Sistemi Operativi

Corso di Laurea in Informatica

a.a. 2020-2021

Gabriele Tolomei

Dipartimento di Informatica

Sapienza Università di Roma

tolomei@di.uniroma1.it

SAPIENZA
UNIVERSITÀ DI ROMA

Useful Information

Class schedule

- Monday: 3 p.m. - 6 p.m.
- Wednesday: 2 p.m. - 4 p.m.

Useful Information

Class schedule

- Monday: 3 p.m. - 6 p.m.
- Wednesday: 2 p.m. - 4 p.m.

Contacts

- email: tolomei@di.uniroma1.it
- website: https://github.com/gtolomei/operating-systems
- moodle: https://elearning.uniroma1.it/course/view.php?id=11838
- Google Meet: https://meet.google.com/sfi-siup-ubd

Useful Information

Class schedule

- Monday: 3 p.m. - 6 p.m.
- Wednesday: 2 p.m. - 4 p.m.

Office hours

- Arranged online by appointment

Contacts

- email: tolomei@di.uniroma1.it
- website: https://github.com/gtolomei/operating-systems
- moodle: https://elearning.uniroma1.it/course/view.php?id=11838
- Google Meet: https://meet.google.com/sfi-siup-ubd

Useful Information

Class schedule

- Monday: 3 p.m. - 6 p.m.
- Wednesday: 2 p.m. - 4 p.m.

Contacts

- email: tolomei@di.uniroma1.it
- website: https://github.com/gtolomei/operating-systems
- moodle: https://elearning.uniroma1.it/course/view.php?id=11838
- Google Meet: https://meet.google.com/sfi-siup-ubd

Office hours

- Arranged online by appointment

Exam

- Quiz + Oral (*optional*)

Class Material

- Released on the class website **and** on moodle
- 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)
  - Uploading class material (e.g., slides, 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. 60 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)
- Oral Session:
  - Questions and exercises on the subjects covered during the whole semester

The 4 Golden Rules of Behavior (*Bundle*)

1. Remember to wash or sanithize your hands frequently

The 4 Golden Rules of Behavior (*Bundle*)

1. Remember to wash or sanithize your hands frequently
2. Stay at home in case of fever (higher than 37.5 C°) or flu symptoms

The 4 Golden Rules of Behavior (*Bundle*)

1. Remember to wash or sanithize your hands frequently
2. Stay at home in case of fever (higher than 37.5 C°) or flu symptoms
3. Keep a distance of at least 1 meter between you and anyone else

The 4 Golden Rules of Behavior (*Bundle*)

1. Remember to wash or sanithize your hands frequently
2. Stay at home in case of fever (higher than 37.5 C°) or flu symptoms
3. Keep a distance of at least 1 meter between you and anyone else
4. Wear your face mask while in class and on any public area where social distancing cannot be maintained

The 4 Golden Rules of Behavior (*Bundle*)

1. Remember to wash or sanithize your hands frequently
2. Stay at home in case of fever (higher than 37.5 C°) or flu symptoms
3. Keep a distance of at least 1 meter between you and anyone else
4. Wear your face mask while in class and on any public area where social distancing cannot be maintained

Be sure to know and familiarize with the guidelines!

The 4 Golden Rules of Behavior (*Bundle*)

source: Sapienza
https://www.youtube.com/watch?v=mVEjo0DC19I&feature=youtu.be

Outline of the Course

- Introduction

Outline of the Course

- Introduction
- Processes and Threads

Outline of the Course

- Introduction
- Processes and Threads
- Memory Management

Outline of the Course

- Introduction
- Processes and Threads
- Memory Management
- File System and I/O

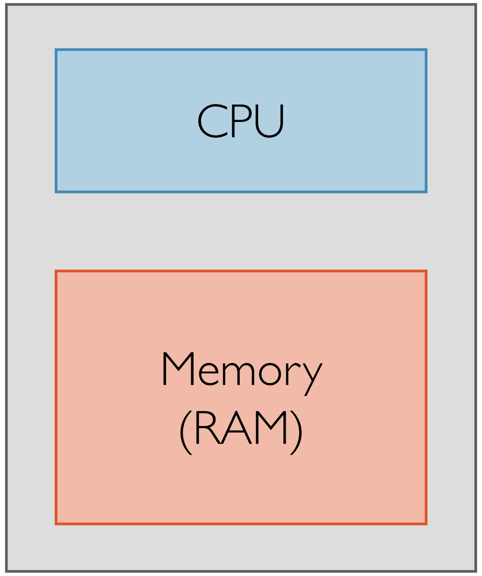
Outline of the Course

- Introduction
- Processes and Threads
- Memory Management
- File System and I/O
- Advanced Topics
  - Protection/Security?
  - Distributed/Mobile Systems?

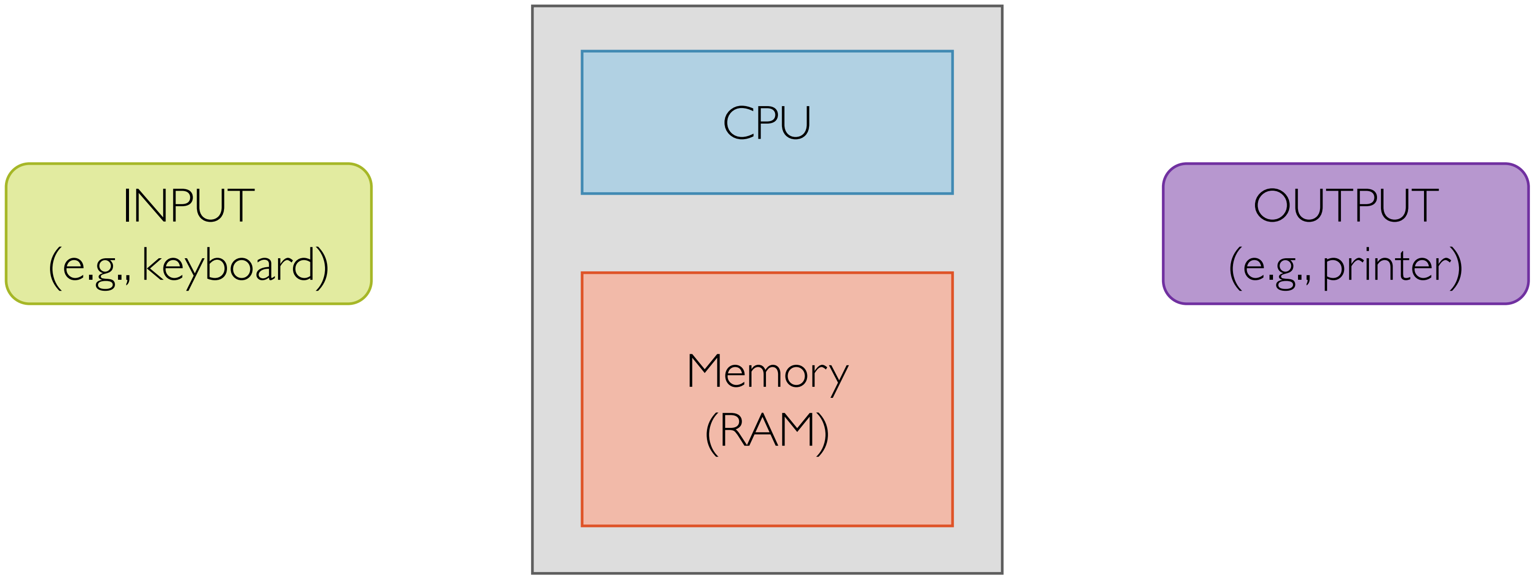
Language and Naming Conventions

- As you may have noticed, slides are all written in english!
- 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!

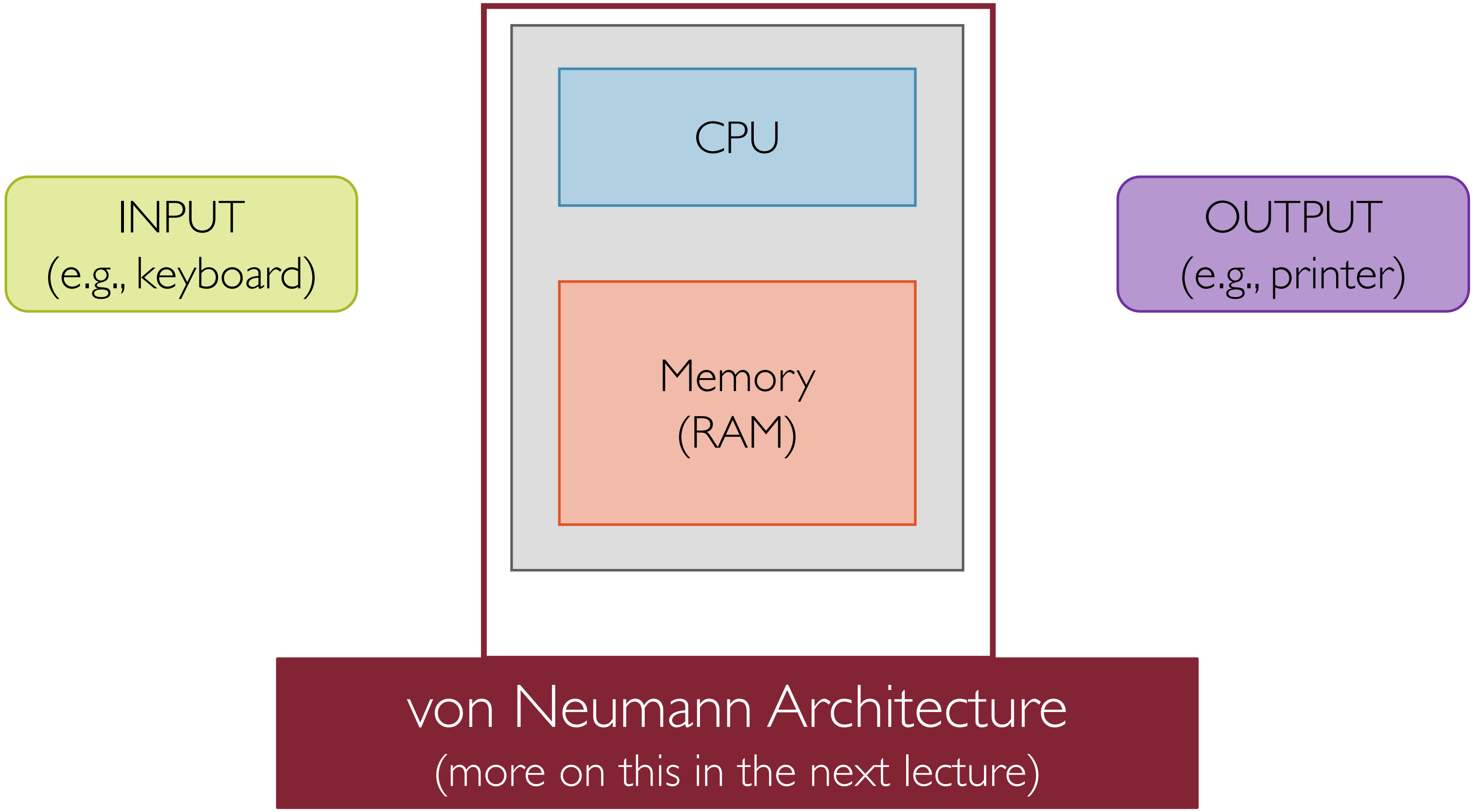
High-Level View of a Computer System



High-Level View of a Computer System



High-Level View of a Computer System



What is an Operating System?

What is an Operating System?

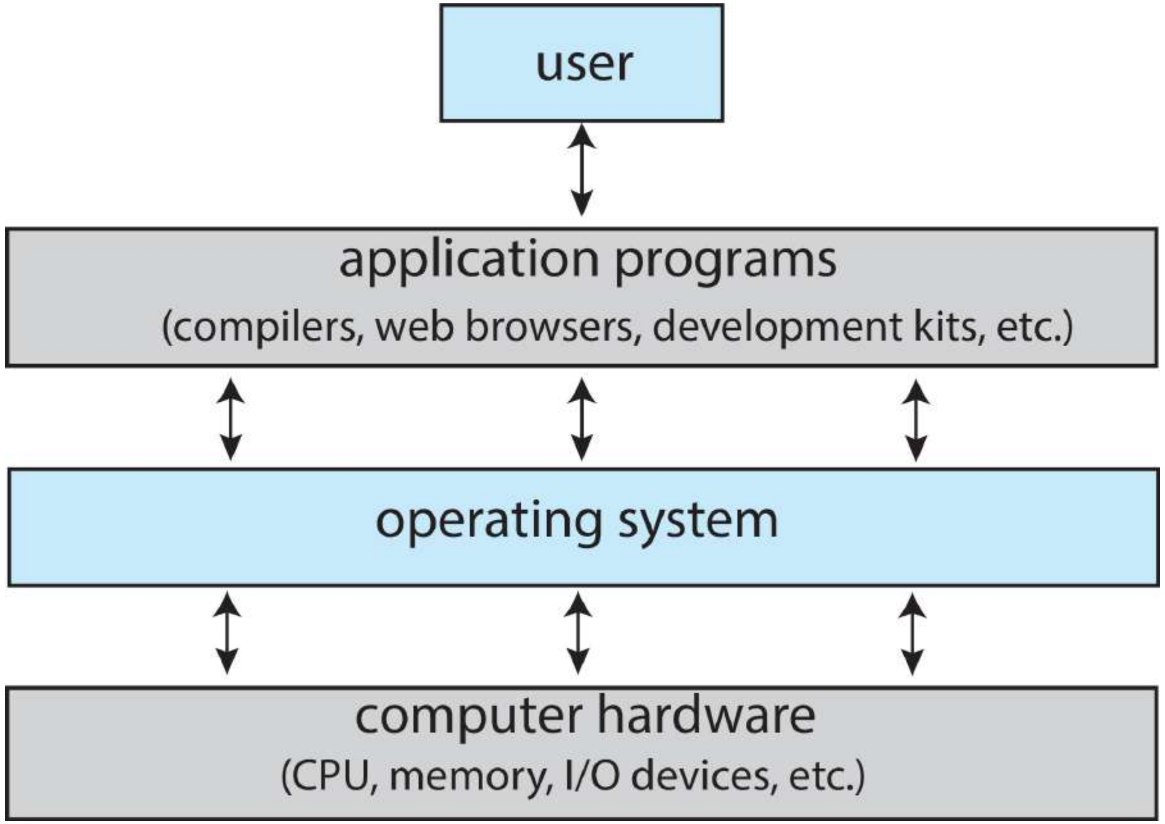
- There exists no universally accepted definition!

What is an Operating System?

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

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

Computer System Overview



What is Inside an Operating System?

- Again, no single answer to this question!

What is Inside an Operating System?

- Again, no single answer to this question!
- It is a system design choice to decide what to include in the OS

What is Inside an Operating System?

- Again, no single answer to this question!
- 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.

What is Inside an Operating System?

- Again, no single answer to this question!
- 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.

OS Wears Many Hats

- Referee (Resource Manager)
  - Manages shared physical resources: CPUs, memory, I/O, etc.
  - To achieve fairness and efficiency

OS Wears Many Hats

- Illusionist (Virtual Machine)
  - Virtualize any physical resource

OS Wears Many Hats

- Illusionist (Virtual Machine)
  - Virtualize any physical resource
  - 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

OS Wears Many Hats

- 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

History of Operating Systems

Phase 1: Expensive HW, Cheap Humans

- 1 machine : M users
- Hand-programmed systems
- Single-user console systems (mainframes)
- Batch systems
- Multi-programming systems

1945-55: Vacuum Tubes and Plugboards

- Used by a restricted and skilled group of people
- All programming was done in machine language directly
- Basically, no OS whatsoever!
- Problem: ?

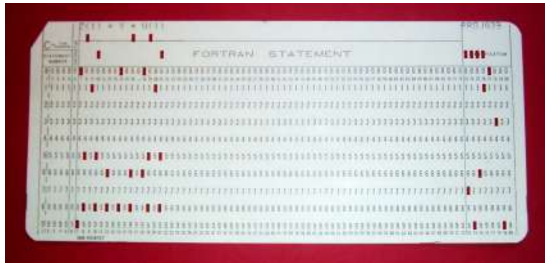
1945-55: Vacuum Tubes and Plugboards

- Used by a restricted and skilled group of people
- All programming was done in machine language directly
- Basically, no OS whatsoever!
- Problem: low utilization of expensive HW

Phase 1: Expensive HW, Cheap Humans

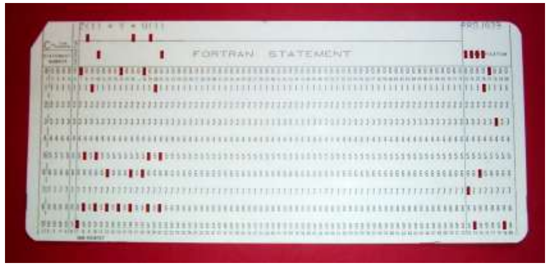
- 1 machine : M users
- Hand-programmed systems
- Single-user console systems (mainframes)
- Batch systems
- Multi-programming systems

1955-65: Mainframes



- One user at a time interacting with the machine as program runs
- Programs are written on punched cards
- Executes one thing at a time: no overlap between computation and I/O
- Primitive OS: program loader
- Problem: ?

1955-65: Mainframes



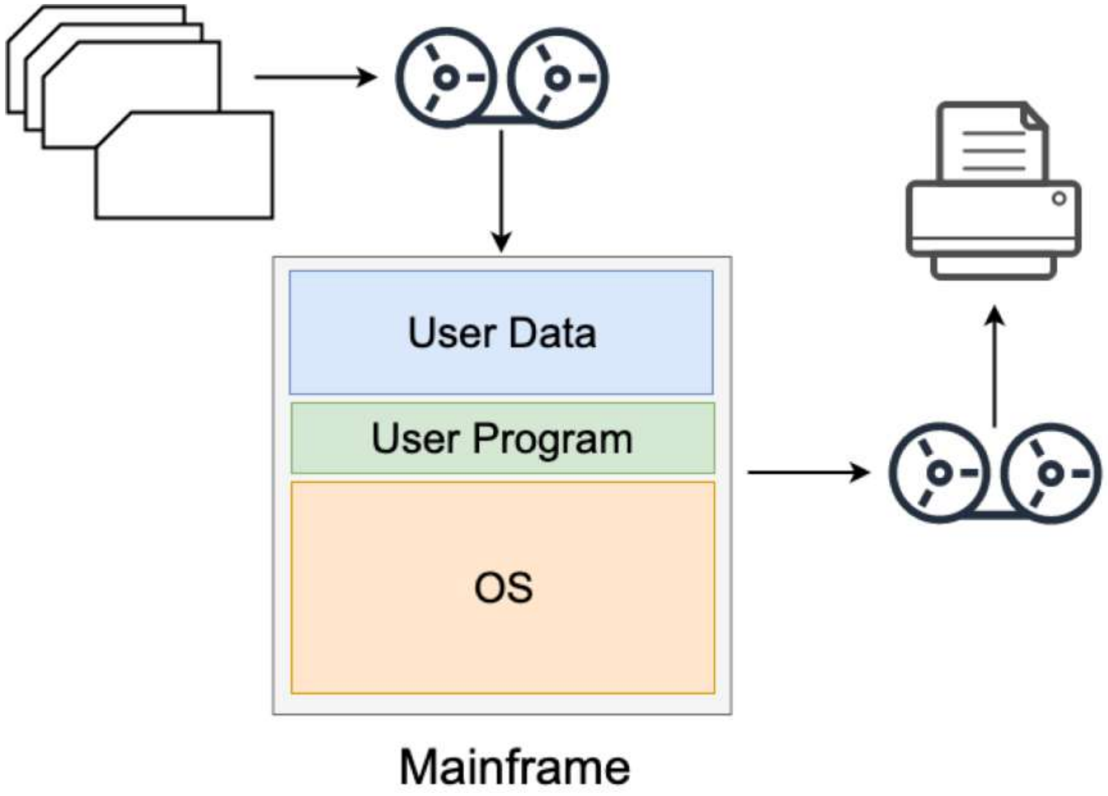
- One user at a time interacting with the machine as program runs
- Programs are written on punched cards
- Executes one thing at a time: no overlap between computation and I/O
- Primitive OS: program loader
- Problem: inefficient for multiple users

Phase 1: Expensive HW, Cheap Humans

- 1 machine : M users
- Hand-programmed systems
- Single-user console systems (mainframes)
- Batch systems
- Multi-programming systems

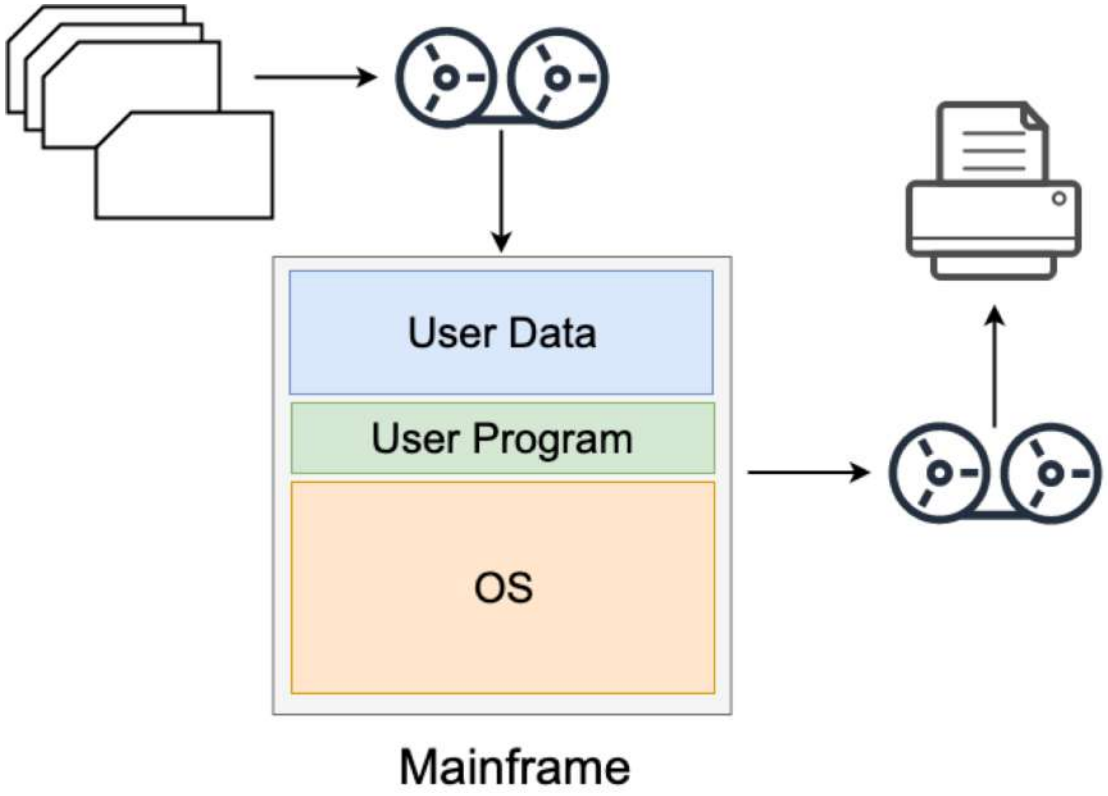
1955-65: Batch Systems

- Execute multiple jobs in batch
- Users submit jobs (on cards or tapes)
- Technician still schedules jobs
- OS loads and run jobs
- More efficient use of the machine
- Problem: ?



1955-65: Batch Systems

- Execute multiple jobs in batch
- Users submit jobs (on cards or tapes)
- Technician still schedules jobs
- OS loads and run jobs
- More efficient use of the machine
- Problem: still one job at a time!

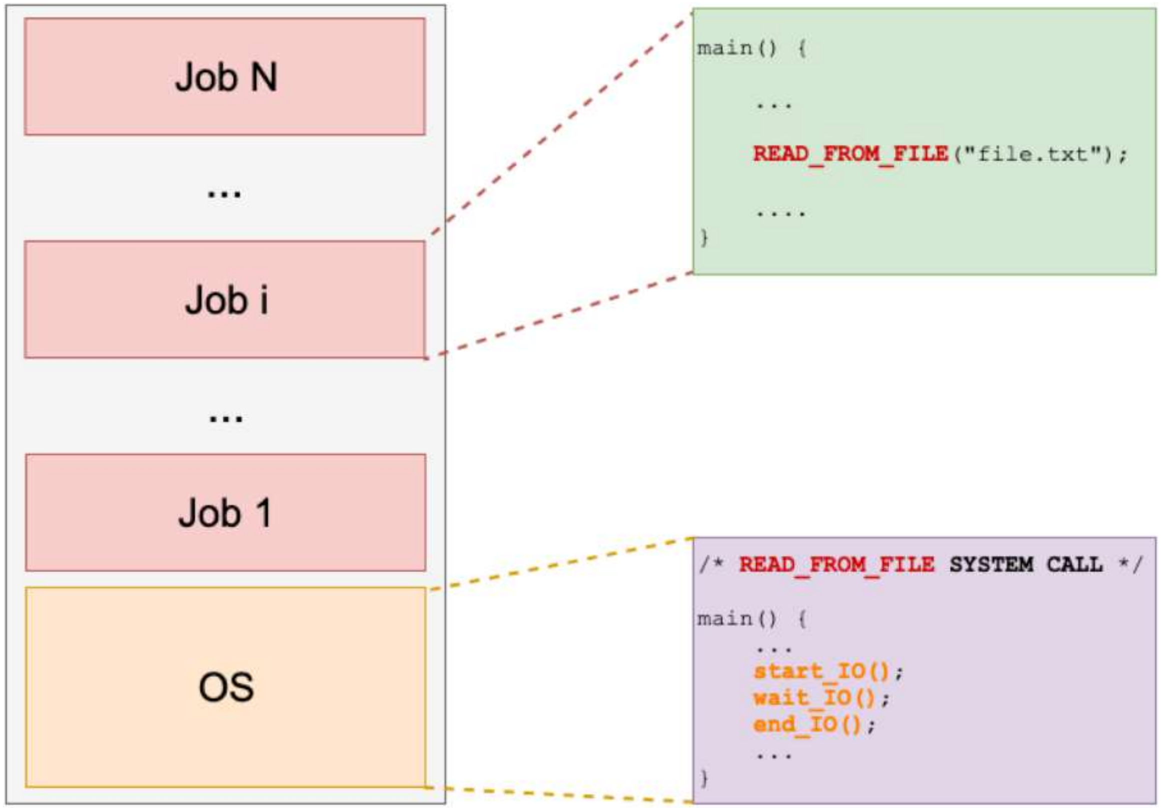


Phase 1: Expensive HW, Cheap Humans

- 1 machine : M users
- Hand-programmed systems
- Single-user console systems (mainframes)
- Batch systems
- Multi-programming systems

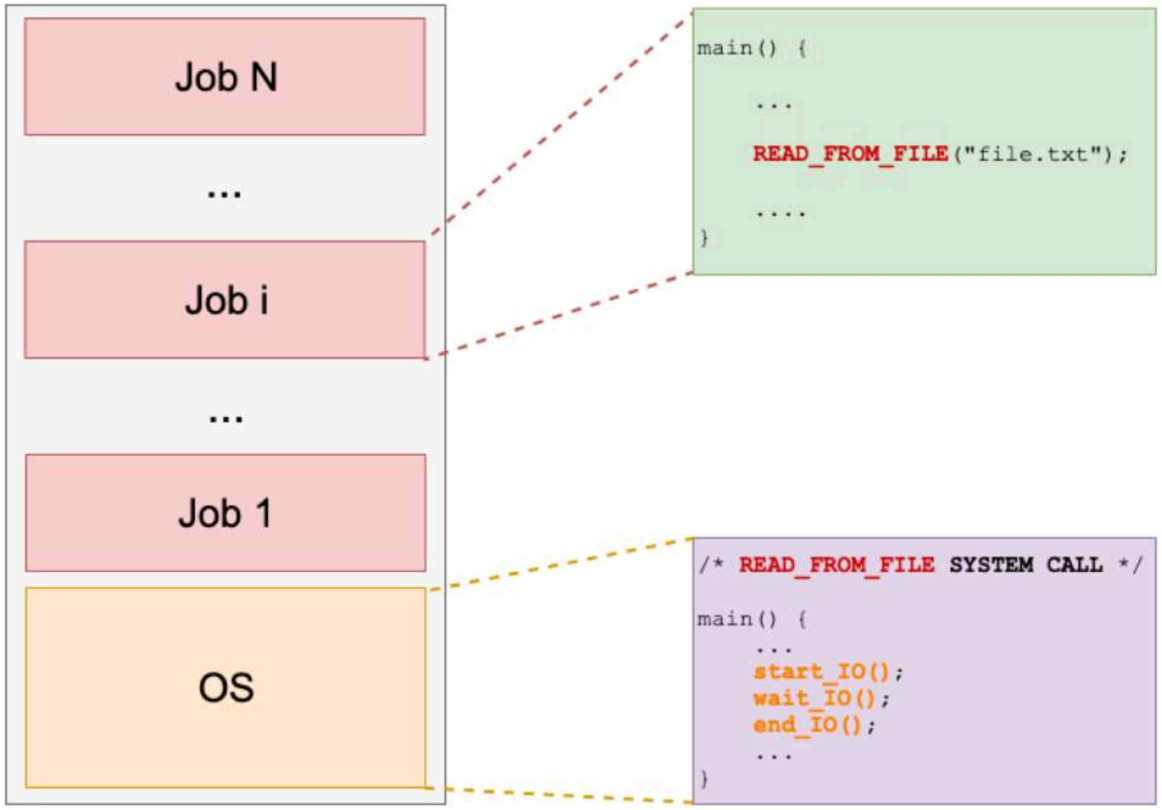
1955-65: Multiprogramming Systems

- Keep several jobs loaded in memory
- Multiplex CPU between jobs
- OS responsibilities:
  - job scheduling
  - memory protection
  - I/O operations
- Problem: ?

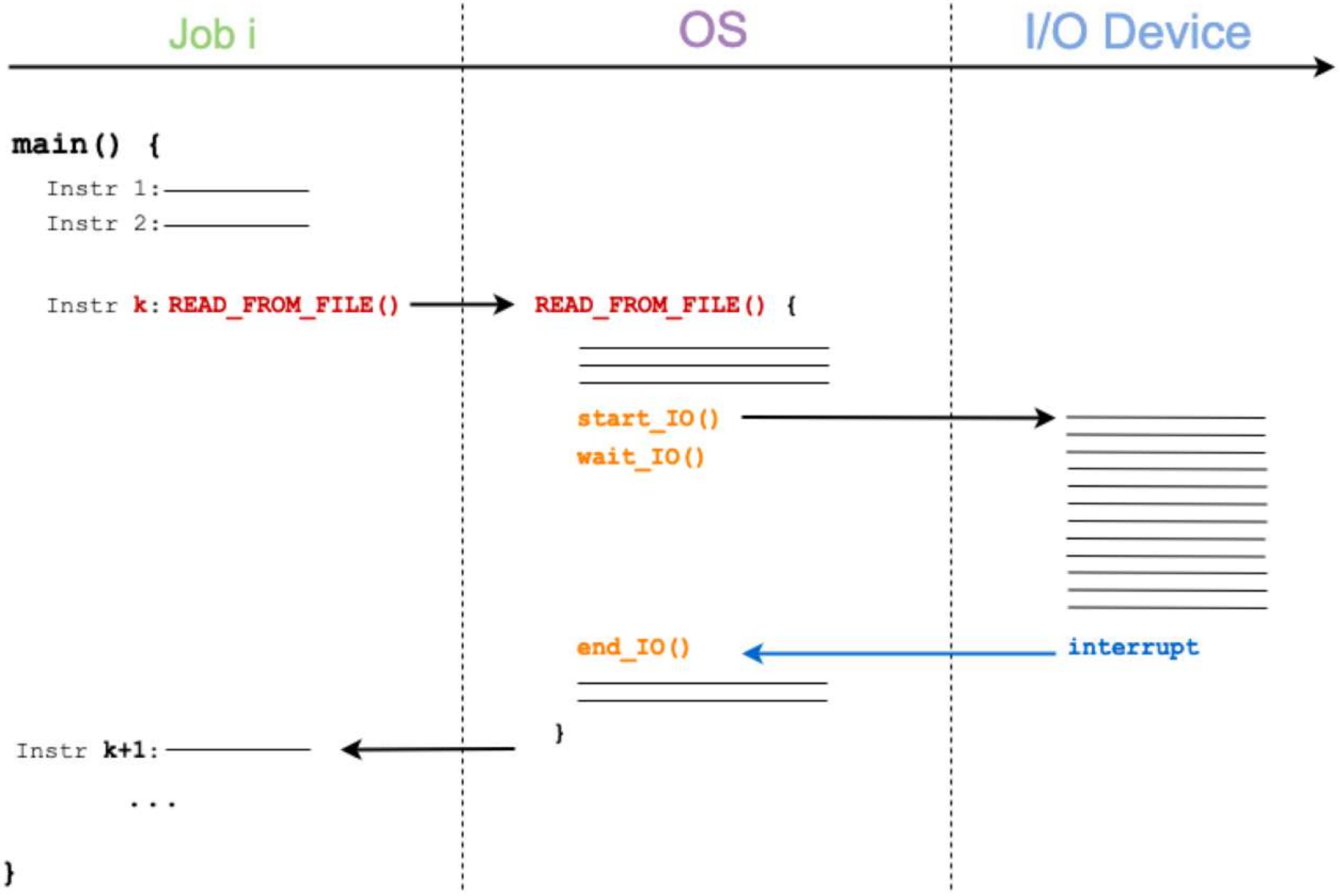


1955-65: Multiprogramming Systems

- 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

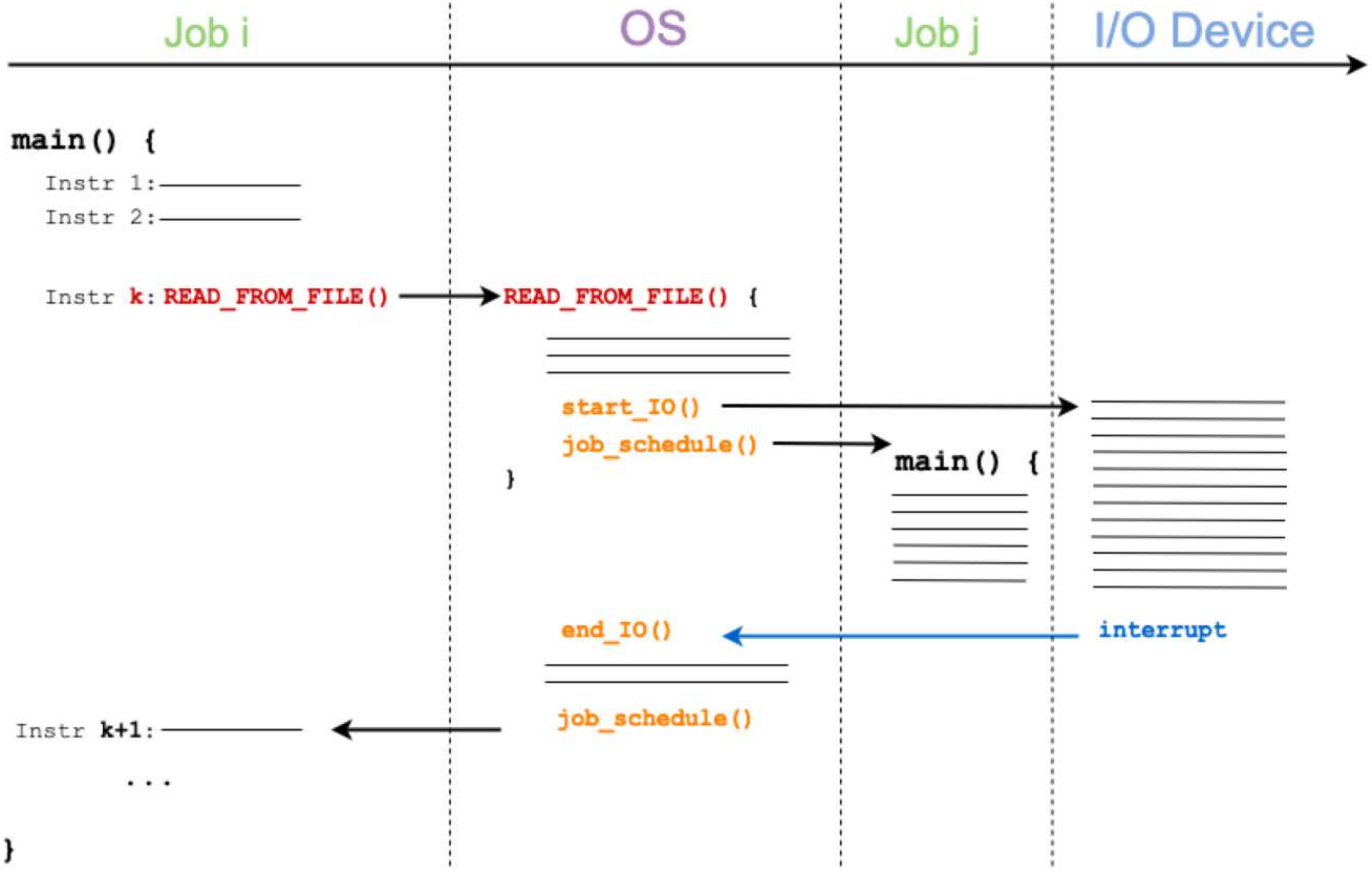


Blocking I/O



Job i
OS
I/O Device
main() {
Instr 1:
Instr 2:
Instr k: READ_FROM_FILE()
READ_FROM_FILE() {
start_IO()
wait_IO()
end_IO()
interrupt
}
Instr k+1:
...
}

Non-Blocking I/O



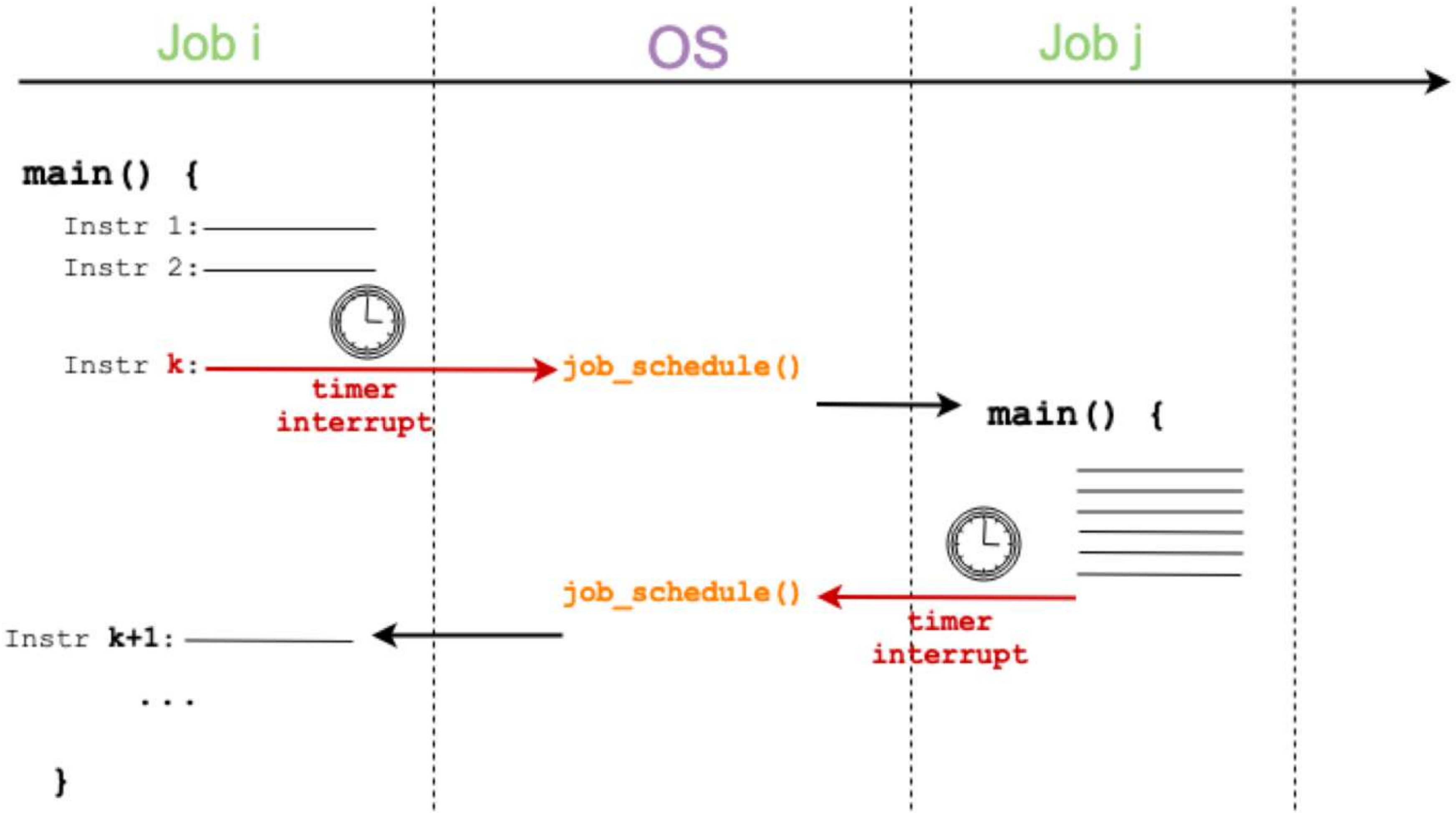
Phase 2: Cheap HW, Expensive Humans

- 1 machine : M users (still)
- Time-sharing systems

1970-: Time-sharing

- 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 and Dennis Ritchie → UNIX OS

Pseudo-parallelism



<u>Phase 3</u>: Very Cheap HW, Very Expensive Humans

- Personal Computing → 1 machine : 1 user

Phase 3: Very Cheap HW, Very Expensive Humans

- Personal Computing → 1 machine : 1 user
- Distributed/Ubiquitous Computing → M machines : 1 user

1980's: Personal Computers

- Initially, simple OSs:
  - No multiprogramming, concurrency, memory protection, etc.
- Later on:
  - Networking, file sharing, Graphical User Interfaces (GUIs)
- IBM PCs (1981) and Apple Macintosh (1984)

1990's-: Personal Computers (and more)

- PCs are now equipped with a fully fledged OS:
  - Windows NT (1991)
  - Mac OS X and related (2001)
  - Linux (1991)

1990's-: Personal Computers (and more)

- PCs are now equipped with a fully fledged OS:
  - Windows NT (1991)
  - Mac OS X and related (2001)
  - Linux (1991)
- Several new (computing) environments where an OS is needed:
  - Transportations: airplanes, cars, etc.
  - Telecommunications: smartphones
  - Home appliances: smart TVs

1990's-: Personal Computers (and more)

- PCs are now equipped with a fully fledged OS:
  - Windows NT (1991)
  - Mac OS X and related (2001)
  - Linux (1991)
- Several new (computing) environments where an OS is needed:
  - Transportations: airplanes, cars, etc.
  - Telecommunications: smartphones
  - Home appliances: smart TVs
- Plus, the Web has made everything distributed!

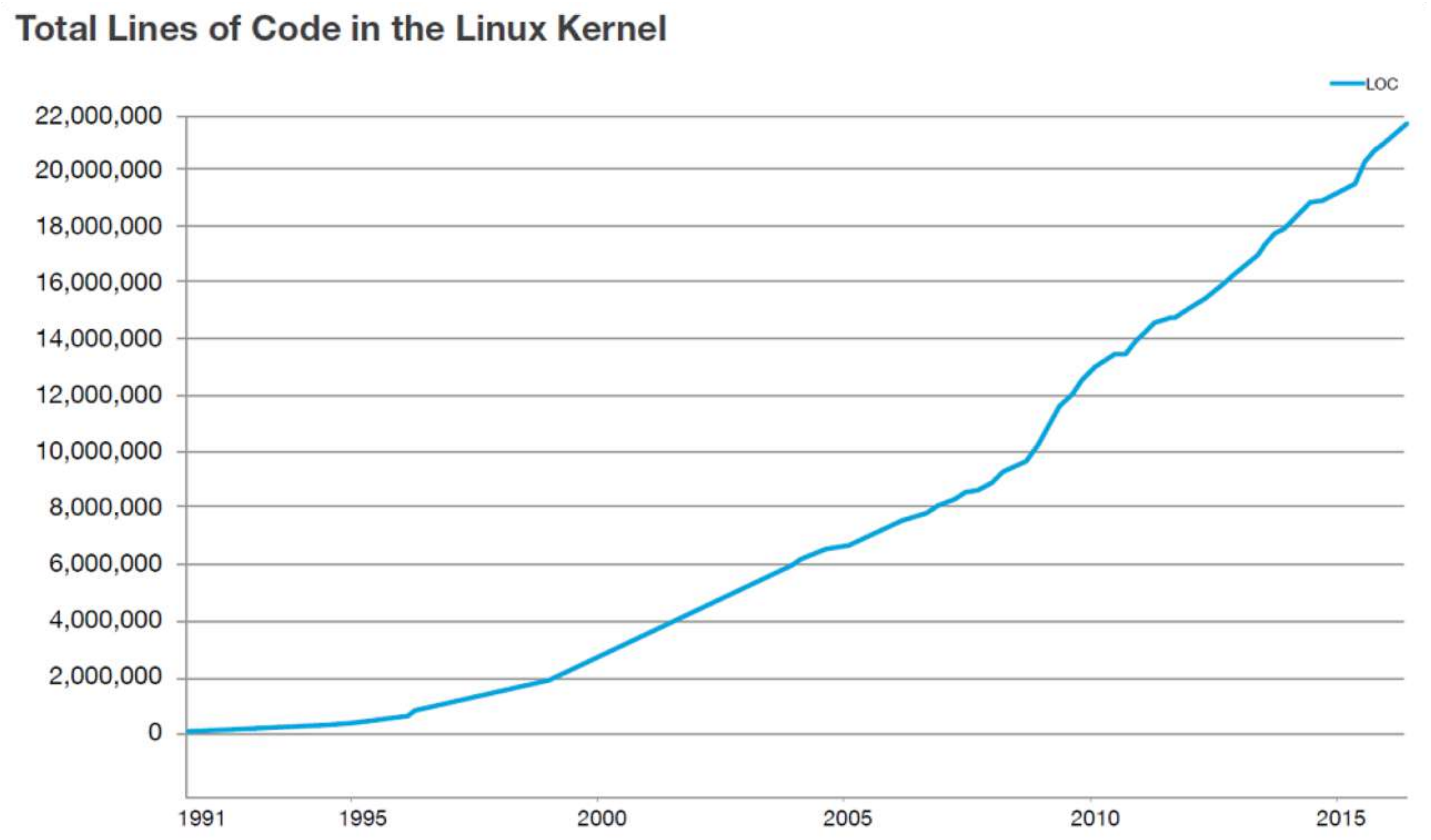
New Trends in OS Design

- 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)

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)
- Open-source OS (Linux)
  - Allows developers to contribute to OS development
  - Excellent research platform to experiment with

Linux Kernel Size



Why Study OSs?

- To learn important concepts of computer science
  - Abstraction
    - Virtualize any physical resource (CPUs, memory, I/O, etc.)

Why Study OSs?

- To learn important concepts of computer science
  - Abstraction
    - Virtualize any physical resource (CPUs, memory, I/O, etc.)
  - Systems Design Tradeoffs
    - Performance vs. Cost of OS abstractions
    - Performance vs. Complexity of OS design
    - HW vs. SW implementation of key features

Why Study OSs?

- To learn important concepts of computer science
  - Abstraction
    - Virtualize any physical resource (CPUs, memory, I/O, etc.)
  - Systems Design Tradeoffs
    - Performance vs. Cost of OS abstractions
    - Performance vs. Complexity of OS design
    - HW vs. SW implementation of key features
  - How computers work

Large Computer Systems

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

Large Computer Systems

- The world is increasingly dependent on computer systems
  - Large, complex, interconnected, distributed, etc.
- Huge demand for experts who deeply understand and can build such systems, which need to be:
  - Reliable, effective, efficient, secure, etc.

Large Computer Systems

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

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

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
  - 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

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

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

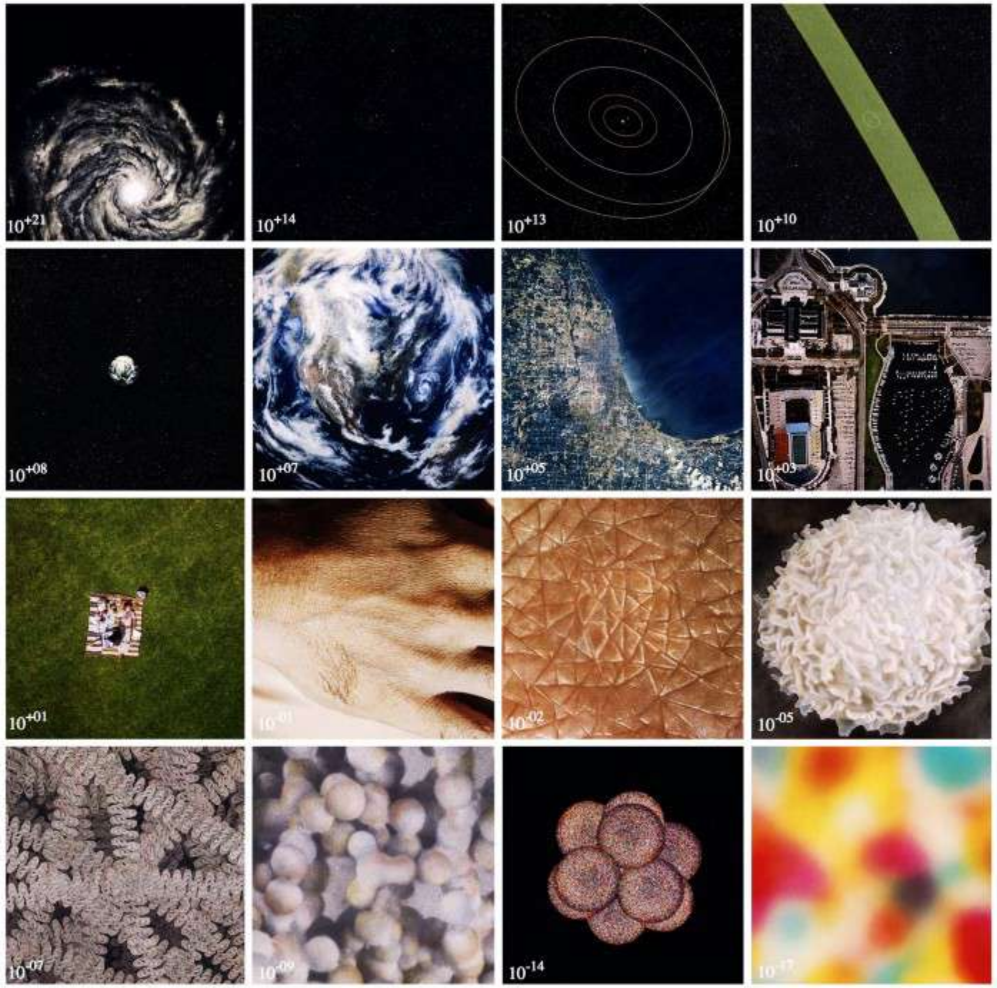
	1956 (IBM RAMAC 305)	Today (Western Digital)	Δ (orders of magnitude)
Capacity (MB)	5	15,000,000	+7
Size (inch)	24 (x50)	3.5	-3
Cost ($/MB)	640 (per month)	~0.000018	-9

Architectural Trends: Orders of Magnitude

$10^0 = 1$

source: Powers of Ten (1977)
https://www.youtube.com/watch?v=0fKBhvDjuy0

Architectural Trends: Orders of Magnitude



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

Summary

- Basic roles of an Operating System
- A brief history of Operating Systems

Summary

- Basic roles of an Operating System
- A brief history of Operating Systems
- Operating Systems as large and complex computer systems

Summary

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