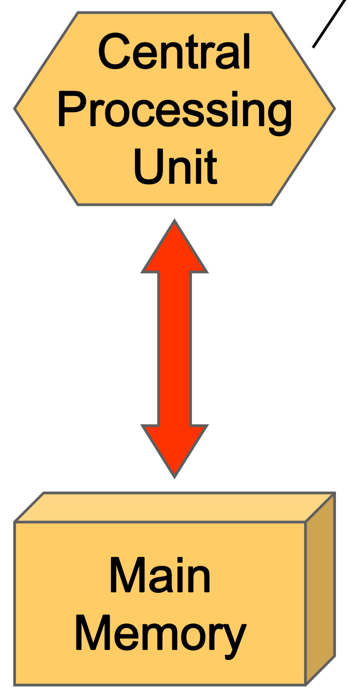
Introduction to Computer System and Architecture

CPU and Main Memory

Chip that executes program commands

Intel Pentium 4
Sun ultraSPARC III



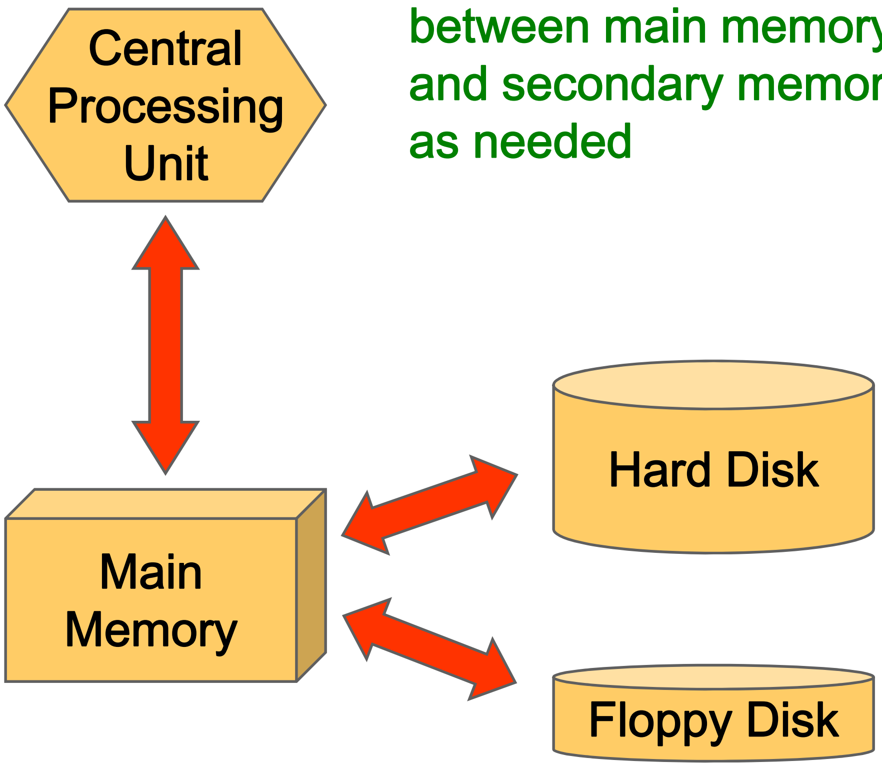
Primary storage area for programs and data that are in active use

Synonymous with RAM

Secondary Memory Devices

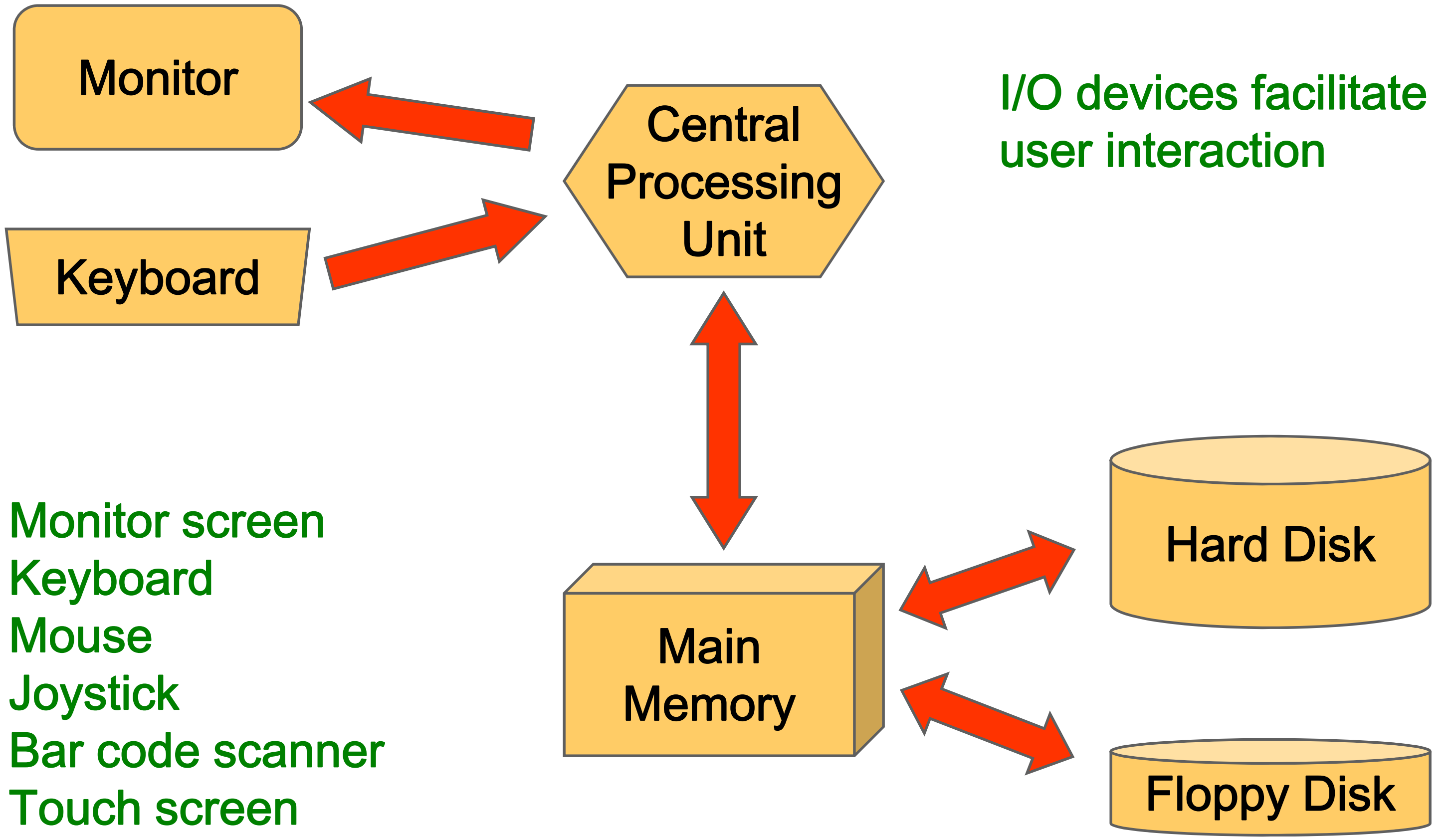
Secondary memory devices provide long-term storage

Hard disks
Floppy disks
ZIP disks
Writable CDs
Writable DVDs
Tapes



Information is moved between main memory and secondary memory as needed

Input / Output Devices



I/O devices facilitate user interaction

Monitor screen
Keyboard
Mouse
Joystick
Bar code scanner
Touch screen

Software Categories

- Operating System
  - controls all machine activities
  - provides the user interface to the computer
  - manages resources such as the CPU and memory
  - Windows XP, Unix, Linux, Mac OS
- Application program
  - generic term for any other kind of software
  - word processors, missile control systems, games
- Most operating systems and application programs have a *graphical user interface* (GUI)

Representing Text Digitally

- Every character is stored as a number, including spaces, digits, and punctuation
- Corresponding upper and lower case letters are separate characters

H i ,   H e a t h e r .

72 105 44 32 72 101 97 116 104 101 114 46

- A common code is ASCII (American Standard Code for Information Interchange).

Binary Numbers

- Once information is digitized, it is represented and stored in memory using the *binary number system*
- A single binary digit (0 or 1) is called a *bit*
- Devices that store and move information are cheaper and more reliable if they have to represent only two states
- A single bit can represent two possible states, like a light bulb that is either on (1) or off (0)
- Permutations of bits are used to store values

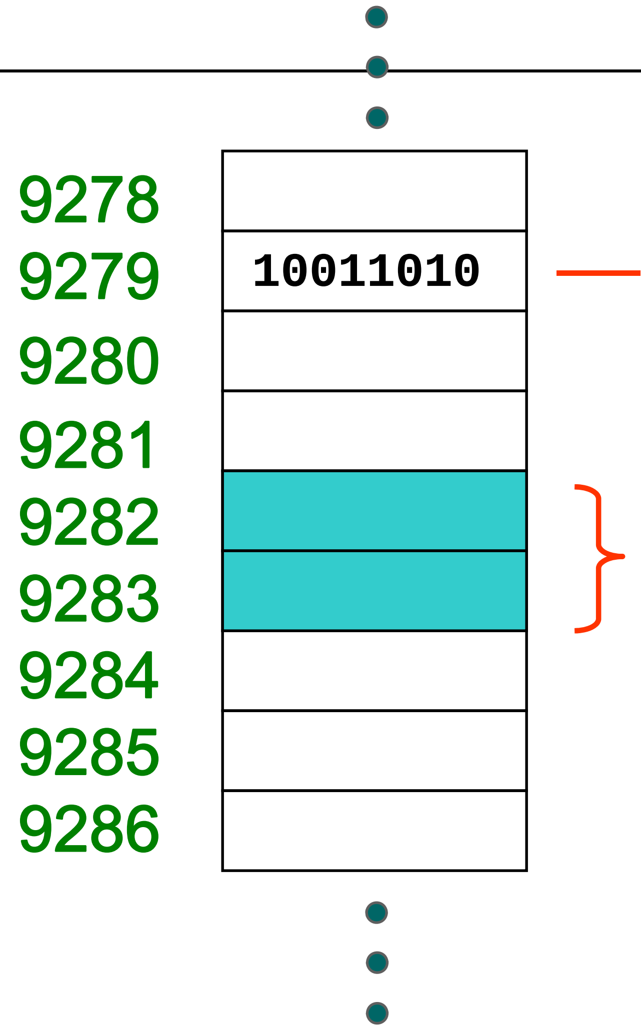
Bit Permutations

- Each permutation can represent a particular item
- There are 2^N permutations of N bits
- Therefore, N bits are needed to represent 2^N unique items

How many items can be represented by

1 bit ?	2^1	**= 2 items**
2 bits ?	2^2	**= 4 items**
3 bits ?	2^3	**= 8 items**
4 bits ?	2^4	**= 16 items**
5 bits ?	2^5	**= 32 items**

Storing Information



Each memory cell stores a set number of bits (usually 8 bits, or one *byte*)

Large values are stored in consecutive memory locations

Storage Capacity

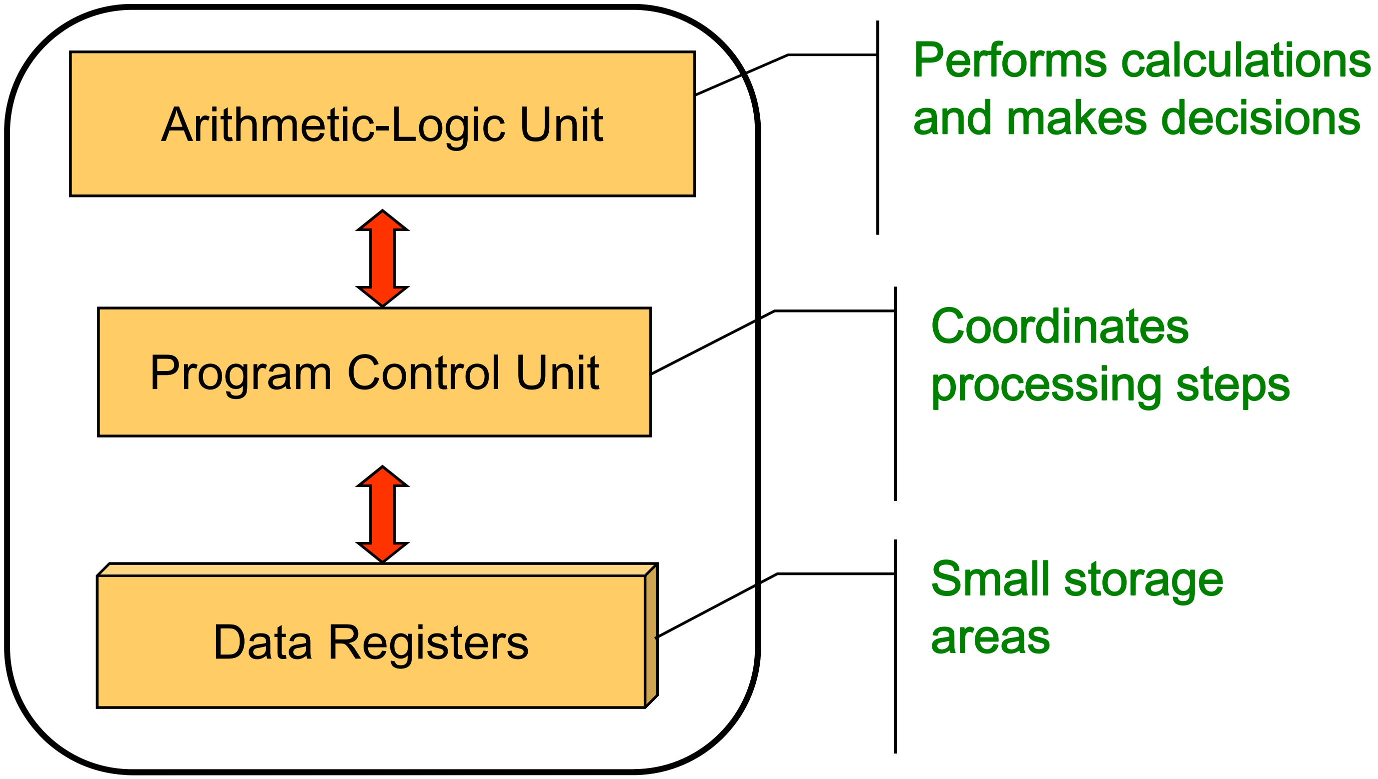
- Every memory device has a *storage capacity*, indicating the number of bytes it can hold
- Capacities are expressed in various units:

Unit	Symbol	Number of Bytes
kilobyte	KB	2^{10} = 1024
megabyte	MB	2^{20} (over 1 million)
gigabyte	GB	2^{30} (over 1 billion)
terabyte	TB	2^{40} (over 1 trillion)

Memory

- Main memory is *volatile* - stored information is lost if the electric power is removed
- Secondary memory devices are *nonvolatile*
- Main memory and disks are *direct access* devices - information can be reached directly
- The terms *direct access* and *random access* often are used interchangeably
- A magnetic tape is a *sequential access* device since its data is arranged in a linear order - you must get by the intervening data in order to access other information

The Central Processing Unit (CPU)

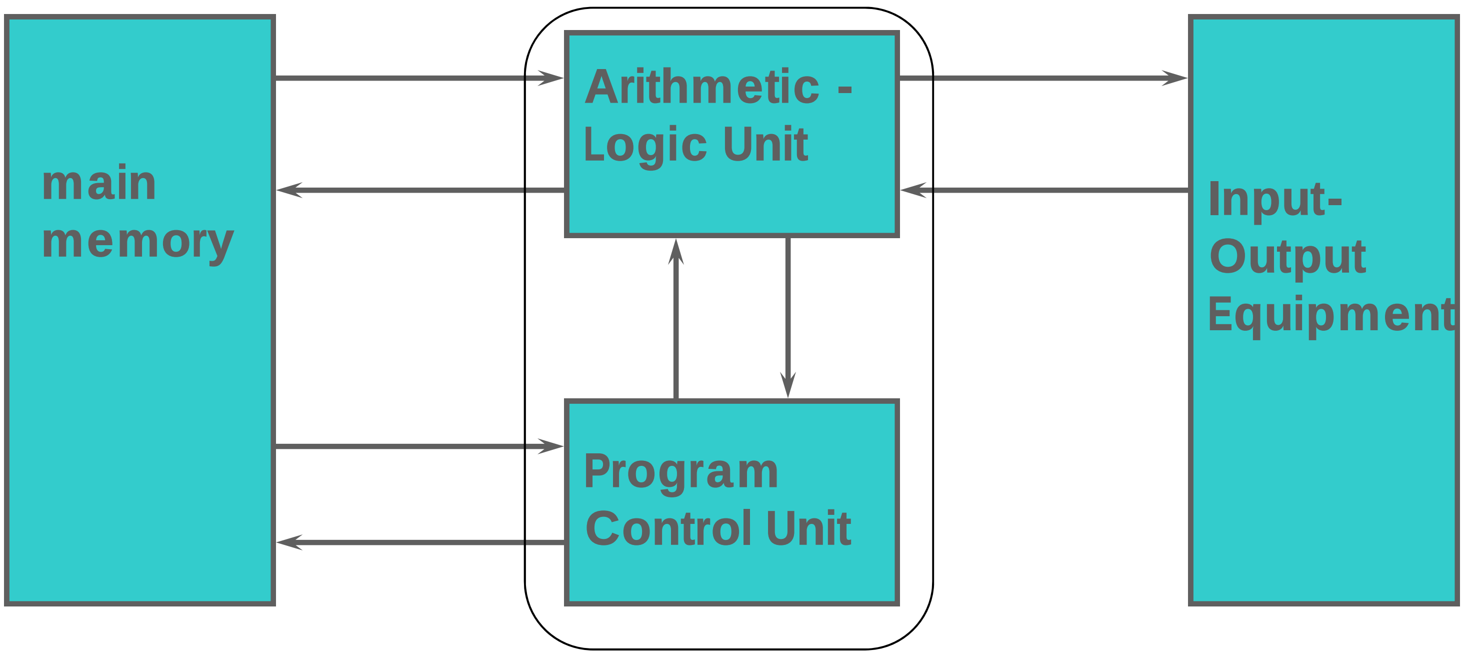


CPU - Microprocessor

- A CPU is on a chip called a *microprocessor*

Simple Machine Organization

- von Neumann machine
  - ALU performs transfers between memory and I/O devices



Simple CPU (no data registers)

CPU

- A CPU is a sequential circuit
- It repeatedly reads and executes an **instruction** from its memory
- Machine language program is a set of instructions drawn from CPU instruction set.
- An instruction is composed of one instruction **operation**, and a number of **operands**
  - Operand means the data needed for the operation
  - For example:

    1-operand format: use the accumulator (AC) register

    e.g. Load A (It means AC $\leftarrow$ A)

CPU speed

- The speed of a CPU is controlled by the *system clock*
- The system clock generates an electronic pulse at regular intervals
- The pulses coordinate the activities of the CPU
- The speed is usually measured in *gigahertz* (GHz)

e.g. 2.8 GHz means 2.8 billion pulses per second

Von Neumann Architecture

Execution unit is the same as Arithmetic-Logic unit

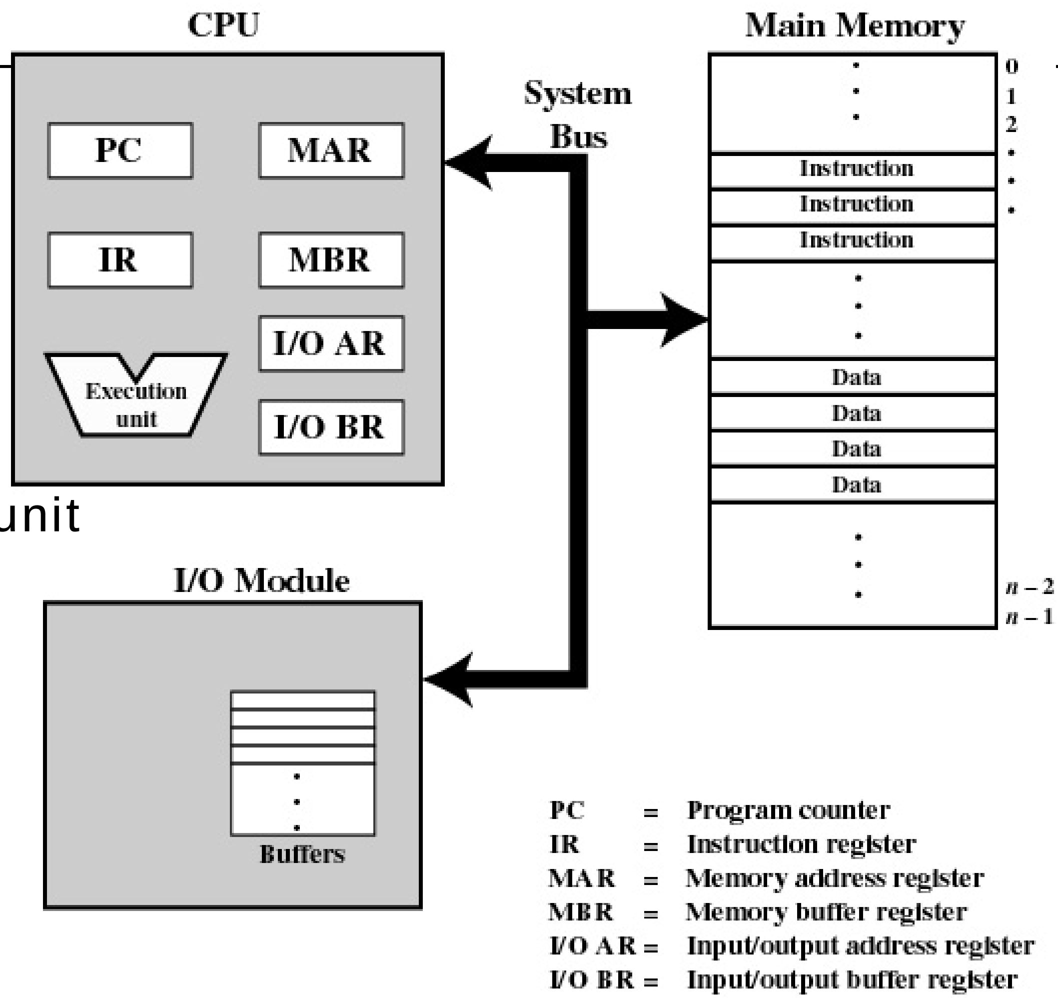


Figure 1.1 Computer Components: Top-Level View

Type of Instructions

- Processor-memory
  - transfer data between processor (register) and memory
- Processor-I/O
  - data transferred to or from a peripheral device
- Data processing
  - arithmetic or logic operation on data
- Control
  - alter sequence of execution

Instruction Set Principles

- Multiple data registers in CPU
- Data registers can be used to hold intermediate results during execution of instructions
- They are instruction-visible

  e.g. R1, R2, R3
- 2-operand format: one of the operands is both a source and result

  e.g. Add R1,B (It means R1 $\leftarrow$ R1+B)
- 3-operand format: result and two source operands

  e.g. Add R3,R1,R2 (It means R3 $\leftarrow$ R1+R2)

Different Kinds of Instruction Sets

- Different kinds of computer architecture and the corresponding instruction sets

Stack	1-operand format (AC) Accumulator	2-operand format Register (register-memory)	3-operand format Register (load-store)
Push A	Load A	Load R1,A	Load R1,A
Push B	Add B	Add R1,B	Load R2,B
Add	Store C	Store C,R1	Add R3,R1,R2
Pop C			Store C,R3

FIGURE 2.1 The code sequence for C = A + B for four instruction sets.

- Examples of instruction operation: Load, Add, Store
- Examples of memory address: A, B, C
- Examples of registers: Accumulator (AC), R1, R2, R3

Example of Program Compilation

- Suppose there is a C statement in the source program:

  A = A + B

- Suppose the CPU supports single-operand accumulator-kind of instructions.
- After compilation, this statement is translated into 3 instructions:

  LOAD B (AC ← memory address B)
  ADD A (AC ← AC + memory address A)
  STORE A (memory address A ← AC)

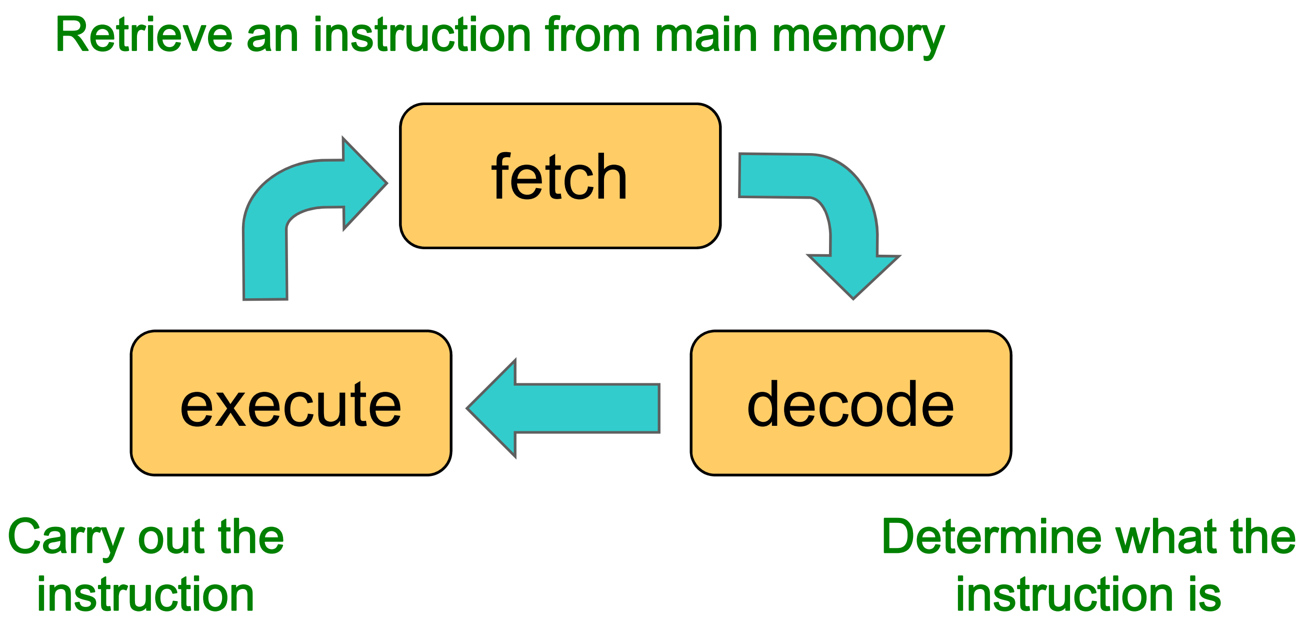
  - LOAD B means that it loads the content referenced by address B to the internal accumulator register AC
  - ADD A means that it adds the content referenced by address A to the internal accumulator register AC
  - STORE A means that it stores the content of the internal accumulator register AC into the memory location referenced by address A

Instruction Set Principles – Control Registers

- Used by processor to control the operation of the processor
- Program Counter (PC)
  - Contains the address of an instruction to be fetched
- Instruction Register (IR)
  - Contains the instruction most recently fetched

Instruction Cycle

- The CPU continuously follows the *fetch-decode-execute cycle:*



Instruction Fetch and Execute

- Program counter (PC) holds the address of the instruction to be fetched next.
- The processor fetches the instruction from memory.
- Program counter is incremented by one unit after each fetch so that the processor knows where the next instruction is.
- Fetched instruction is placed in the instruction register (IR).

Example of Program Execution

- Recall that the C statement A=A+B has been compiled into the following instructions:
  - LOAD B (AC ← memory address B)
  - ADD A (AC ← AC + memory address A)
  - STORE A (memory address A ← AC)
- When the user executes the executable file, the operating system will:
  - place those three instructions starting from a memory address such as 300
  - allocate a memory address such as 940 for the variable B
  - allocate a memory address such as 941 for the variable A

Example of Program Execution

0001 1001 0100 0000
1 9 4 0
LOAD 940

0101 1001 0100 0001
5 9 4 1
ADD 941

0010 1001 0100 0001
2 9 4 1
STORE 941

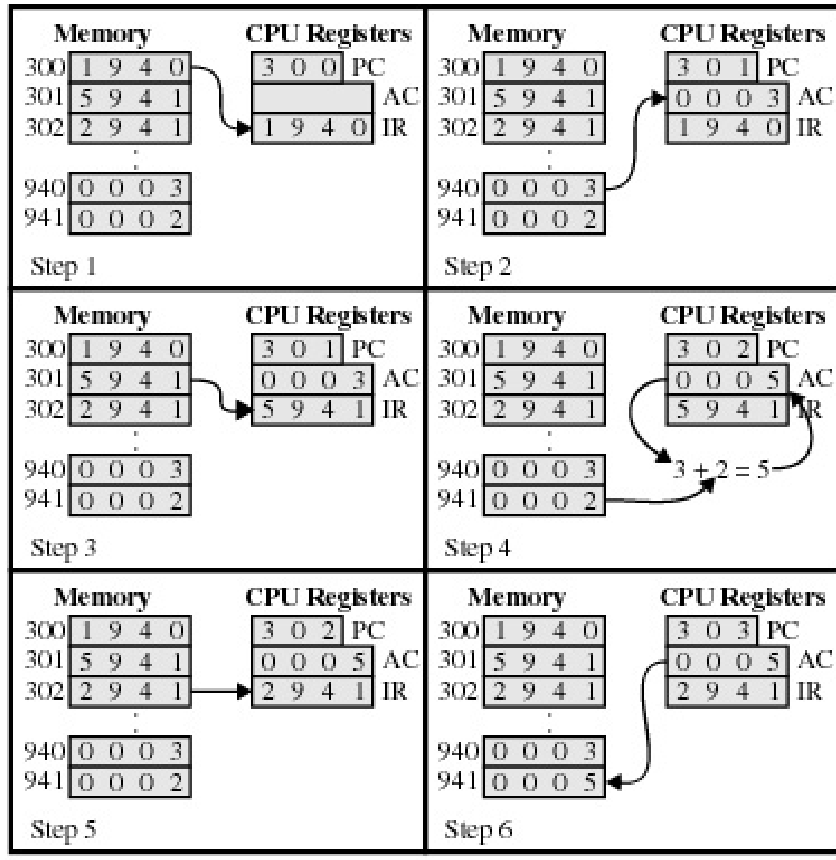


Figure 1.4 Example of Program Execution (contents of memory and registers in hexadecimal)

Instruction Set Principles – Instruction Encoding Examples

Operation & no. of operands	Address specifier 1	Address field 1	• • •	Address specifier n	Address field n

(a) Variable (e.g., VAX)

Operation	Address field 1	Address field 2	Address field 3

(b) Fixed (e.g., DLX, MIPS, Power PC, Precision Architecture, SPARC)

Operation	Address specifier	Address field

Operation	Address specifier 1	Address specifier 2	Address field

Operation	Address specifier	Address field 1	Address field 2

(c) Hybrid (e.g., IBM 360/70, Intel 80x86)

Instruction Set Principles – Status Registers

- Used for controlling the execution of instructions
- Program Status Word (PSW)
  - Condition Codes or Flags
    - Bits set by the processor hardware as a result of operations
    - Can be accessed by a program but not altered

      e.g. positive result, negative result, zero, overflow

Examples of Control Flow Instructions

Example instruction	Instruction name	Meaning
J name	Jump	PC←name; $((PC+4)-2^{25}) \leq$ name $< ((PC+4)+2^{25})$
JAL name	Jump and link	R31←PC+4; PC←name; $((PC+4)-2^{25}) \leq$ name $< ((PC+4)+2^{25})$
JALR R2	Jump and link register	Regs[R31]←PC+4; PC←Regs[R2]
JR R3	Jump register	PC←Regs[R3]
BEQZ R4,name	Branch equal zero	if (Regs[R4]==0) PC←name; $((PC+4)-2^{15}) \leq$ name $< ((PC+4)+2^{15})$
BNEZ R4,name	Branch not equal zero	if (Regs[R4]!=0) PC←name; $((PC+4)-2^{15}) \leq$ name $< ((PC+4)+2^{15})$

FIGURE 2.24 Typical control-flow instructions in DLX.

ALU Components

- ALU does arithmetic and logical comparisons
- AC = accumulator holds results
  - MQ = memory-quotient holds second portion of long results
  - MBR = memory buffer register holds data while operation executes