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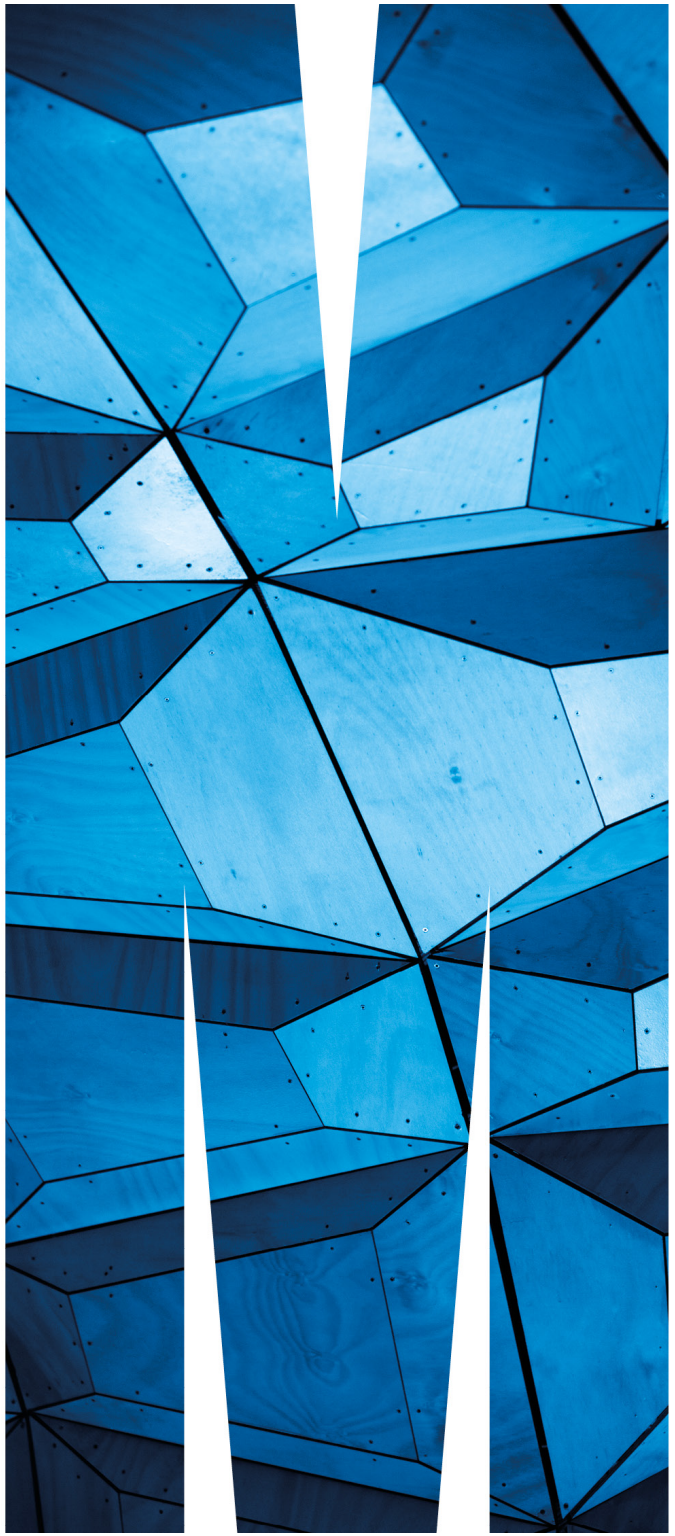
TECHNOLOGY



# FIT2100 Semester 2 2020

# Lecture 1:
# Computer System Overview

## (Reading: Stallings, Chapter 1)

Week 1

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# CONTEXT

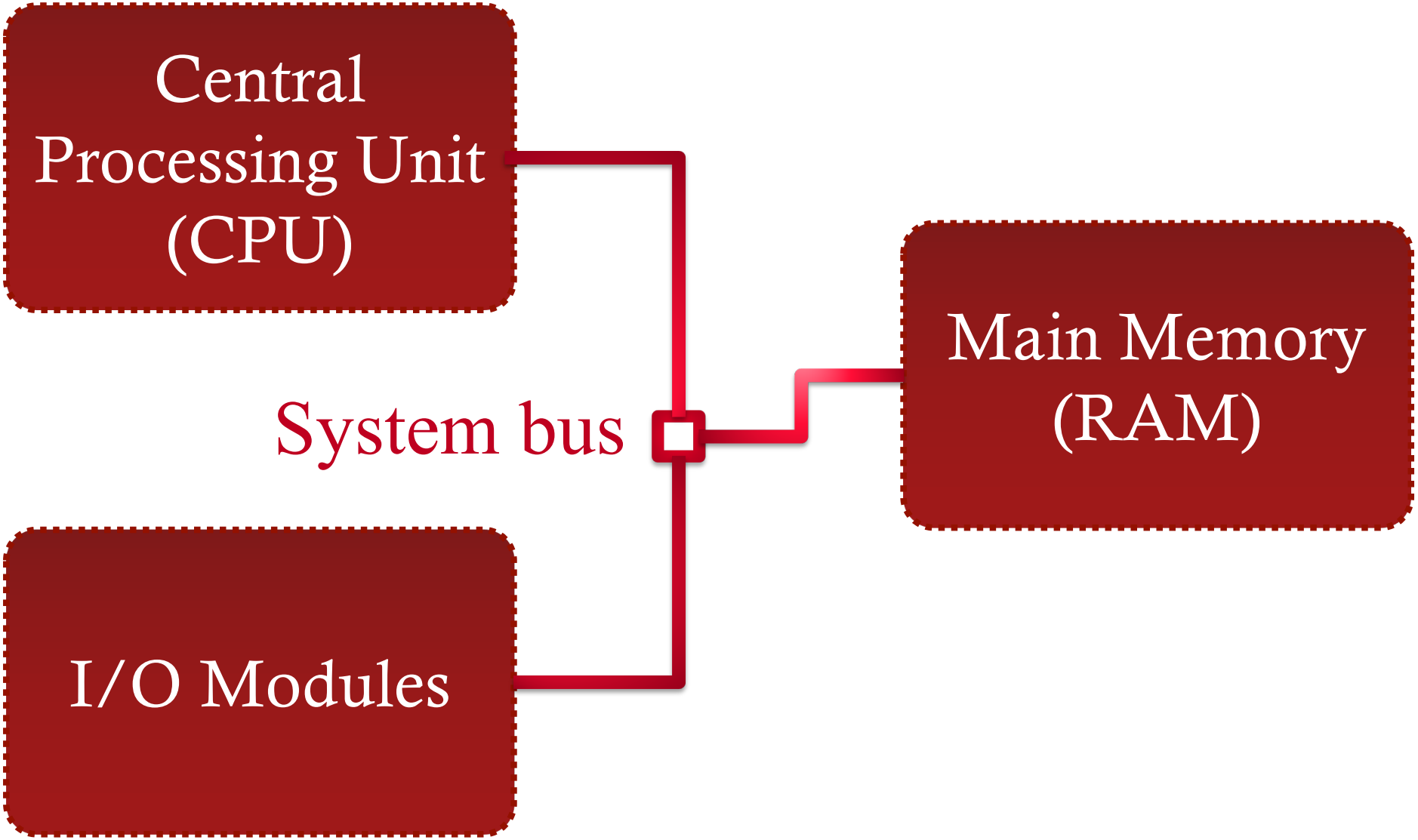
- An Operating System…
  - Manages hardware resources on behalf of the user
  - Provides services to other programs
  - Makes the computer more useful
- Designing an operating system is like **playing a game**
  - Games have rules
  - The hardware sets the rules
  - Let's try to figure out what some of the rules are…

## Lecture 1: Learning Outcomes

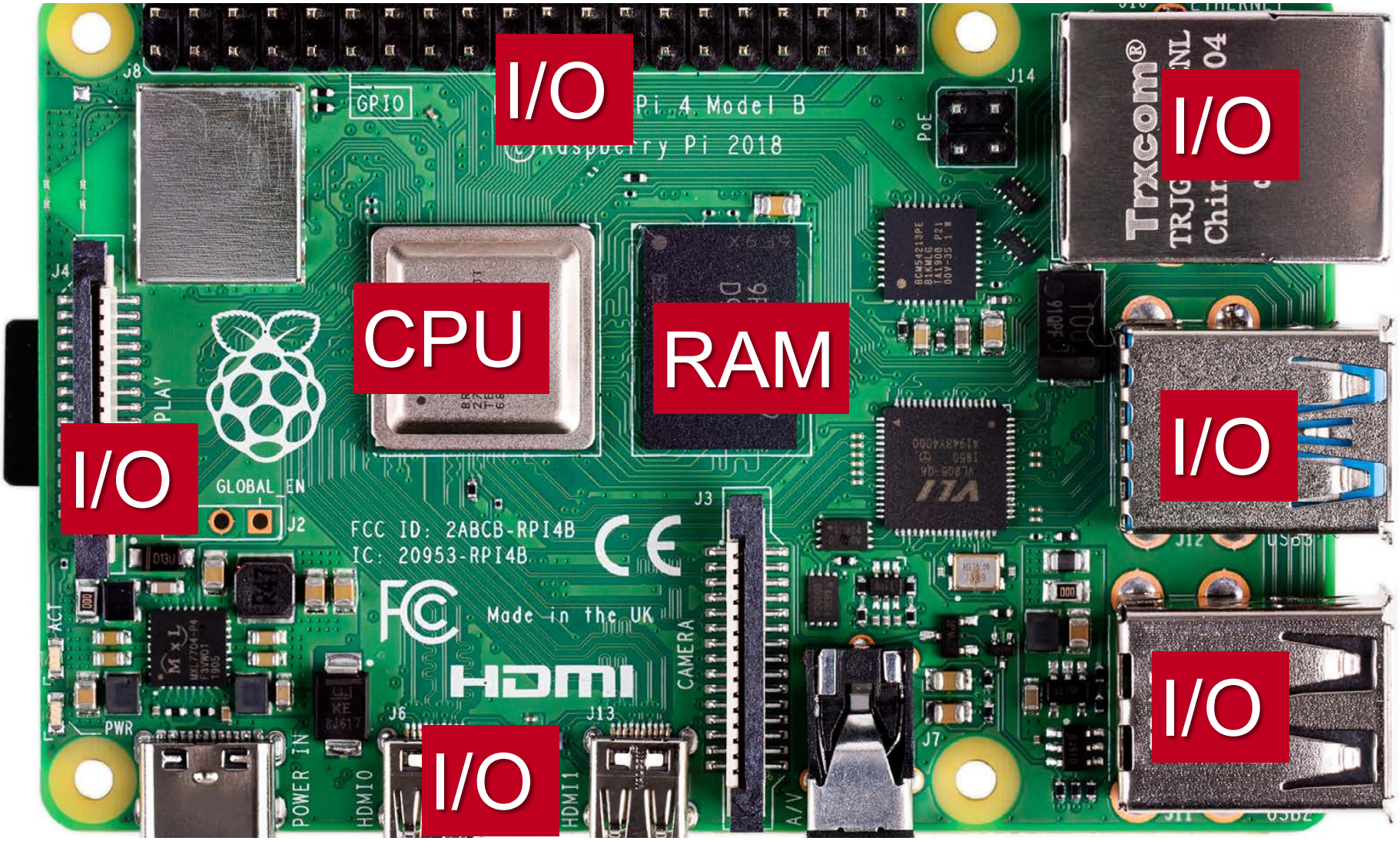
- Upon the completion of this lecture, you should be able to:
  - Understand the building blocks of a computer system
  - Explain the steps taken by a processor to execute a program instruction
  - Discuss the concept of interrupts and how and why a processor uses interrupts
  - Discuss the typical computer memory hierarchy


# What are the basic elements of a computer system?

# Computer System: Basic Elements



# Raspberry Pi 4 (just an example)



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# Central Processing Unit (CPU)

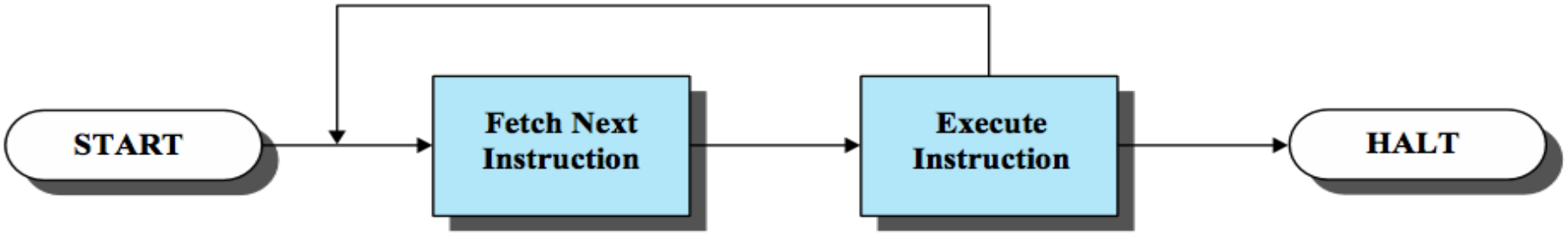
What is a CPU?

# Central Processing Unit (CPU)

- A *program interpreter* built in hardware.
  - What kind of programs can it run?
    - Machine code
- **RULE 1 → The CPU can only run instructions written in its own machine code**
  - C: you must **compile** your entire C program into machine code before it can be loaded into the CPU
    - Entire program runs in the native language of CPU
  - Python: a special **interpreter** program reads your instructions and does everything on your behalf
    - Convenient to code; *much* slower to execute

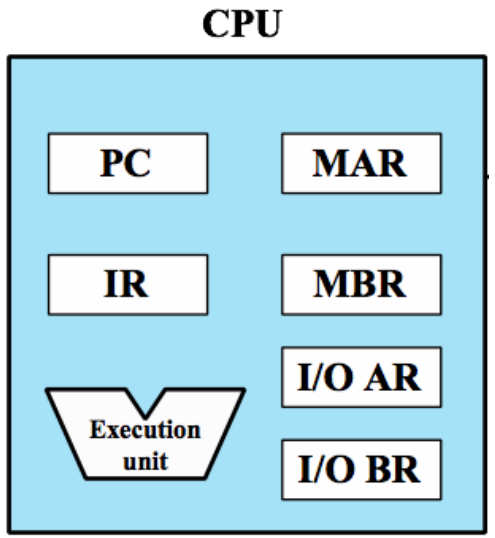
# Basic Instruction Cycle

- The CPU **fetches** each instruction from main memory, **decodes** and **executes** it.
- Then fetch the next instruction and repeat.



# What happens inside the CPU?

- CPU contains a number of **registers**
  - Very fast working memory for various values
  - Each register is like a **variable** built in hardware rather than software.
- PC: program counter
  - Stores **memory address** of next instruction in program
- IR: instruction register
  - Stores the current machine code **instruction** being worked on
- Assorted registers for working with data.



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What is main memory?

Main Memory (RAM)

# Main Memory

- Stores data and programs that have been loaded for execution
- **RULE 2** → Program must be loaded into main memory before it can be run
  - Otherwise the CPU can't fetch the instructions

- Volatile
  - Contents of the memory is lost when the computer is shut down
- A.k.a. real memory or primary memory or random access memory

# How can memory be represented?


- You can think of main memory as a long list of bytes
  - Each byte element stores an 8-bit value (e.g. 0-255)
  - Each byte element is *indexed* by a **memory address**
- Examples of data types (our 32-bit VM environment)
  - a single character code value (**char**) requires 1 byte.
  - An integer (**int**) is made up of 4 bytes put together
  - (An **instruction** is also 4 bytes → 32 bits)
- **RULE 3** → To access something in memory, you need to know its starting address, and how many bytes you need.

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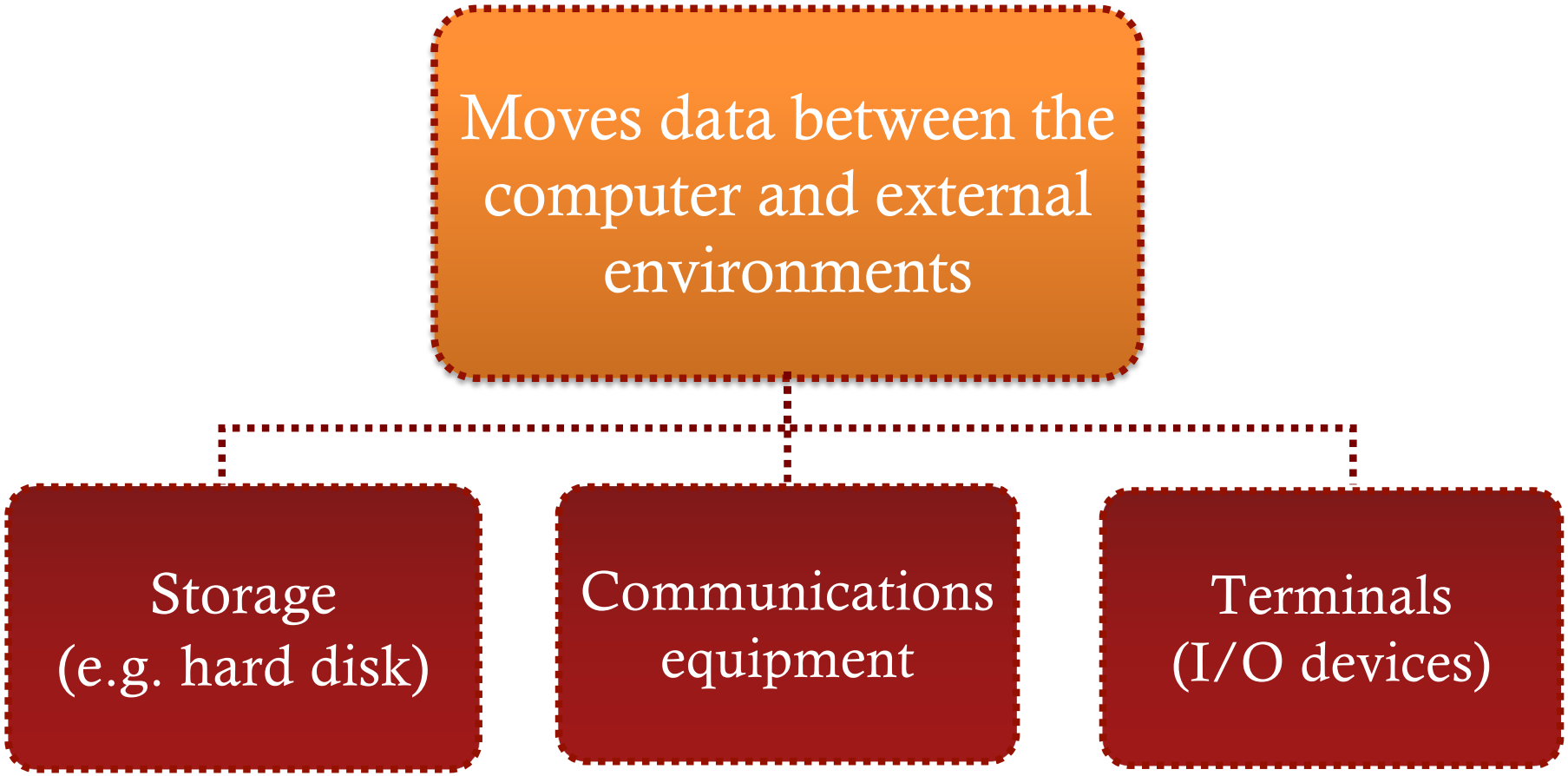
# What are I/O Modules?

I/O Modules

# I/O Modules


Moves data between the computer and external environments
Storage (e.g. hard disk)
Communications equipment
Terminals (I/O devices)

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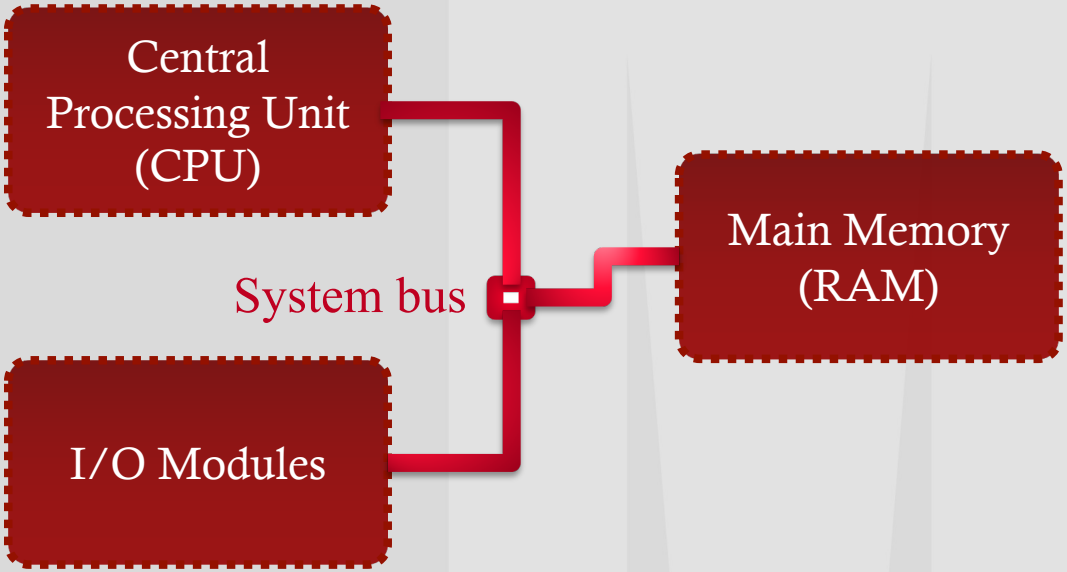
# What about the system bus?



# System Bus

- Provides for means of communication among processors, main memory, and I/O modules
- Comprises of:
  - Address bus
  - Data bus
  - Control bus

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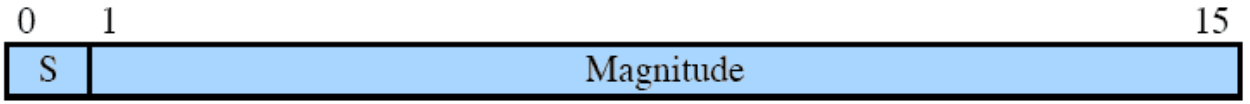
# How does a program get executed by a processor?

# Example: A "Hypothetical" Processor (Stallings textbook)


**(a) Instruction format**




**(b) Integer format**

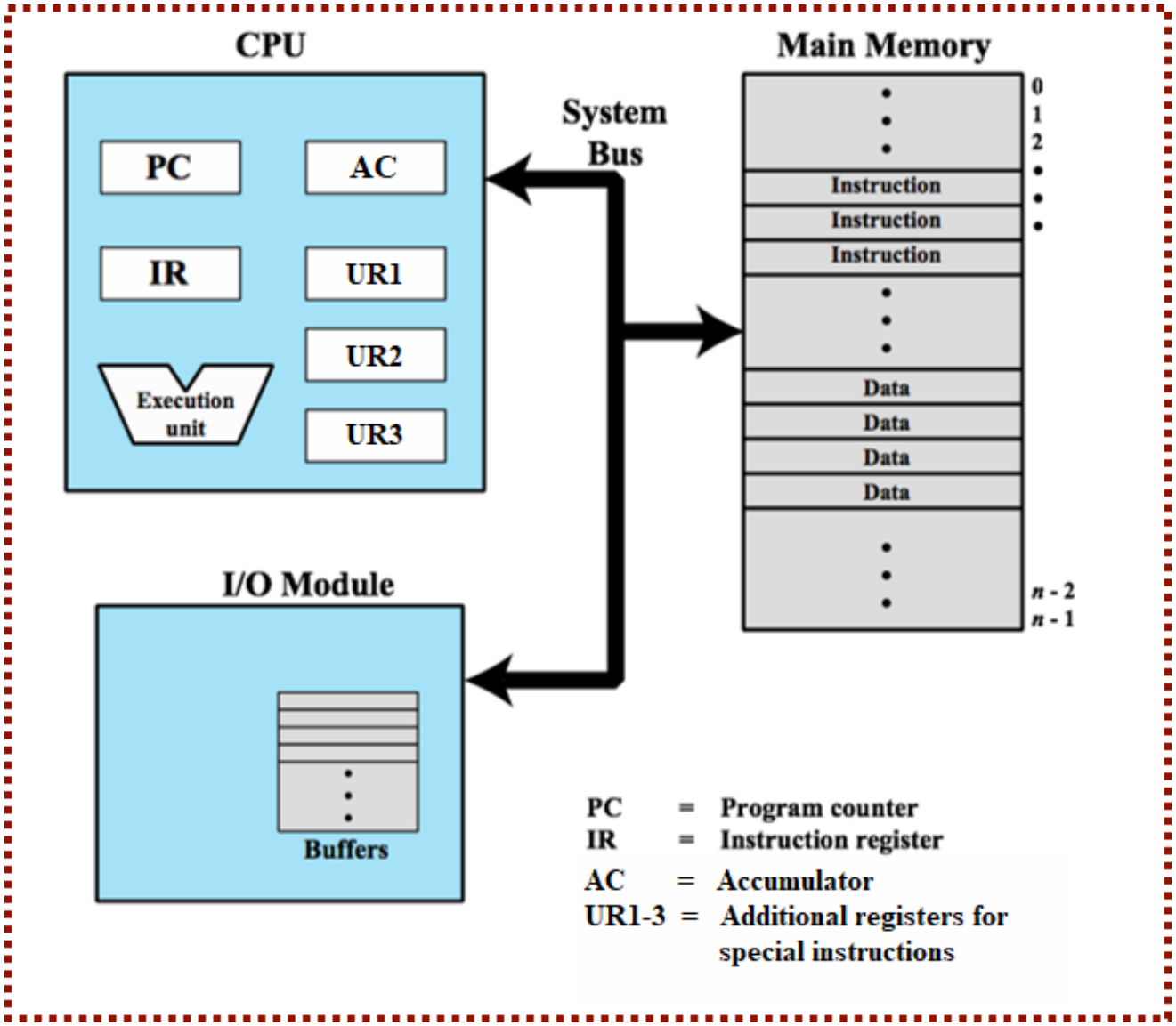
Program counter (PC) = Address of instruction
Instruction register (IR) = Instruction being executed
Accumulator (AC) = Temporary storage

**(c) Internal CPU registers**

0001 = Load AC from memory
0010 = Store AC to memory
0101 = Add to AC from memory

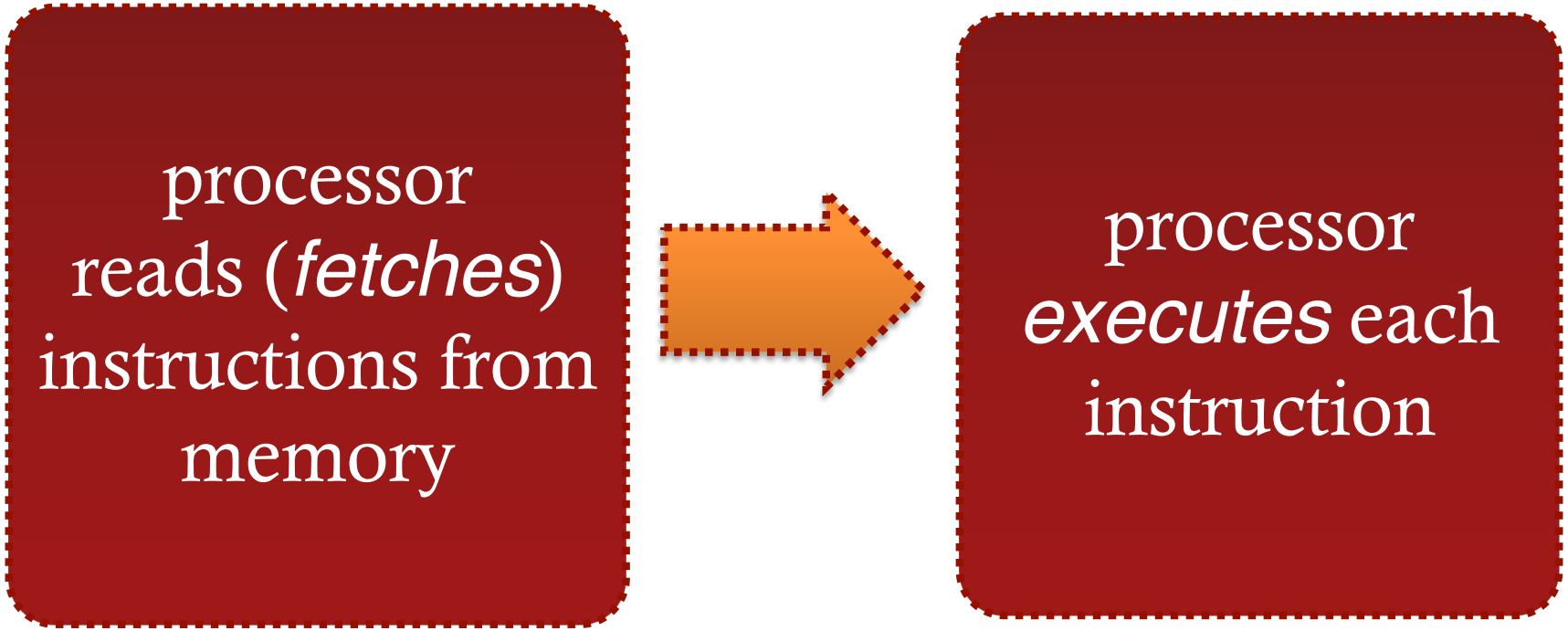
**(d) Partial list of opcodes**

# Computer Components: Top-level View



# Instruction Execution: Two Steps

- A program consists of a set of instructions stored in memory



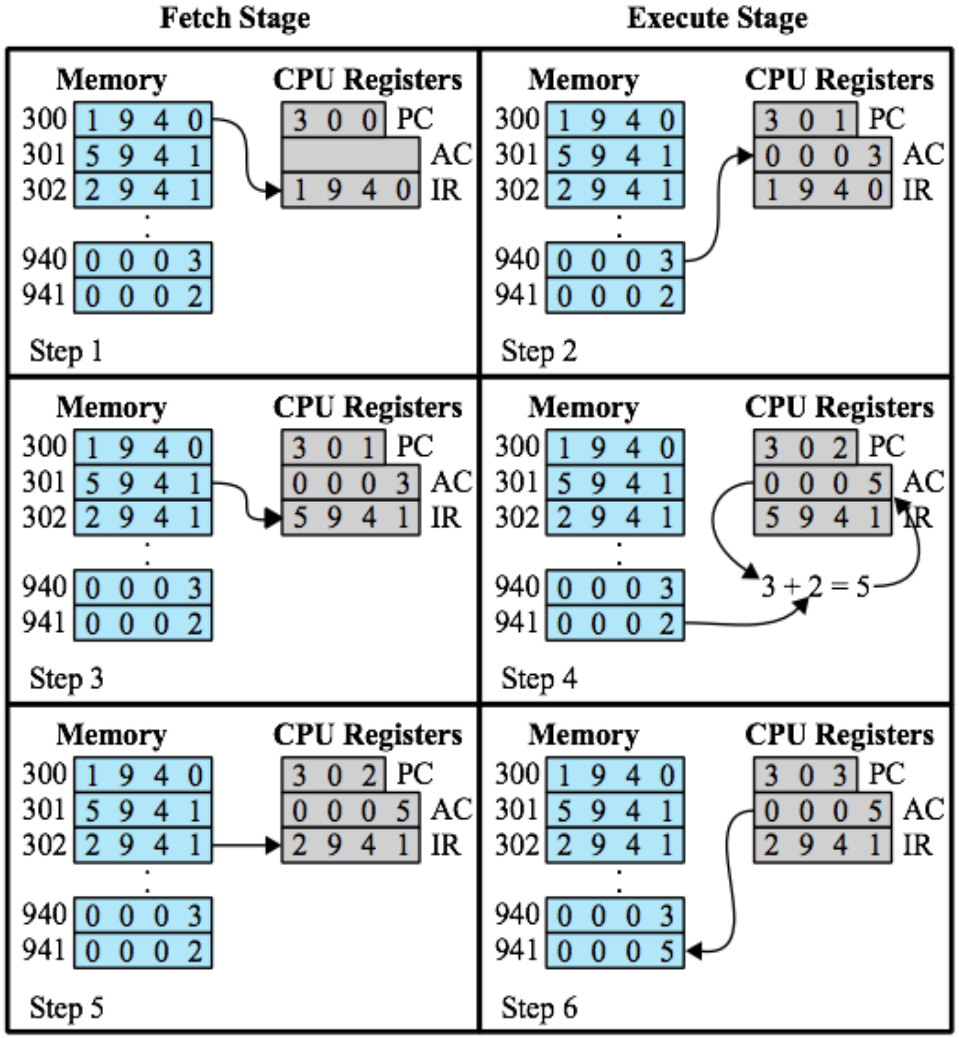
# Fetch Stage

- The processor fetches the instruction from memory
- Program Counter (PC) holds address of the instruction to be fetched next
- PC is incremented after each fetch in order to fetch the next instruction

# Execute Stage

- Fetched instructions are loaded into Instruction Register (IR)
- The processor interprets the instruction and performs the required action
- Four categories of actions:
  - Processor-memory (load and store instructions)
  - Processor-I/O (system calls)
  - Data processing (arithmetic and logical operations)
  - Control (flow of execution)

# Example: Program Execution




| Opcode | | Action |
|---|---|---|
| 0001 | **1** | Load to AC |
| 0010 | **2** | Store in AC |
| 0101 | **5** | Add to AC from RAM |

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# What are interrupts?
# Why a processor uses interrupts

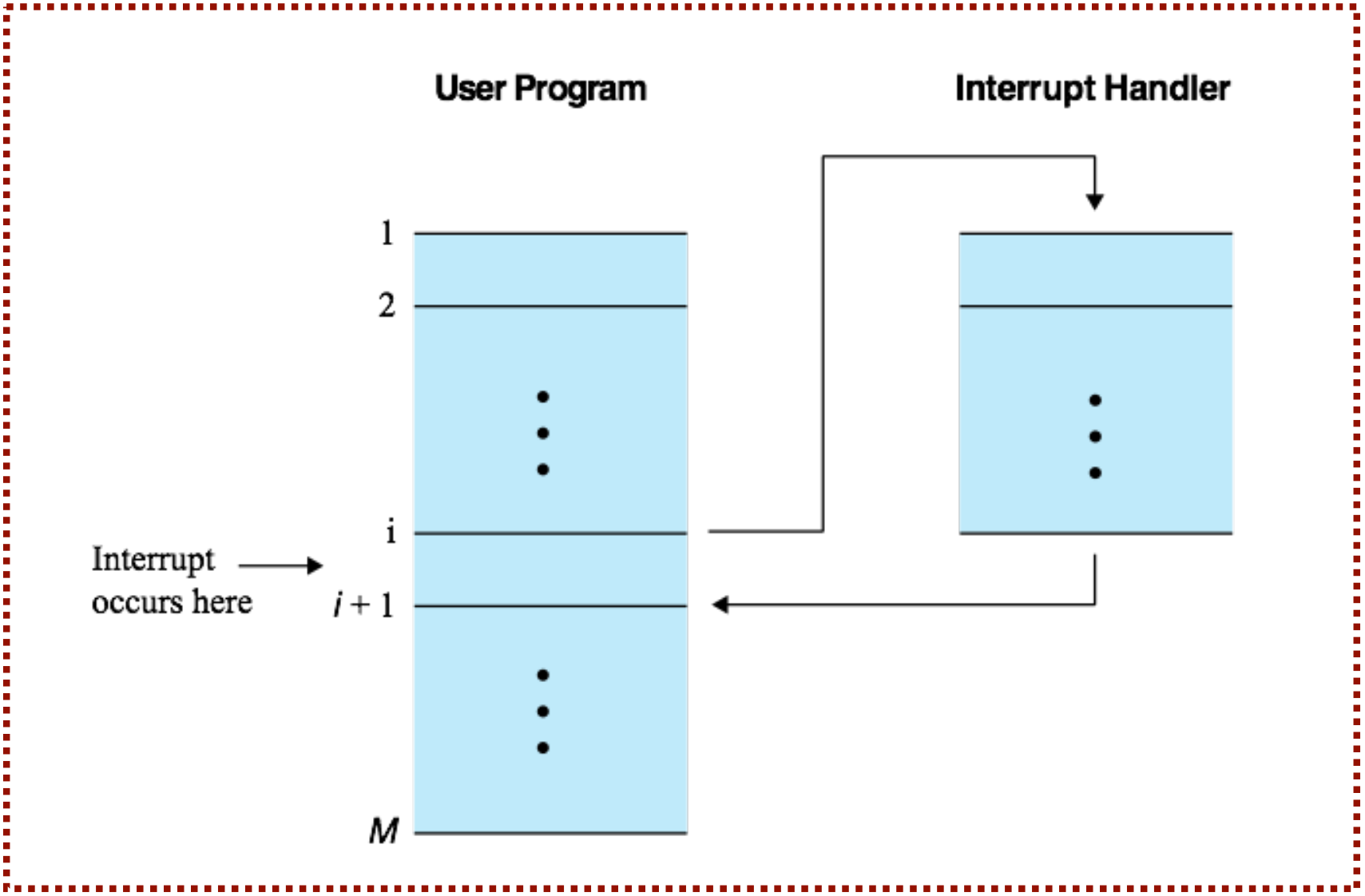
# Interrupts

- Mechanisms where the normal sequencing of the processor can be interrupted
- Provided to improve processor utilisation
- Most I/O devices are slower than the processor
  - Processor must pause to wait for the I/O device to complete its operation
  - Wasteful use of the processor

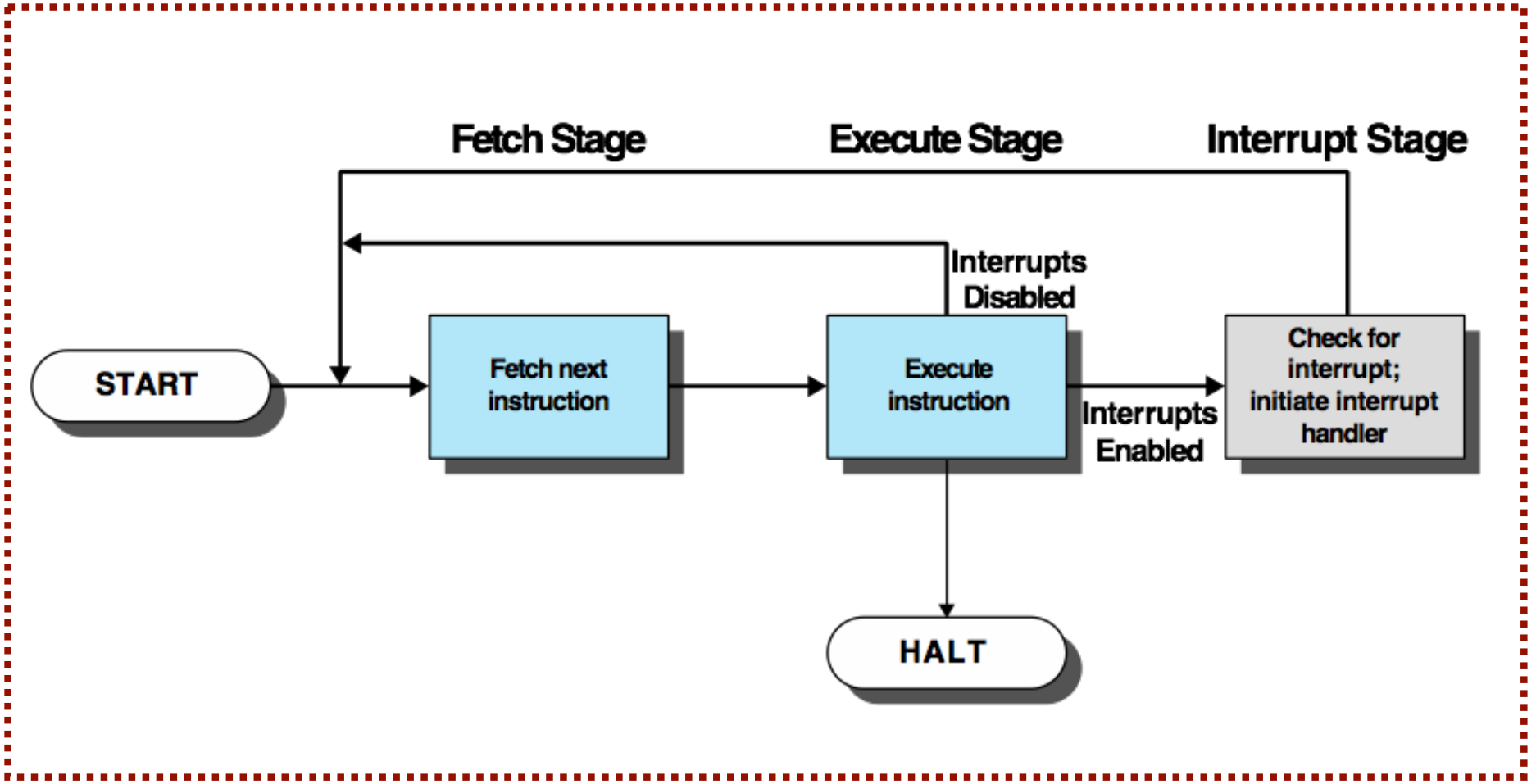
# Common Classes of Interrupts

| | |
|---|---|
| **Program** | Generated by some condition that occurs as a result of an instruction execution, attempt to execute an illegal machine instruction, and reference outside a user's allowed memory space. |
| **Timer** | Generated by a timer within the processor. This allows the operating system to perform certain functions on a regular basis. |
| **I/O** | Generated by an I/O controller, to signal normal completion of an operation or to signal a variety of error conditions. |
| **Hardware** | Generated by a failure, such as power failure or data corruption. |

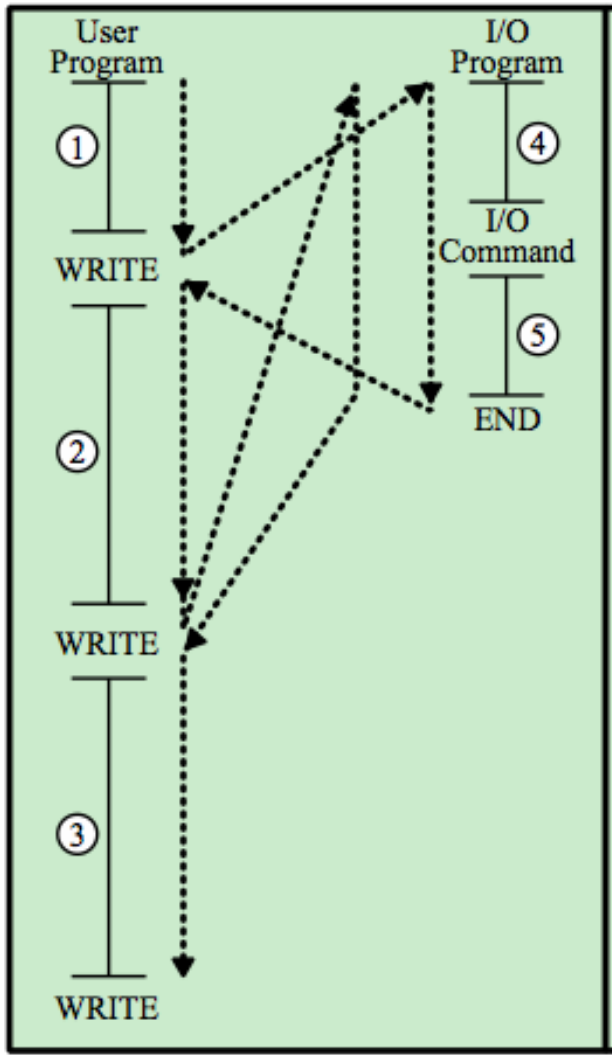
# Interrupts: Transfer of Control



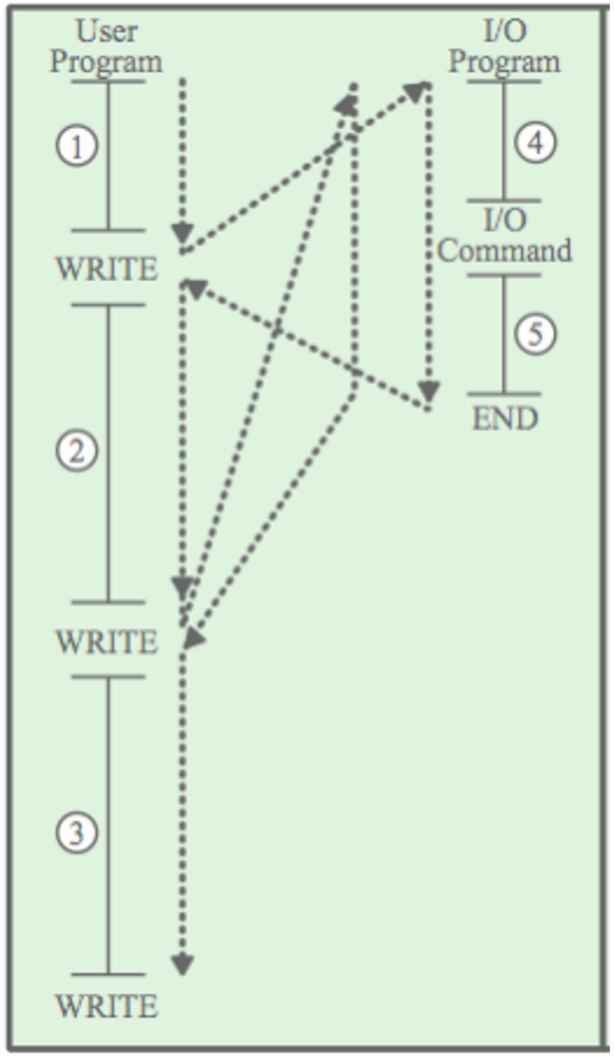
# Instruction Cycle: With Interrupts

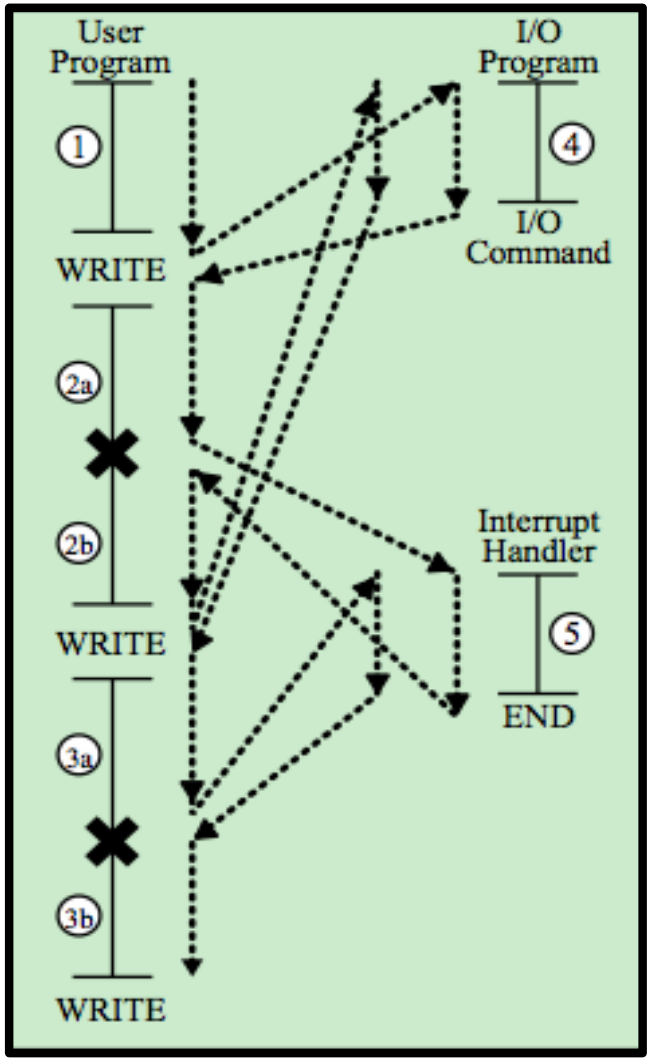


# Flow of Control: Without Interrupts

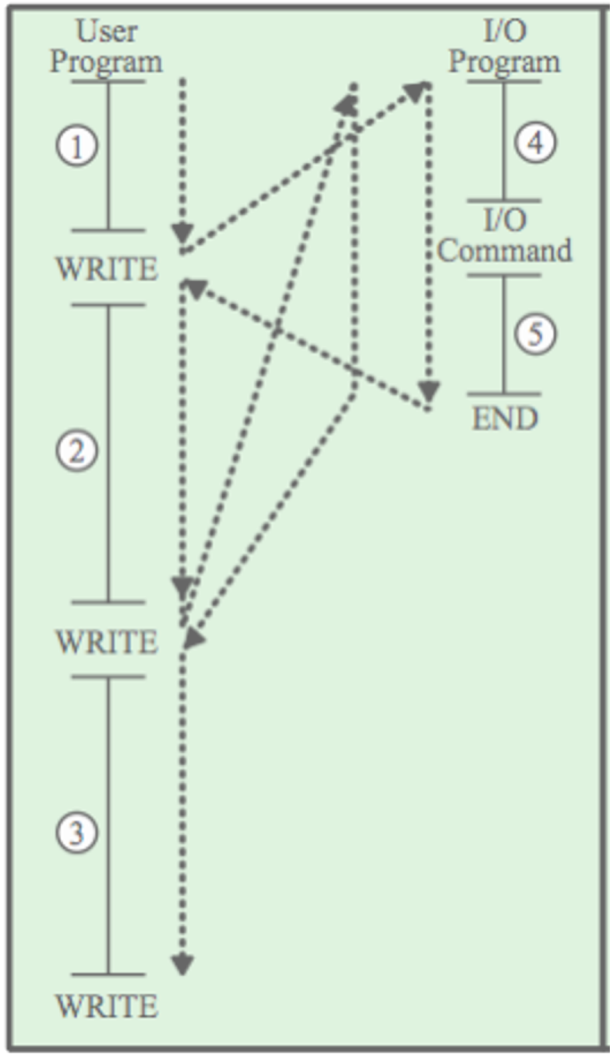


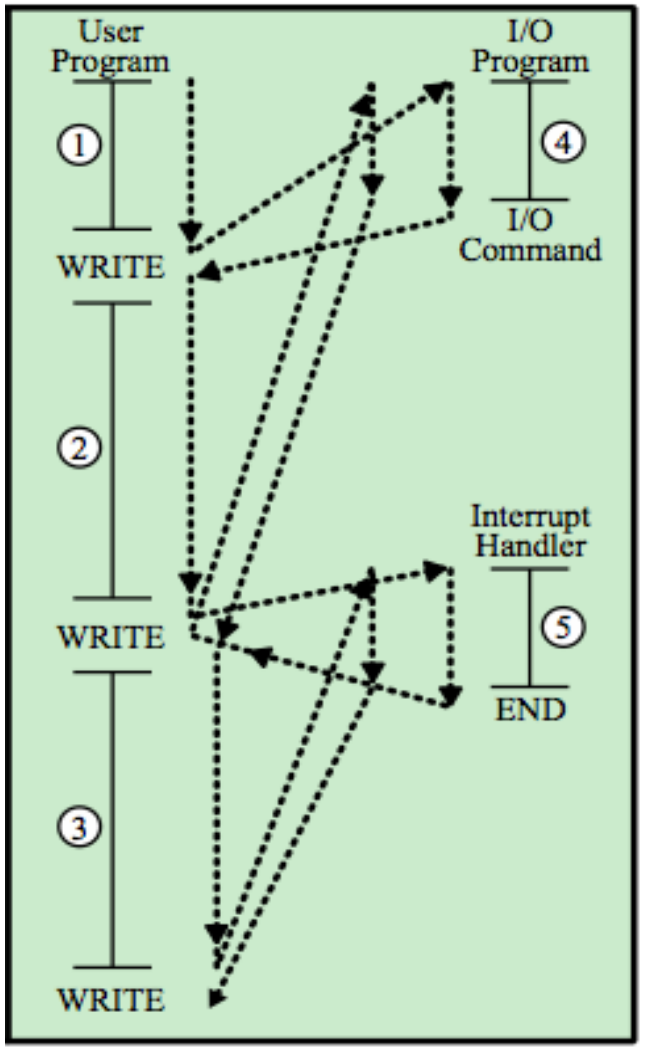
# Flow of Control: Short I/O Wait



# Flow of Control: Long I/O Wait



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We now know the rules of RAM.
What are the design constraints?

# Computer Memory

- Major constraints in a computer memory:
  - Amount (capacity)
  - Speed (access time)
  - Expense (cost)
- Memory must be able to keep up with the processor
- Cost of memory must be reasonable in relationship to other components

# Memory Relationships

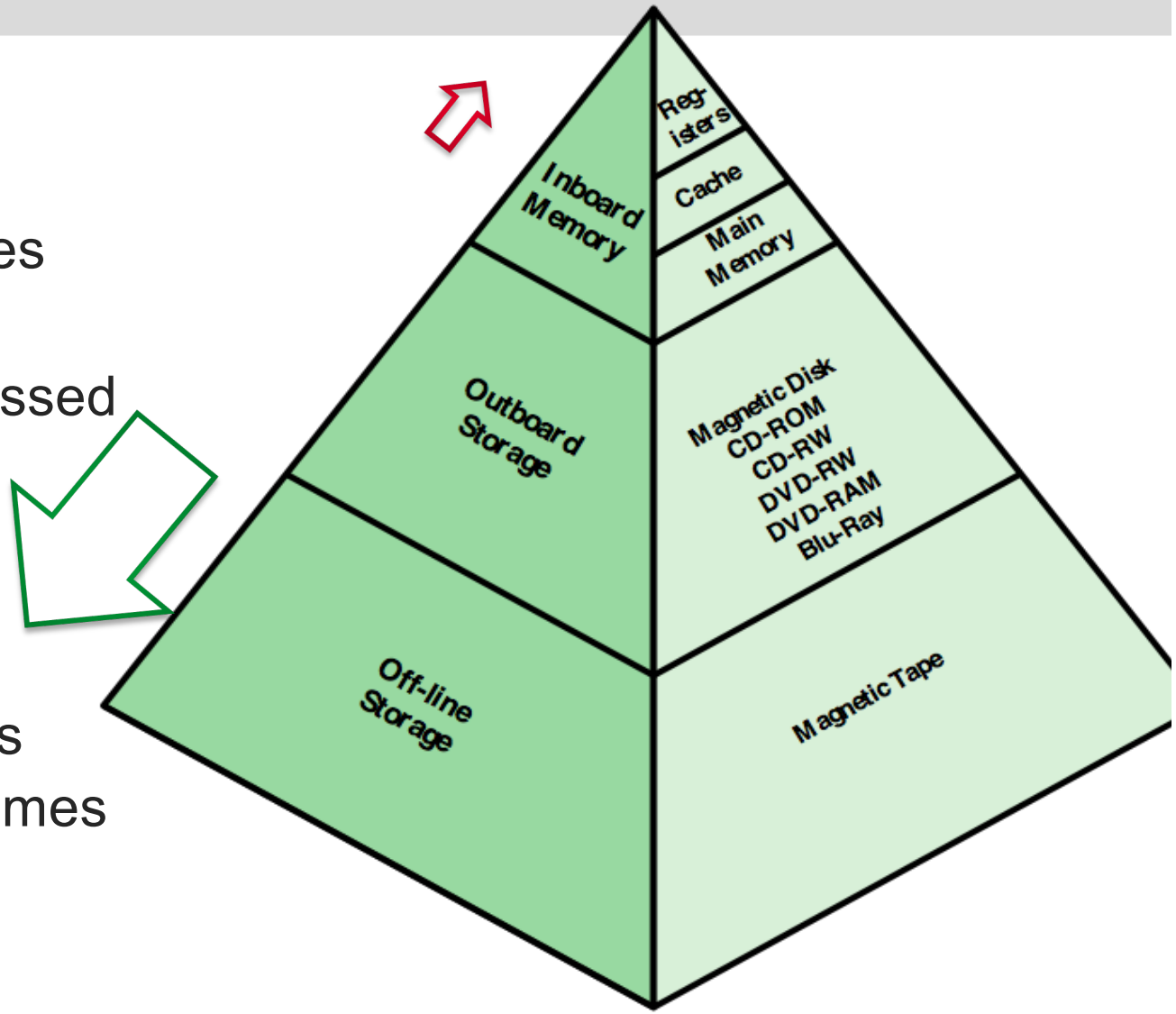
Faster access time = greater cost per bit

Greater capacity = smaller cost per bit

Greater capacity = slower access speed

# Memory Hierarchy

- **Closer to the CPU:**
  - Fast access times
  - Small capacity
  - Frequently-accessed data
- **Moving down the hierarchy:**
  - Cheaper per bit
  - Bigger capacities
  - Slower access times
  - Less frequently accessed



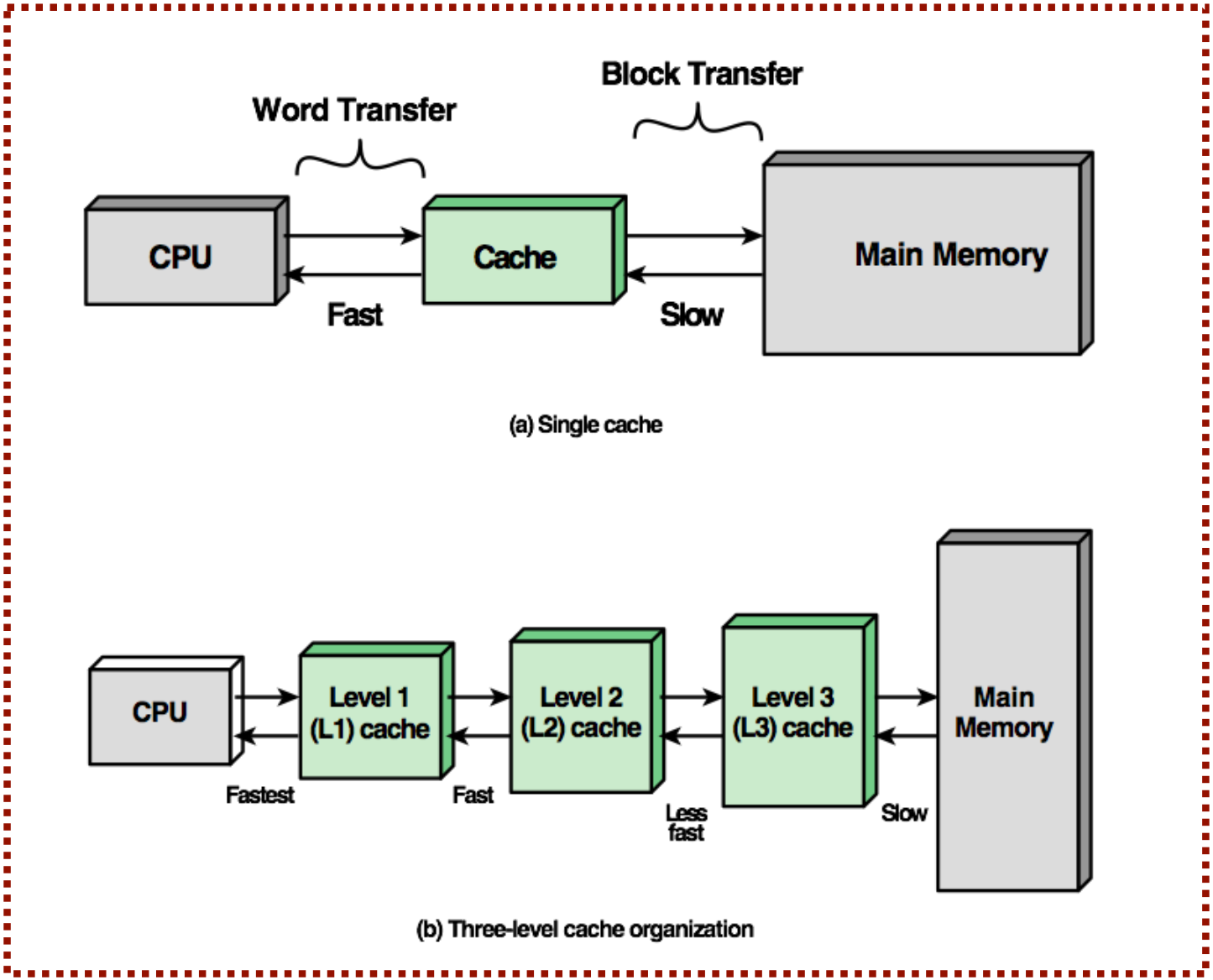
# Principle of Locality

- Memory references by the processor tend to cluster
- Data is organised so that the percentage of accesses to each successively lower level is substantially less than that of the level above
- Can be applied across more than two levels of memory
  - Registers (fastest, smallest, most expensive)
  - Main memory (slower, larger, less expensive, *volatile*)
  - Secondary memory (slowest, much larger, least expensive, *non-volatile*)

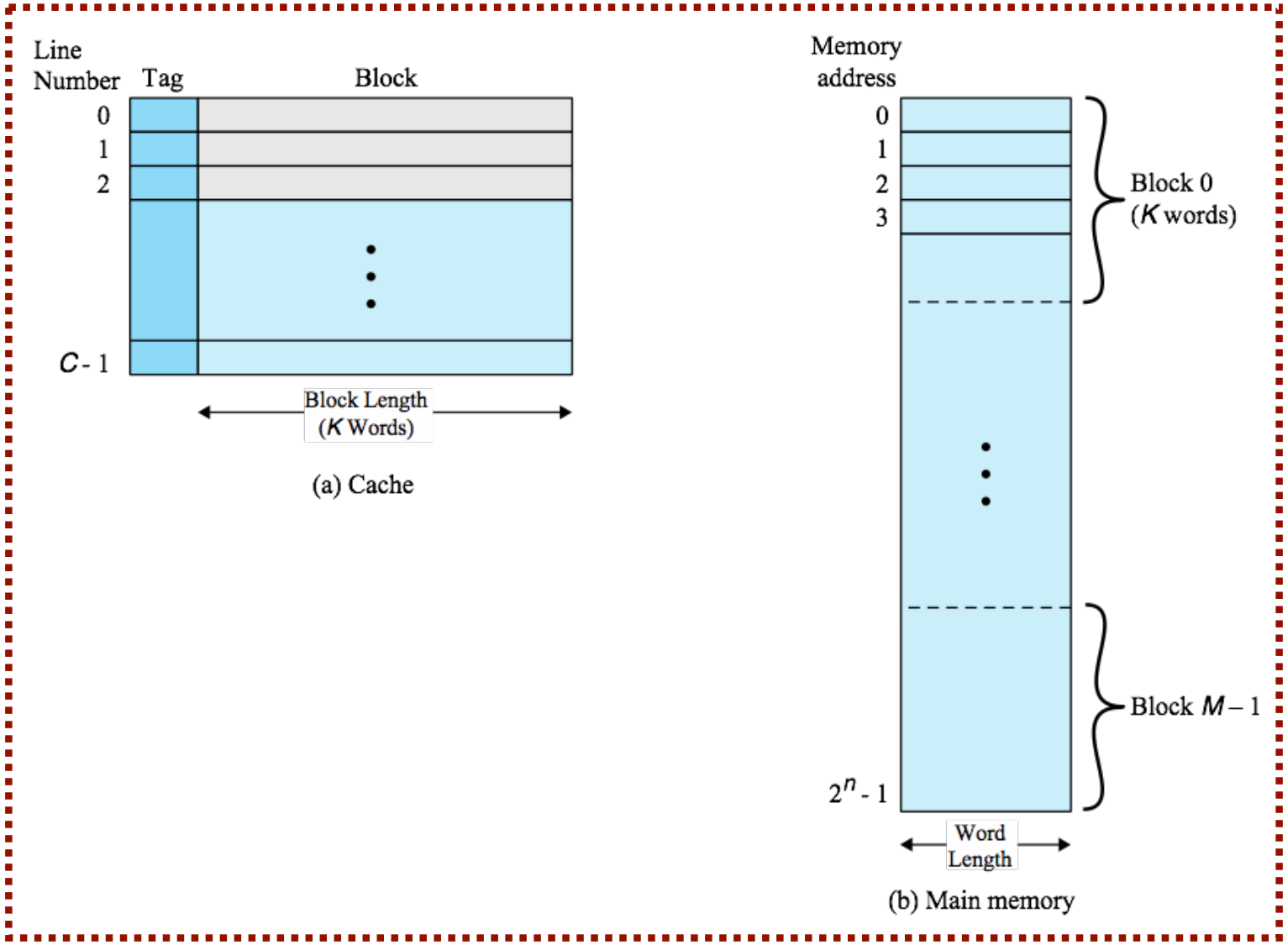
# Cache Memory

- Cache contains a copy of portion of main memory
- Exploit the principle of locality with a small, fast memory
  - Because of locality of reference, it is likely that many of the future memory references will be to other bytes within the block
- Processor first checks the cache
  - If not found, a block of main memory is read into the cache

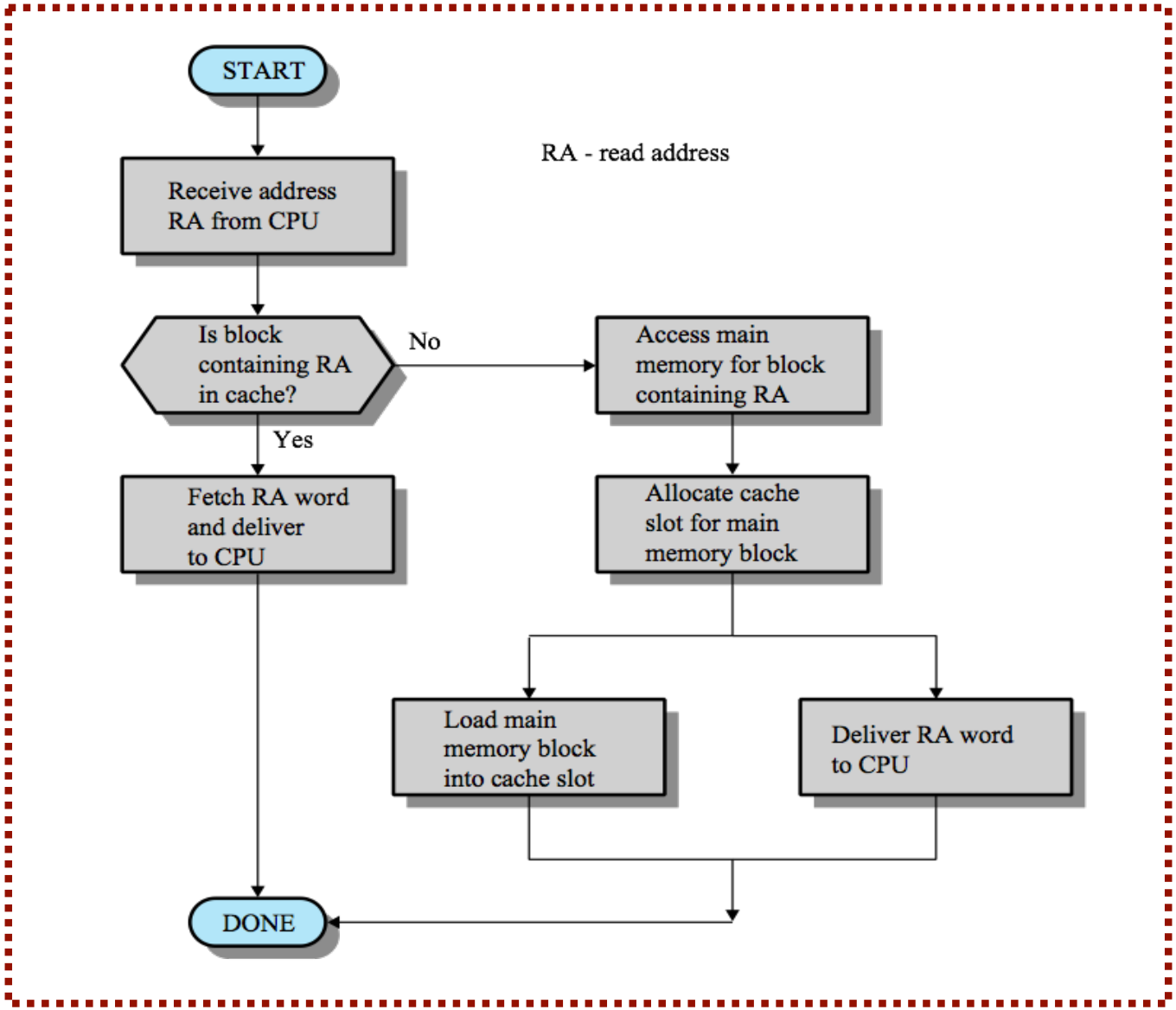
# Cache Memory vs Main Memory



# Structure: Cache Memory vs Main Memory



# Cache: Read Operation



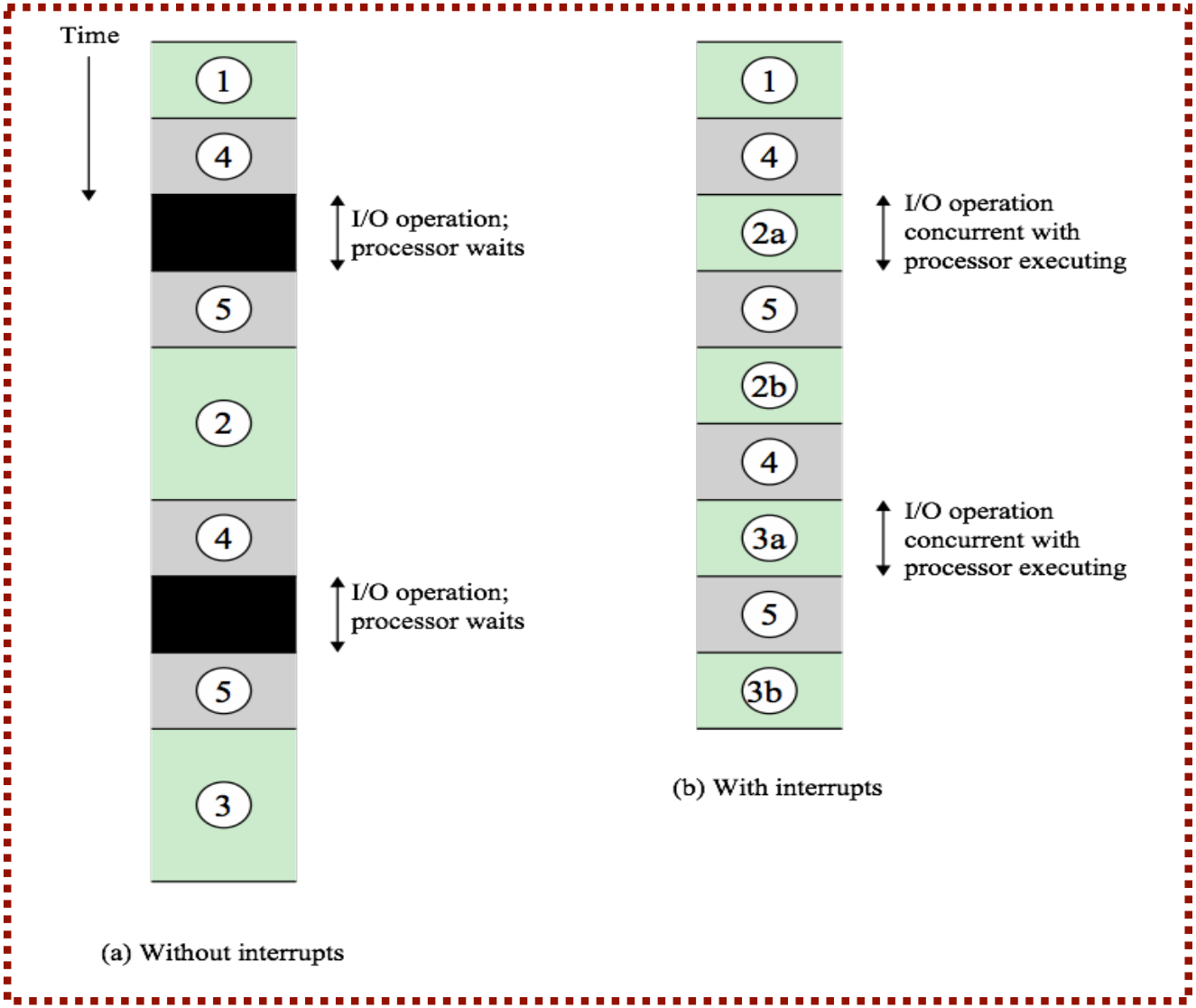
# Lecture 1: Summary

- So far, we have discussed:
  - Basic elements of a computer system
  - Instruction execution cycle
  - Interrupts and interrupt processing
  - Memory hierarchy and cache memory
  - Some rules of the game
- Next week:
  - Overview of operating systems
- Reading:
  - Stallings, Chapter 1 (9th or 8th Edition)

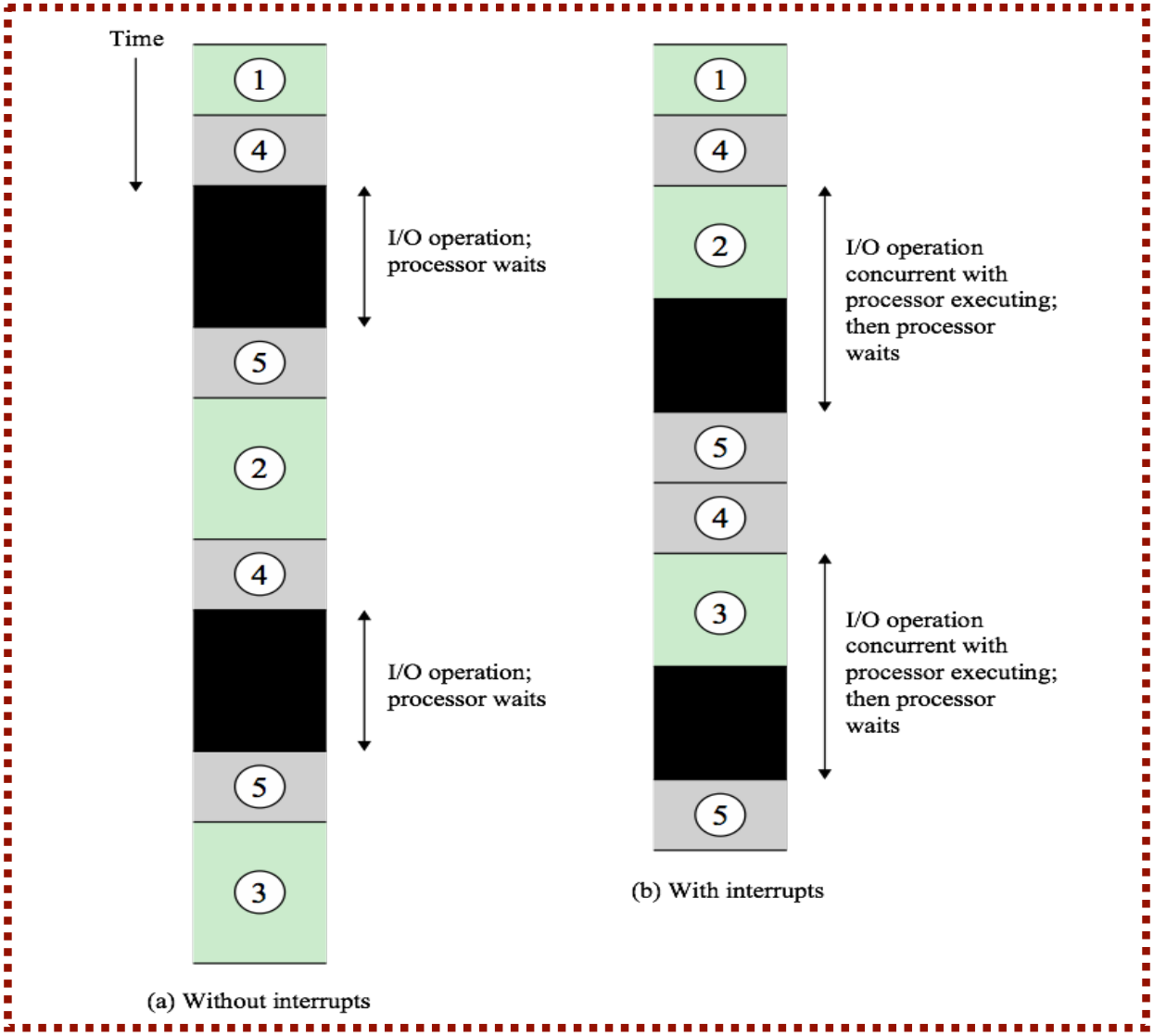
Reminder: Tutorials this week. Practicals next week.

# Supplementary slides

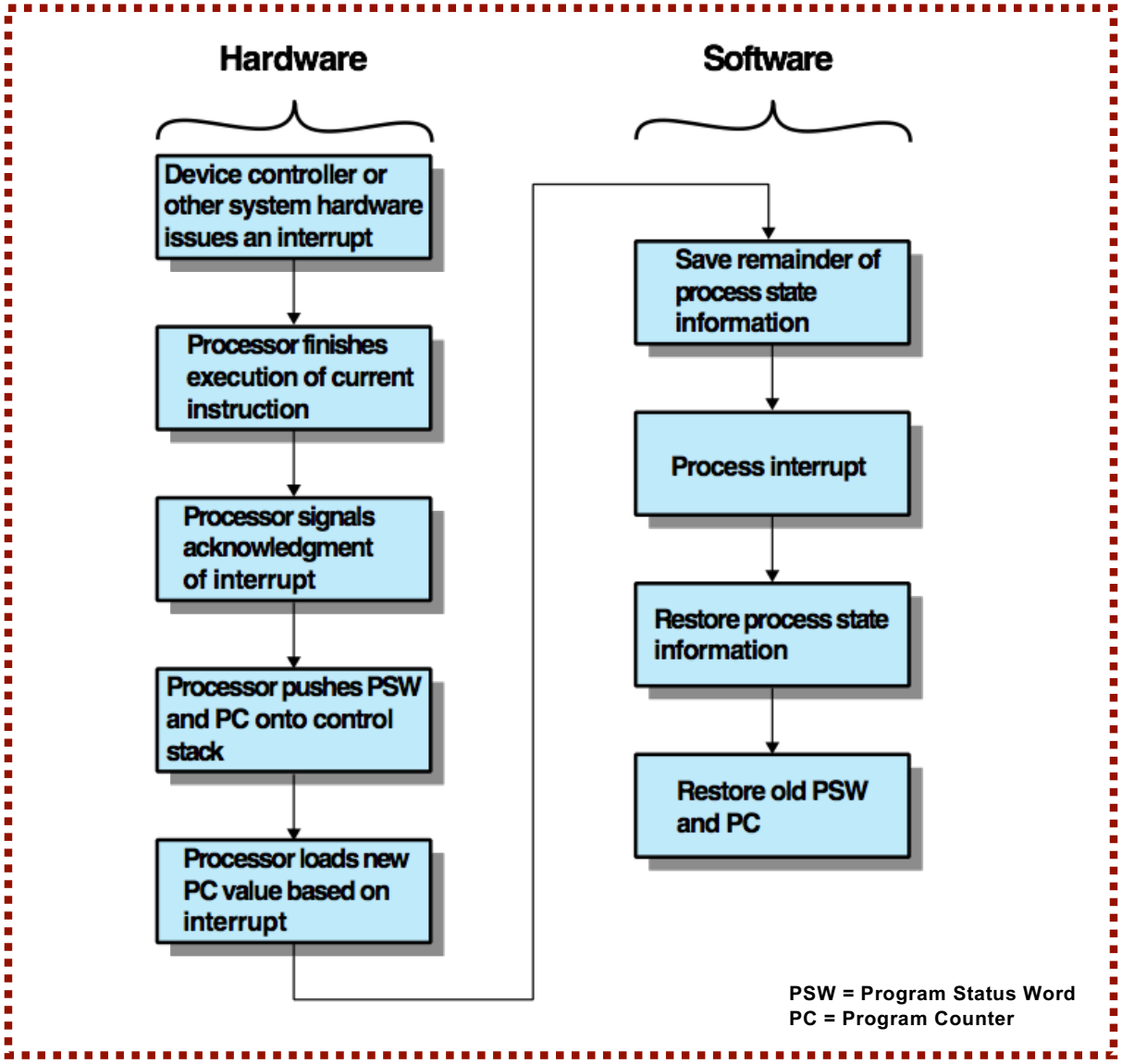
# Program Timing: Short I/O Wait



# Program Timing: Long I/O Wait



# Simple Interrupt Processing

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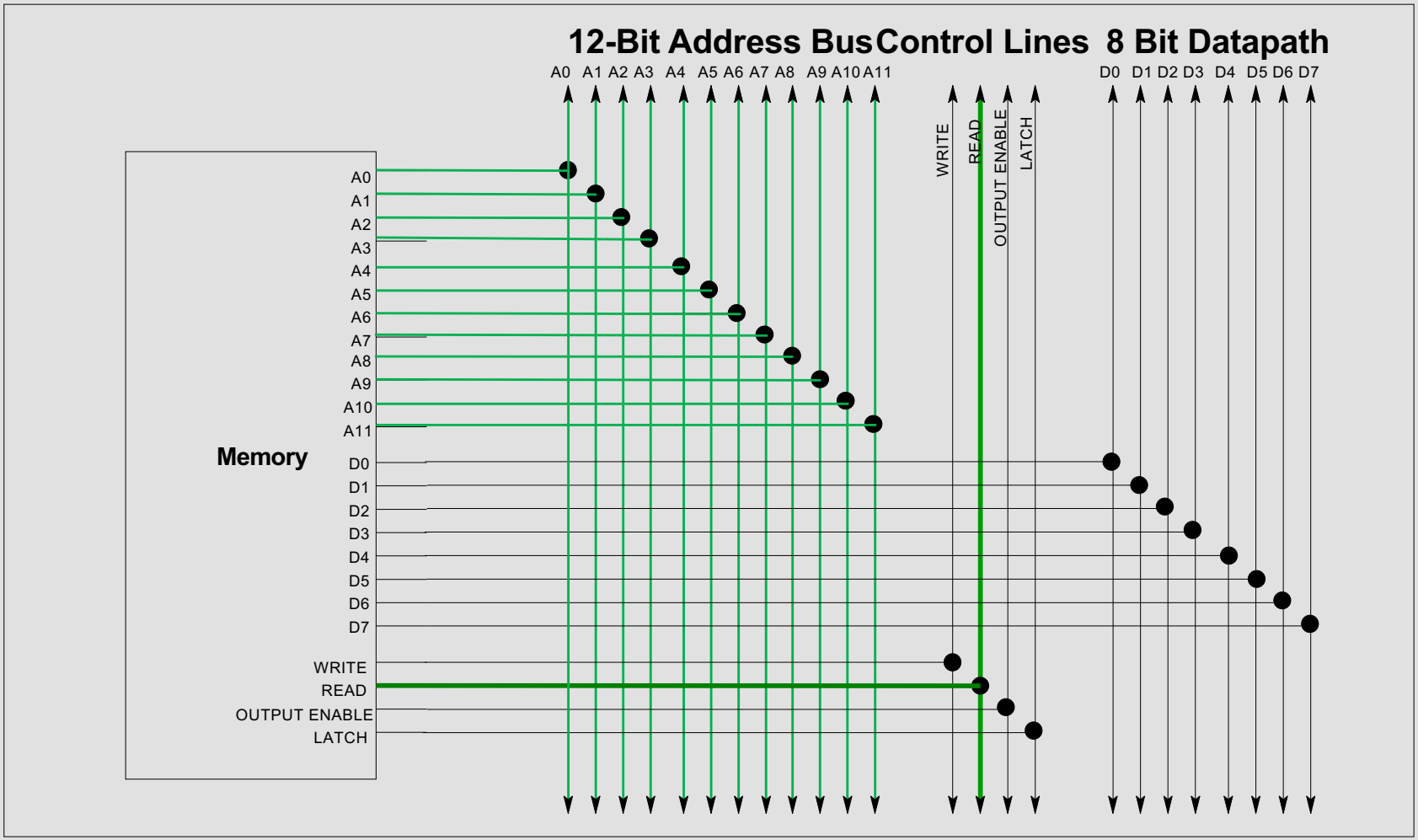
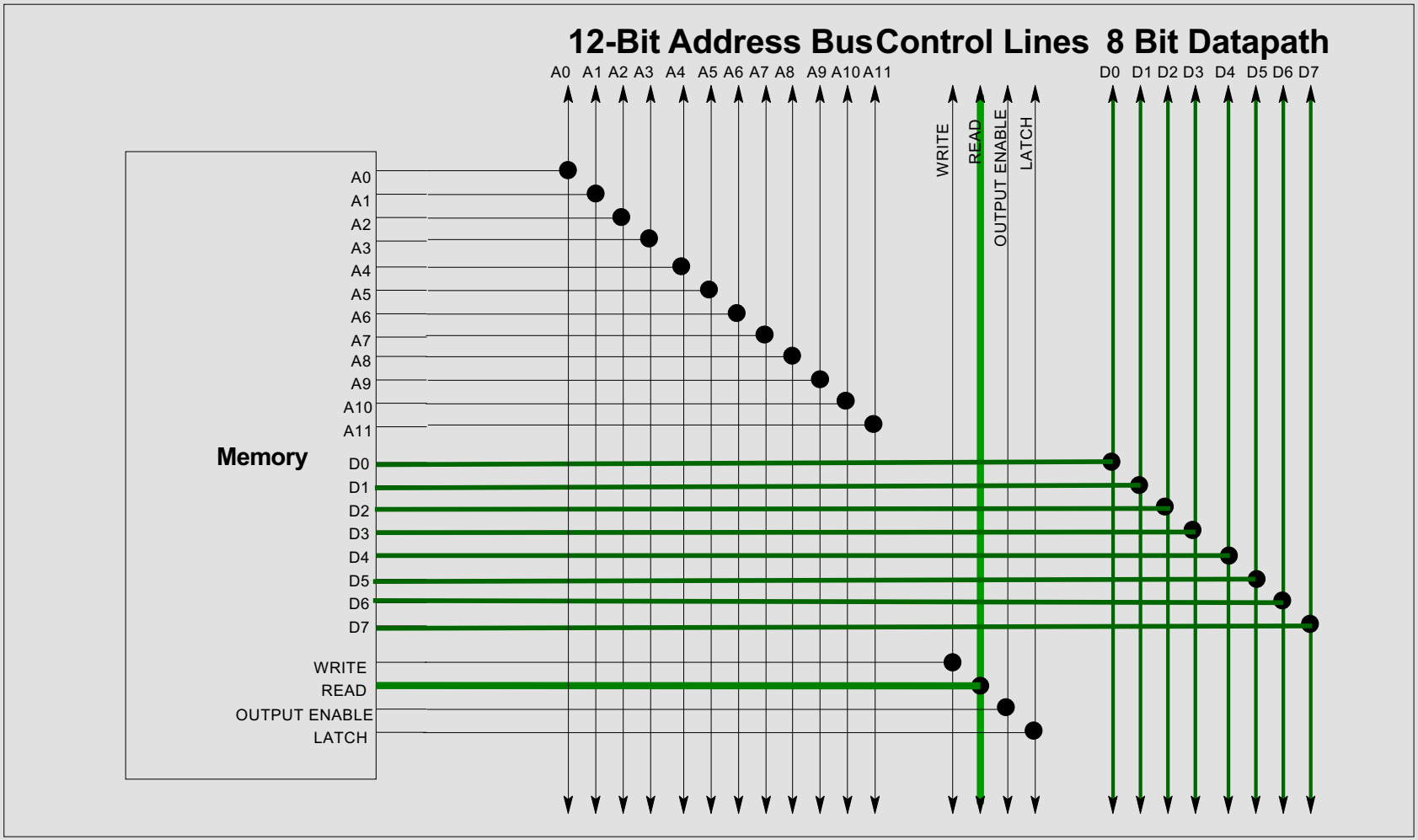
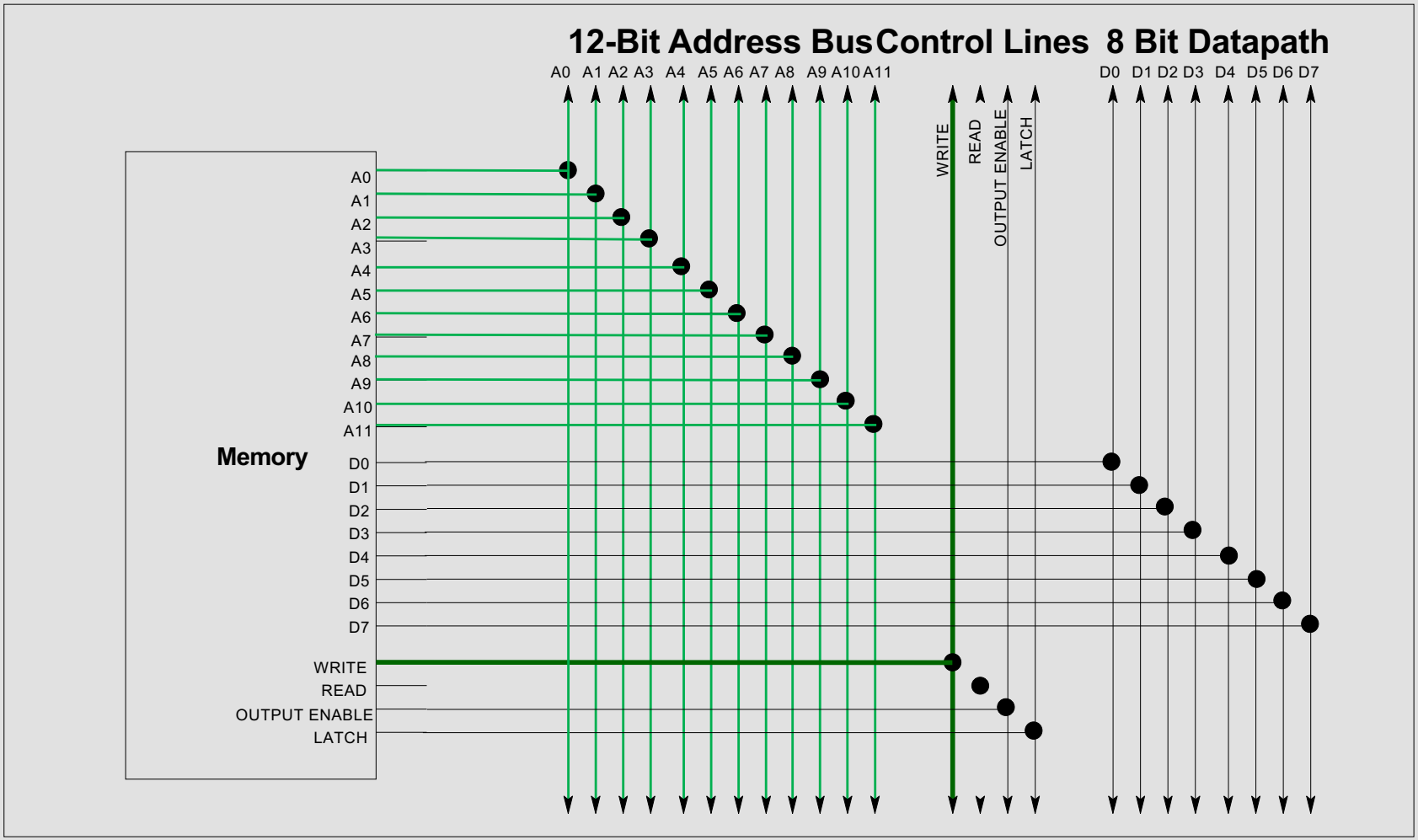
# Reading: Assert Read Address and Control



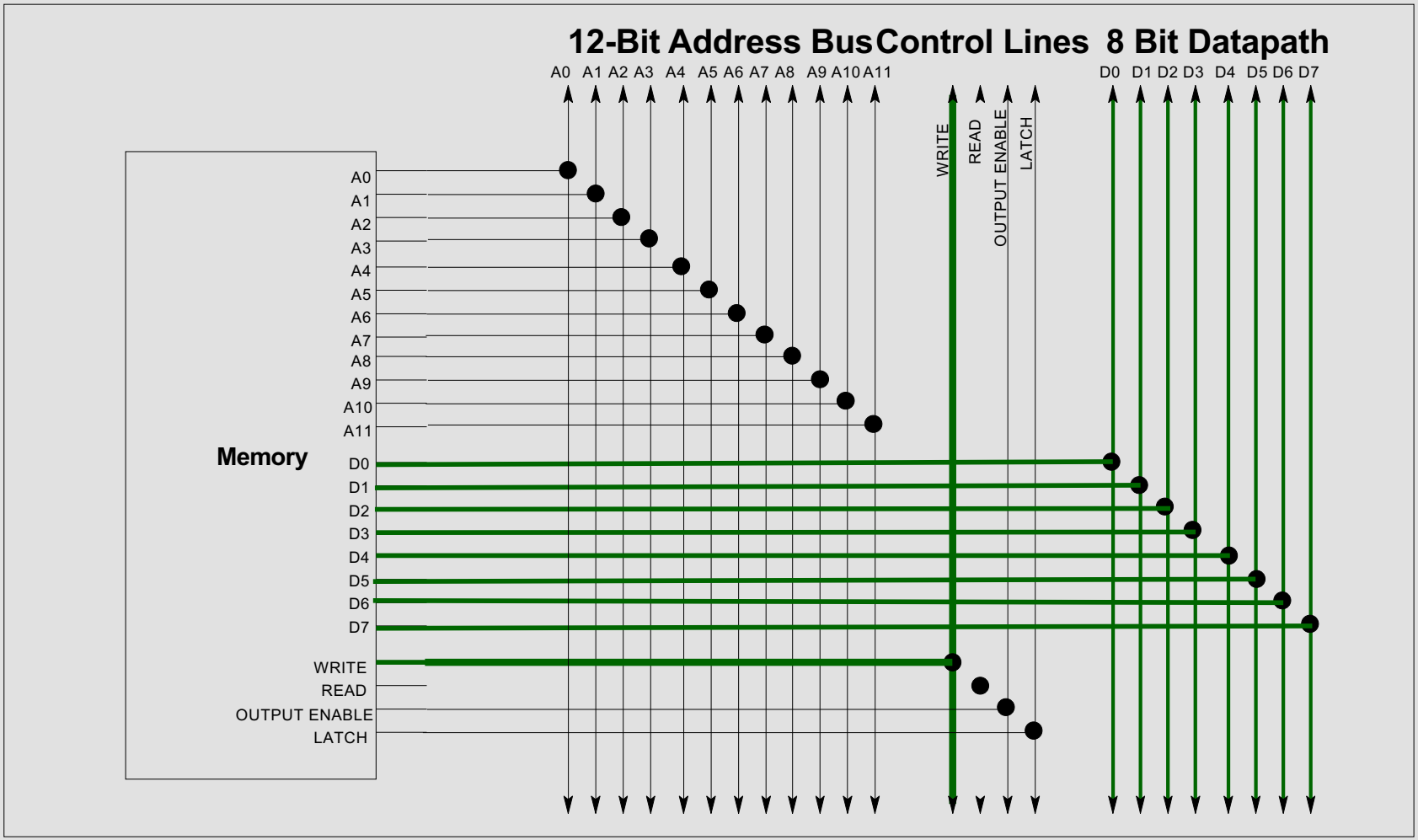
# Reading From Memory: Obtain Read Data



# Writing: Assert Write Address and Control



# Writing: Assert Write Data



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# HEY, THAT WAS WEIRD

## WE ARE NOW BACK IN FIT2100

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