Chapter 4

Computer Programs and the Program Execution Process

Outline

- Computer Programs and program execution
- Computer Program execution process and the CPU
- The Operating System Functions and components
- About Programming languages

Program

- **The behaviour of the computer is controlled by a set of step-by-step instructions called program.**
- **Everything interesting or useful about a computer behaviour results from its program rather than the hardware it carries it.**
- **The computer processes information by executing a program stored in memory.**
- **The execution takes place with in the CPU and is controlled by the CU.**

Program Execution

- The operating system reads the program into memory
  - adds it to a list of programs that want to execute
- It gives it a time slice of the CPU
  - adds it to a list of programs that are executing
- It saves the current state of the CPU when it gives another program a time slice of the CPU
  - Context switching
- It can restore the state of the CPU

Program Execution

- Executing a program requires the CPU to examine each program instruction and send out the command signals required to perform each instruction.
- Although instructions are normally performed consecutively (in sequence), they can be skipped (branched) or repeated (loop) under program control. (control structures)
- During execution, data can be entered by the operator (user), from a saved file, or from memory.
- After processing, the program output can be displayed or printed as a result.

When you double click on an icon to run a program, here is what happens:

1. The program, which is stored inside the hard disk drive, is transferred to the RAM memory.
2. The CPU, using a circuit called memory controller, loads the program data from the RAM memory as directed by the OS. A program is a series of instructions to the CPU.
3. The data, now inside the CPU, is processed.
4. What happens next will depend on the program. The CPU could continue to load and execute the program or could do something with the processed data, like displaying something on the screen.

The sequence of CPU steps can be expressed in pseudocode:

loop

fetch the instruction pointed by (the value in) IP

advance the instruction pointer (IP)

decode the instruction

if memory operand needed, read value from memory

execute the instruction

if result is memory operand, write result to memory

continue loop

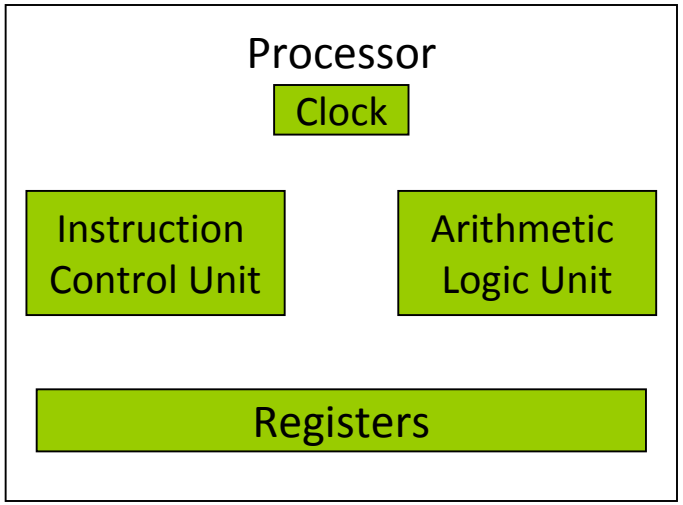


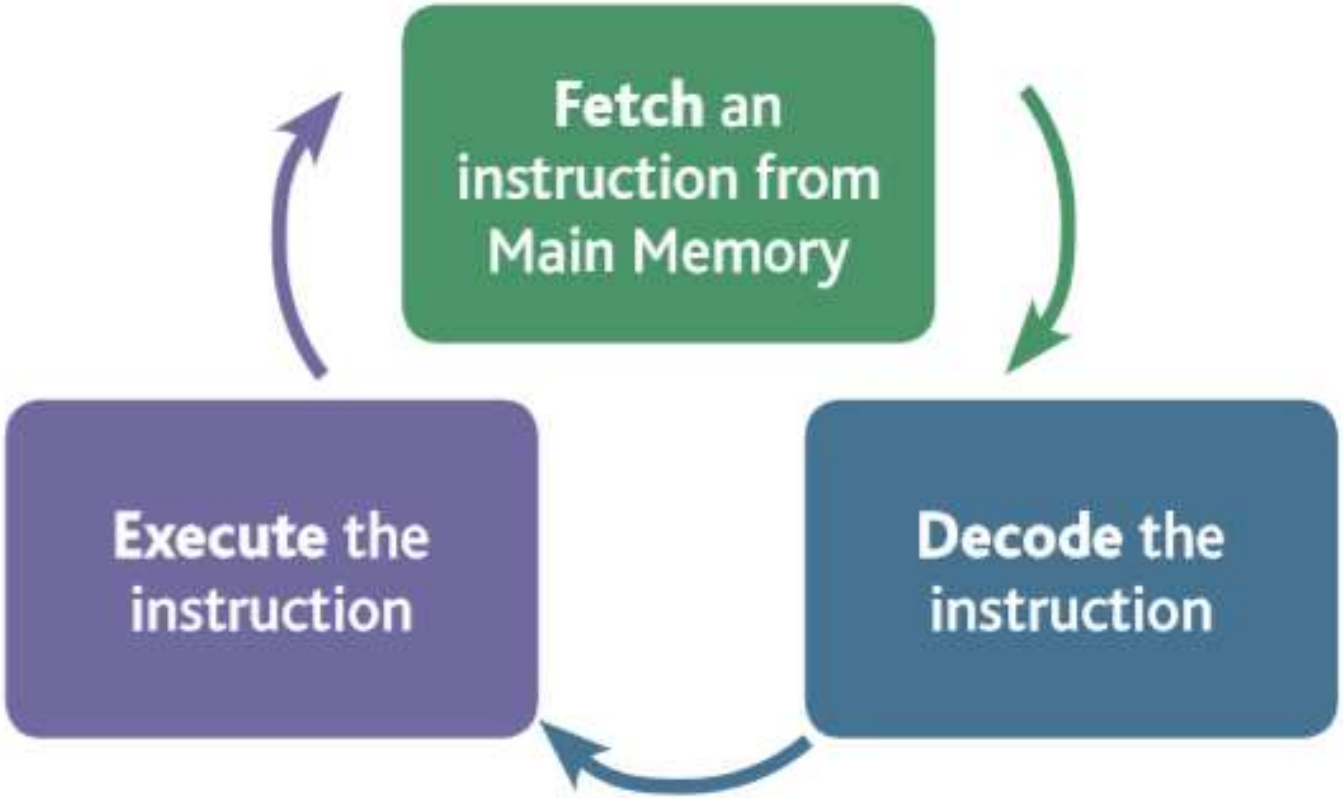
Table 5: List of simple CPU instructions.

Instruction	Description
`NOP`	No operation
`INPUT`	Load Input into A register
`OUTPUT`	Move A register to Output register
`JMP <addr>`	JMP to address <addr> in program memory
`LOAD A,#<value>`	Load <value> into the A register
`INC A`	Increment the value in register A by 1
`MOV B,A`	Move register A into register B
`ADD A,B`	Add register A to register B and store result in register A
`HALT`	Halt execution

The CPU

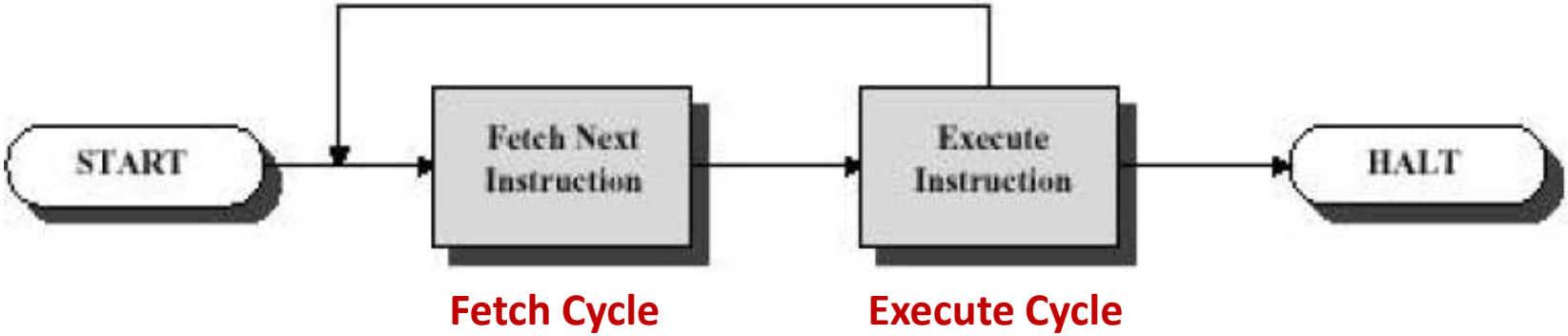
- **CPU = Central Processing Unit**
- **Internal clock ticks very fast (e.g., 2.6 GHz = 2.6 billion ticks per second)**
  - **activities are synchronized to start on a clock tick**
  - **some activities take more than one clock tick**
- **Instruction execution is automatic**
  - **(tick) find memory address of next instruction**
  - **(tick) retrieve instruction from memory**
  - **(tick) decode the instruction**
  - **(tick) fetch argument from memory if necessary**
  - **(tick) execute instruction**
  - **(tick) store result in memory if necessary**

The CPU Fetch-Execute Cycle



The CPU consists of a control unit, registers, the arithmetic and logic unit, the instruction execution unit, and the interconnections among these components.

- Processing required for a single instruction is called an instruction cycle (Fetch-Execute Cycle), and can be viewed as shown below: **2 Steps**

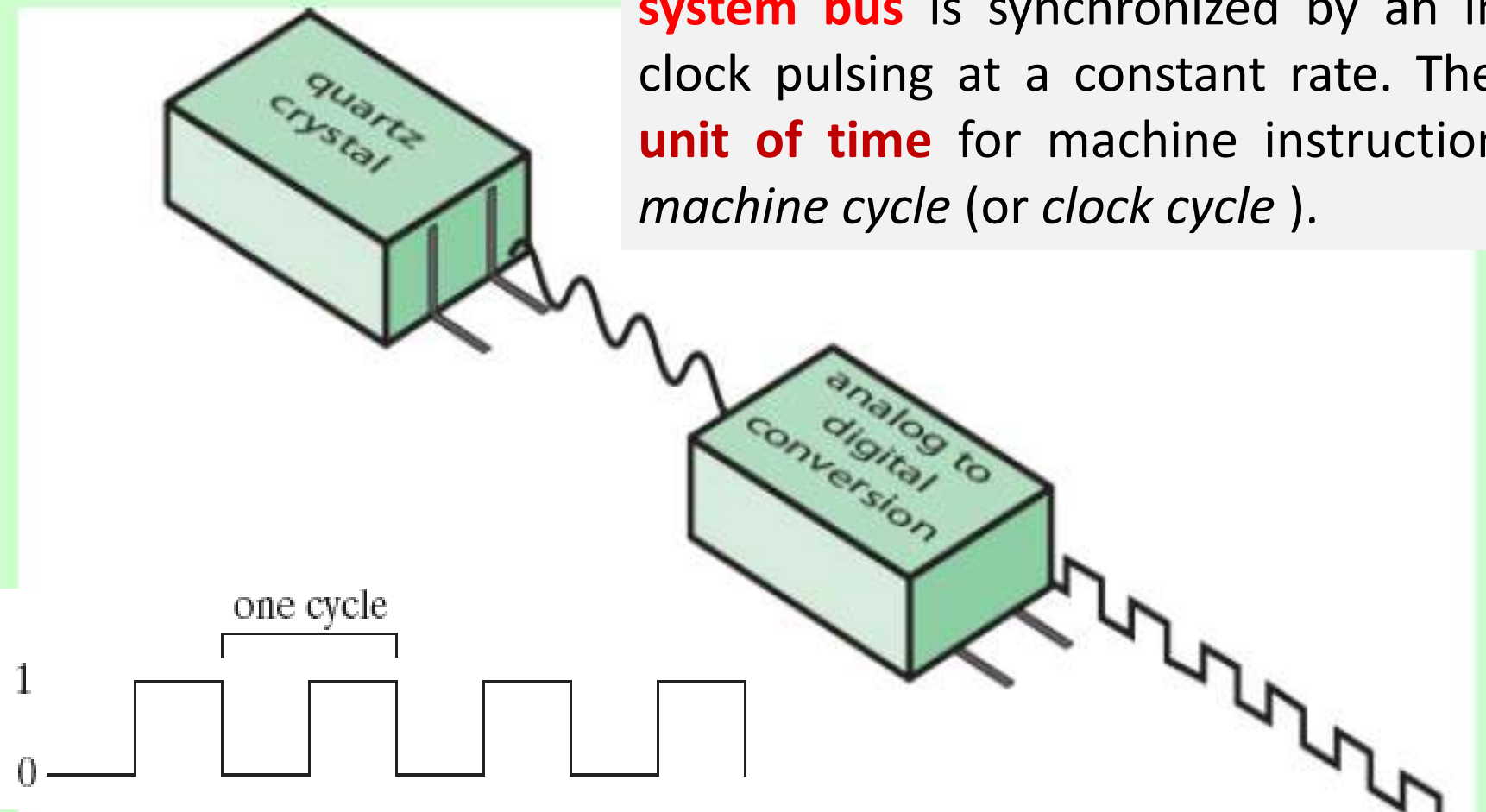


- Fetch – CPU(CU) reads an instruction from a location in memory and decodes the instruction (determine what it means)
  - Program counter (PC/Instruction Pointer) register keeps track of which instruction executes next
  - Normally, CPU increments PC after each fetch
  - Fetched instruction is loaded into the instruction register (IR)

- Execute - CPU executes the instruction
  - May involve several operations
  - May utilize previously changed state of CPU
  - General categories:
    - CPU-Memory: Data may be transferred from CPU to memory or vice-versa
    - CPU-IO: Data may be transferred between CPU and an I/O module
    - Data Processing: CPU (ALU) may perform some arithmetic or logic operation on the data
    - Control: An instruction may specify that the sequence of execution be altered

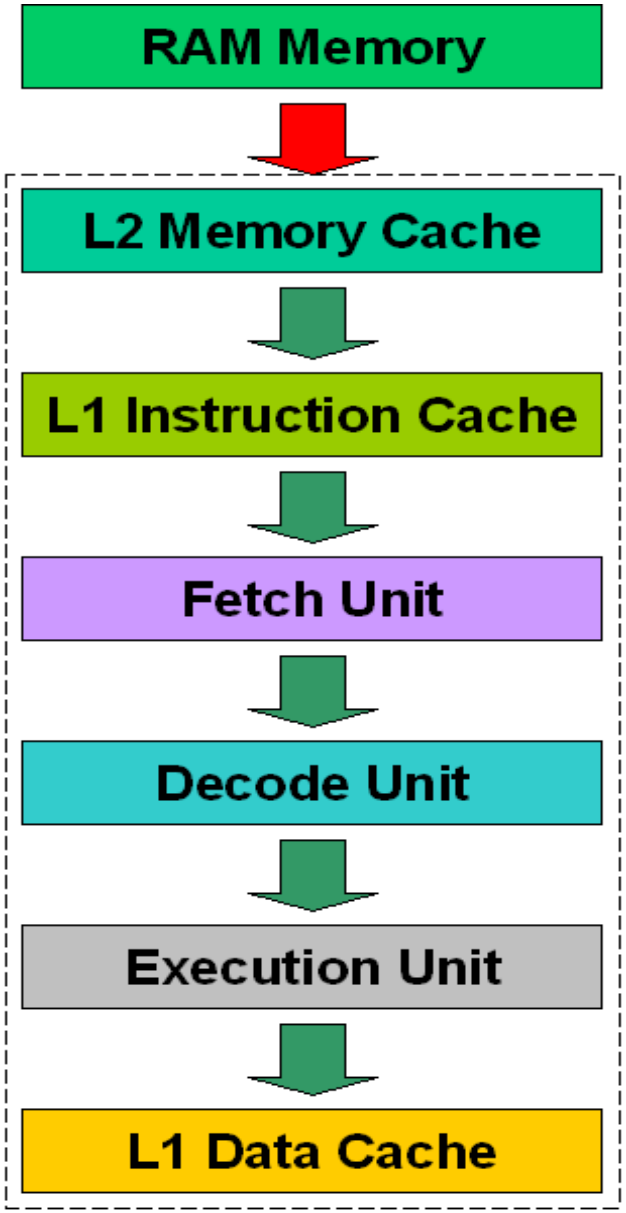
System Clock

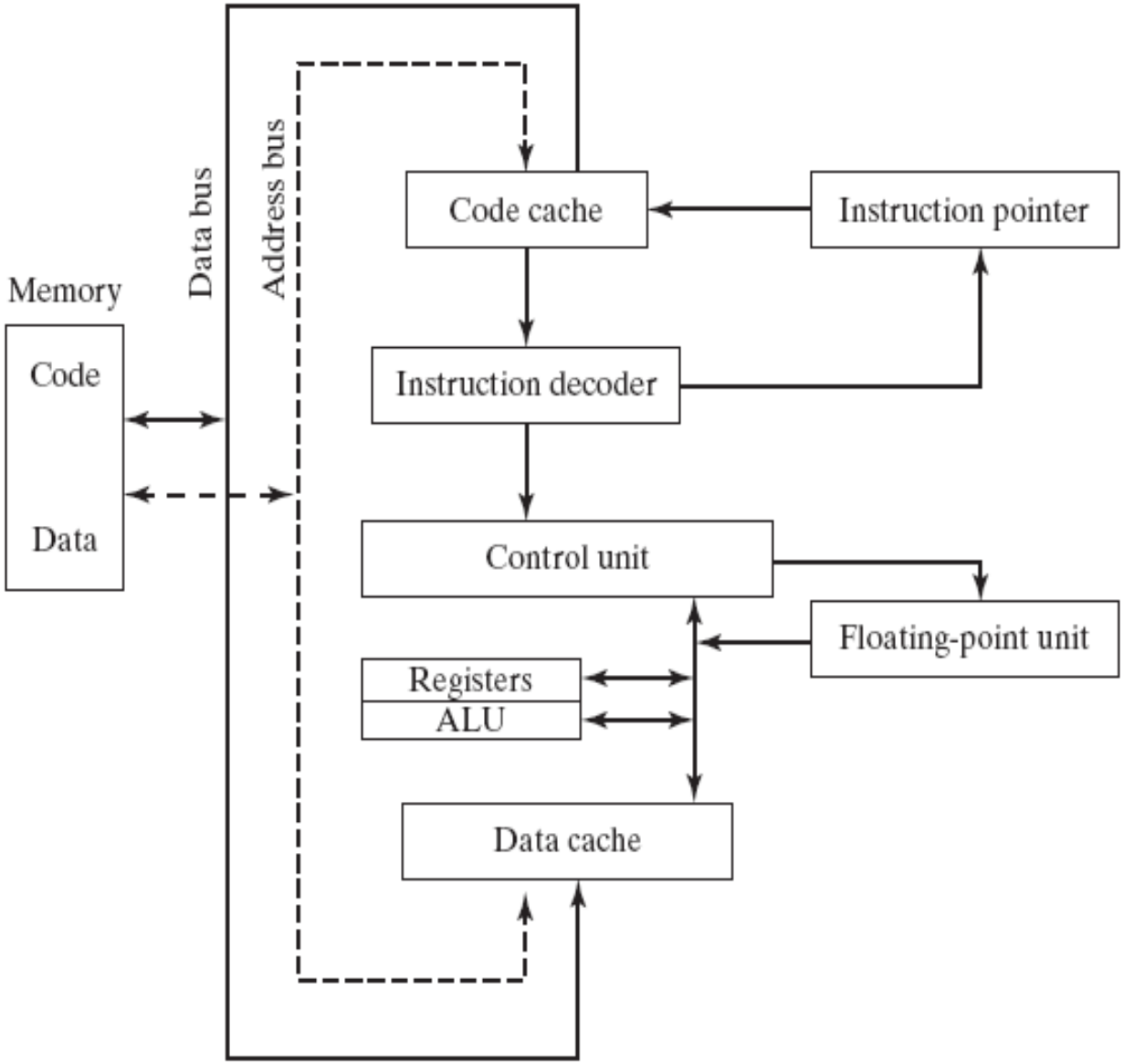
Each operation involving the CPU and the **system bus** is synchronized by an internal clock pulsing at a constant rate. The **basic unit of time** for machine instructions is a *machine cycle* (or *clock cycle*).



How much time will take to execute an instruction that takes ten cpu cycles (10 clock ticks) in a 4 ghz processor?

Simplified block diagrams of a modern CPU



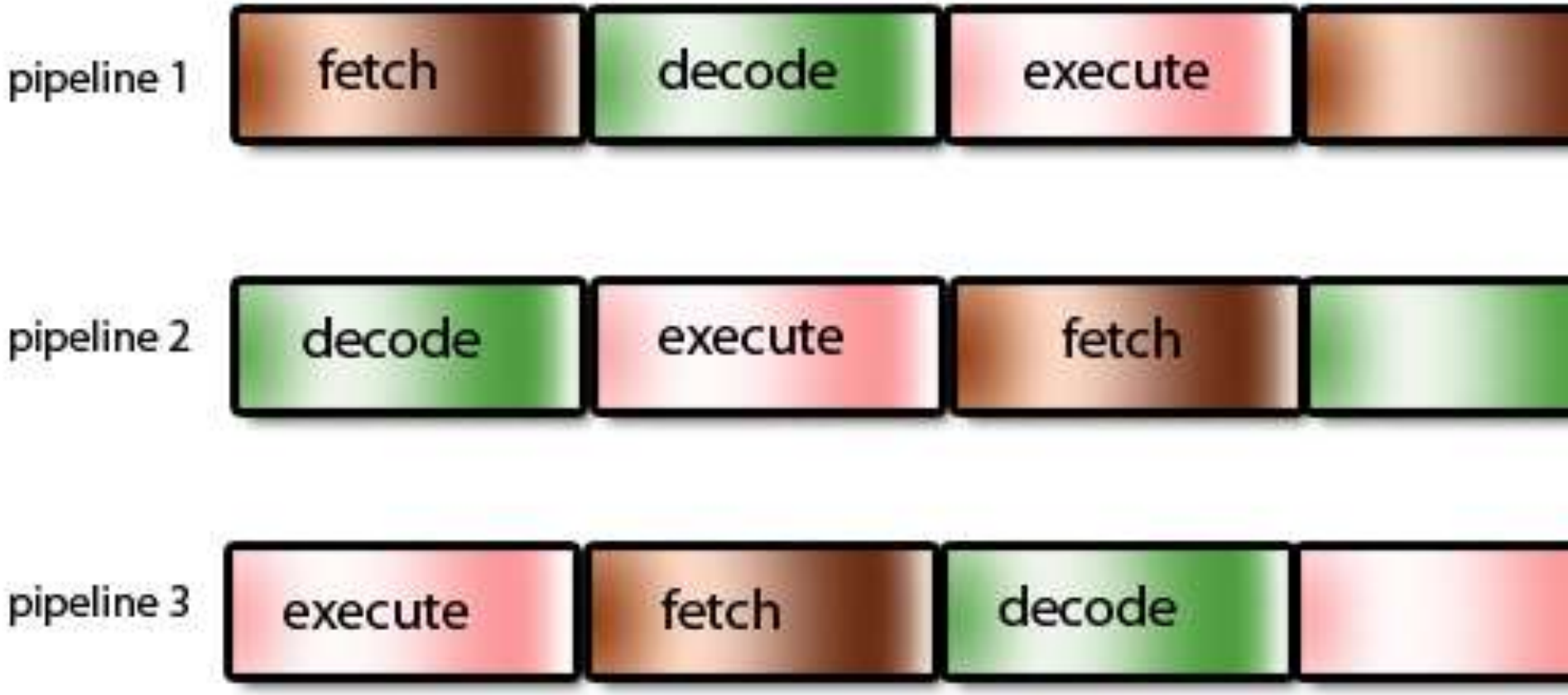


CPU Cont...

- Instruction execution takes place in discrete steps
  - —Fetch, decode, load and store, arithmetic or logical
  - —Usually require multiple clock cycles per instruction
- Pipelining → simultaneous execution of instructions

CU starts execution of next instruction while other instructions are still being processed in other parts of the CPU (or while waiting for some response).

Parallel processing with pipelines



Each pipeline is a separate part of the CPU

CPU Cont…

Processor speed depends on:

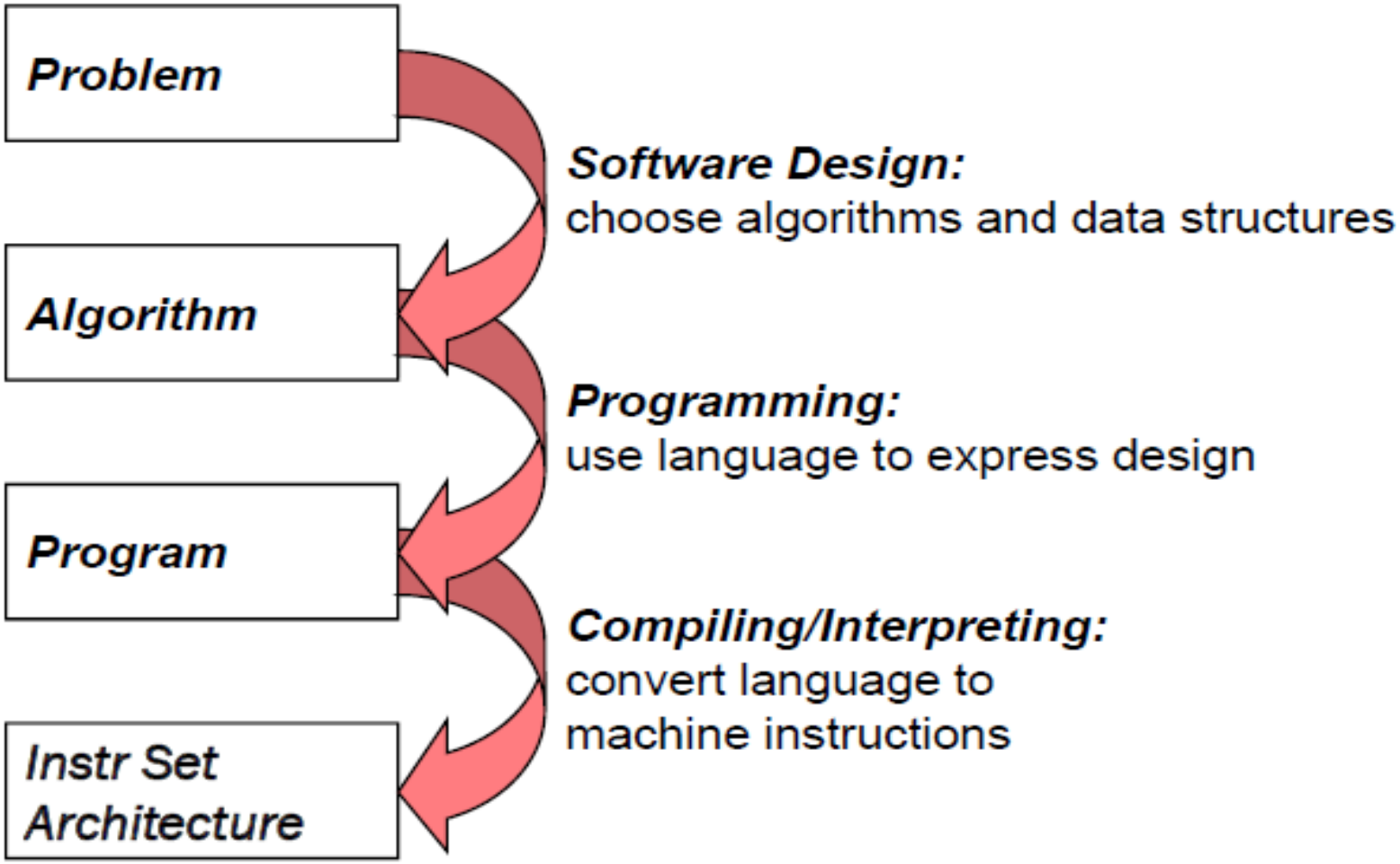
- Internal Clock Speed
- Type of Instruction Set
- Processor Implementation
- Compiler Design (efficient binary executable)
- Cache and Memory Hierarchy
- etc…

Reading Assignment: CISC & RISC, MIPS & MFLOPS

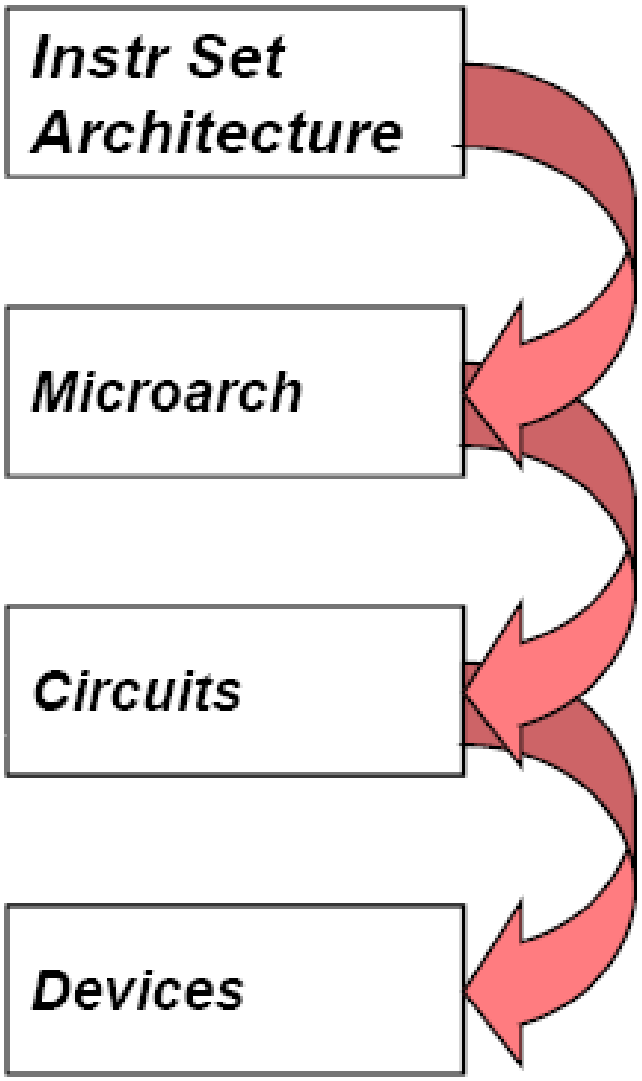
Transformations Between Layers

How do we solve a problem using a computer?

A systematic sequence of transformations between layers of abstraction.



Deeper and Deeper…



Processor Design:
choose structures to implement ISA

Logic/Circuit Design:
gates and low-level circuits to implement components

Process Engineering & Fabrication:
develop and manufacture lowest-level components

Descriptions of Each Level

Problem Statement
- stated using "natural language"
- may be ambiguous, imprecise

Algorithm
- step-by-step procedure, guaranteed to finish
- definiteness, effective computability, finiteness

Program
- express the algorithm using a computer language
- high-level language, low-level language

Instruction Set Architecture (ISA)
- specifies the set of instructions the computer can perform
- data types, addressing mode

Descriptions of Each Level (cont.)

Microarchitecture

- detailed organization of a processor implementation
- different implementations of a single ISA

Logic Circuits

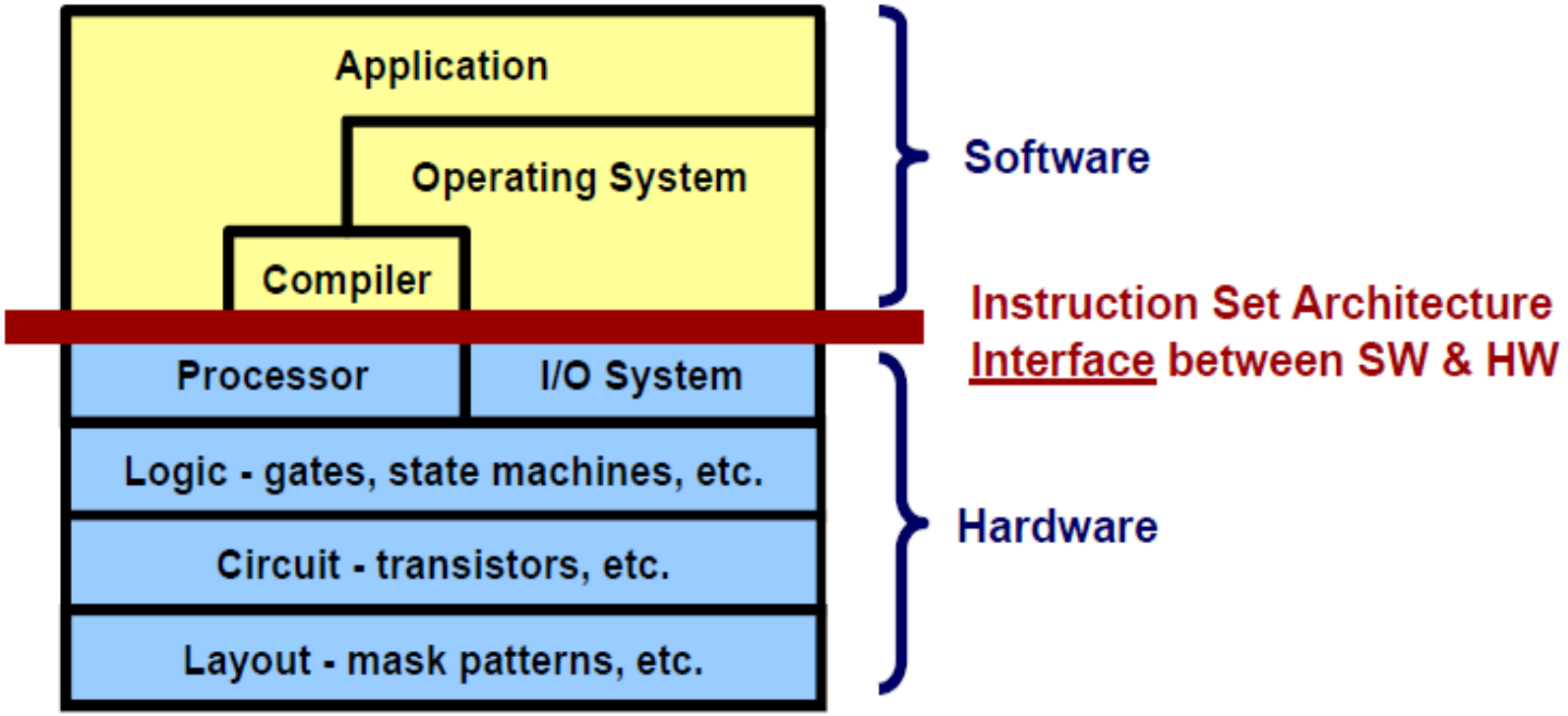
- combine basic operations to realize microarchitecture
- many different ways to implement a single function (e.g., addition)

Devices

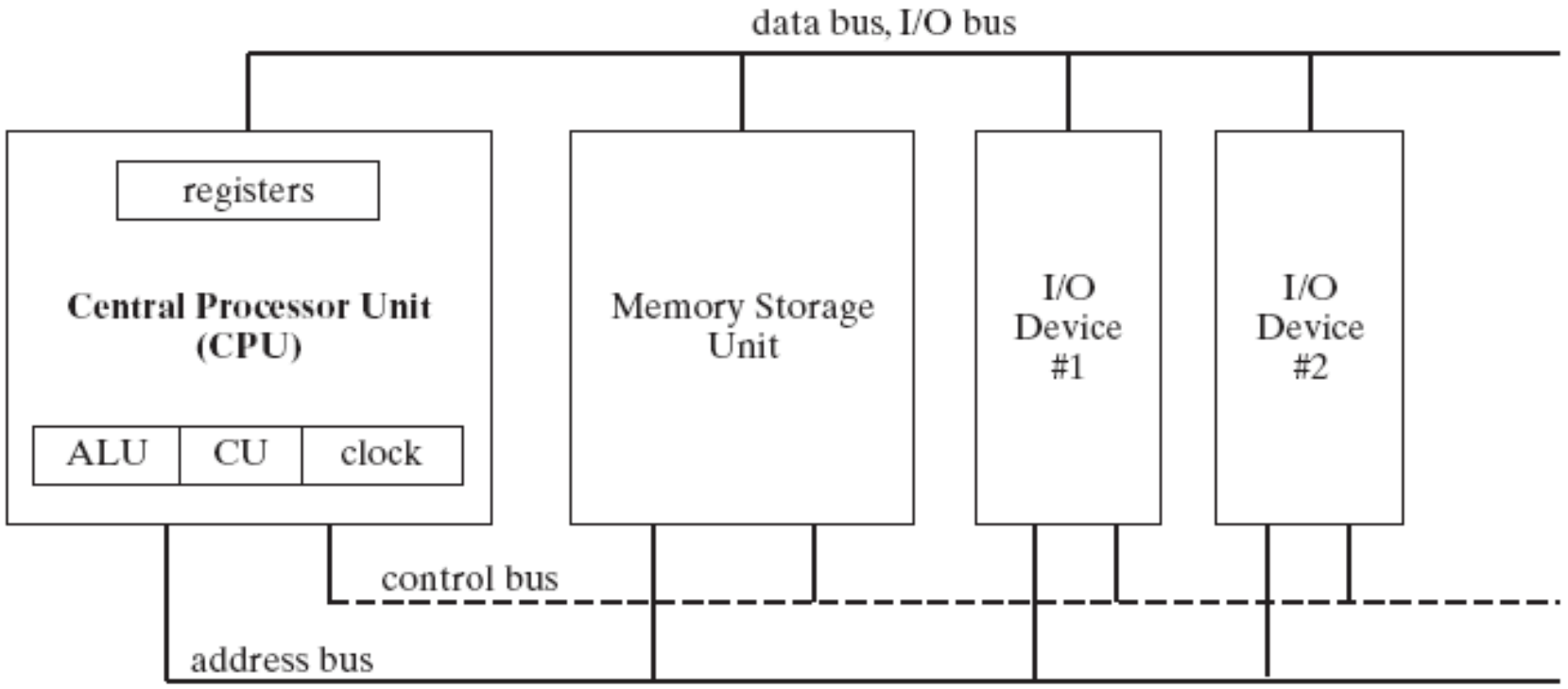
- properties of materials, manufacturability

Instruction Set Architecture (ISA) - The Hardware-Software Interface

- The most important abstraction of computer design



Block Diagram of a Microcomputer.



- Address bus width limits the amount of memory that can be installed in the computer

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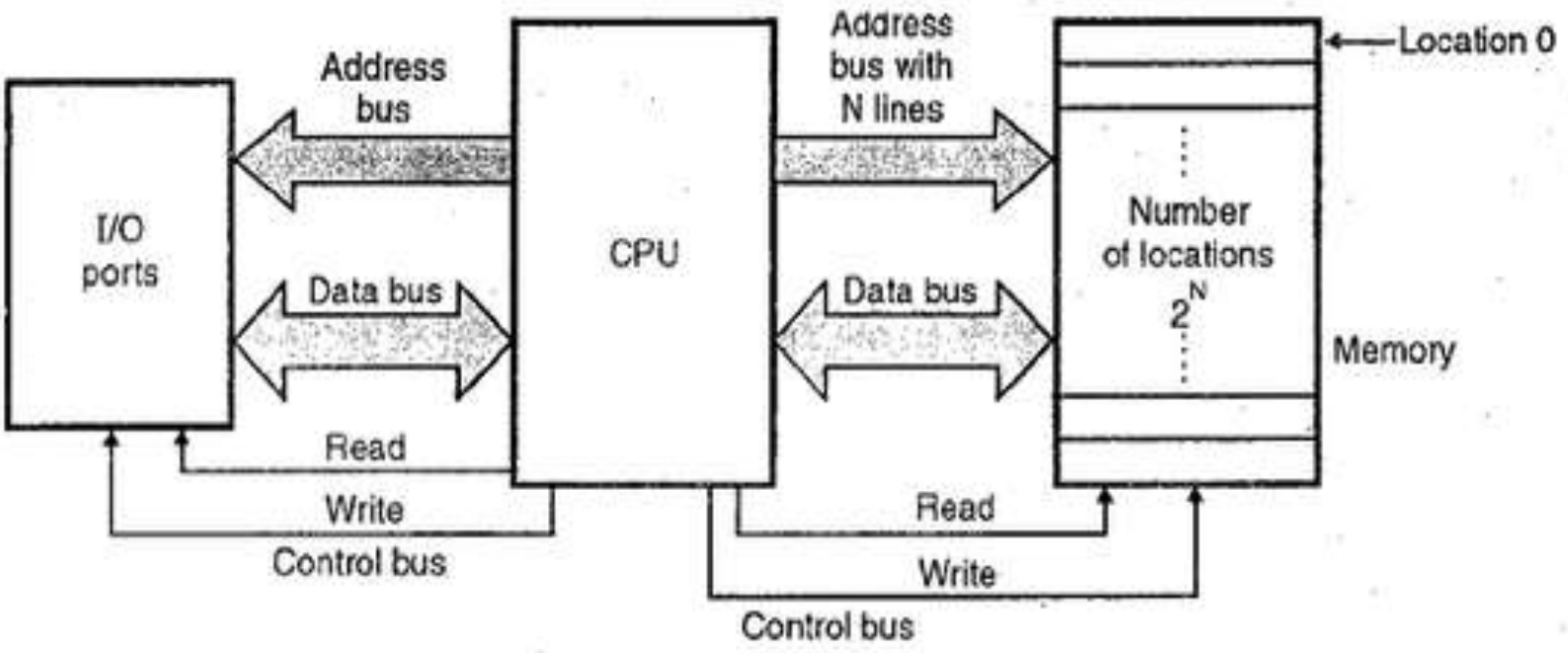
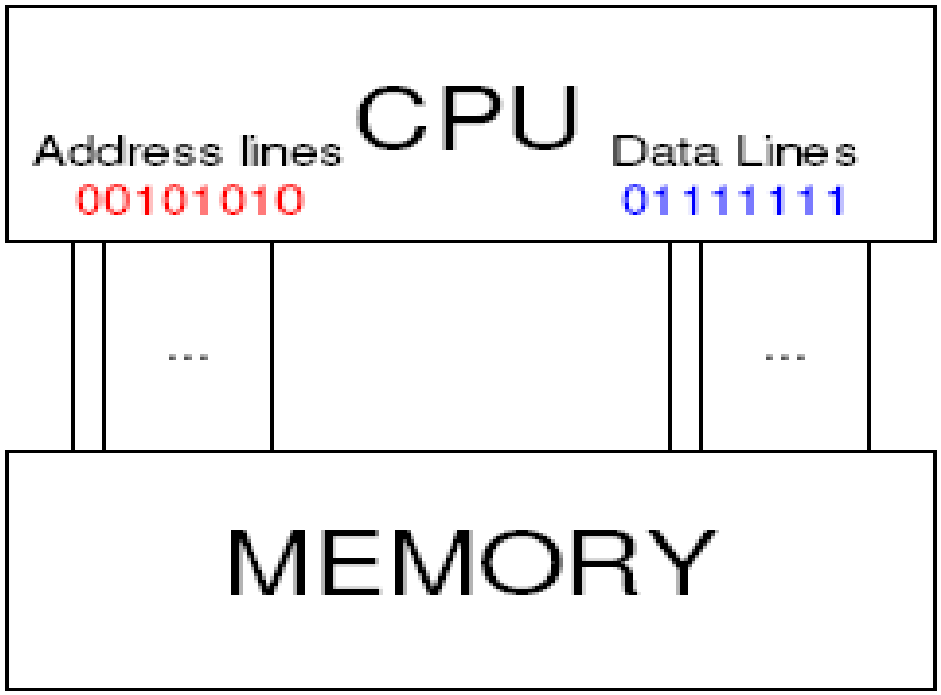
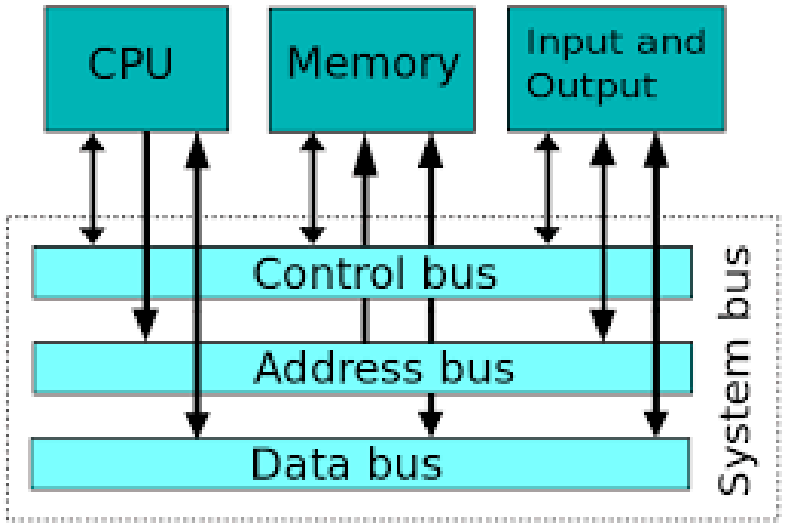


The three types of buses and their utility

A single 1- 0 transmission is referred to as a clock cycle or bus cycle

Memory makes data available if CPU issues address on the address bus





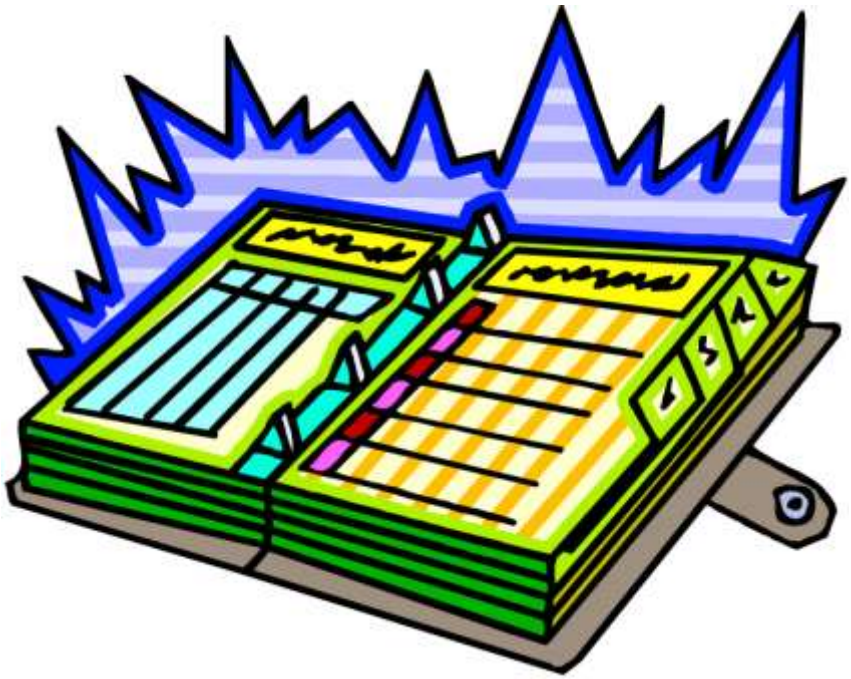
Memory Location 42 contains the number 127

Computer Startup

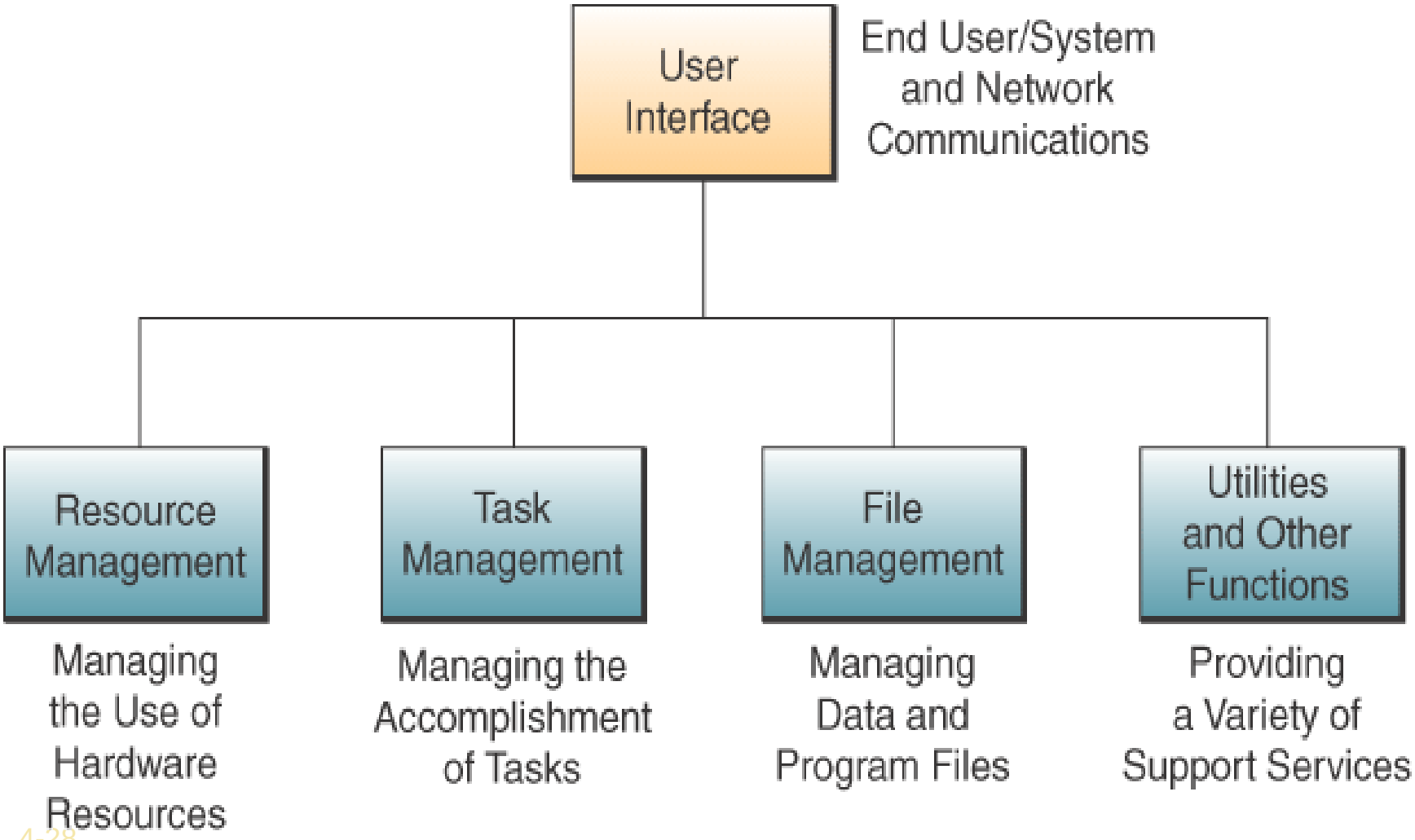
- The power is turned on
  - The Basic Input/Output System (BIOS)
    - Loads from a memory chip (ROM) and executes
    - Initializes the hardware (keyboard, disk drive, mouse, etc)
  - Then loads the operating system into memory and executes it
- The Operating System waits for user input
- The user starts a program
  - By double clicking on an icon or file
  - Or by click on Start > Program > Some Program

Operating System - Organizer

- Keep track of executing programs
  - Give them time with the CPU
  - A program gets a slice of time with the CPU
- Keep track of memory
  - Decide when to move some data to disk (virtual memory)
- Keep track of disk space
  - Decide where to store stuff
- Interface with the user
  - Accept input via keyboard and mouse
- Keep track of devices
  - USB drives, cameras, etc
- Provides networking capabilities



Operating System basic functions



Operating System

- Integrated system of programs that
  - Manages the operations of the CPU
  - Controls the input/output and storage resources and activities of the computer system
  - Provides support services as computer executes applications programs
  - Maximizes the productivity of a computer system by operating it in the most efficient manner

The Operating System and the Kernel

kernel: The operating system kernel is the part of the operating system that responds to system calls, interrupts and exceptions.

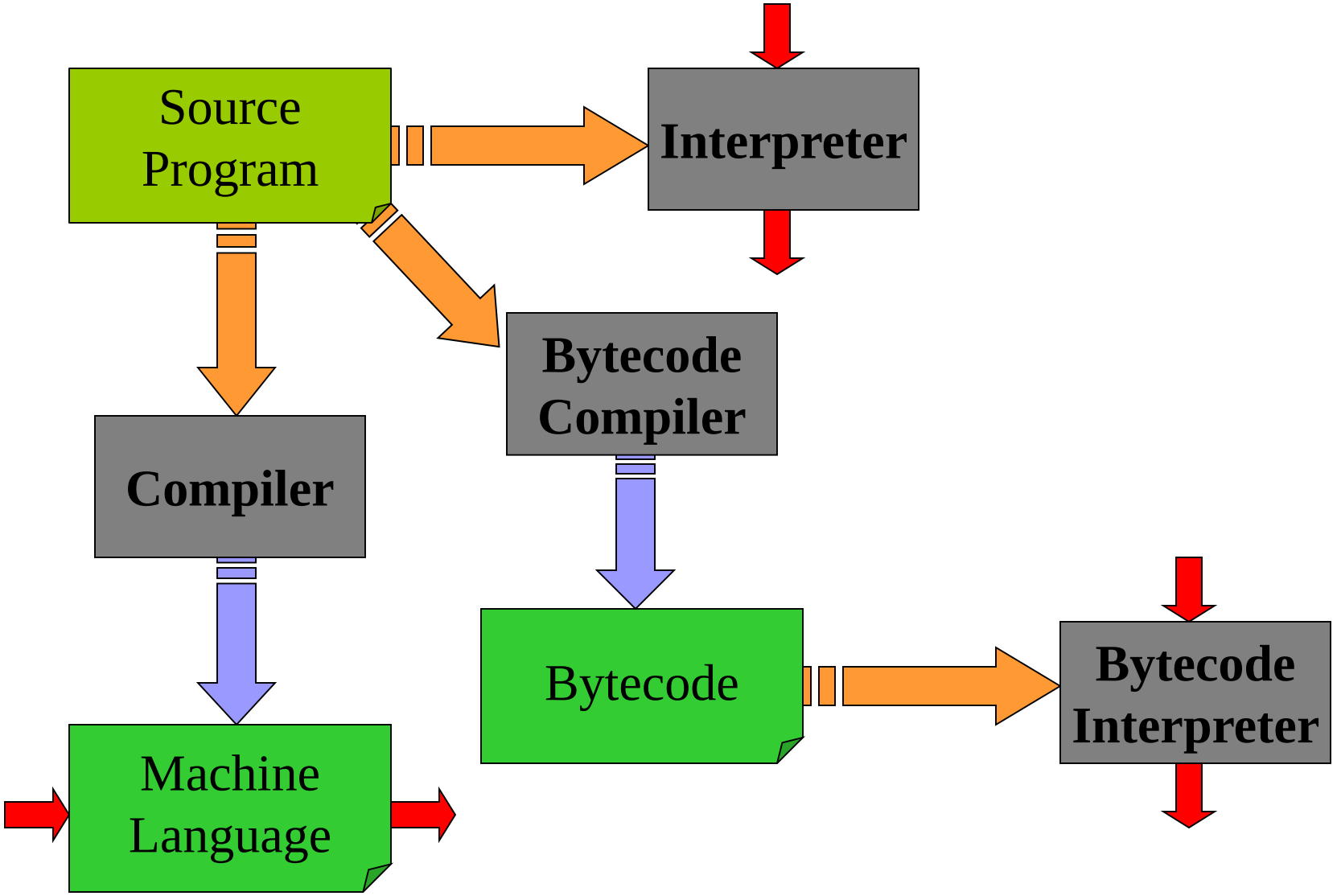
Ex. system("cls"); from C++ source, in <stdlib.h>

operating system: The operating system as a whole includes the kernel, and may include other related programs that provide services for applications.

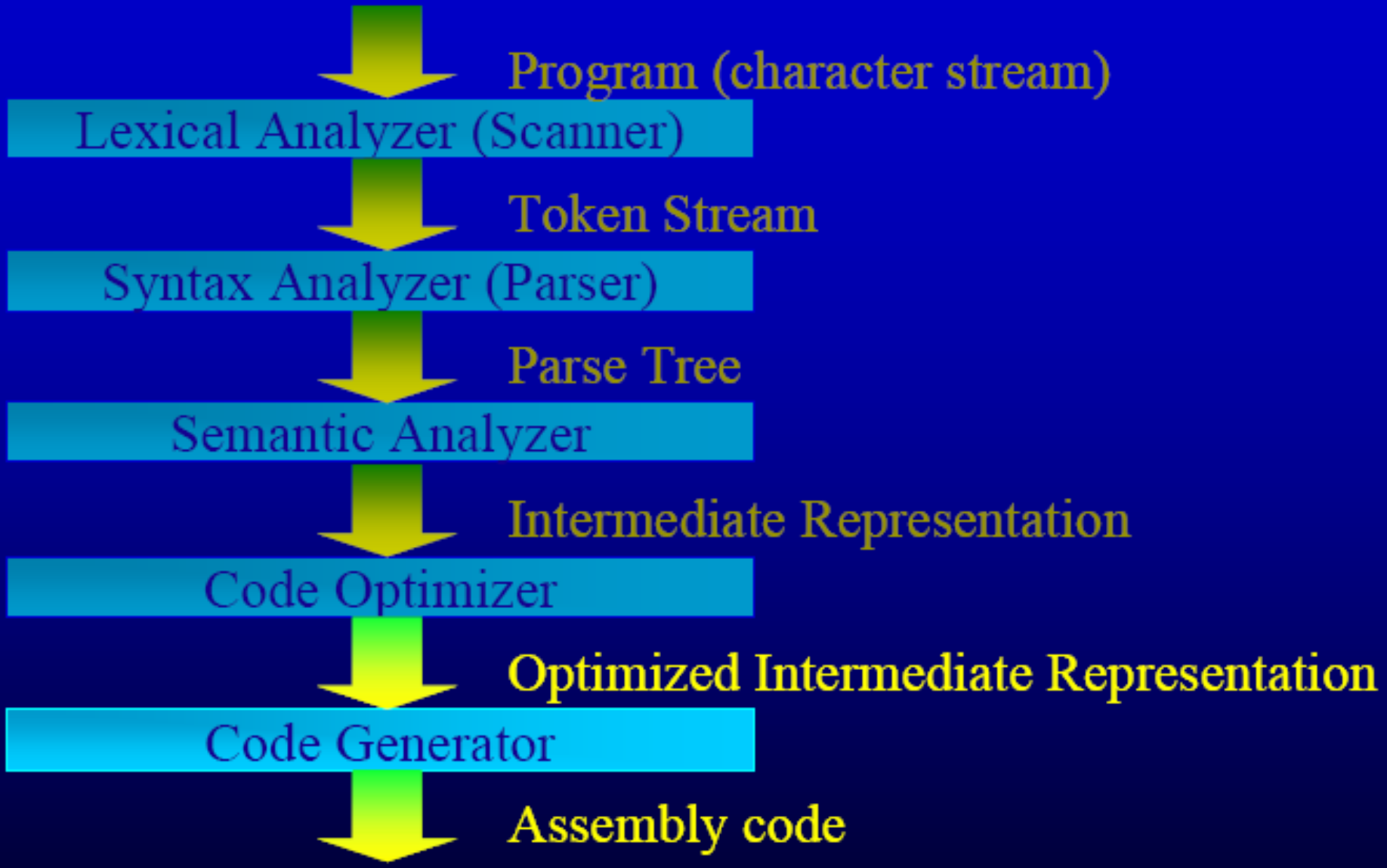
This may include things like:

- utility programs
- command interpreters
- programming libraries

Programs can be executed in different ways.



Anatomy of a Compiler



Classification of programming languages

Imperative

- Procedural: C, Ada, **Pascal**, **Algol**, **FORTRAN**, . . .
- Object oriented: **Scala**, C#, Java, **Smalltalk**, **SIMULA**, . . .
- Scripting: Perl, Python, PHP, javascript, . . .

Declarative

- Functional: Haskell, SML, Lisp, Scheme, . . .
- Logic: Prolog
- Dataflow: Id, Val
- Constraint-based: spreadsheets
- Template-based: XSLT

Why are there so many languages?

- Evolution.
- Special purposes.
- Personal preference.