Sistemi Operativi I

Corso di Laurea in Informatica
2025-2026

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SAPIENZA
UNIVERSITÀ DI ROMA

Useful Information

<u>Class schedule</u>

- **Tuesday:** 1 PM – 4 PM

- **Thursday:** 1 PM – 3 PM

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Contacts

- email: tolomei@di.uniroma1.it
- website: https://github.com/gtolomei/operating-systems
- moodle: https://elearning.uniroma1.it/course/view.php?id=20049

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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 <= 14/30 → FAIL
    - 15/30 <= score <= 17/30 → ORAL REQUIRED
    - score >= 18/30 → PASS (oral upon request by the student)

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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 III: Process Synchronization**

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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!

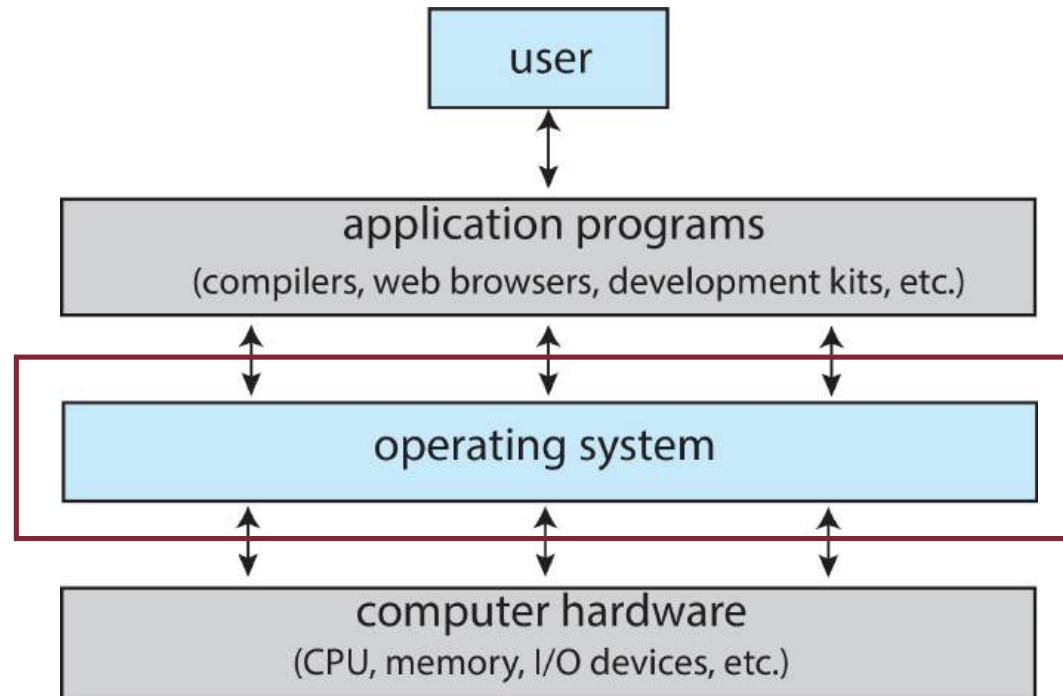# What is an Operating System?

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- There exists no universally accepted definition!
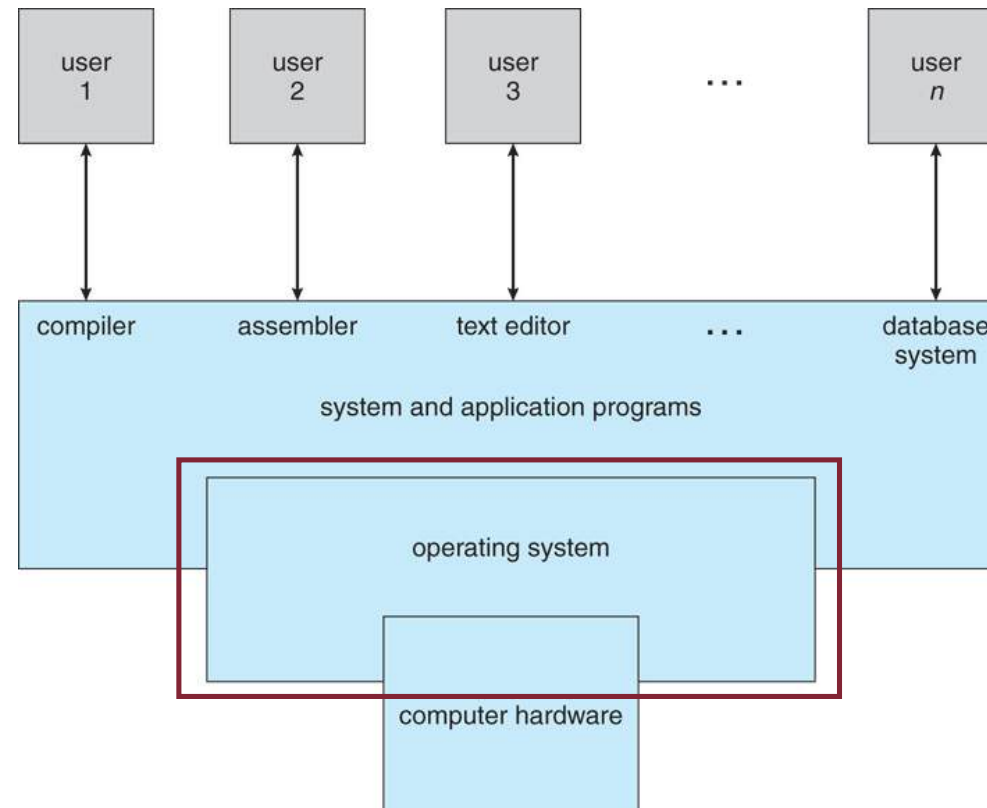
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- However, the definition below is quite appropriate:

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

Computer System Overview

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- 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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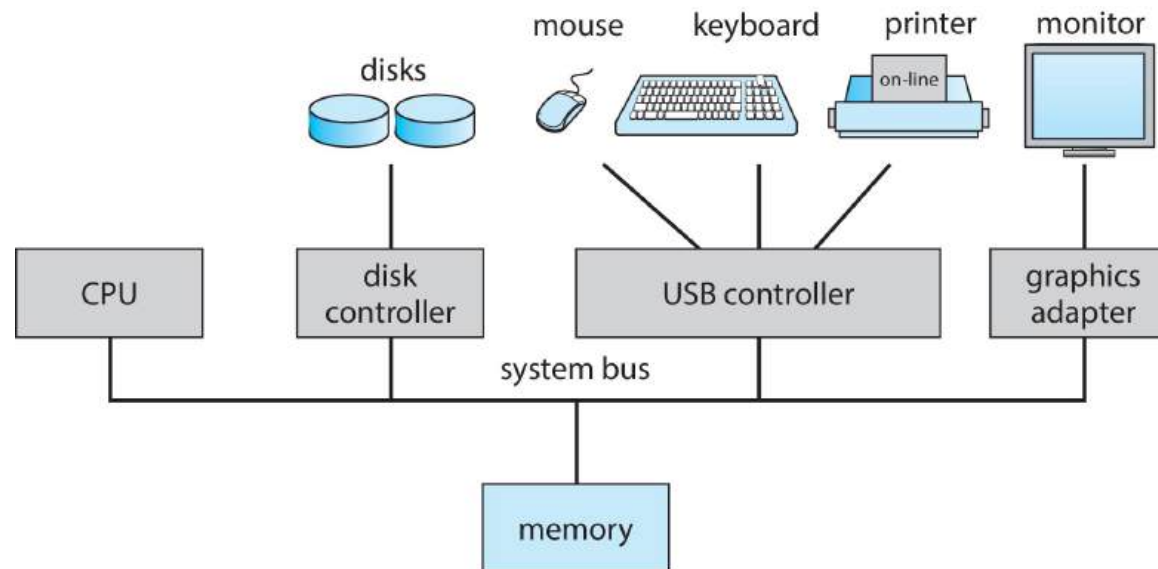
- Glue (HW/SW Interface)

  - 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
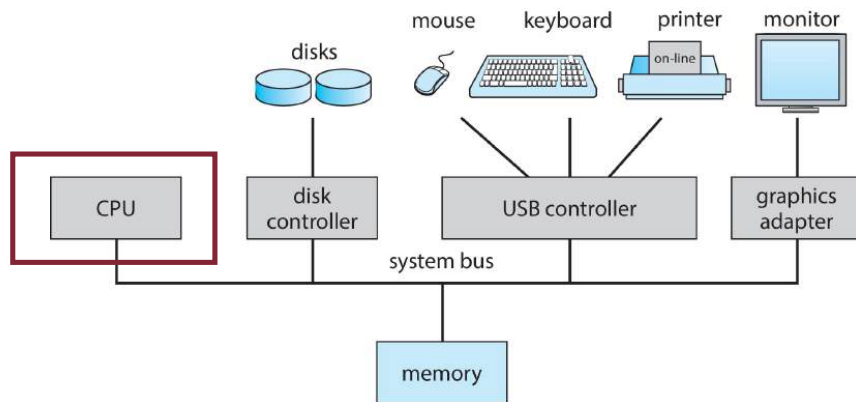
Computer System Organization
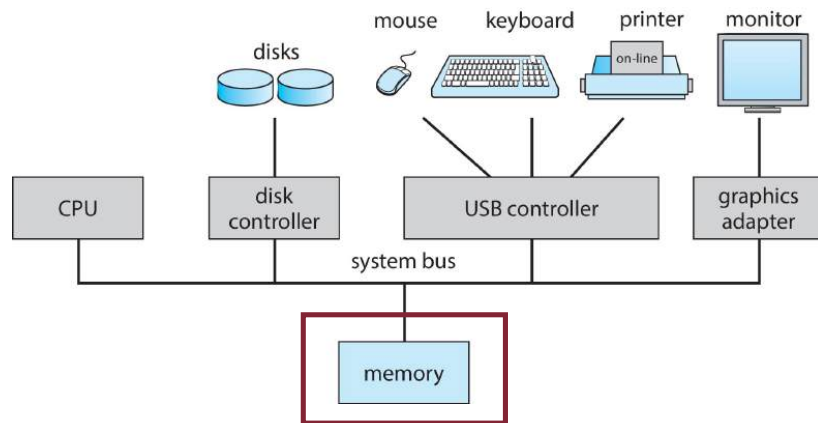
High-Level View of a Computer

High-Level View of a Computer

CPU

- The processor that performs the actual computation

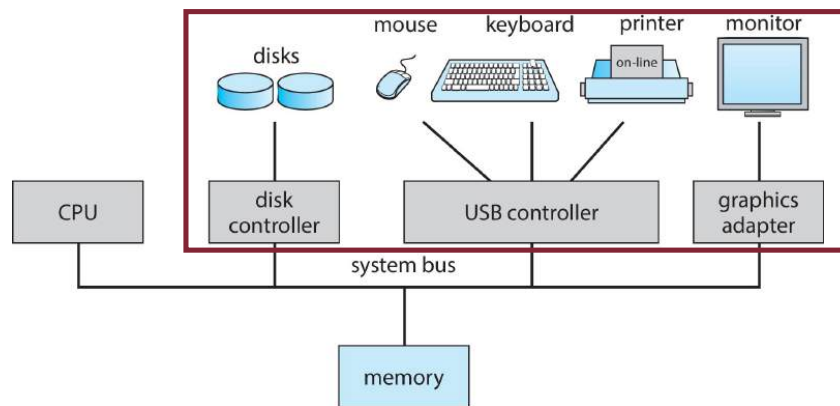- Multiple cores are now common in modern architectures

High-Level View of a Computer

Main Memory

- Stores data and instructions used by the CPU

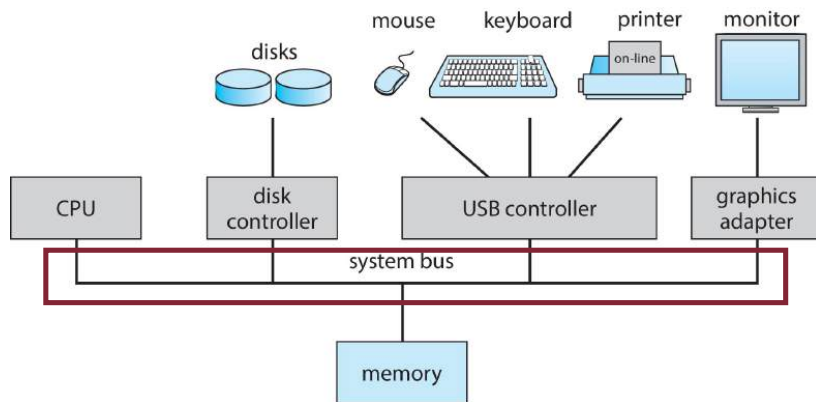- Shared between CPU and I/O

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
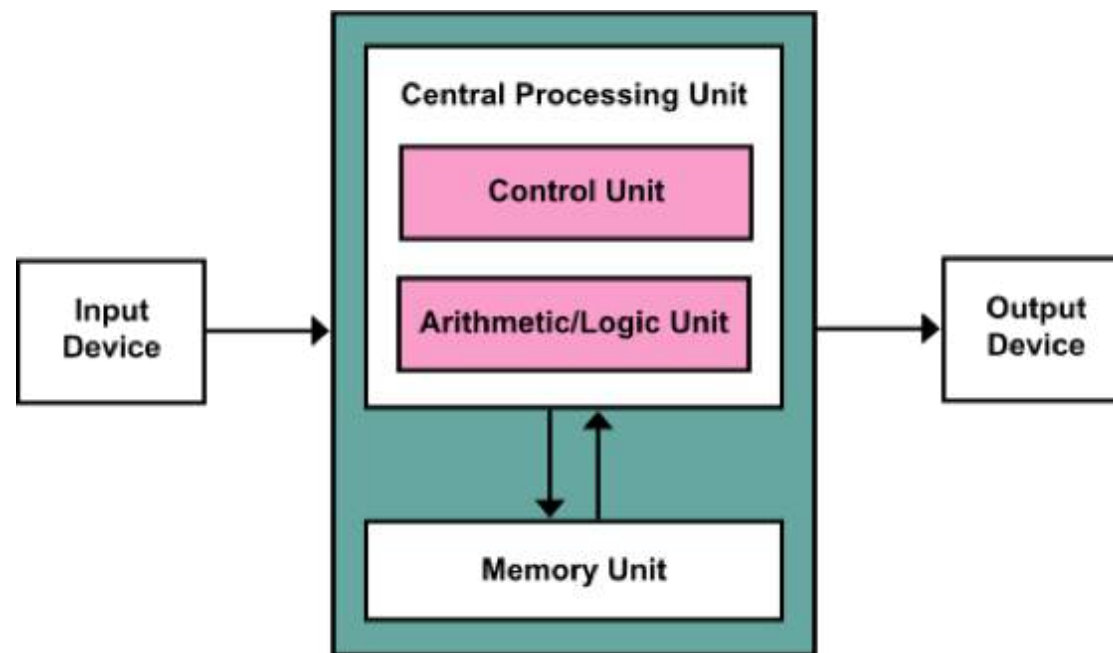 - etc.

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

John von Neumann

von Neumann Architecture

von Neumann Architecture

Executes instructions (i.e., basic arithmetical/logical computations) sequentially, using internal registers
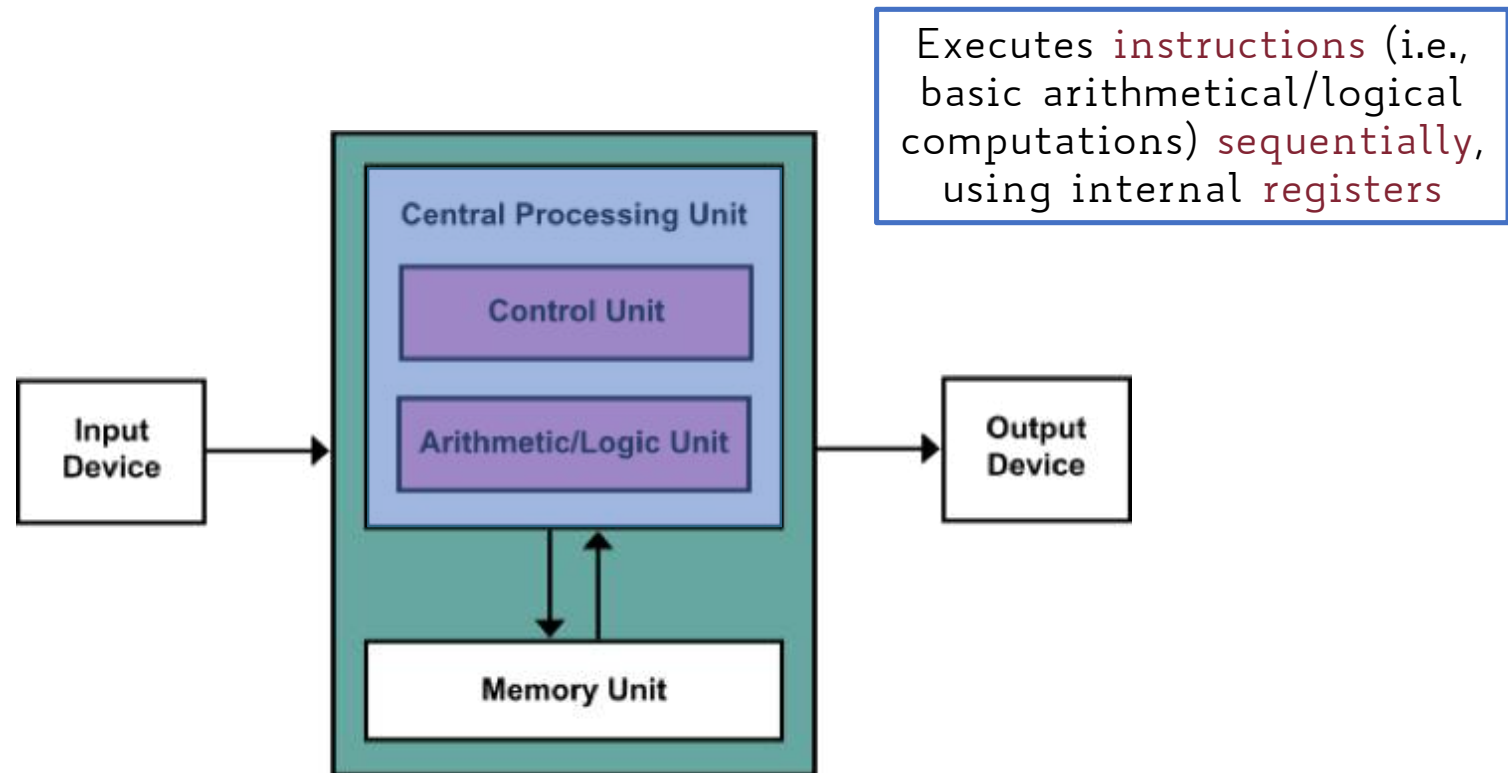
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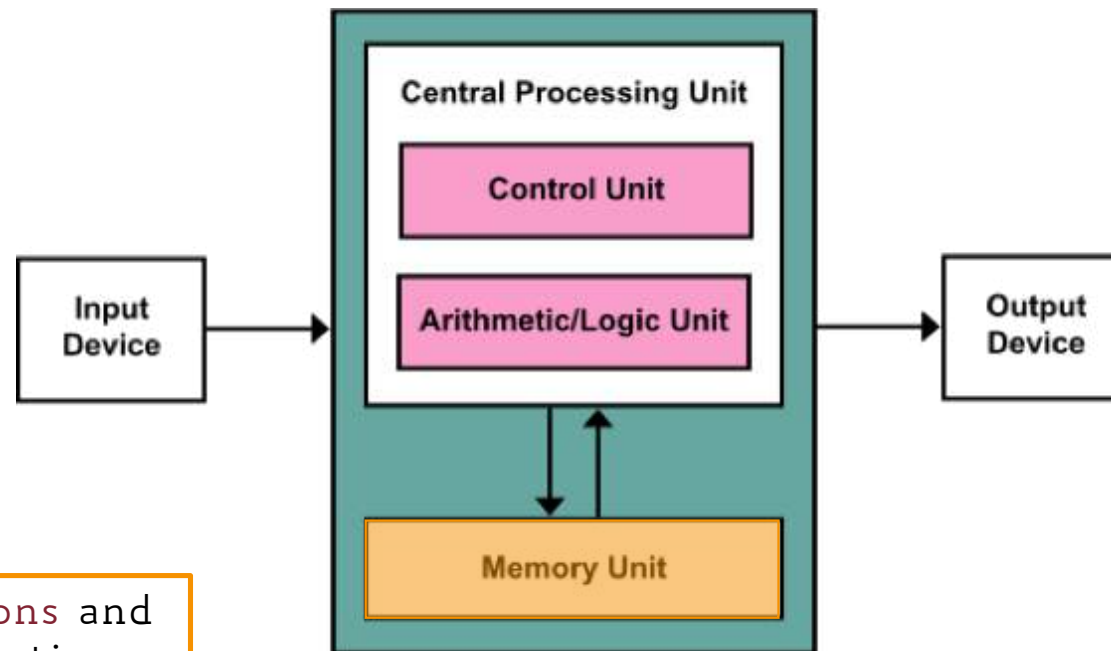
Contains instructions and data (which instructions operate on)

Central Processing Unit (CPU)

Instruction Cycle

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  DECODE

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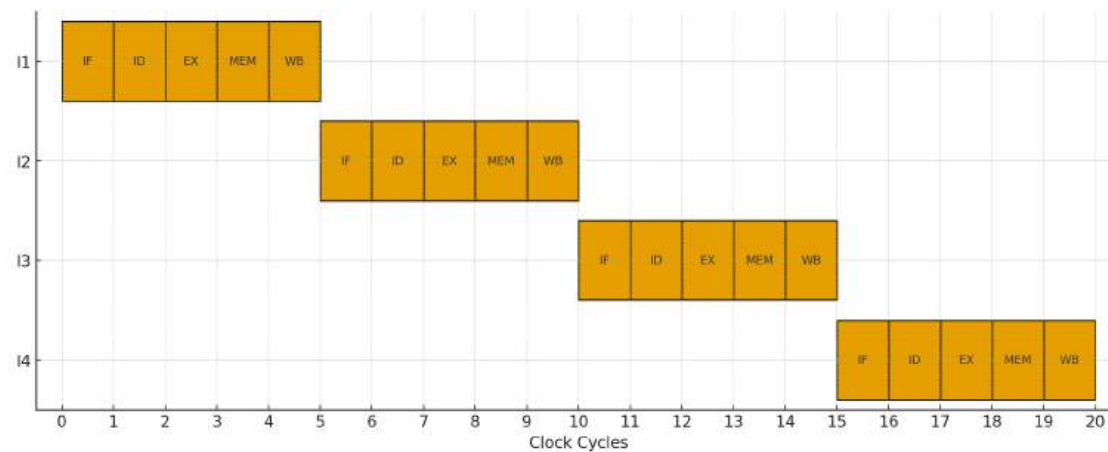
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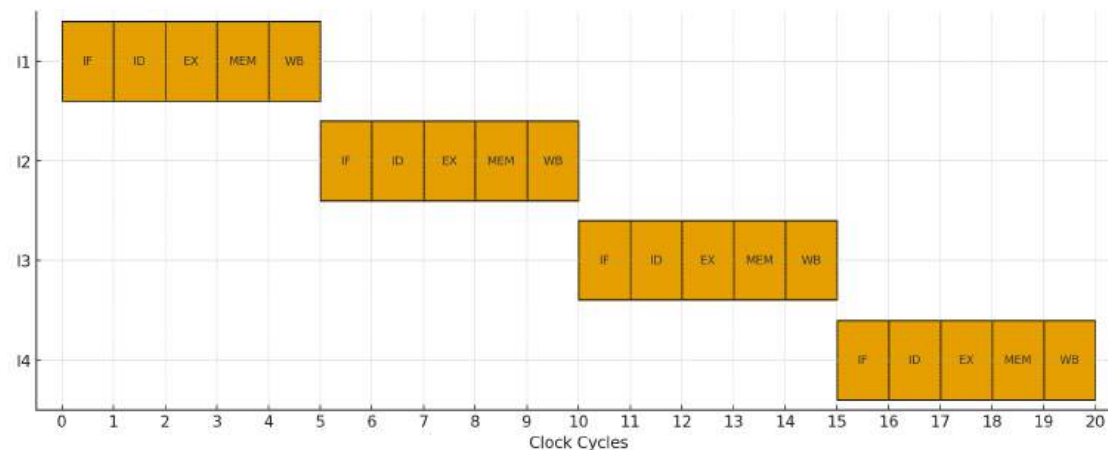4 instructions: I1,… I4
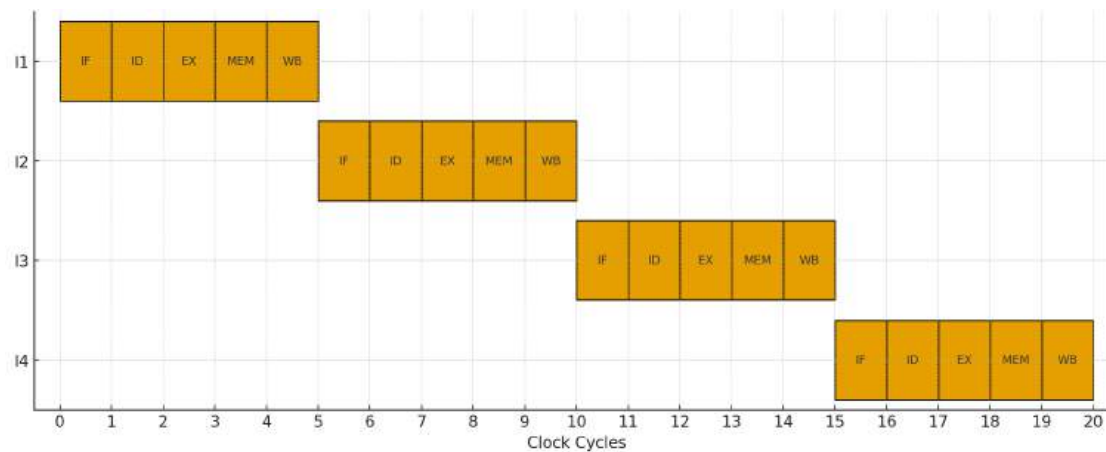
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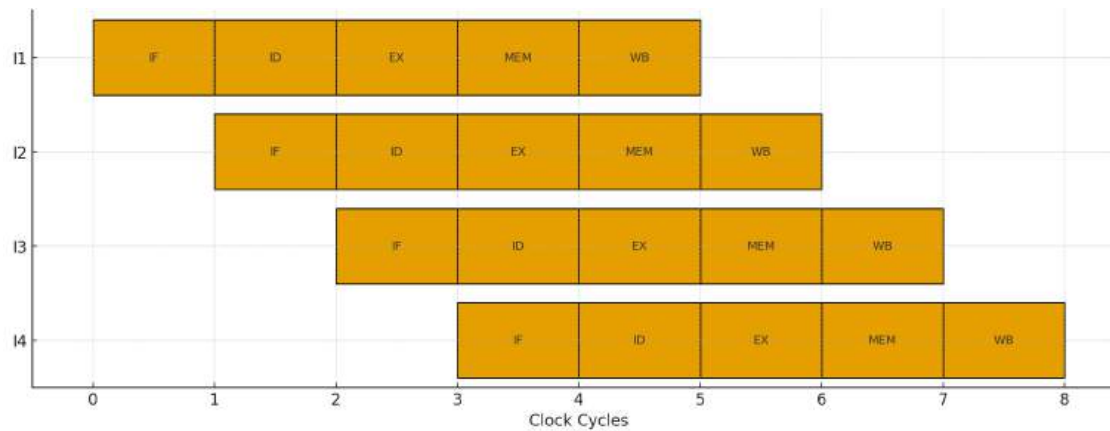
Assumption:
Each stage takes one clock cycle
(may not always be the case!)

5 Cycles per Instruction (CPI)

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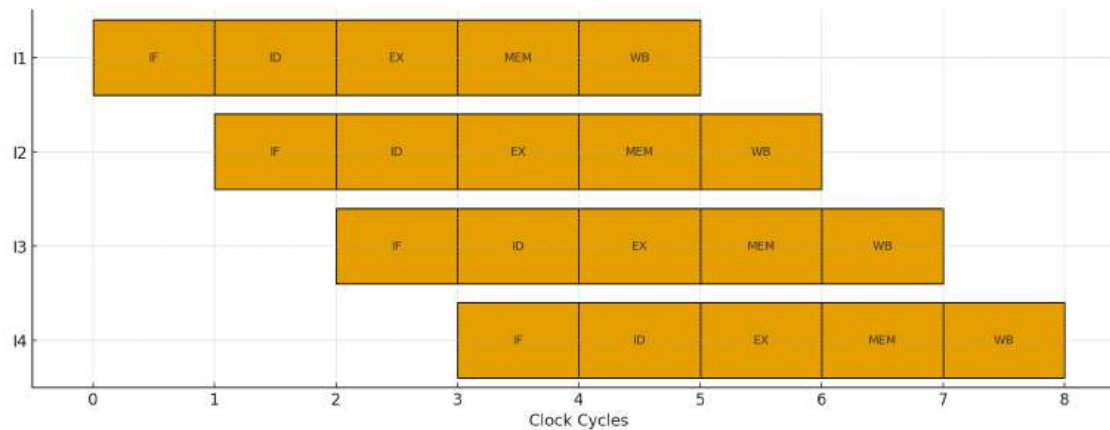
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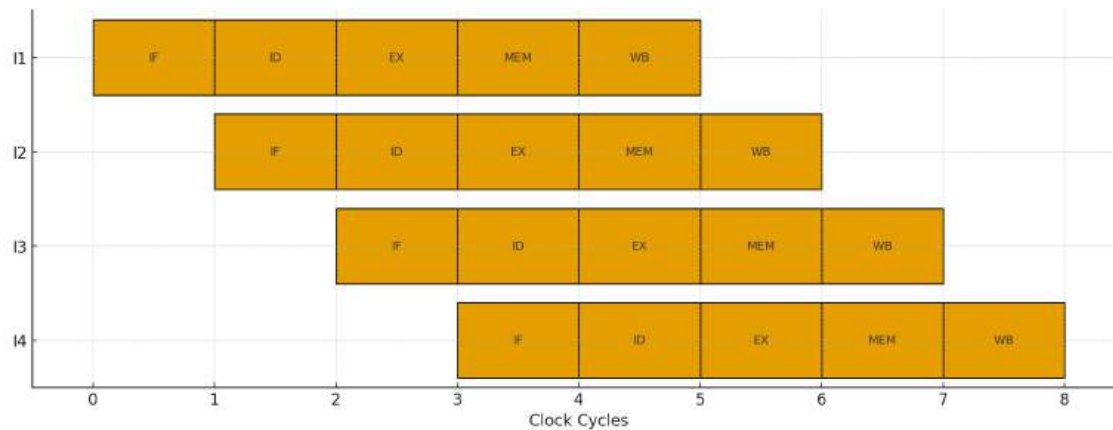(may not always be the case!)

**1 Cycle per Instruction (CPI)
on average**

Instruction Cycle: Pipelined (v.2)
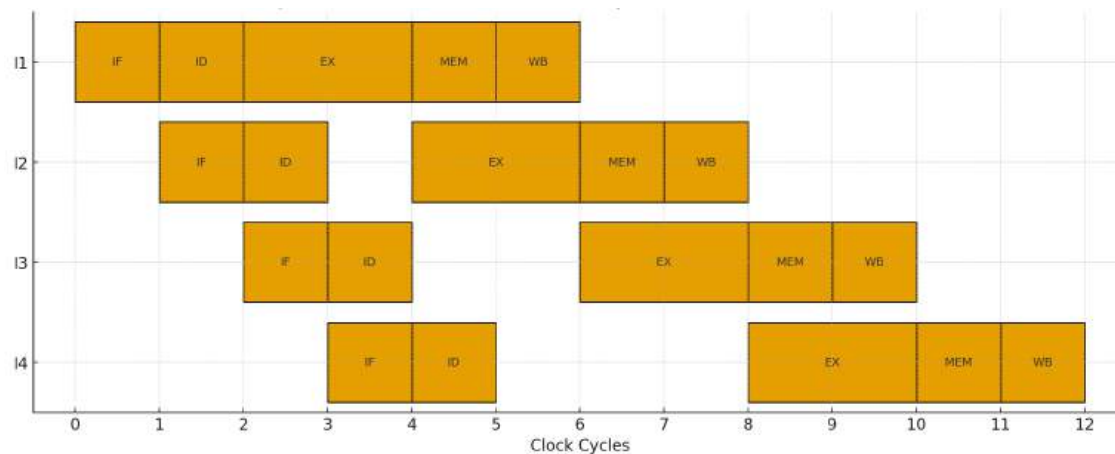
4 instructions: I1,… I4

Each stage runs **in parallel** whenever possible or **wait**

Each stage may take more than one clock cycle
(e.g., EX takes two!)

2 Cycles per Instruction (CPI)
on average

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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	–

Instruction Set (Architecture)

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

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- General-purpose (x86):
  - `eax`, `ebx`, `ecx`, etc.

- 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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- Higher resiliency to failures

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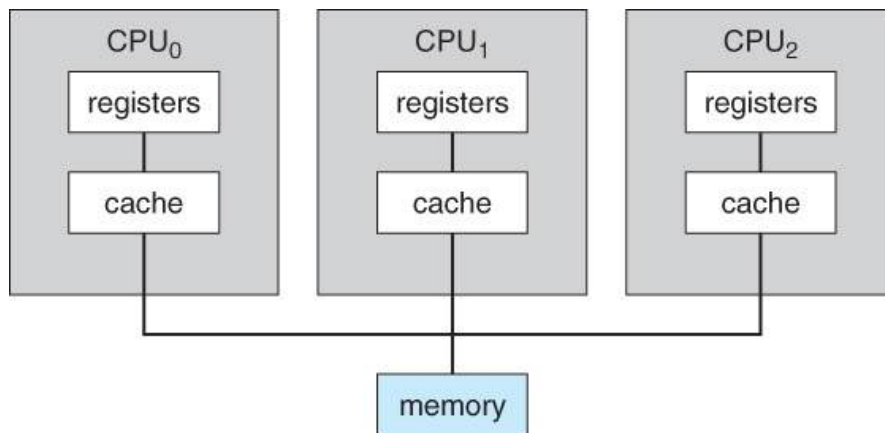
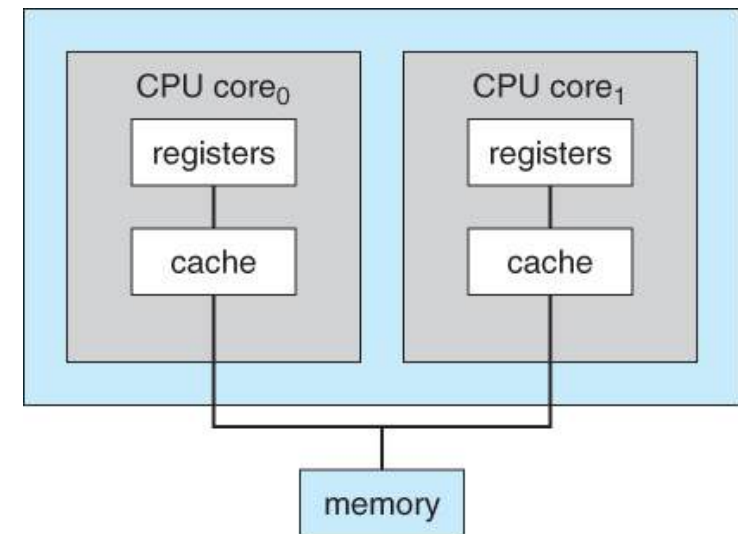**Our main focus!**

Multi-Processor Systems

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Multi-Processor Systems: Examples

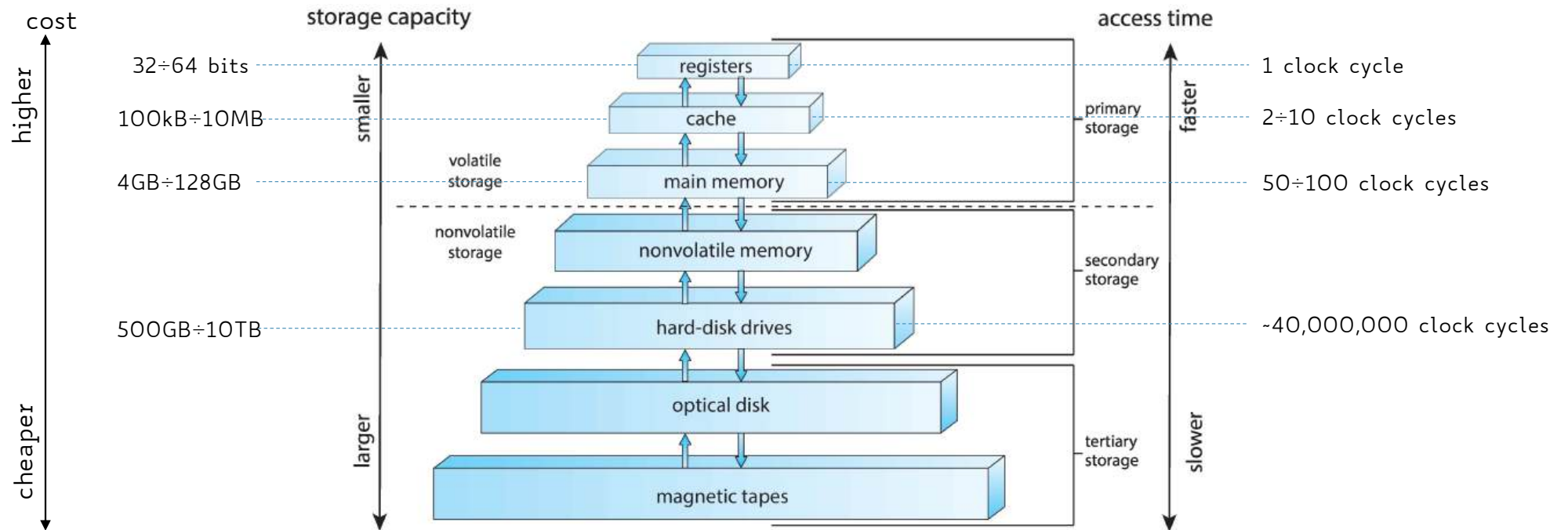## Symmetric Multiprocessing Architecture

Multicore Architecture

Memory

Memory Hierarchy

Memory Hierarchy

managed by the architecture

cost

higher

cheaper

storage capacity

32÷64 bits

100kB÷10MB

4GB÷128GB

500GB÷10TB

smaller

larger

volatile storage

nonvolatile storage

registers

cache

main memory

nonvolatile memory

hard-disk drives

optical disk

magnetic tapes

access time

primary storage

secondary storage

tertiary storage

faster

slower

1 clock cycle

2÷10 clock cycles

50÷100 clock cycles

~40,000,000 clock cycles

Memory Hierarchy

managed by the architecture

	storage capacity		access time
cost			
higher	32÷64 bits	registers	1 clock cycle
	100kB÷10MB	cache · primary storage	2÷10 clock cycles
	4GB÷128GB · volatile storage	main memory	50÷100 clock cycles
	nonvolatile storage	nonvolatile memory · secondary storage	
	500GB÷10TB	hard-disk drives	~40,000,000 clock cycles
		optical disk · tertiary storage	
cheaper		magnetic tapes	

managed by the OS

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- The smallest addressable unit is usually 1 byte

Memory Cell (1)

Cell/Location
8 bits = 1 byte

...

Memory Cell (2)

Cell/Location   32 bits = 4 bytes

...
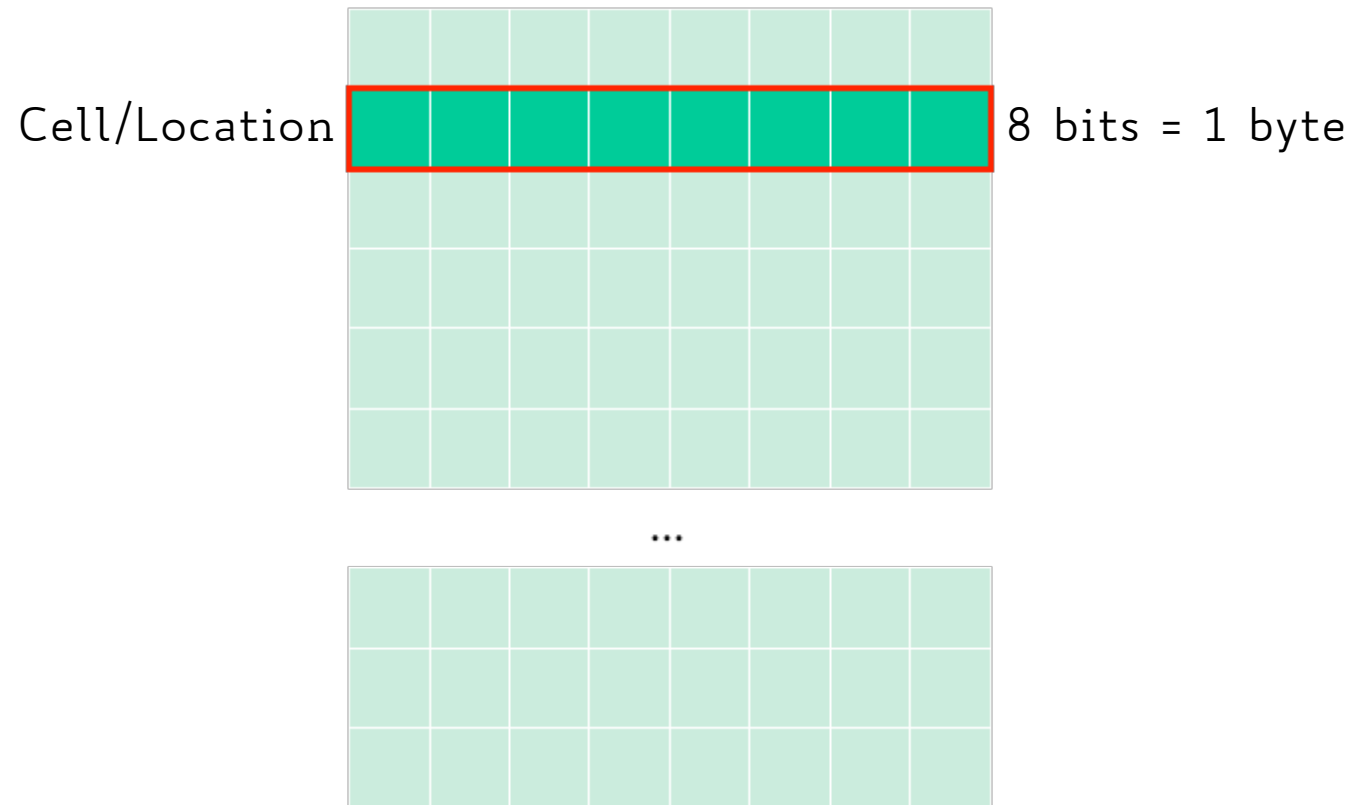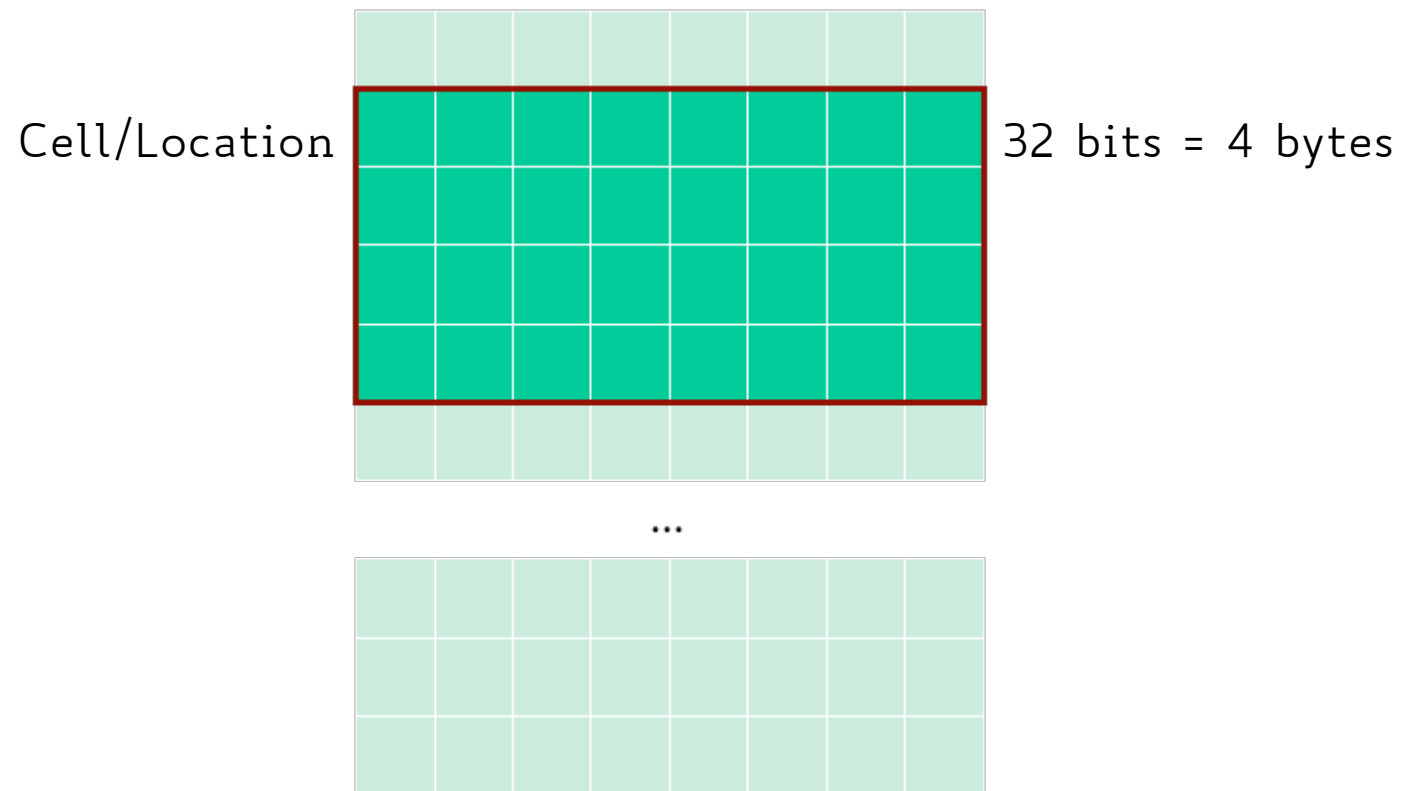
Memory Address (Single Byte)

Computer Buses

System Bus

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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
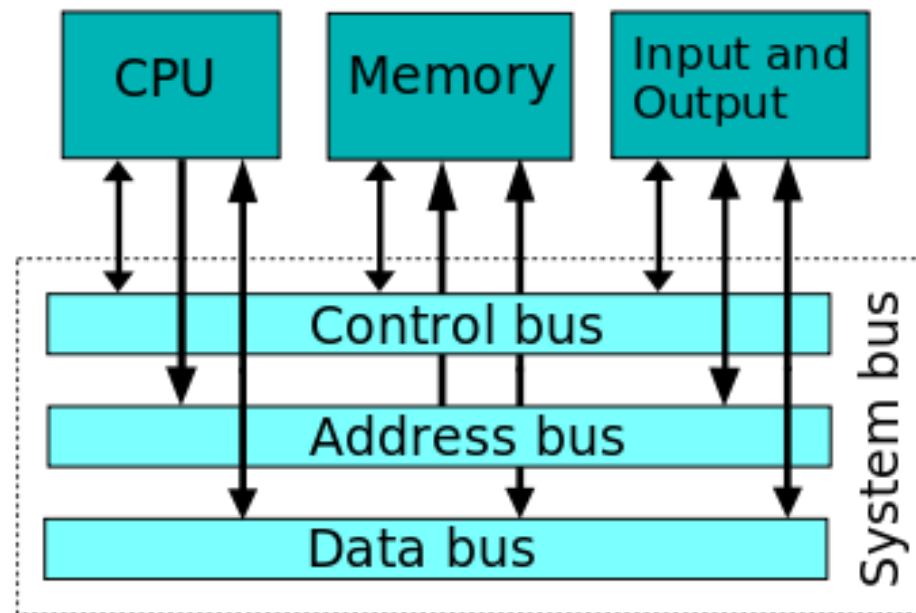
I/O Devices

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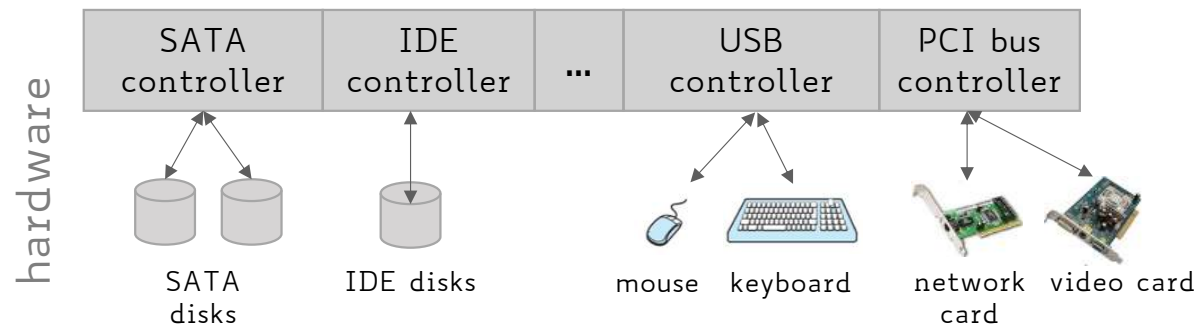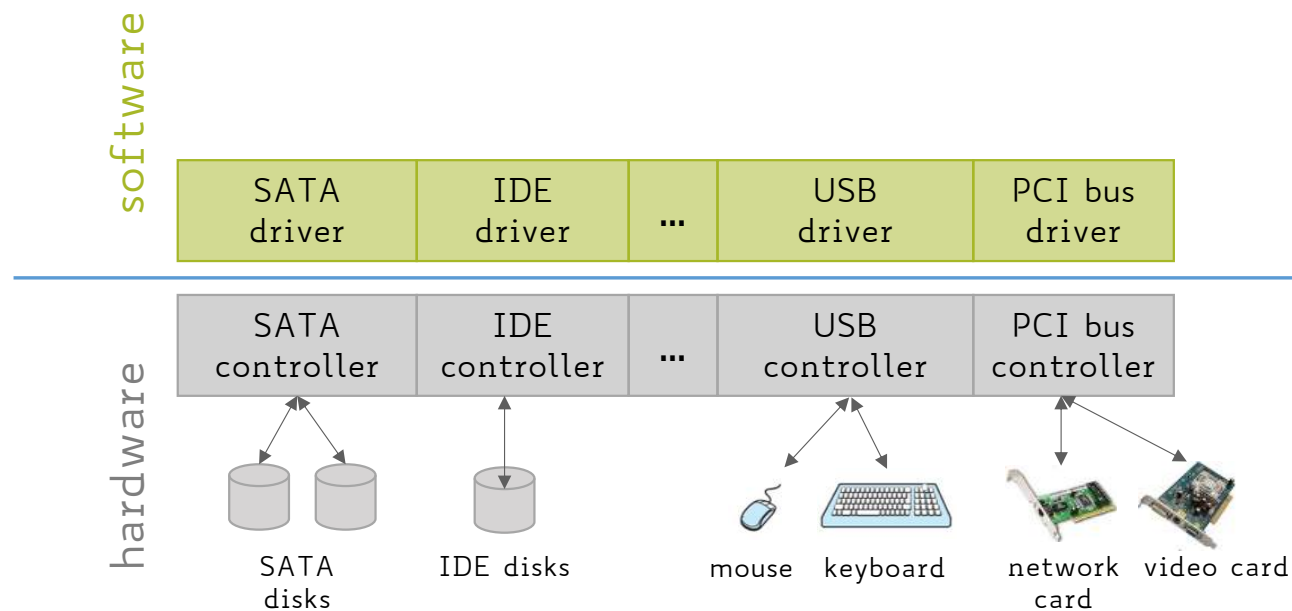 - storage, communications, user-interface, etc.

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- OS talks to a device controller using a specific **device driver**
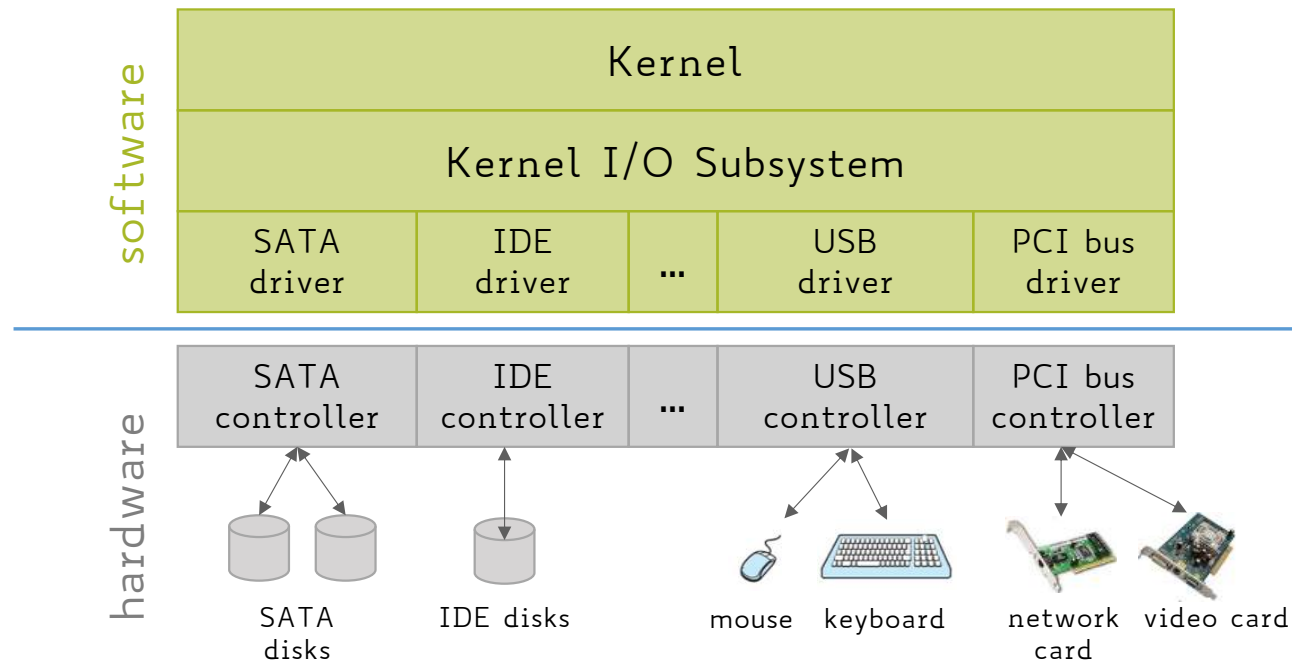
Device Drivers: OS Abstraction

	SATA controller	IDE controller	...	USB controller	PCI bus controller

hardware

SATA disks

IDE disks

mouse   keyboard

network card   video card

Device Drivers: OS Abstraction

software

SATA driver	IDE driver	...	USB driver	PCI bus driver

hardware

SATA controller	IDE controller	...	USB controller	PCI bus controller

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Device Drivers: OS Abstraction

software

Kernel				
Kernel I/O Subsystem				
SATA driver	IDE driver	...	USB driver	PCI bus driver

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SATA controller	IDE controller	...	USB controller	PCI bus controller

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IDE disks

mouse keyboard

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Device Controllers

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  - **Status registers** → provide status information to the CPU about the I/O device (e.g., idle, ready for input, busy, error, transaction complete)

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  - Status registers → provide status information to the CPU about the I/O device (e.g., idle, ready for input, busy, error, transaction complete)

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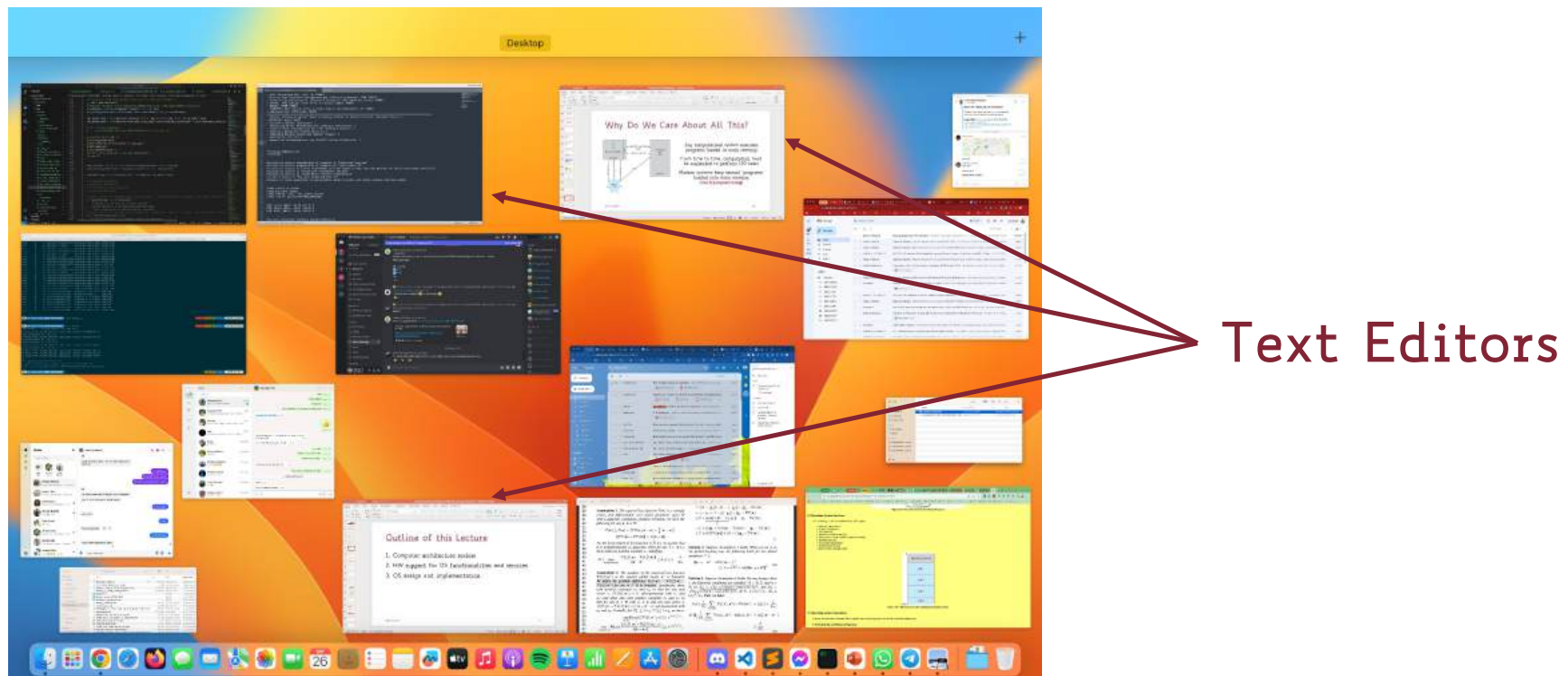 - Data registers → used to read data from or send data to the I/O device
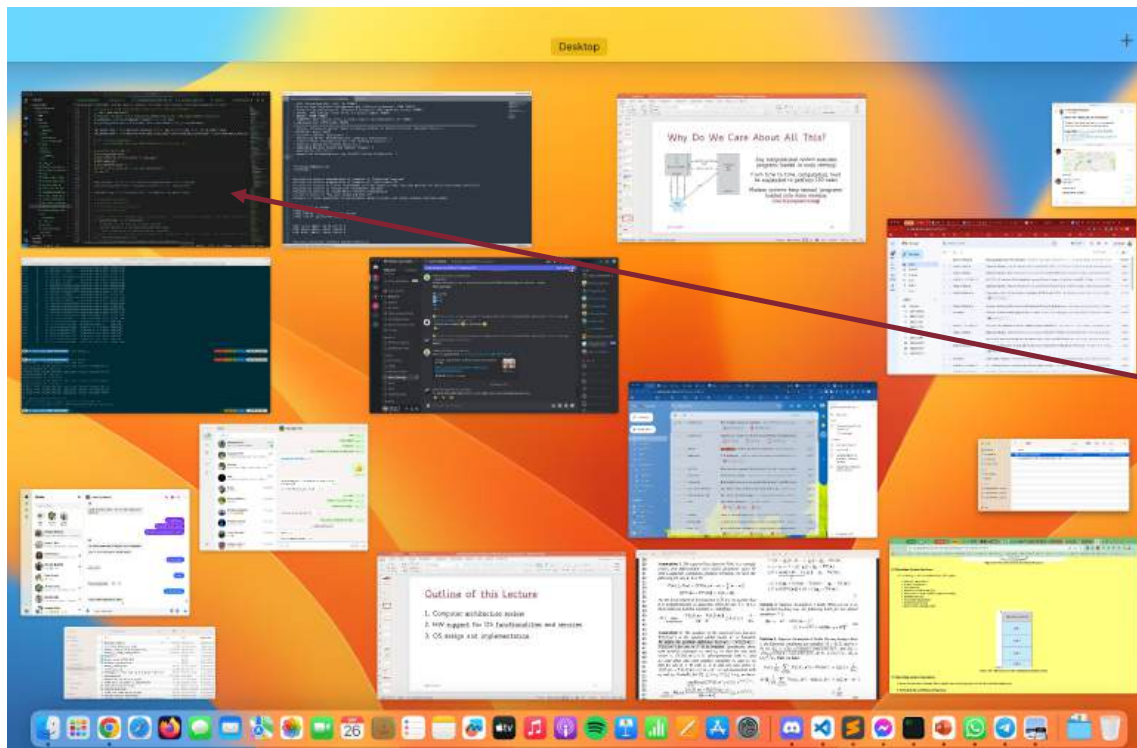
Modern Computer Systems

Many User Applications Running

Web Browsers

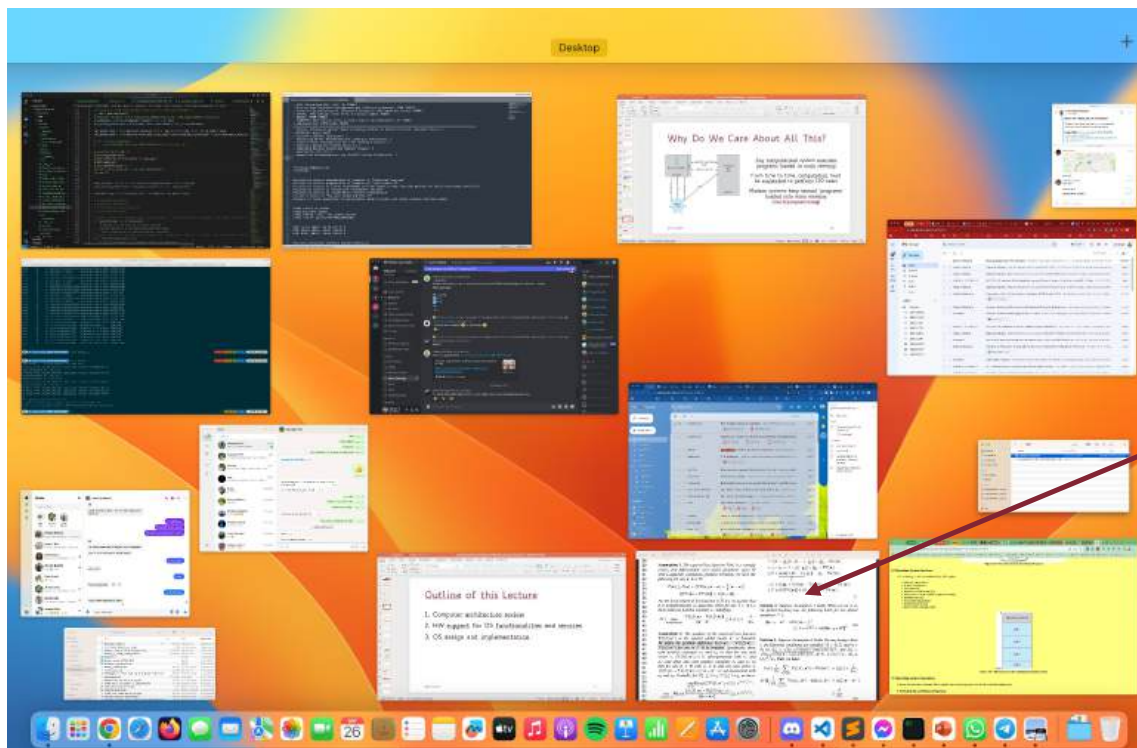# Many User Applications Running
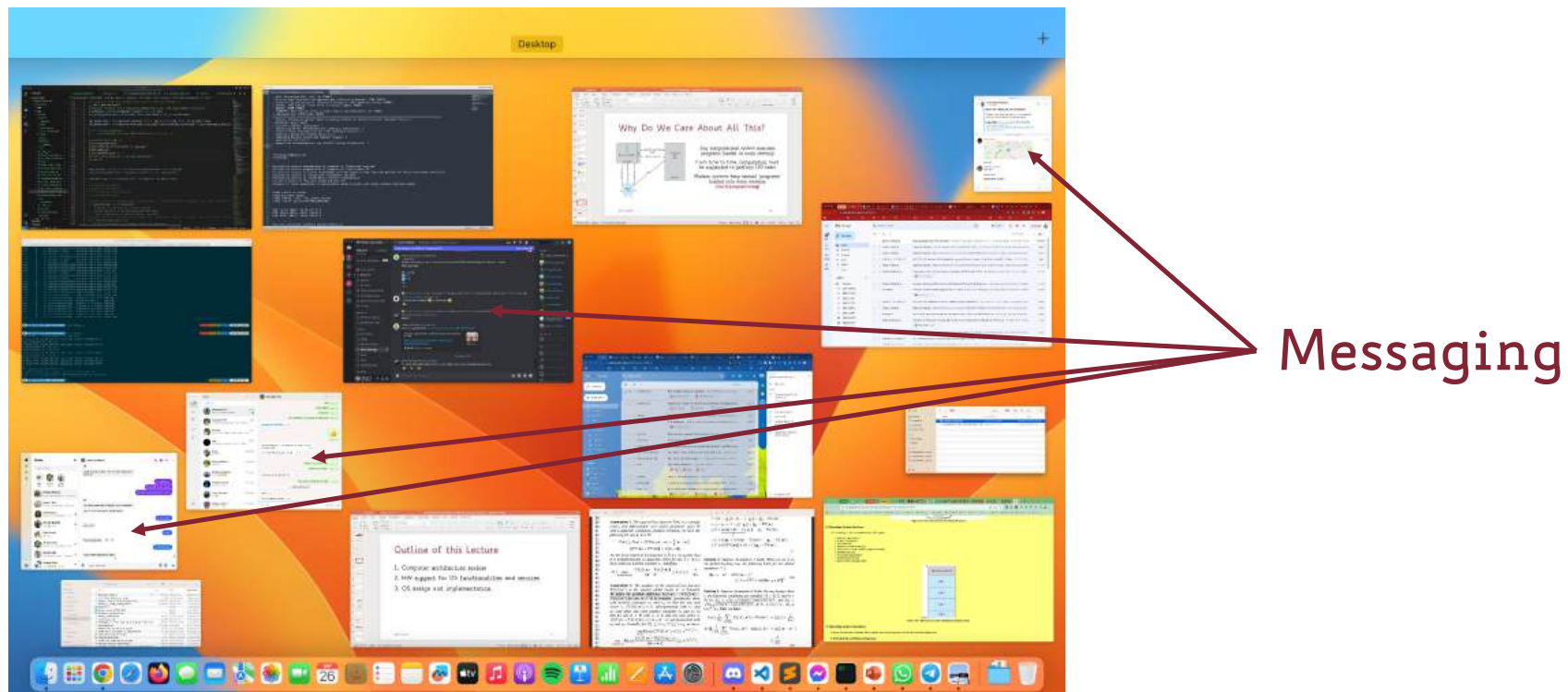

Text Editors
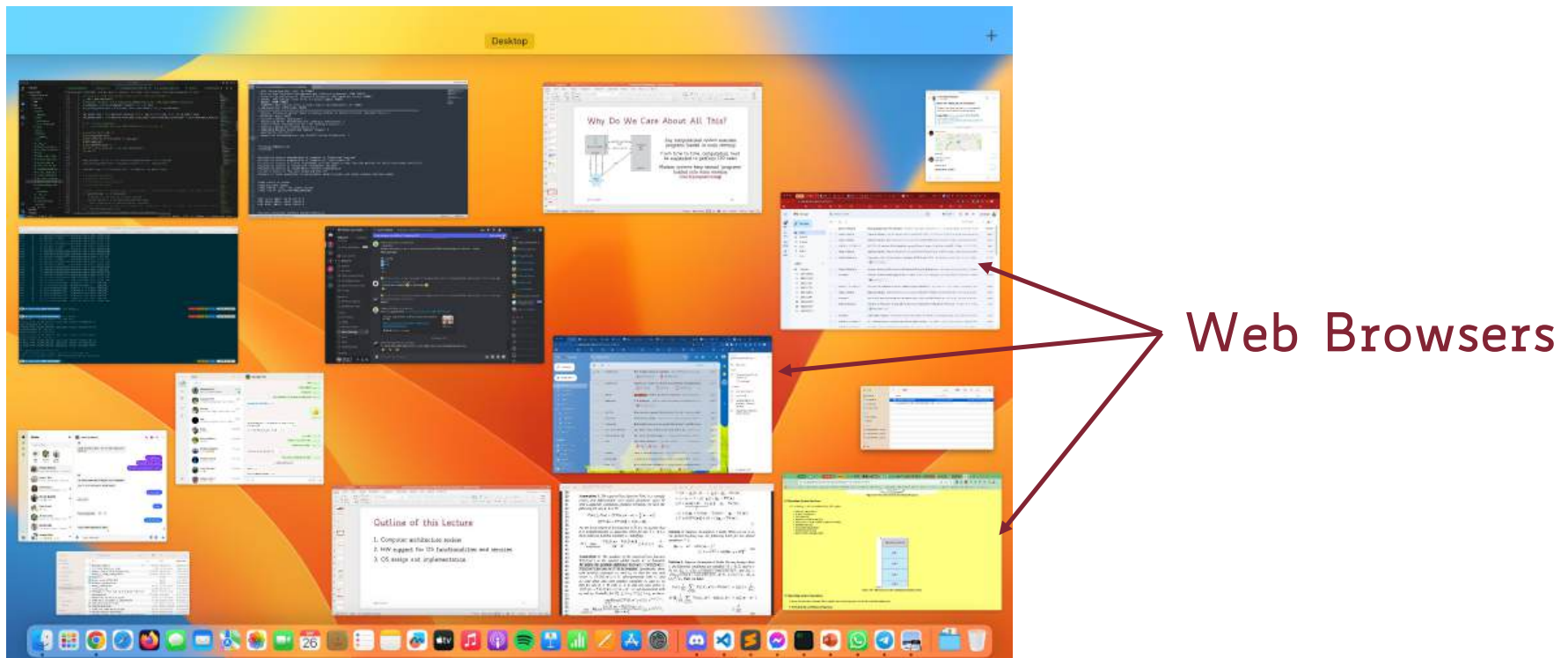
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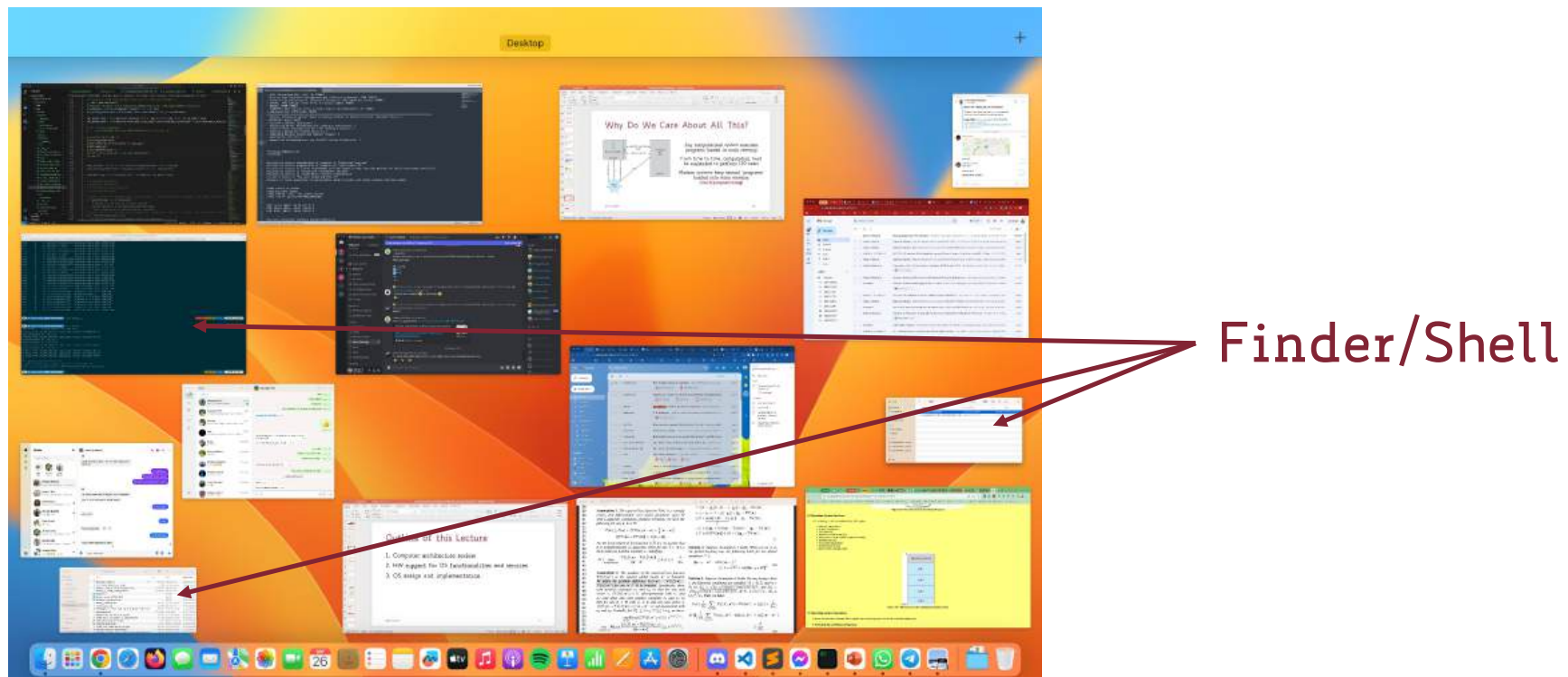

IDE
(code development)

Many User Applications Running

PDF Viewer

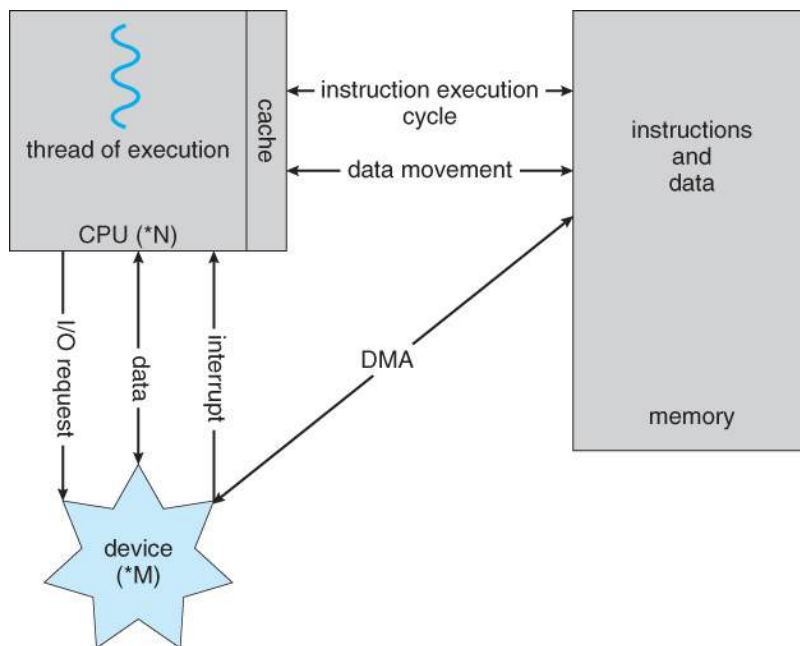# Many User Applications Running

Messaging

Many System Programs Running

Finder/Shell

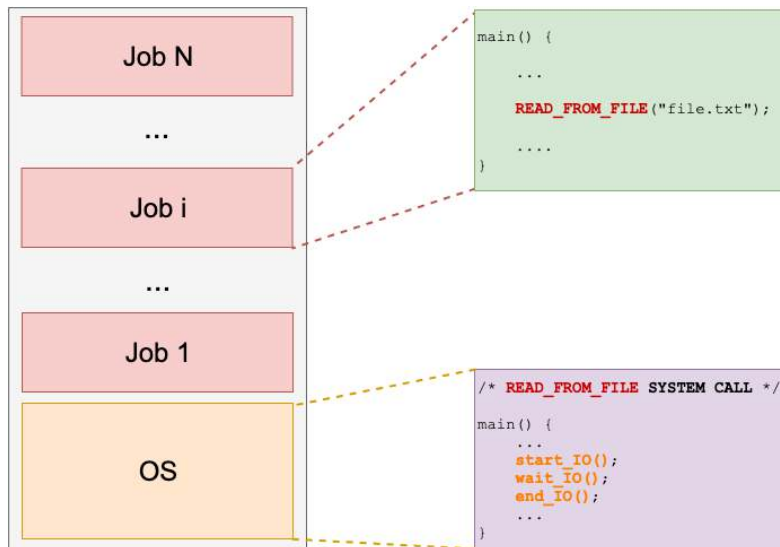# Not Just Laptops/PCs...

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
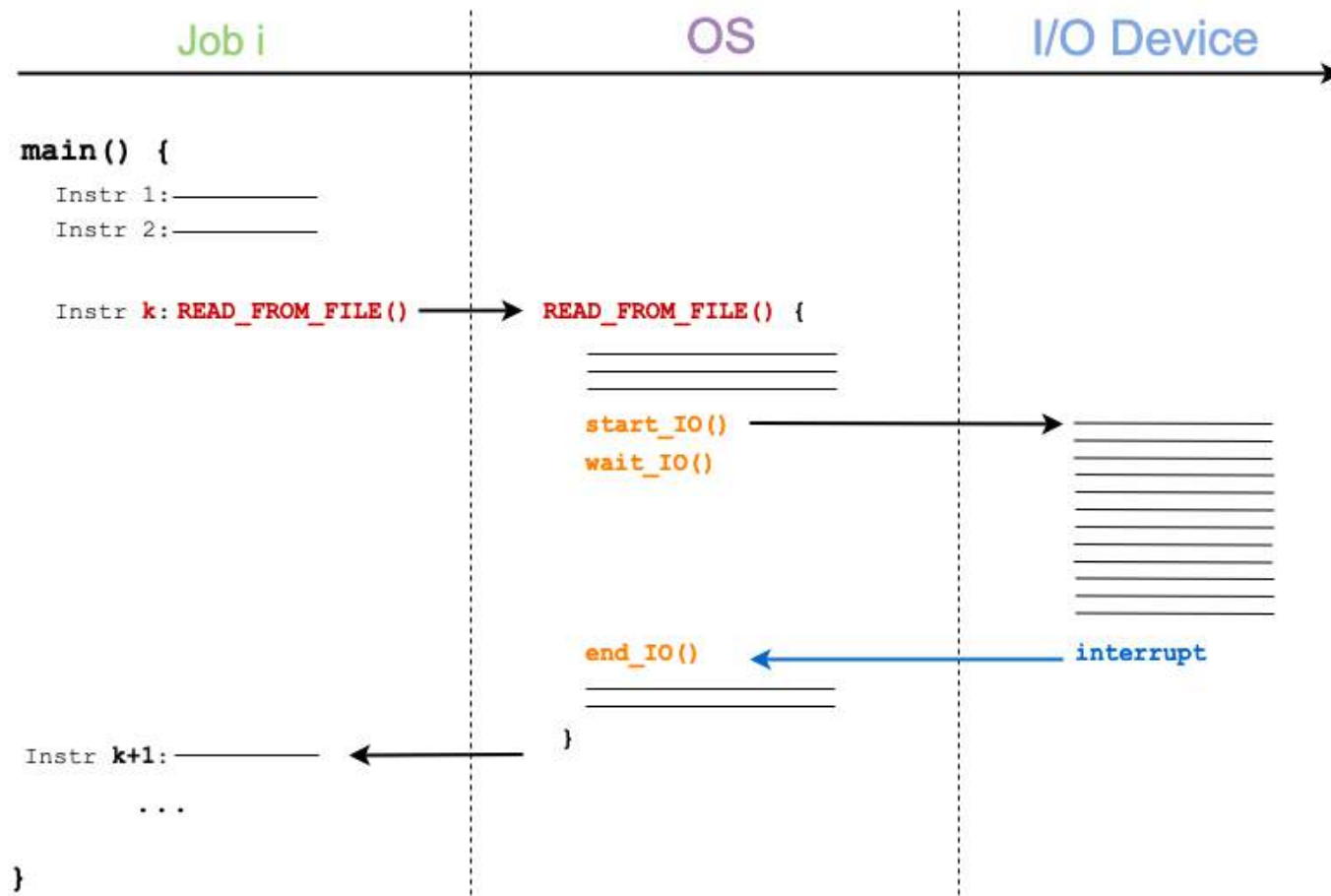
Non-Blocking System I/O
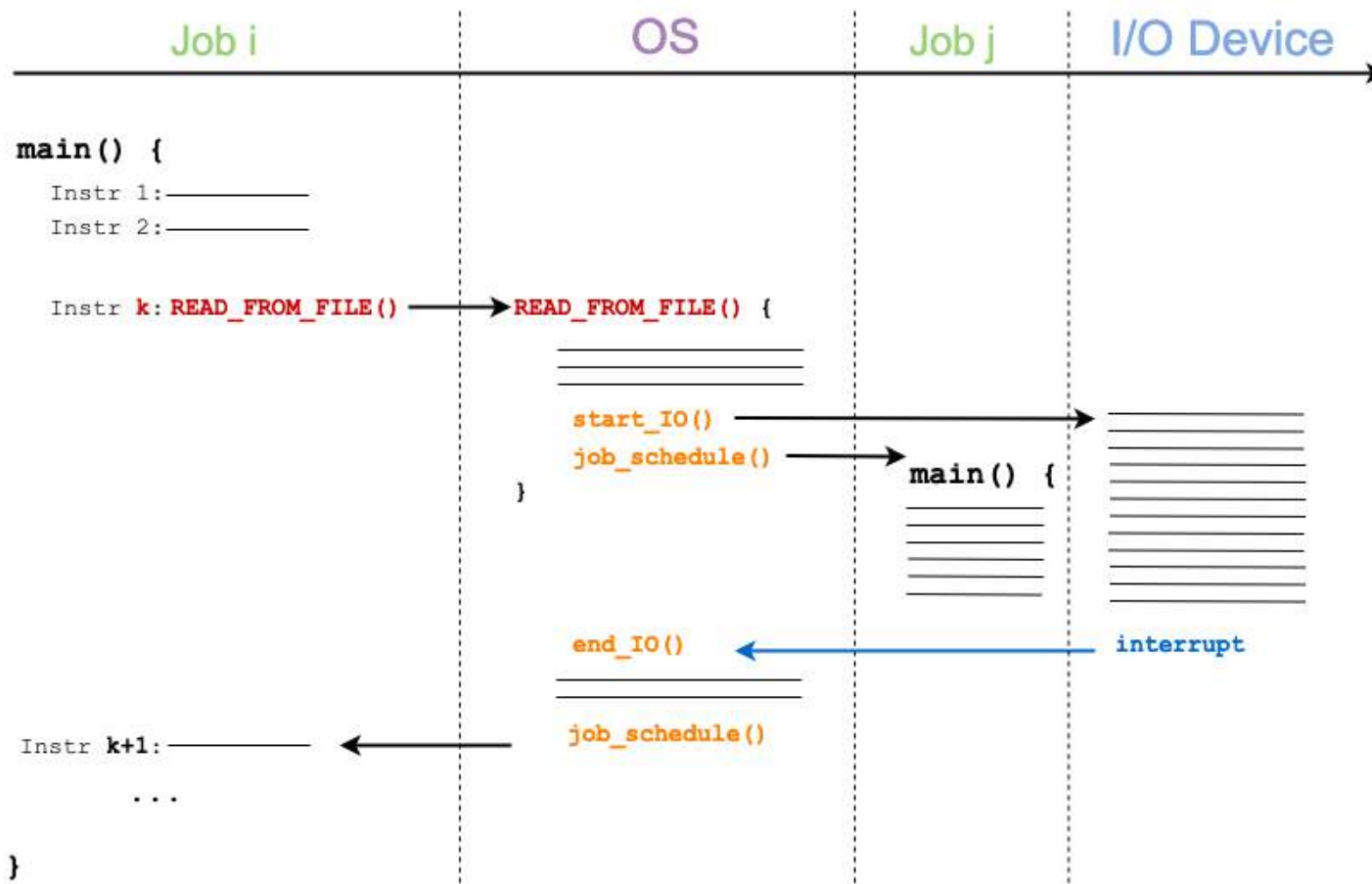
Time-sharing Systems (1970s)

- 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
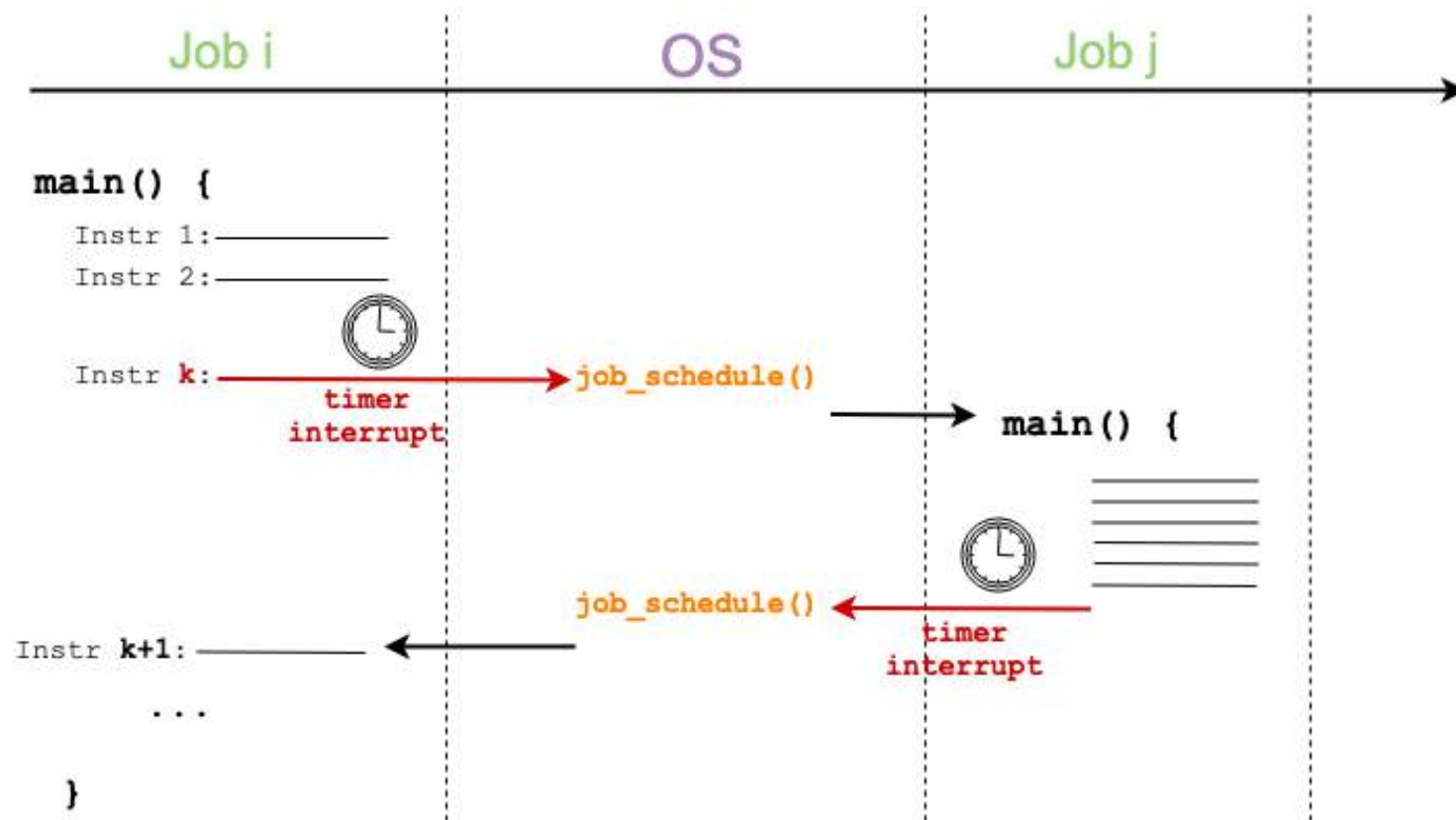
New Trends in OS Design

- Active field of research
  - OS demand is growing (many computing devices are available)
  - New application settings (Web, Cloud, mobile, cars, etc.)
  - Hardware is rapidly changing (new CPUs coming out)

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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
    - Virtualize any physical resource (CPUs, memory, I/O, etc.)

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  - **How computers work**

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- The world is increasingly dependent on computer systems
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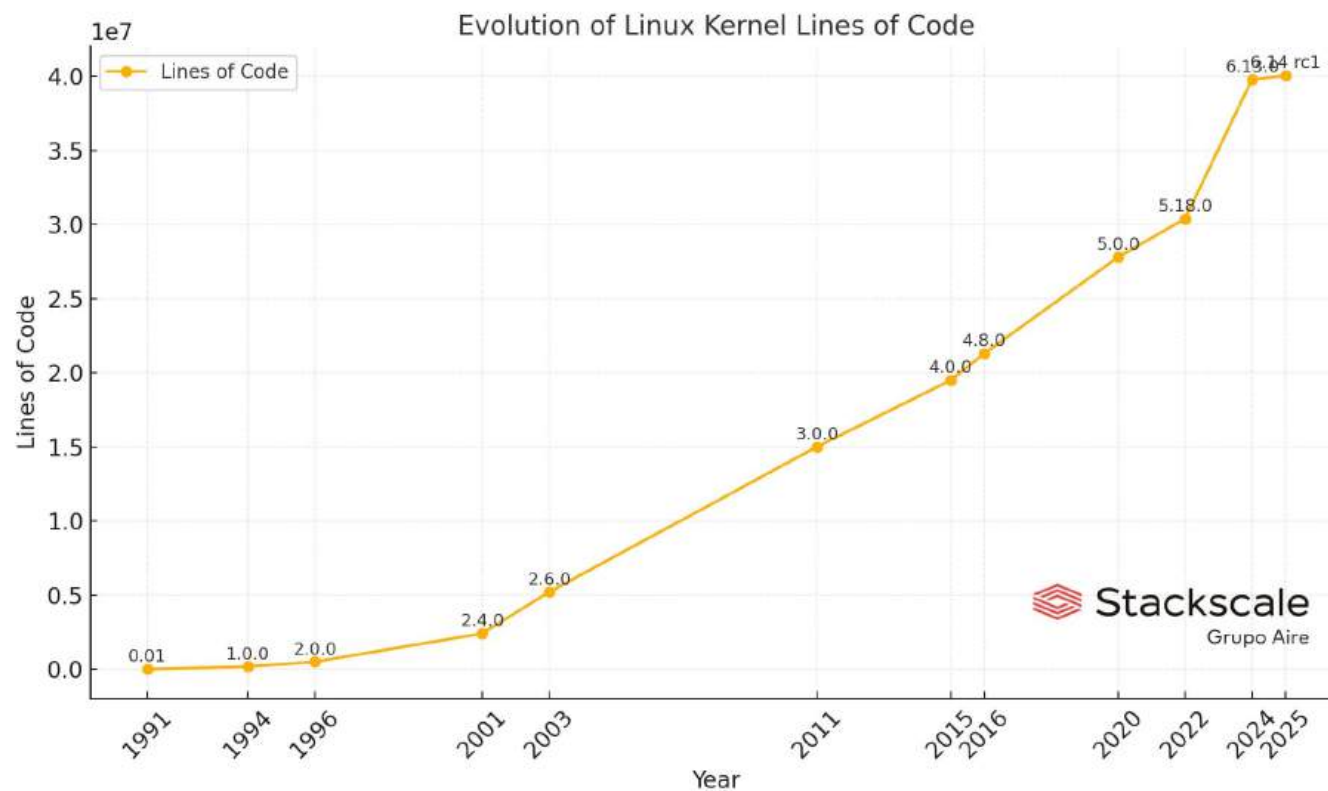
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OS is a great example of a large computer system

Linux Kernel Size (Lines of Code)

~40M LoC as of 2025!

source: https://www.stackscale.com/blog/linux-kernel-surpasses-40-million-lines-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 per clock cycle (1/CPI)	~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

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- New architectural trends open up novel opportunities and challenges in Operating System design