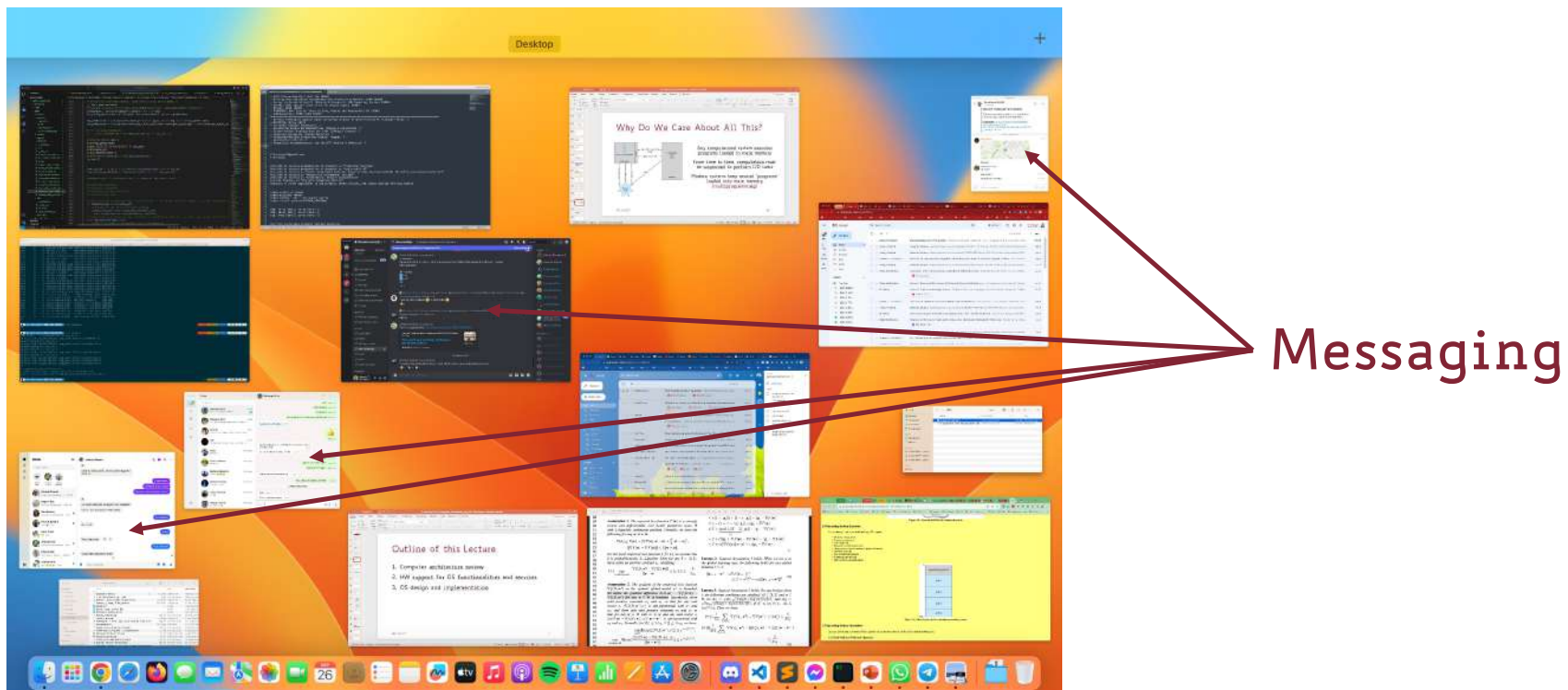


IDE
(code development)

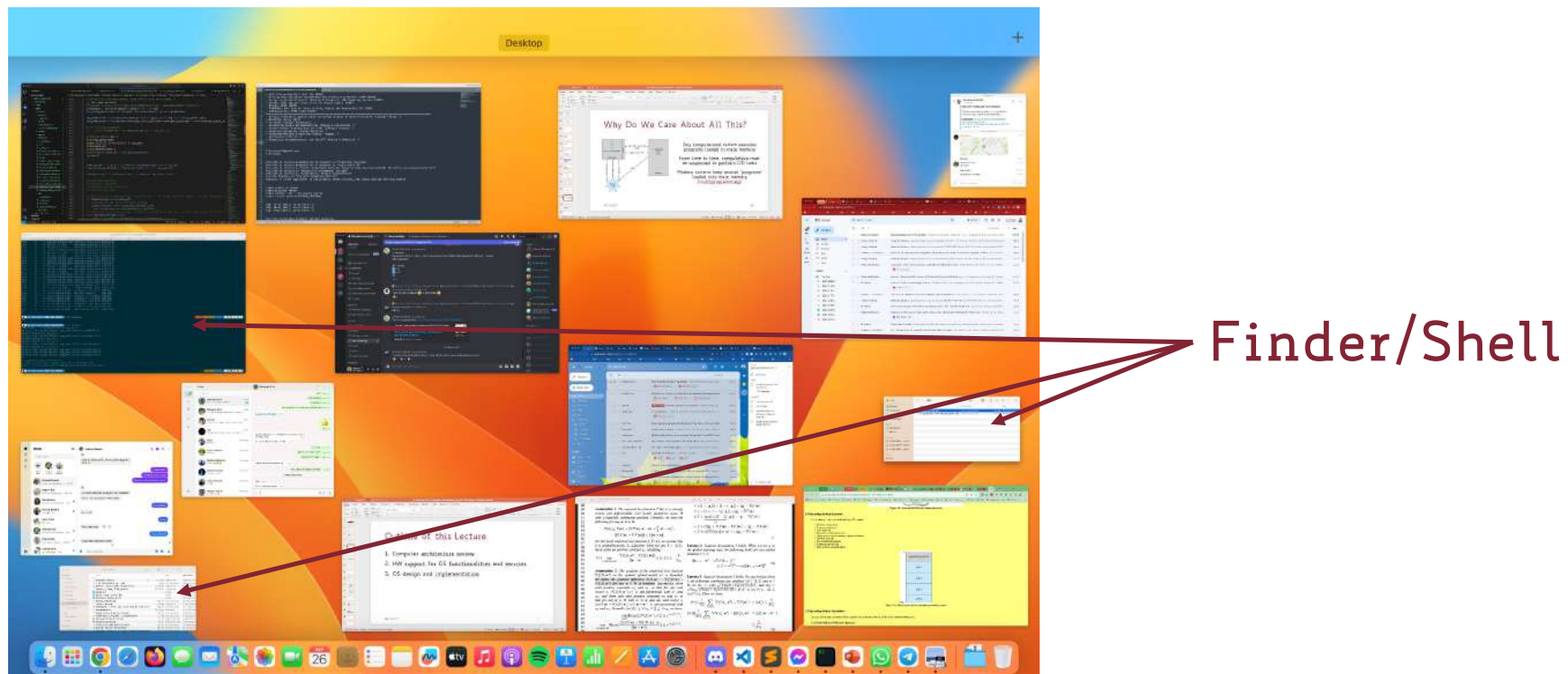
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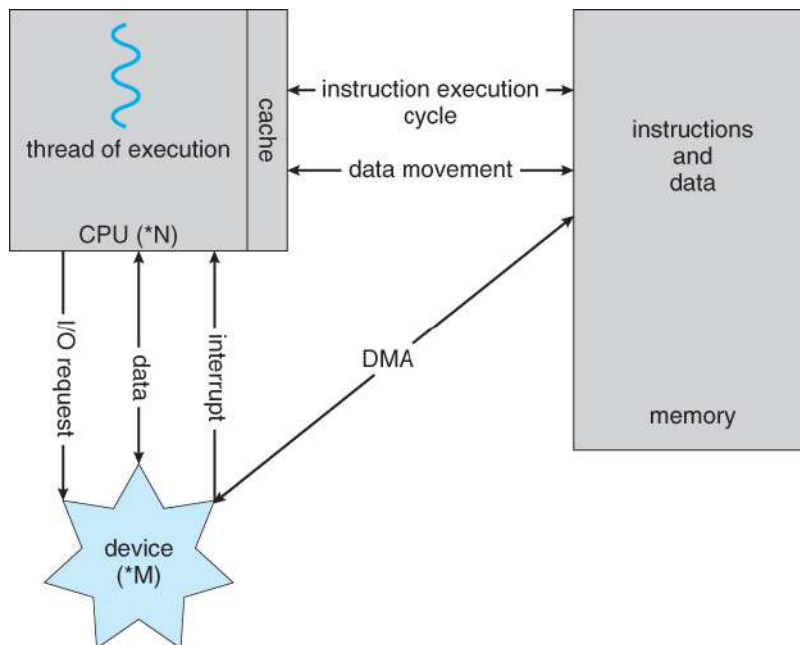
Many System Programs Running



Not Just Laptops/PCs...



Why Do We Care About All This?

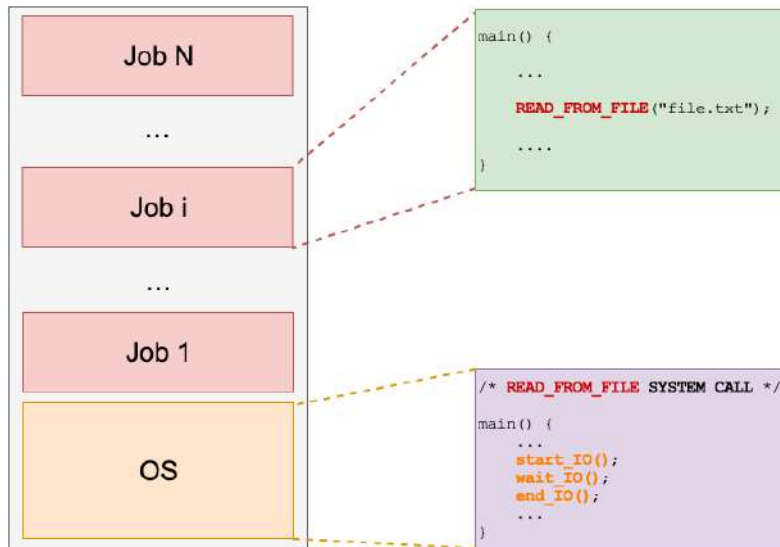


Any computerized system executes programs loaded in main memory

From time to time, computation must be suspended to perform I/O tasks

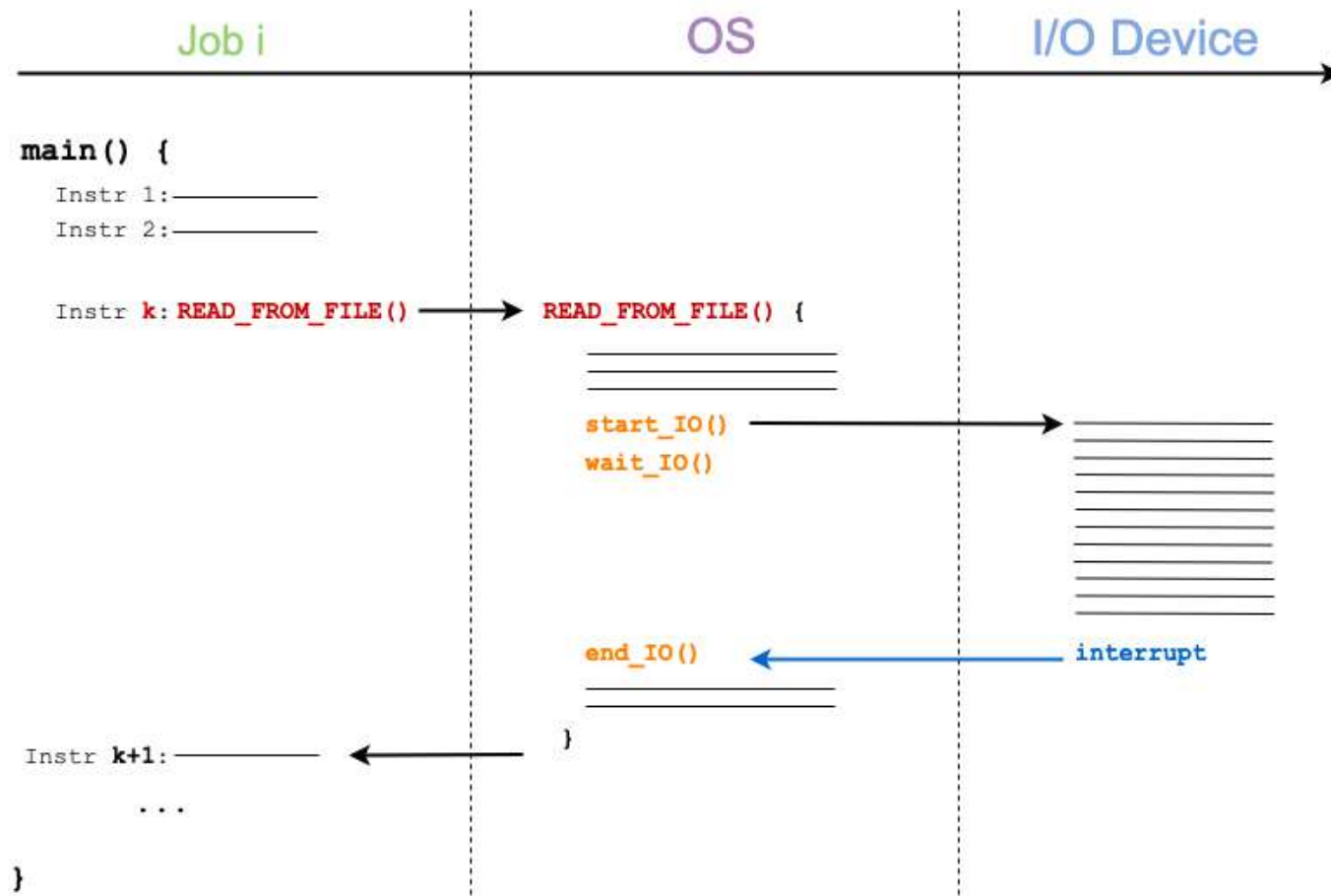
Modern systems keep several "programs" loaded into main memory
(**multiprogramming**)

Multiprogramming Systems (1960s)

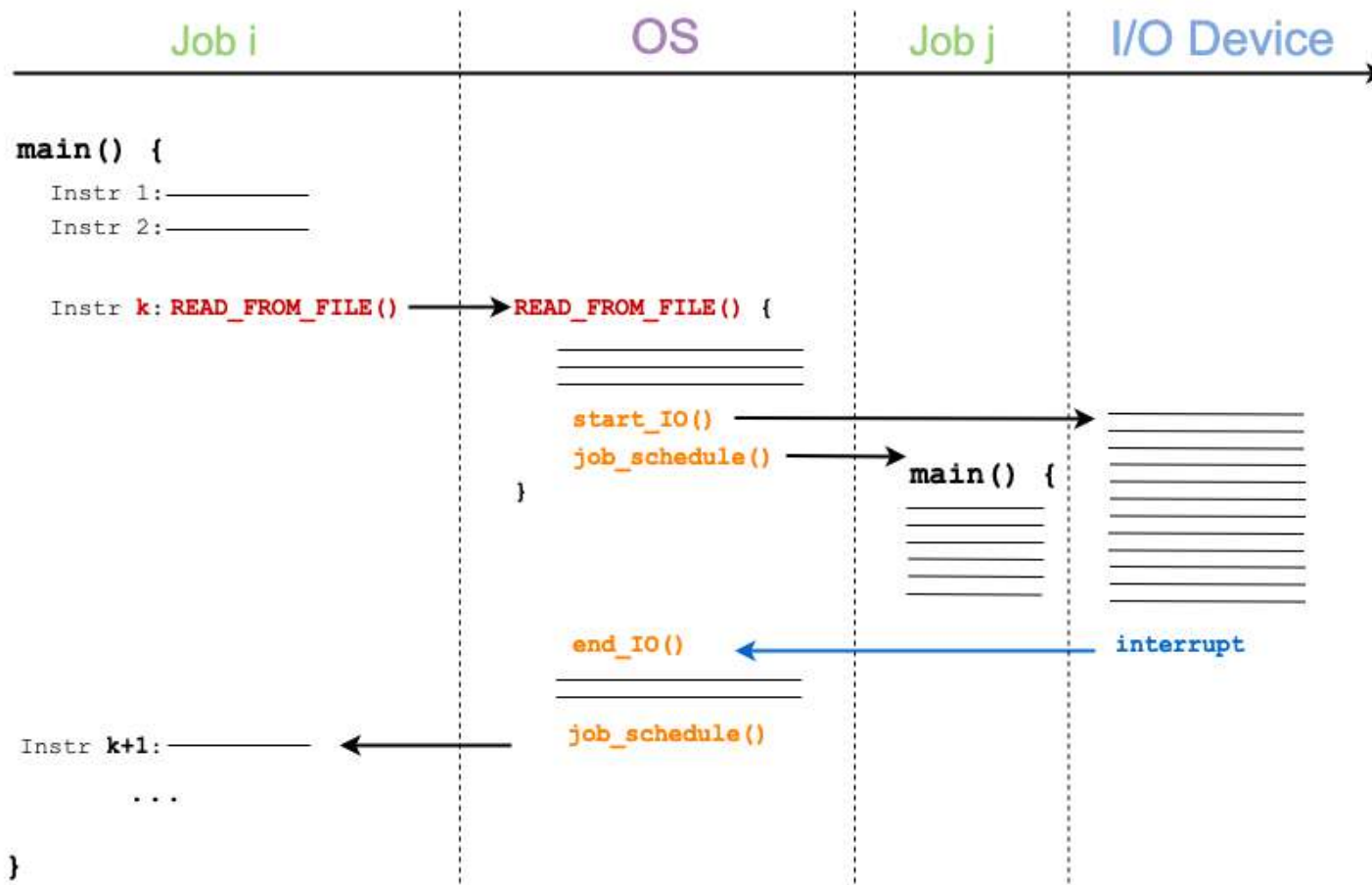


- Keep several jobs loaded in memory
- Multiplex CPU between jobs
- OS responsibilities:
 - job scheduling
 - memory protection
 - I/O operations
- **Problem:** CPU is left **idle** while **blocking** I/O operations take place

Blocking System I/O



Non-Blocking System I/O

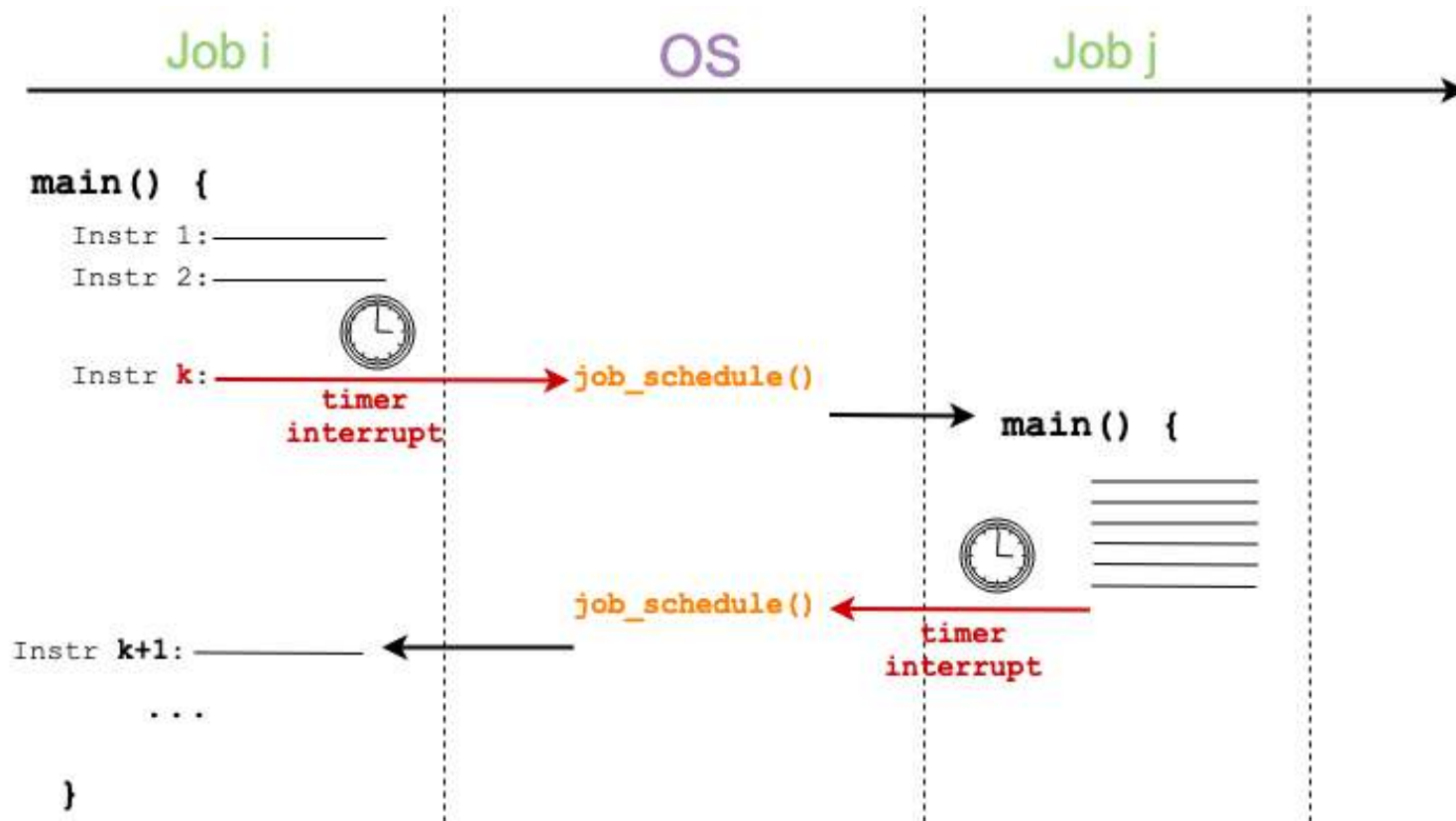


Time-sharing Systems (1970s)



- Many users connected to the same CPU via cheap consoles
- Timer interrupt used to multiplex CPU between jobs
- Illusion of parallelism (pseudo-parallelism)
- Ken Thompson & Dennis Ritchie → **UNIX OS**

Pseudo-parallelism



New Trends in OS Design

- Active field of research
 - OS demand is growing (many computing devices are available)
 - New application settings (Web, Cloud, mobile, cars, etc.)
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- Open-source OS (Linux)
 - Allows developers to contribute to OS development
 - Excellent research platform to experiment with

Why Study OSs?

- To learn important concepts of computer science
 - **Abstraction**
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 - Performance vs. Complexity of OS design
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 - **How computers work**

Large Computer Systems

- The world is increasingly dependent on computer systems
 - Large, complex, interconnected, distributed, etc.

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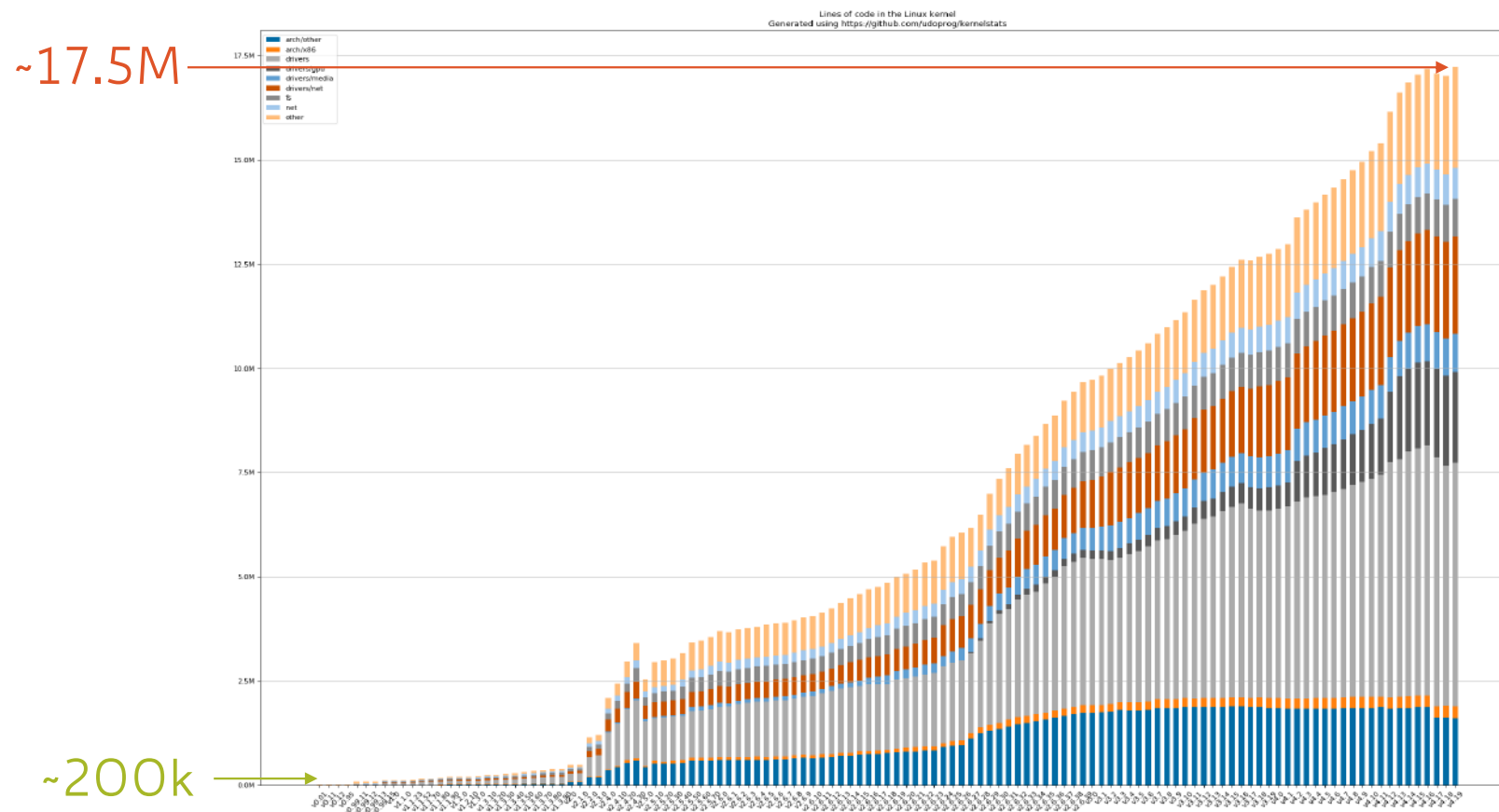
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- Huge demand for experts who deeply understand and can build such systems, which need to be:
 - Reliable, effective, efficient, secure, etc.

OS is a great example of a large computer system

Linux Kernel Size (Lines of Code)



OS as Large Computer System

- Designing large computer systems requires you to know
 - **Each computer:**
 - Architectural details
 - High-level programming language (mostly, C/C++)
 - Memory management
 - Concurrency and scheduling
 - File system and I/O

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 - **Across clusters of computers:**
 - Server architectures
 - Distributed file systems and computing frameworks

OS Design Issues (1)

- **Structure** → How the whole system is organized
- **Concurrency** → How parallel tasks are managed
- **Sharing** → How resources are shared
- **Naming** → How resources are identified by users
- **Protection** → How critical tasks are protected from each other
- **Security** → How to authenticate, authorize, and ensure privacy
- **Performance** → How to make it more efficient (quick, compact)

OS Design Issues (2)

- **Reliability** → How to deal with failures
- **Portability** → How to write once and run anywhere
- **Extensibility** → How to add new features/capabilities
- **Communication** → How to exchange information
- **Scalability** → How to scale up as demand increases
- **Persistency** → How to save task's status
- **Accounting** → How to claim on control resource usage

Architectural Trends: CPU

*Million Instructions Per Second

**1 MHz = 1,000,000 clock cycles per second

	1971 (Intel 4004)	Today (Intel Core i9)	Δ (orders of magnitude)
MIPS*	~0.09	~400,000+	+7
Instructions (fetch, decode, execute) per clock cycle	~0.12	~100+	+3
Clock frequency (MHz)**	0.74	~5,000	+4
Cheap size (μm)	10	0.014	-3

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Moore's law: the number of transistors in a dense integrated circuit doubles about every two years

Architectural Trends: Main Memory

	1973 (DEC PDP-8)	Today (Samsung DDR4)	Δ (orders of magnitude)
Capacity (kB)	12	128,000,000	+7
Cost (\$/MB)	~400,000	~0.005	-8

Architectural Trends: Disk

	1956 (IBM RAMAC 305)	Today (Western Digital)	Δ (orders of magnitude)
Capacity (MB)	5	15,000,000	+7
Size (inch)	24 (x50)	3.5	-3
Cost (\$/MB)	640 (per month)	~0.000018	-9

What's Next?

- Moore's law has hit its limit(?)
 - chip size has physical constraints
 - power vs. heat tradeoff
 - alternatives have already pushed forward the end of it:
 - multicore-manycore processors
 - other approaches are subject of research:
 - molecular/DNA transistors
 - quantum computing

Summary

- Basic roles of an Operating System

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- A brief recap of how computer systems are organized

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- Basic roles of an Operating System
- A brief recap of how computer systems are organized
- Operating Systems as large and complex computer systems
- New architectural trends open up novel opportunities and challenges in Operating System design