CHAPTER

2

PROCESSOR

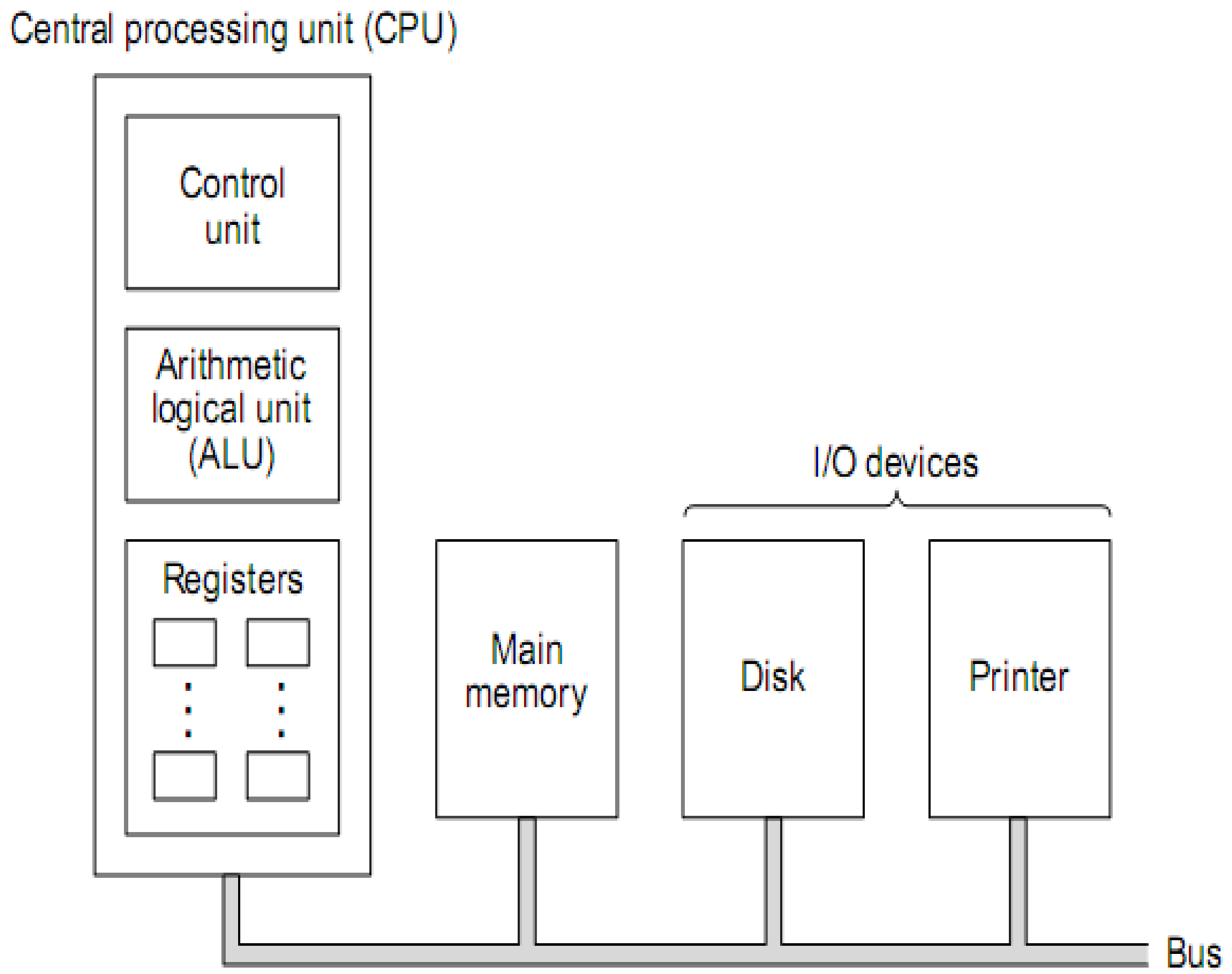
KHOA CÔNG NGHỆ THÔNG TIN
TRƯỜNG ĐẠI HỌC KHOA HỌC TỰ NHIÊN

fit@hcmus

REMIND

- Inside a CPU
- Abstraction layer

- Control Unit
- Datapath
  - ALU (Arithmetic Logic
    Unit)
  - Registers



What will you learn?

- ☐ How programs are translated into the machine language
- ☐ How hardware executes a program
- ☐ How CPU process an instruction
- ☐ Measuring execution time
- ☐ Uniprocessor vs Multiprocessor

Instruction

- The sequence bit that contains the request that the processor must make.
- An instruction consists of 2 part:
  - Opcode: the operation ALU must take
  - Operand: objects affected by the action contained in the code

Instruction Set Architecture (ISA)

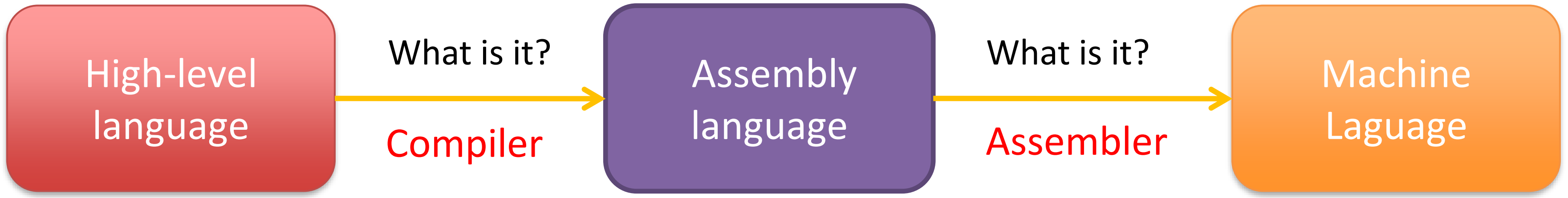
- The format and behavior of a machine-level program is defined by the instruction set architecture
- Different computers have different instruction sets but with many aspects in common
- Commonly ISA:
  - MIPS: used in embedded system
  - ARM: A64, A32, T32
  - Power-PC
  - IA-16: 16-bits processor (Intel 8086, 80186, 80286)
  - IA-32: 32-bits processor (Intel 80368 – i386, 80486 – i486, Pentium II, Pentium III …)
  - IA-64: 64-bits processor (Intel x86-64 - Pentium D…)

ISA design: CISC & RISC

- ☐ Complete Instruction Set Computer (CISC): includes many instructions, from simple to complex
- ☐ Reduced Instruction Set Computer (RISC): consists of only simple instructions

→ *Which one is better?*

Discussion



```
temp = v[k];
v[k] = v[k+1];
v[k+1] = temp;
```

```
lw $t0, 0($2)
lw $t1, 4($2)
sw $t1, 0($2)
sw $t0, 4($2)
```

```
0000 1001 1100 0110
1111 0101
.....
```

fit@hcmus

Assembly Language

- A symbolic representation of machine code, clearer than in machine code
- Each assembly instruction represents exactly one machine instruction
- Ex: Save the value 5 decimal in the register $4

Machine language:	00110100 0000100 00000000 00000101			
Assembly:	ori	$4,	$0,	5
	opcode	*dest reg*	*src reg*	*immediate*

Assembly Language

- Since each processor has its own register structure and instruction set when setting the assembly, it must be clear which processor is set, or the family of the processor.
- Ex:
  - Assembly for MIPS
  - Assembly for the line of Intel 8086 processors

Compiler

- A program that translates high-level language statements into assembly language statements
- Belong to:
  - The system hardware architecture below which it is running
  - The high-level language which it compiles
- Ex:

  Compiler for C <> Compiler cho Java

  Compiler for “C on Windows” <> “C on Linux”

Assembler

- A program that translates a symbolic version of instructions into the machine code
- A single processor (1 set of definitions) can have multiple assemblers from different vendors running on different operating systems.
- Ex: list of assembler for x86 architecture

  A86, GAS, TASM, MASM, NASM
- The Assembly program depends on the assembler it uses

Discussions

- ☐ Who will compile the compiler? (It's also a program)

→ Assembler

- ☐ How the hardware execute a program?

→ Loader & Linker

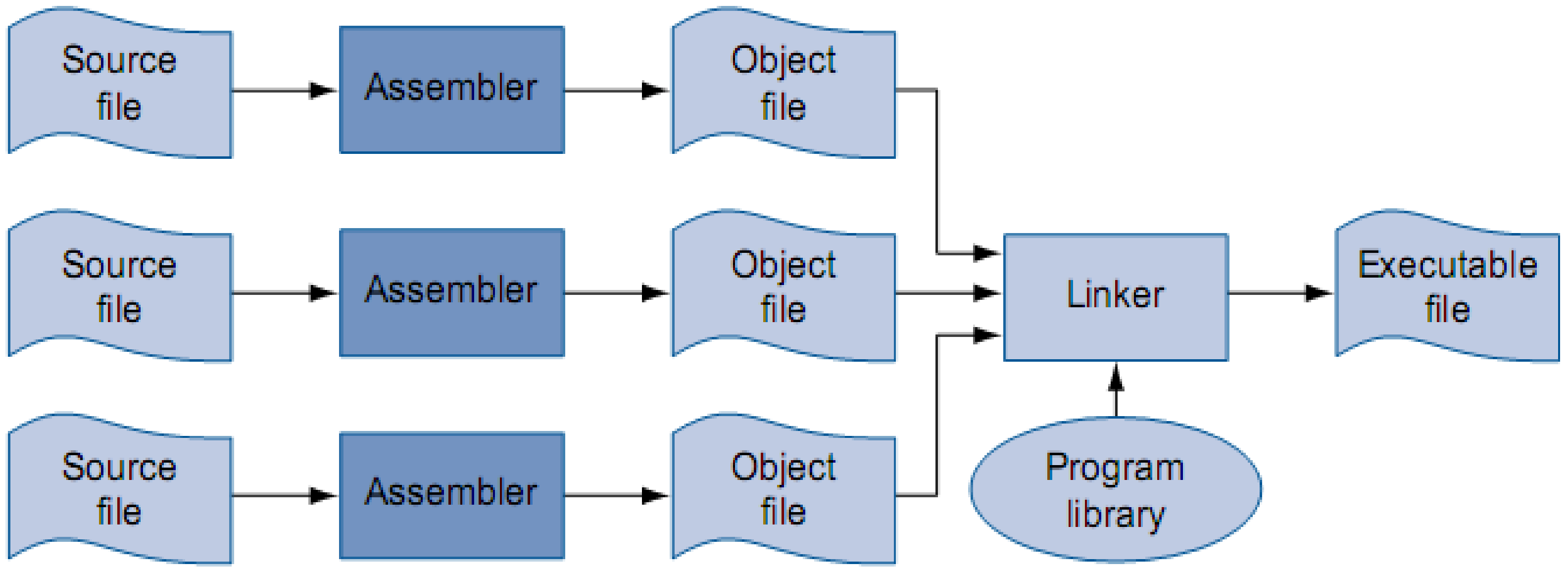
Linker

- A systems program that combines independently assembled machine language programs (object file) and resolves all undefined labels into an executable file.

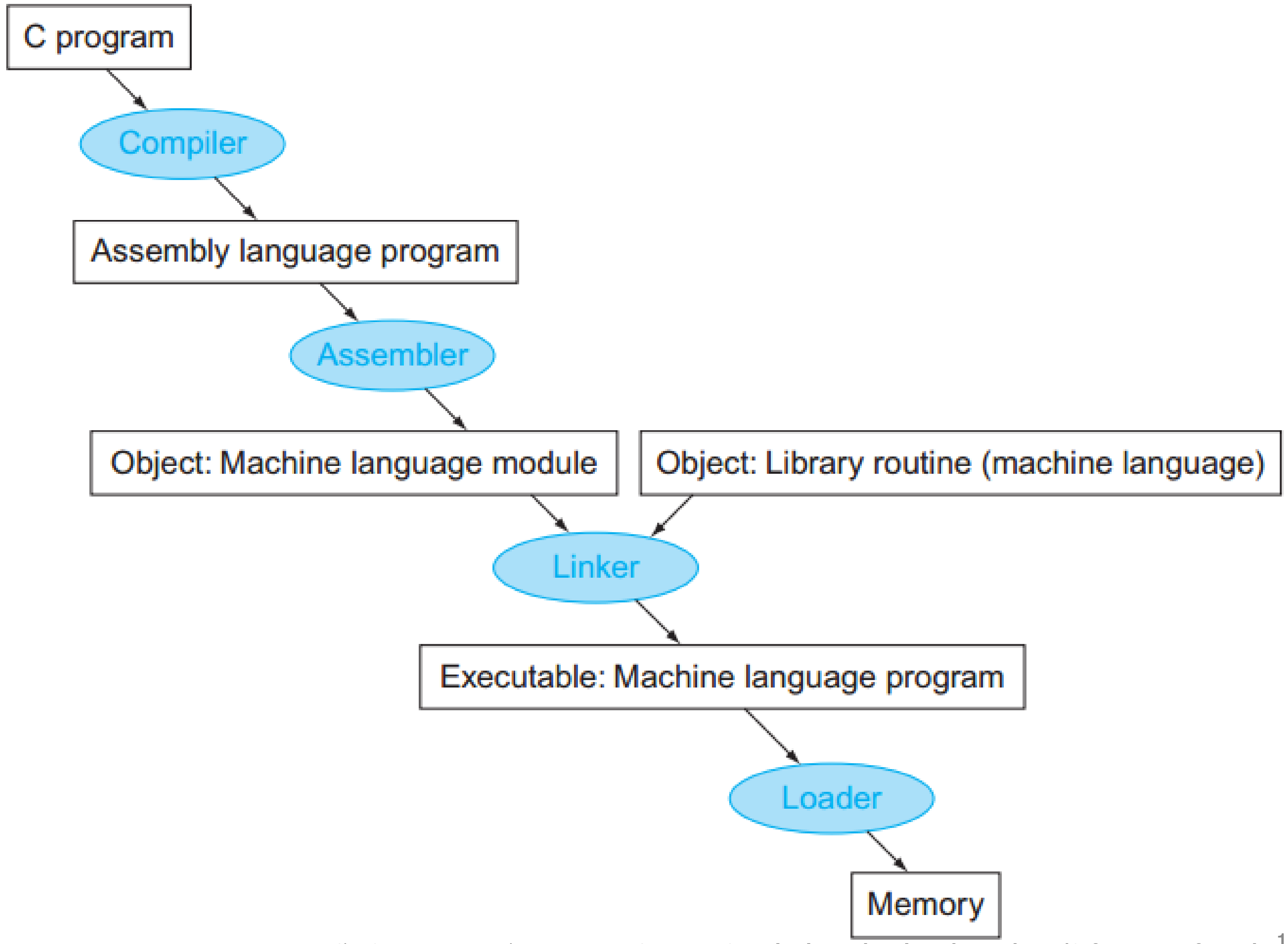
Loader

- A systems program that places an object program in main memory so that it is ready to execute.

Create executable file

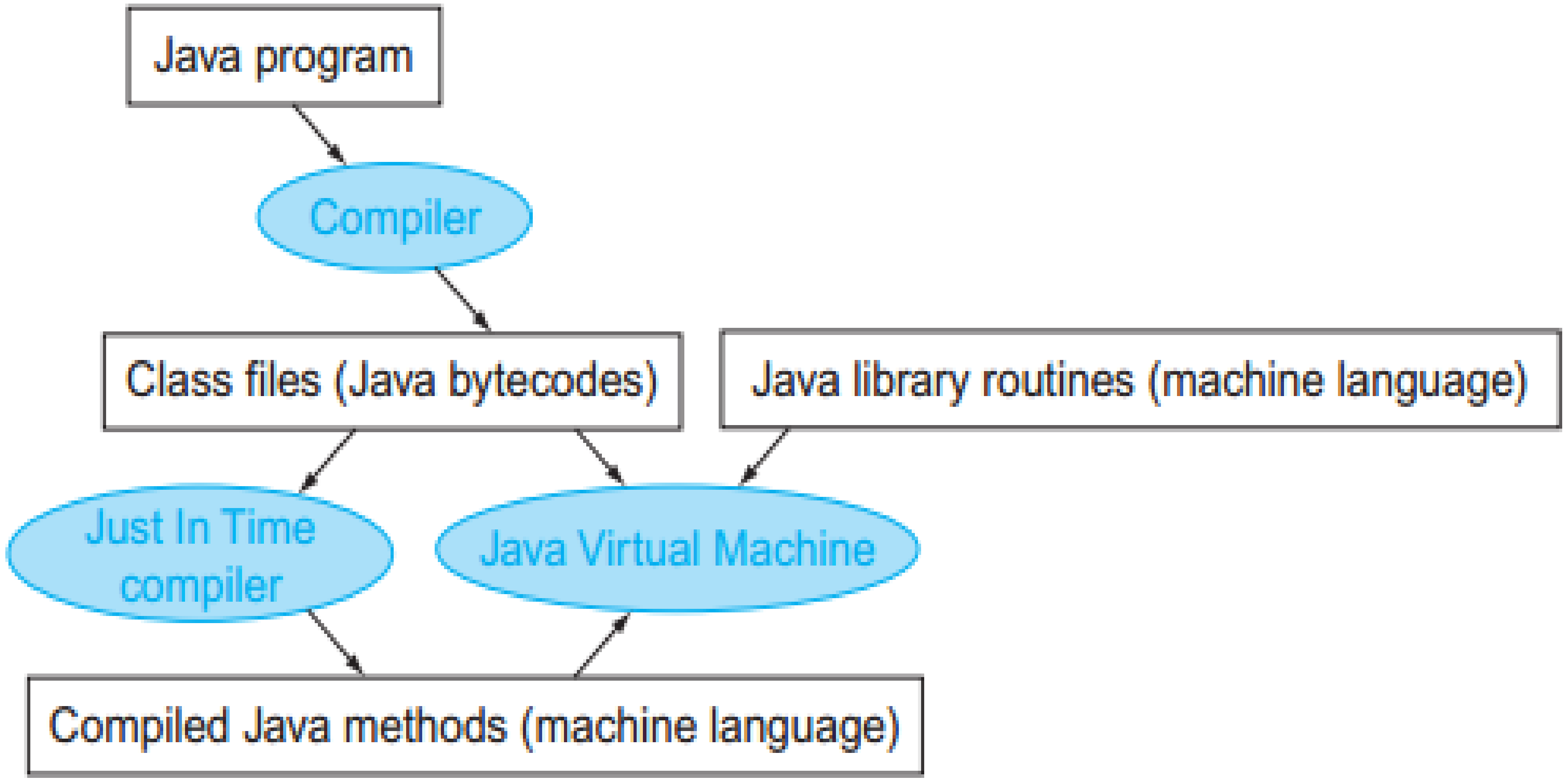


A translation hierarchy for C


C program
Compiler
Assembly language program
Assembler
Object: Machine language module
Object: Library routine (machine language)
Linker
Executable: Machine language program
Loader
Memory

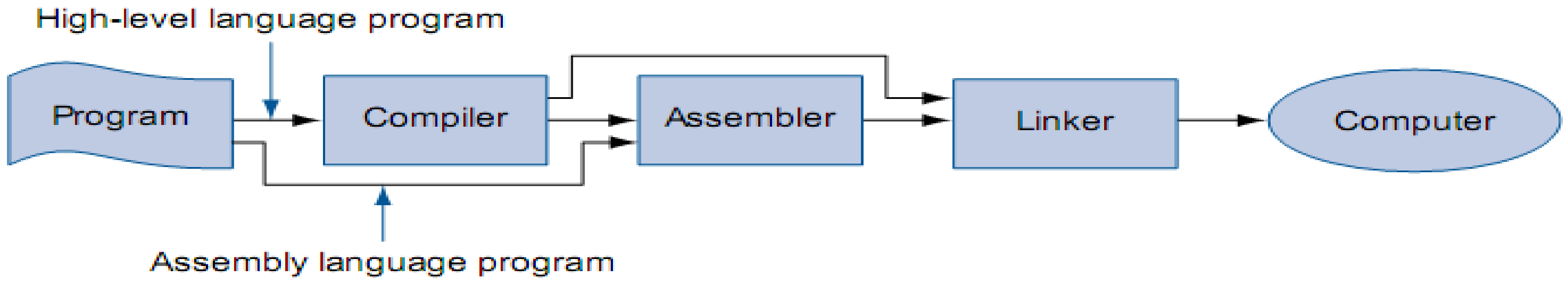
Chap2, A. Patterson and J. L. Hennessy, ***Computer Organization and Design: The Hardware/Software Interface,5th ed, 2014*** *Figure 2.21*

A translation hierarchy for Java


Java program
Compiler
Class files (Java bytecodes)
Java library routines (machine language)
Just In Time compiler
Java Virtual Machine
Compiled Java methods (machine language)

Chap2, A. Patterson and J. L. Hennessy, ***Computer Organization and Design: The Hardware/Software Interface,5th ed, 2014*** *Figure 2.23*

Realistic Model



- Compiler and assembler can be skipped in the certain cases
- In fact, there are several compilers that can create executables on a variety of underlying architecture platforms (cross-platform compiler)
- Ex: Compiler for Java, Cygwin, Code::Block Studio

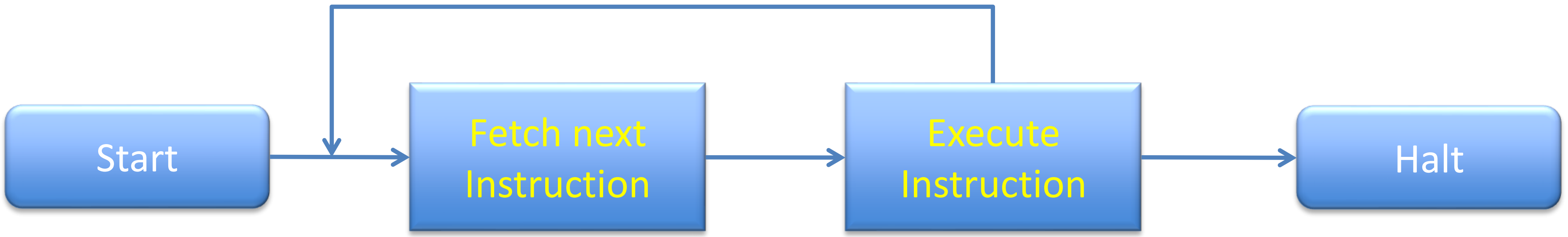
- What is the compiler?
- What is the assembler?
- What is the function of linker?
- What is the function of loader?

fit@hcmus

What will you learn?

- ☐ How programs are translated into the machine language
- ☐ How hardware executes a program
- ☐ How CPU process an instruction
- ☐ Measuring execution time
- ☐ Uniprocessor vs Multiprocessor

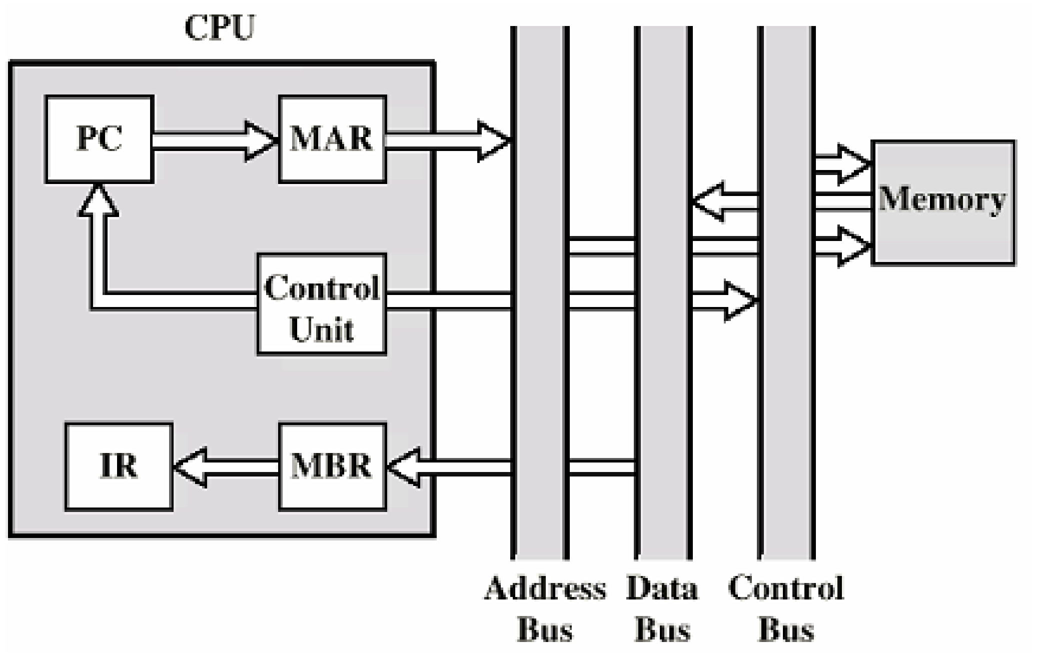
Instruction processing



Instruction Cycle: consists of 2 phases

- Fetch cycle: Transfer data from memory to registers
- Execute cycle: Decode the instruction and execute the requirements of it

Fetch cycle



- PC (Program Counter)

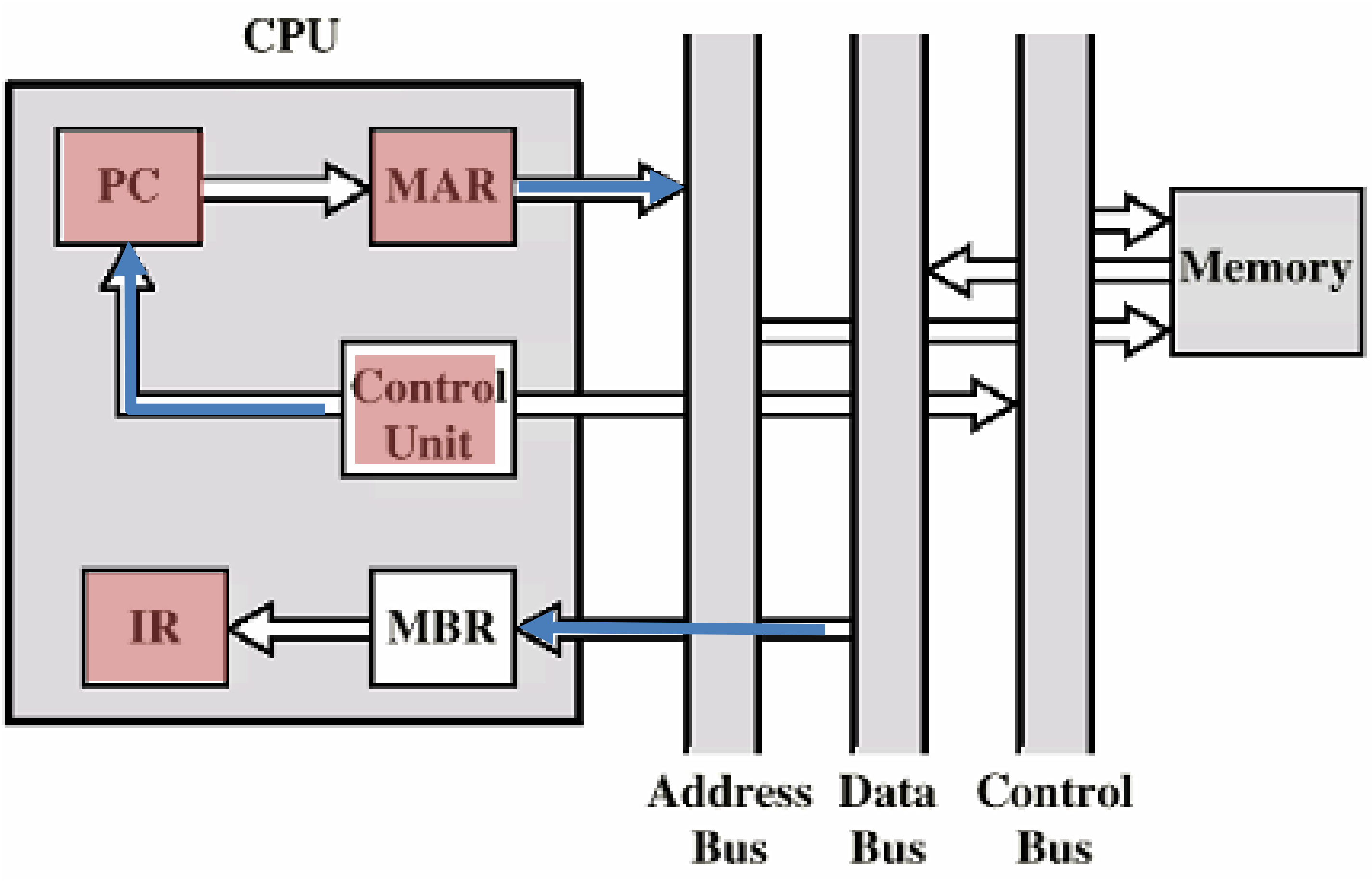
  Store the next instruction's address
- MAR (Memory Address Register)

  Store the address of a location in memory (output to address bus)
- MBR (Memory Buffer Register)

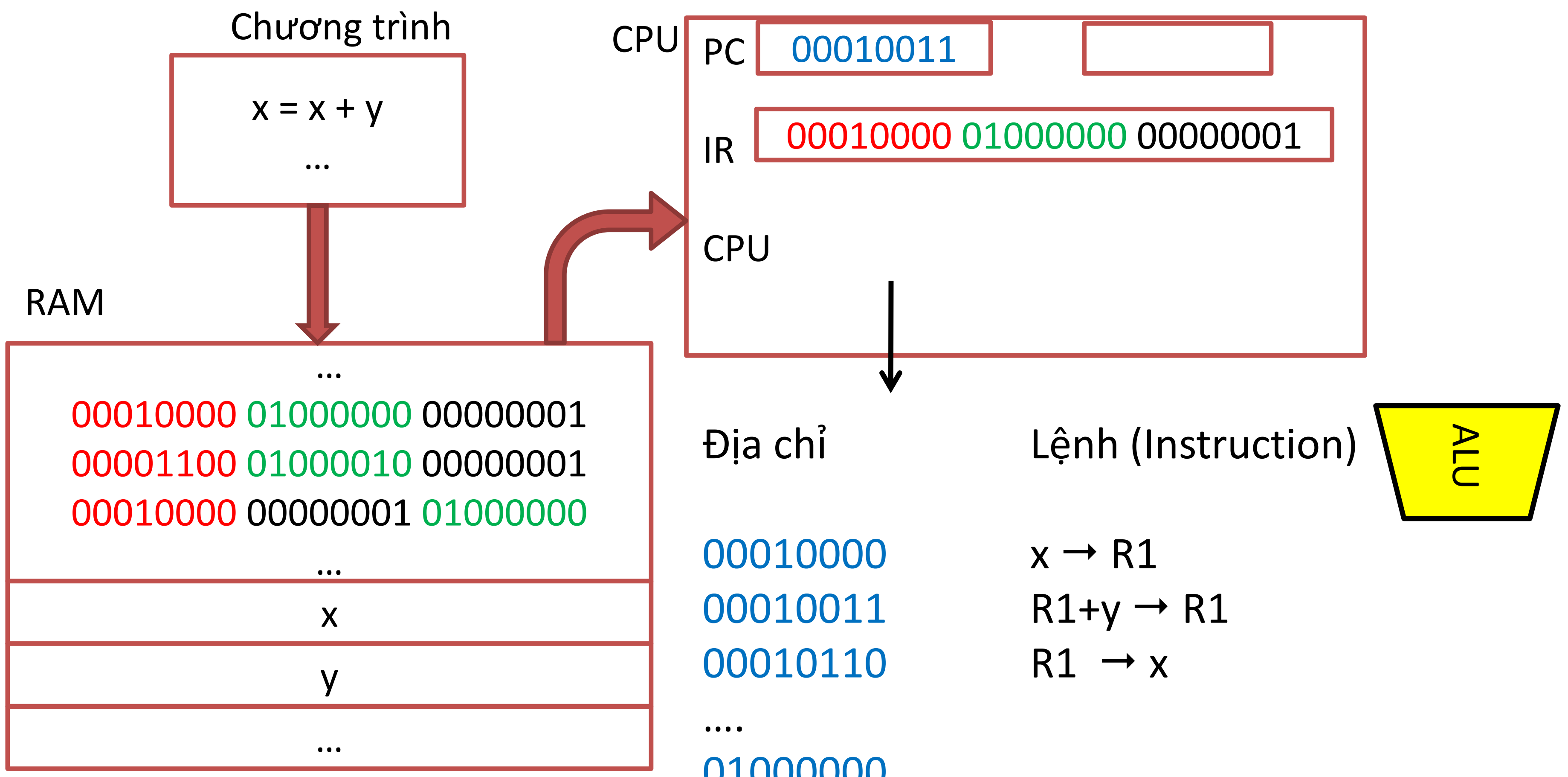
  A word of data to be written to memory or the word most recently read (output to data bus)
- IR (Instruction Register)

  Contain the most recently fetched instruction

Fetch cycle

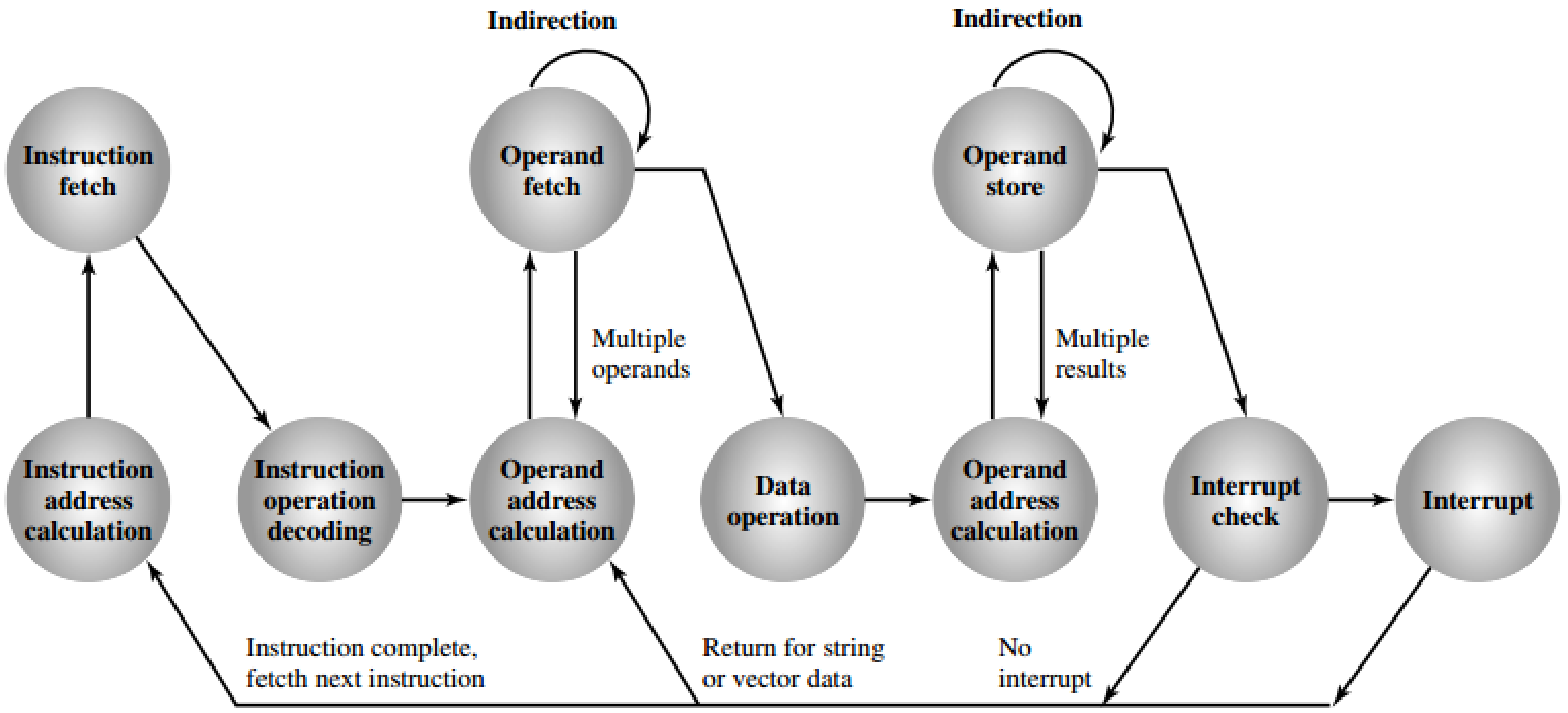

CPU
PC
MAR
Control Unit
IR
MBR
Memory
Address Bus
Data Bus
Control Bus

Example



Địa chỉ	Lệnh (Instruction)
00010000	x → R1
00010011	R1+y → R1
00010110	R1 → x
….	
01000000	….
01000010	….

Execute cycle


Indirection
Indirection
Instruction fetch
Operand fetch
Operand store
Multiple operands
Multiple results
Instruction address calculation
Instruction operation decoding
Operand address calculation
Data operation
Operand address calculation
Interrupt check
Interrupt
Instruction complete, fetcth next instruction
Return for string or vector data
No interrupt

Chap3, William Stalling, ***Computer Organization and Architecture, 8th ed, 2014*** *Figure 3.6*

fit@hcmus

Measuring execution time

Elapsed time

- Total response time, including all aspects: processing, i/o, idle time, OS overhead

CPU time

- Time spent processing a given task
- Comprise user CPU time and system CPU time
- Different program are affected differently by CPU and system performance

Clock Cycles

Instead of reporting execution time in seconds, we often use *cycles*. In modern computers hardware events progress cycle by cycle: in other words, each event, e.g., multiplication, addition, etc., is a sequence of cycles

$$\frac{\text{seconds}}{\text{program}} = \frac{\text{cycles}}{\text{program}} \times \frac{\text{seconds}}{\text{cycle}}$$

cycle time = time between ticks = seconds per cycle
clock rate (*frequency*) = cycles per second (1 Hz. = 1 cycle/sec, 1 MHz. = 10^6 cycles/sec)

CPU Time

$$\text{CPU time} = \frac{Instructions}{Program} \times \frac{CPU\ clock\ cycles}{Instruction} \times \frac{seconds}{CPU\ clock\ cycles}$$

Performance depends on:

- Algorithm
- Programming language
- Compiler
- ISA

Uniprocessor vs Multiprocessor

Constrained by:

- Power
- Instruction-level parallelism
- Memory latency

Multicore microprocessors (>1 processor/ chip)

Requires explicitly parallel programming

- Compare with instruction level parallelism
  - Hardware executes multiple instructions at once
  - Hidden from the programmer
- Hard to do
  - Programming for performance
  - Load balancing
  - Optimizing communication and synchronization

- What is the function of PC Register?
- What is the function of IR Register?
- Sort by instruction execution cycle order