Computer Science 1000: Part #5

Computer Organization

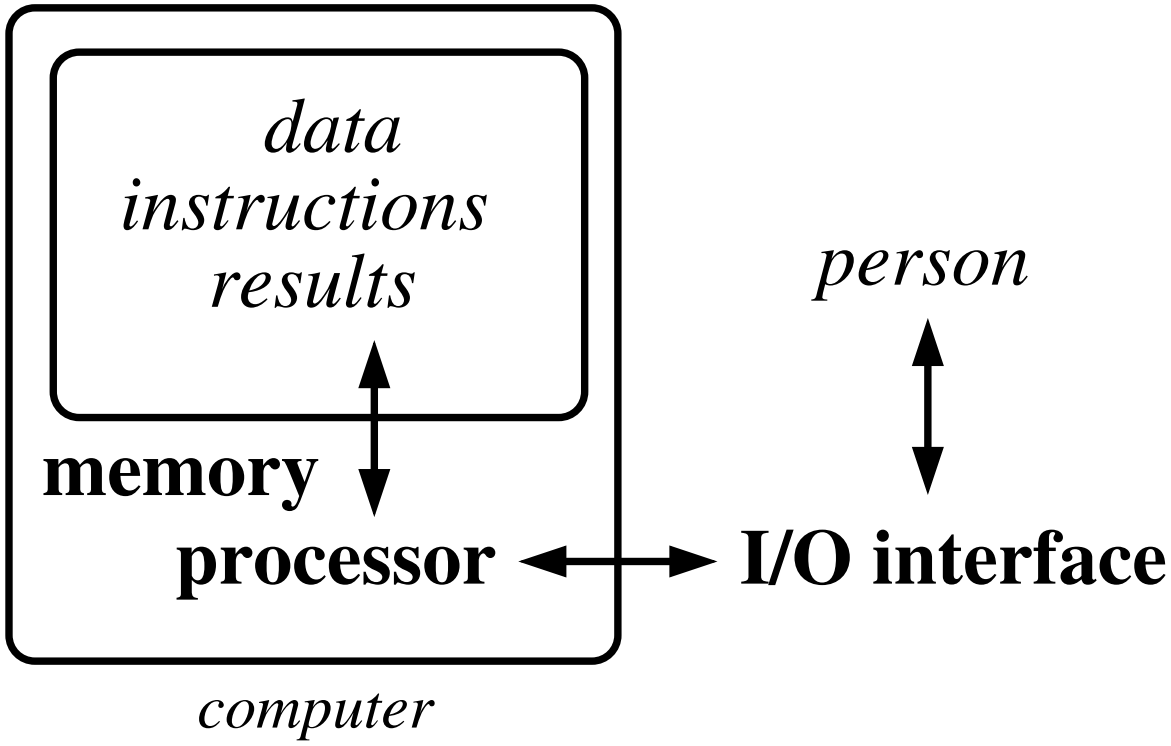
THE VON NEUMANN ARCHITECTURE: AN OVERVIEW

COMPUTER MEMORY

COMPUTER PROCESSOR

IMPLEMENTING COMPUTERS

The Von Neumann Architecture: An Abstract View



Also known as the stored-program architecture

The Von Neumann Architecture: A More Detailed View

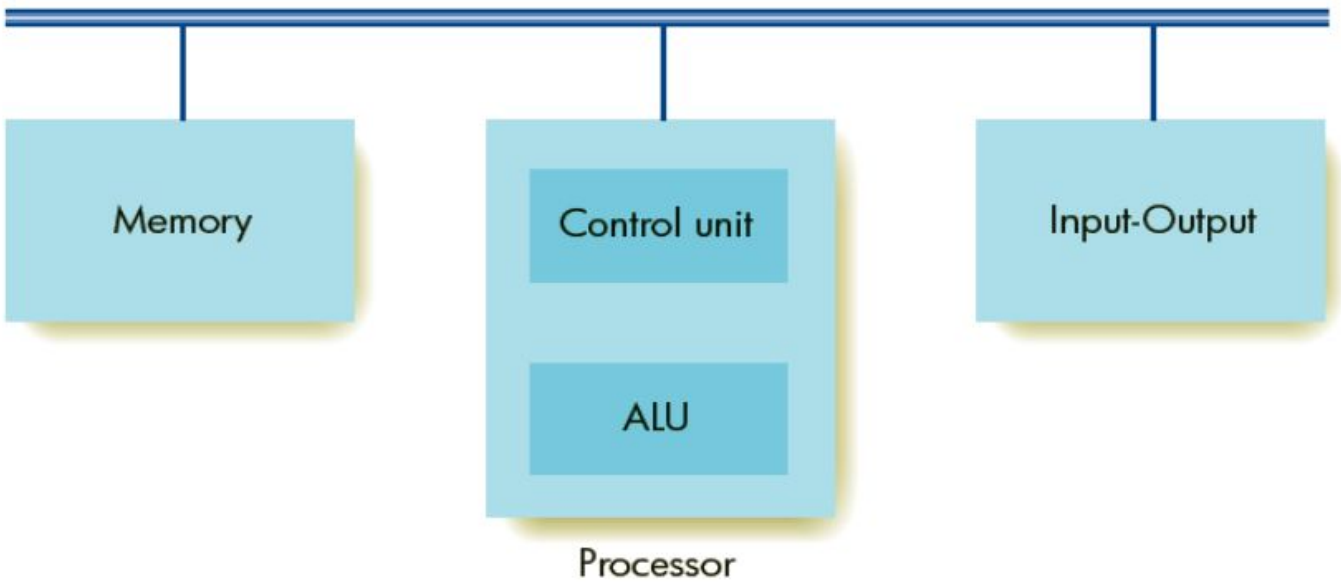


Figure 5.2 Components of the Von Neumann Architecture

The Von Neumann Architecture: A Really Detailed View

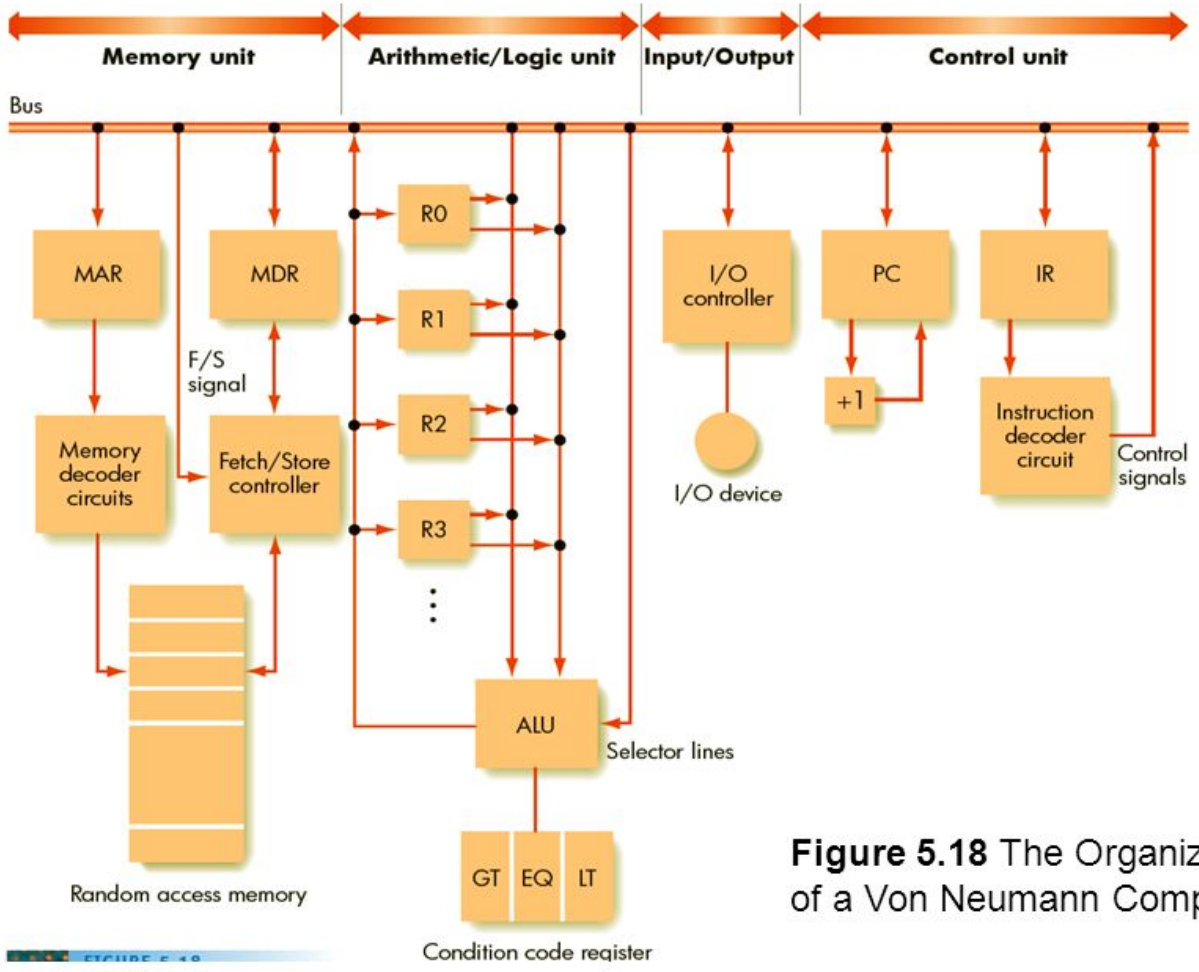


Figure 5.18 The Organization of a Von Neumann Computer

The Von Neumann Architecture: An Operational View

The Von Neumann Execution Cycle:

repeat
    Fetch next instruction
    Decode instruction
    Execute instruction

Computer Memory : Overview

- Focus here on (volatile) **Random-Access Memory (RAM)**, cf. (non-volatile) **Read-Only Memory (ROM)**.
- Three characteristics of RAM:
  1. Divided into fixed-width **cells**, each of which has a unique unsigned-integer **address** $0, 1, 2, \ldots, MAX$ (**address space**).
  2. The cell is the minimal unit of fetch / store access.
  3. All cells have the same access time.
- Crucial to distinguish a memory address and the contents of memory at a particular address, e.g.,

$$\text{address} \Longrightarrow \quad 5743_{10}\text{:} \ \boxed{-29_{10}} \ \Longleftarrow \text{contents}$$

Computer Memory : Overview (Cont'd)

- Standard cell-width $W = 8$ bits (**byte**); standard address $=$ 32 or 64 bits; standard access time $\approx$ 5-10 nanoseconds.
- Memory size stated in terms of number of bytes:

Kilobyte	(KB)	$= 10^3$ (thousand) bytes
Megabyte	(MB)	$= 10^6$ (million) bytes
Gigabyte	(GB)	$= 10^9$ (billion) bytes
Terabyte	(TB)	$= 10^{12}$ (trillion) bytes
Petabyte	(PB)	$= 10^{15}$ (quadrillion) bytes
Exabyte	(EB)	$= 10^{18}$ (quintillion) bytes
Zettabyte	(ZB)	$= 10^{21}$ (sextillion) bytes

$\vdots$

Computer Memory : Overview (Cont'd)

- All communication done via the **Memory Address Register (MAR)** and the **Memory Data Register (MDR)**.
- Two basic operations:
  - Fetch(address):
    1. Load address into MAR
    2. Decode address in MAR
    3. Copy cell contents at address into MDR
  - Store(address, value):
    1. Load address into MAR
    2. Load value into MDR
    3. Decode address in MAR
    4. Copy MDR value into addressed cell

Computer Memory : Internal Structure (Abstract)

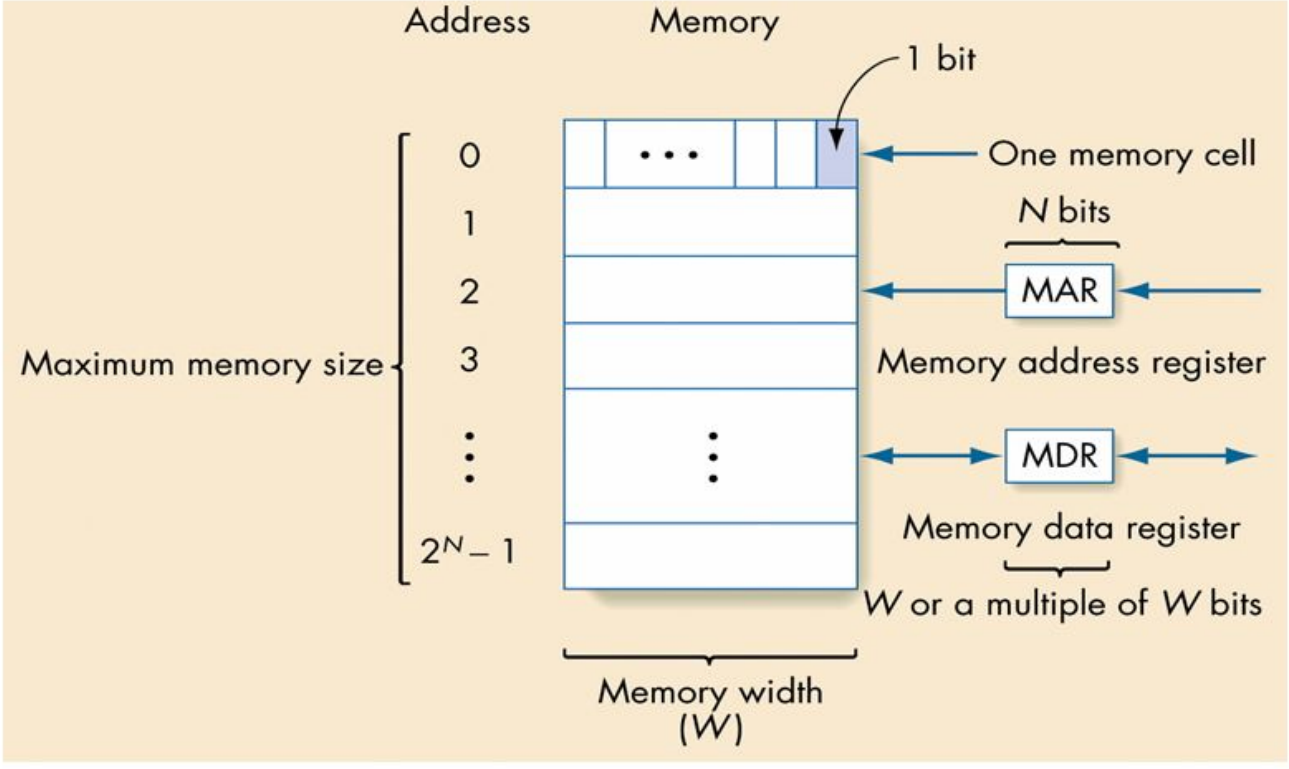


Figure 5.3
Structure of Random Access Memory

Computer Processor: Overview

- Two main parts:
  1. **Arithmetic Logic Unit (ALU)**: Performs arithmetic and logical operations.
  2. **Control Unit**: Handles interpretation and execution of program instructions. This involves directing the operations of the ALU and memory as well as interacting with the I/O controller.
- Both the ALU and the Control Unit have their own associated groups of special-purpose registers associated with their internal operations.

Computer Processor: The Arithmetic Logic Unit (ALU)

- Two types of ALU registers:
  1. **Value Registers (R0, R1, R2, . . .)**: A set of 16–128 registers which contain data for current and upcoming operations as well as intermediate results.
  2. **Condition Code Register (CCR)**: A collection of bits specifying the results (1 if true, 0 if false) of the most recently executed value comparison, e.g., LT (less-than), EQ (equal-to), GT (greater-than).
- Value registers communicate with memory and the ALU and can specified as either the left or right operand.
- The CCR communicates with the ALU, which passes the value of any condition-bit as requested to the control unit.

Computer Processor: The Arithmetic Logic Unit (ALU) (Cont'd)

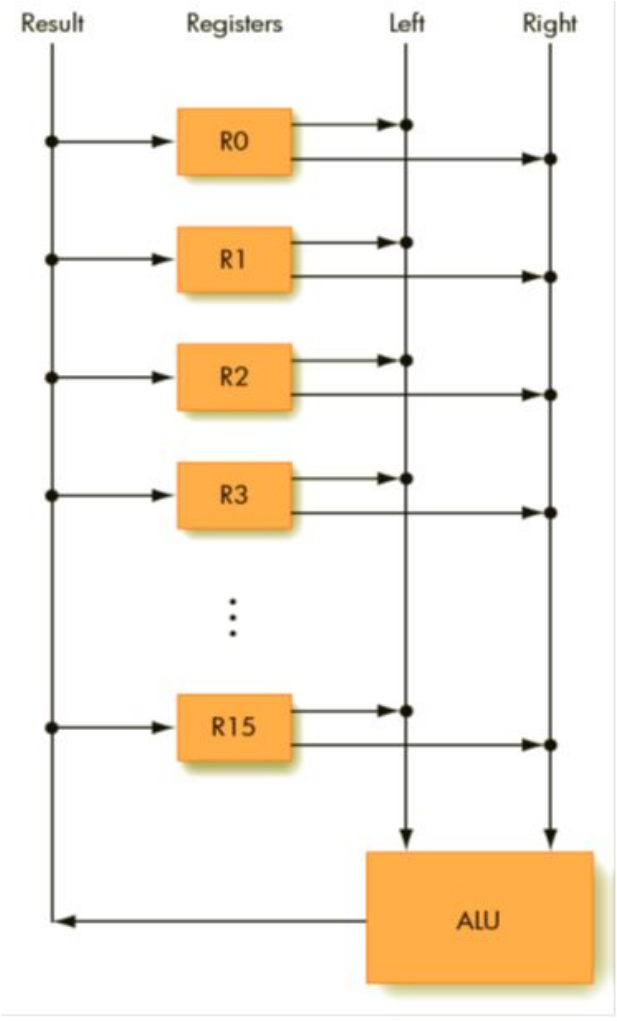


Figure 5.11 Multiregister ALU Organization

Computer Processor: The Arithmetic Logic Unit (ALU) (Cont'd)

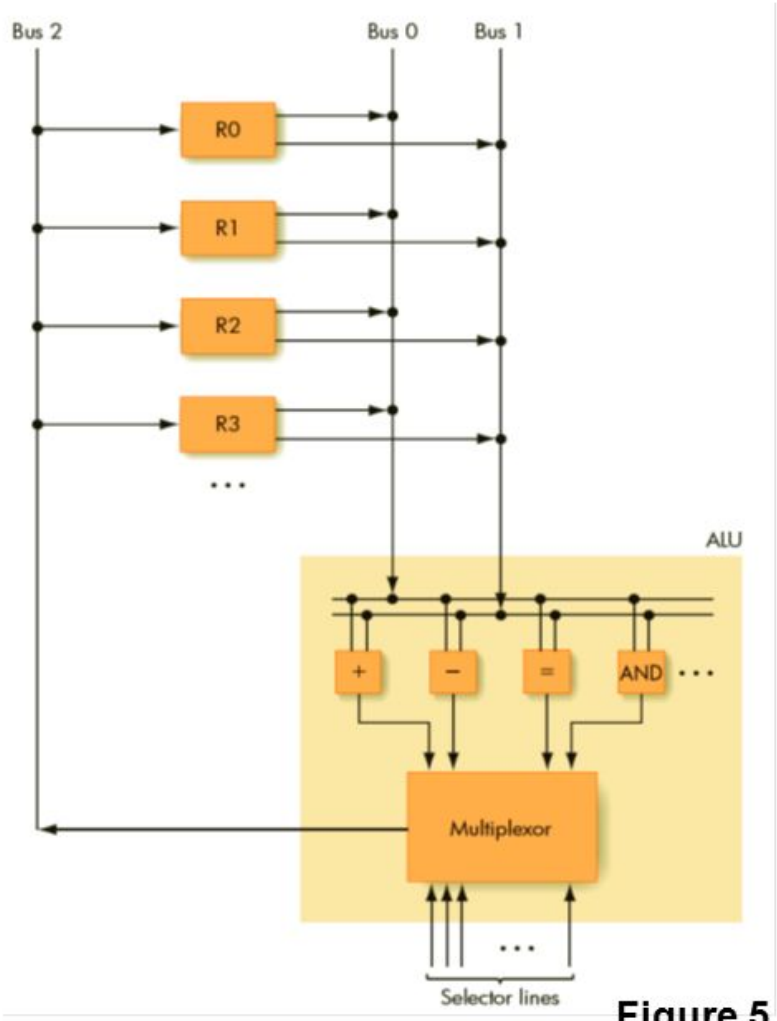


Figure 5.13 Overall ALU Organization

Computer Processor: The Control Unit

- Two Control Unit registers:
  1. **Program Counter (PC)**: Holds address in memory of next instruction to be executed.
  2. **Instruction Register (IR)**: Holds the current instruction being executed. This includes not only the op-code (IR_{op}) but the addresses of the instruction operands (IR_{add}, e.g., memory / ALU value registers).
- Instruction decoder circuitry uses the the k-bit opcode in the instruction in the IR to specify the appropriate one of the 2^k signals to that instruction's execution circuitry and/or other computer components.

Computer Processor: The Control Unit (Cont'd)

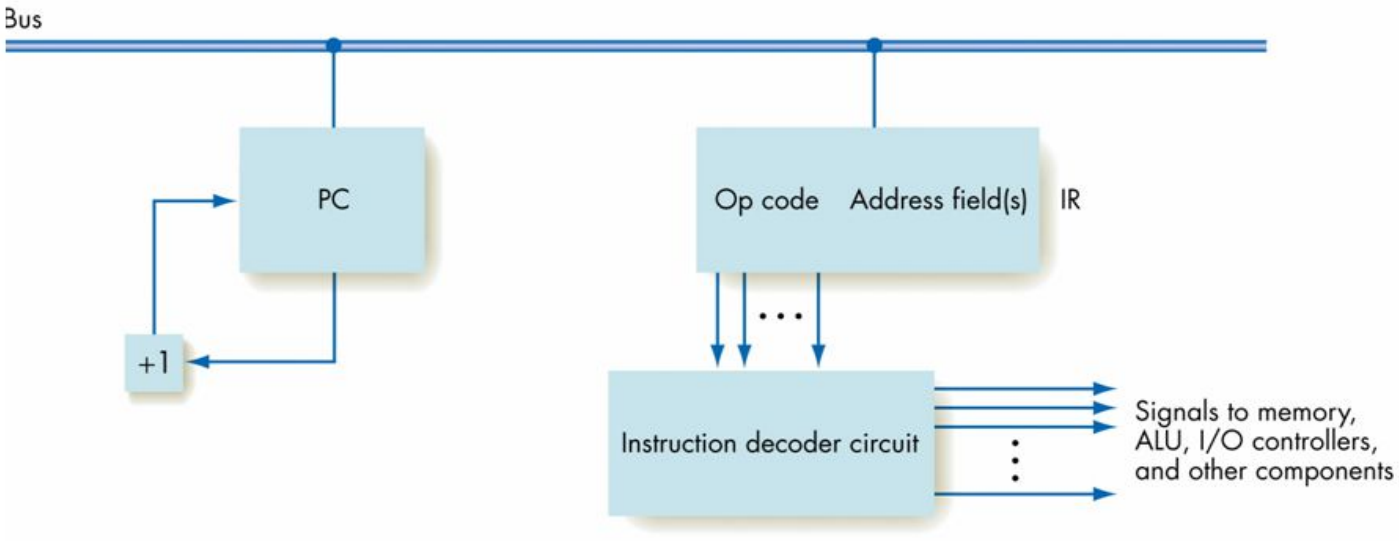


Figure 5.16
Organization of the Control Unit Registers and Circuits

Computer Processor: Machine Language

- An instruction = op-code + 0–3 address fields, e.g.,

op-code	address-1	address-2
000101	000000110011	000010001100
COMPARE	Addr1	Addr2

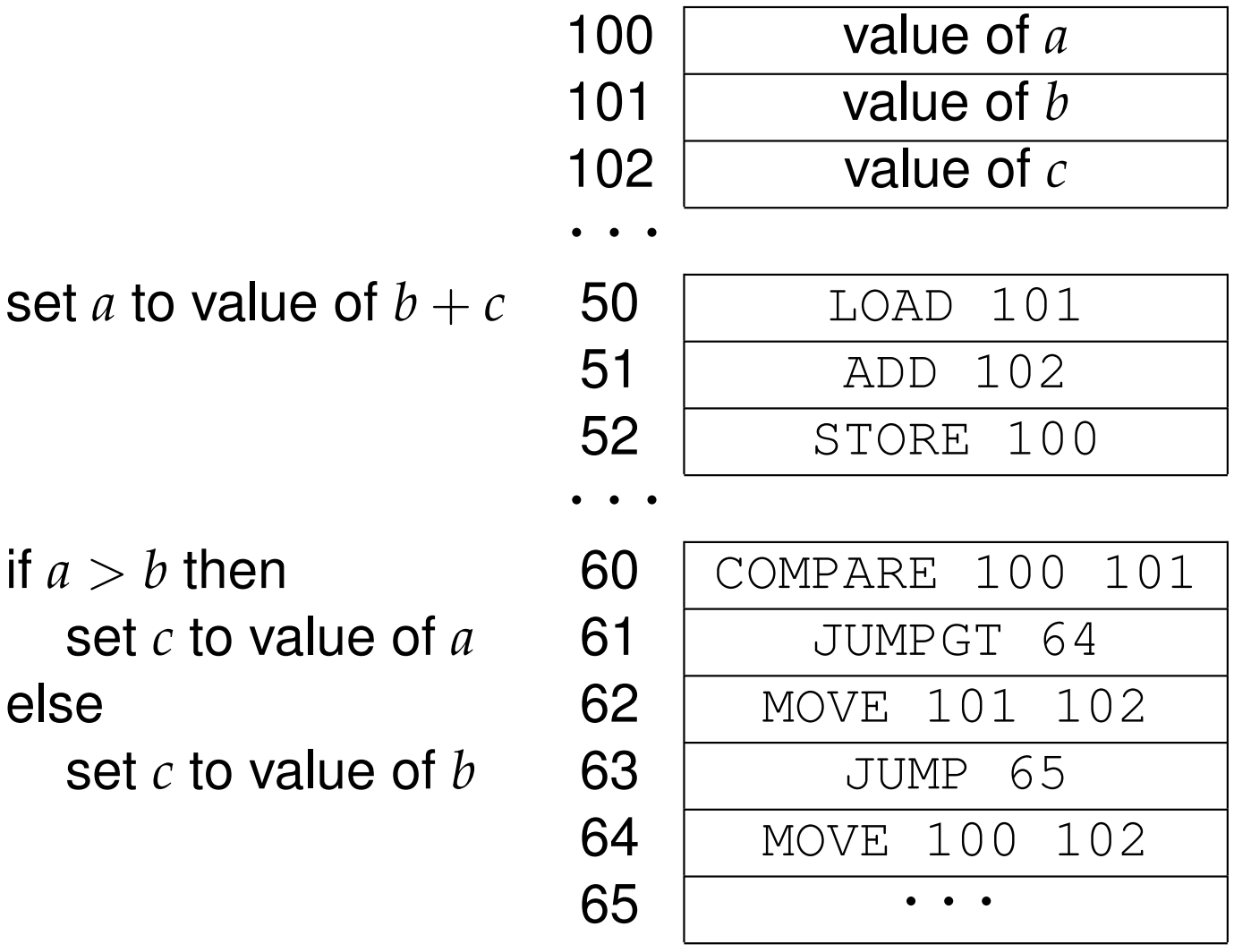
- Is part of either **Reduced or Complex Instruction Set Computer (RISC / CISC)** machine language; differ in tradeoff of required hardware vs. resulting program size.

Computer Processor: Machine Language (Cont'd)

Four types of machine language instructions:

1. **Data Transfer**: Move values between memory cells and/or ALU registers, e.g., `LOAD Addr1, LOAD Addr2, MOVE Addr1 Addr2.`
2. **Arithmetic**: Perform arithmetic / logical operations on values in memory cells and/or ALU registers, e.g., `ADD Addr1 Addr2 Addr3, ADD Addr1 Addr2.`
3. **Comparison**: Compare two values and set CCR bits, e.g., `COMPARE Addr1 Addr2.`
4. **Branch**: Alter next instruction to be executed (often on basis of preceding comparison), e.g., `JUMP Addr1, JUMPGT Addr1, HALT.`

Computer Processor: Machine Language (Cont'd)



The Von Neumann Architecture: A Detailed View Redux

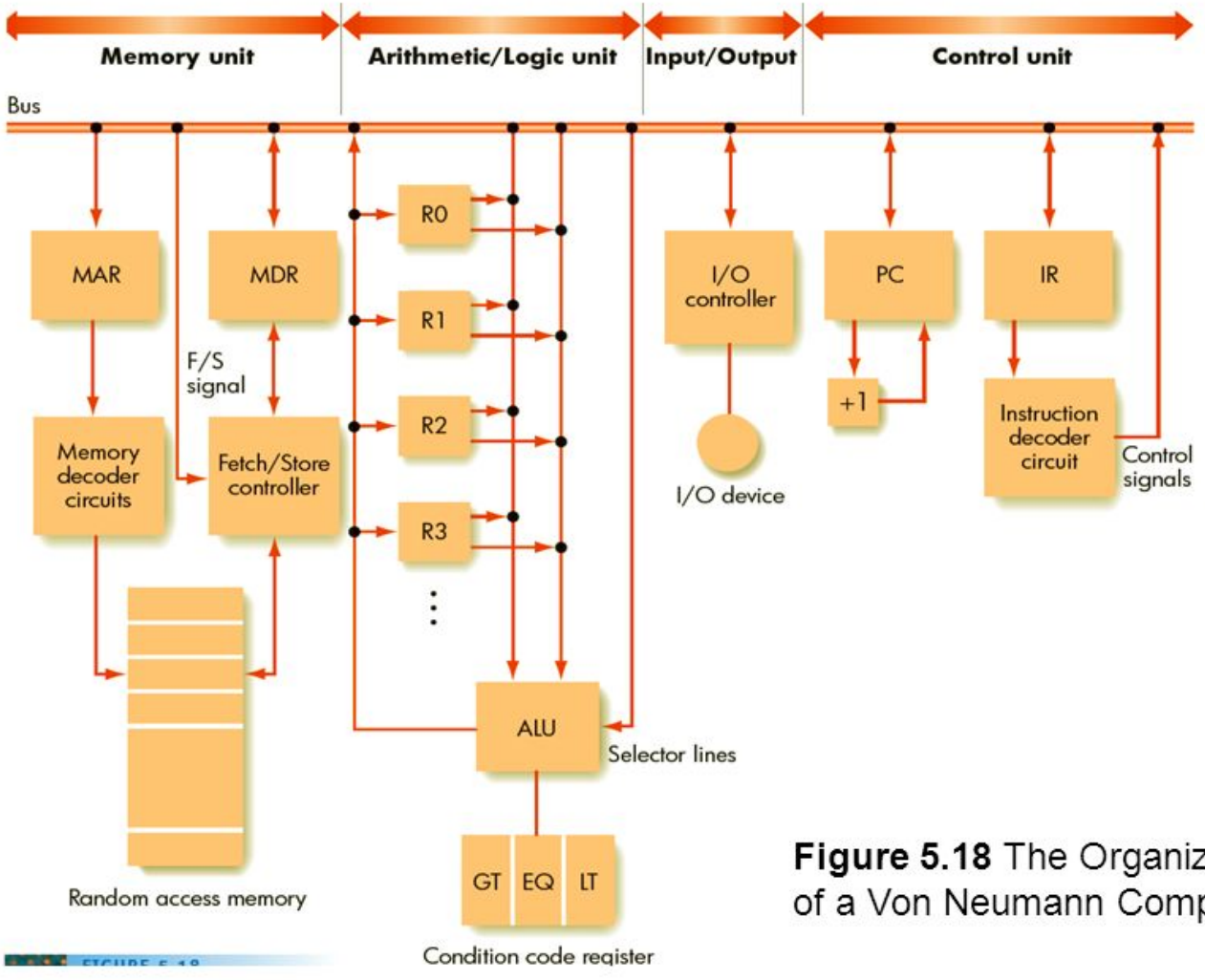


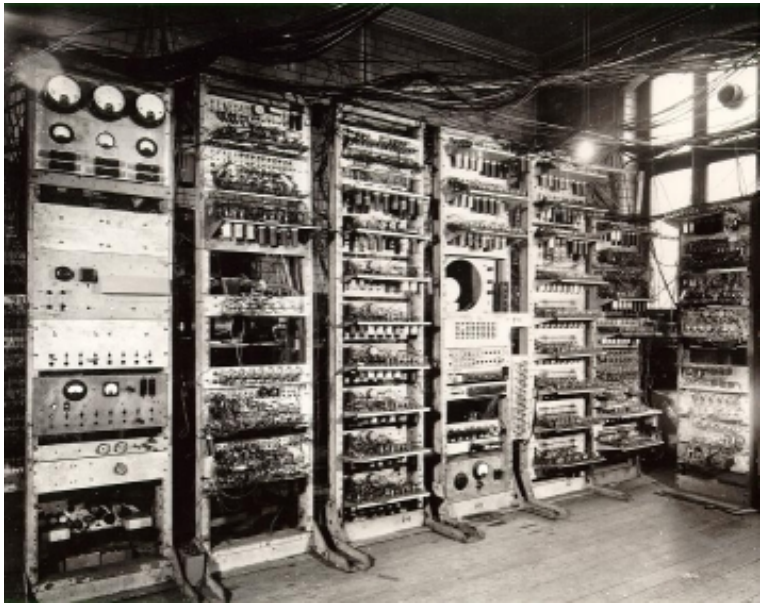
Figure 5.18 The Organization of a Von Neumann Computer

The Von Neumann Architecture: An Operational View Redux

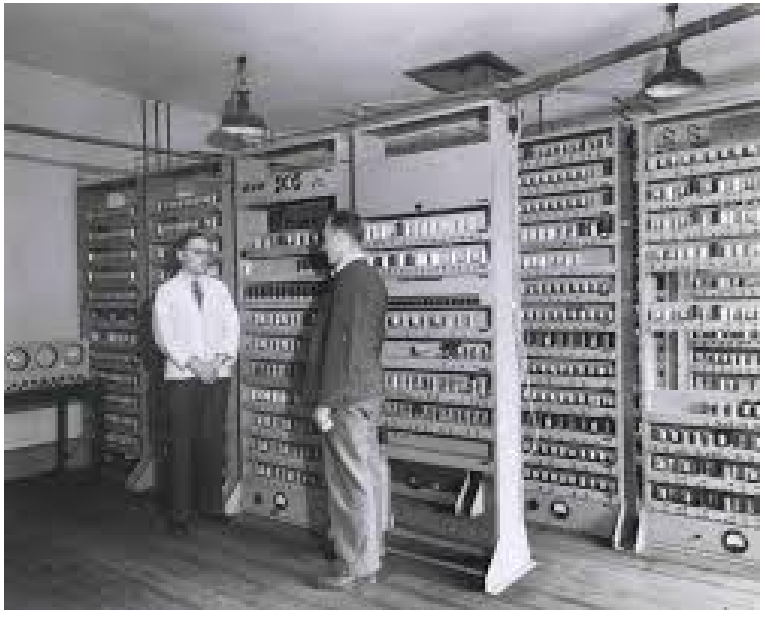
The Von Neumann Execution Cycle:

while no `HALT` or fatal error do
Fetch next instruction
Decode instruction
Execute instruction

Implementing Computers: Beginnings



SSEM ("Baby")
(1948, U. Manchester)



EDSAC
(1949, U. Cambridge)

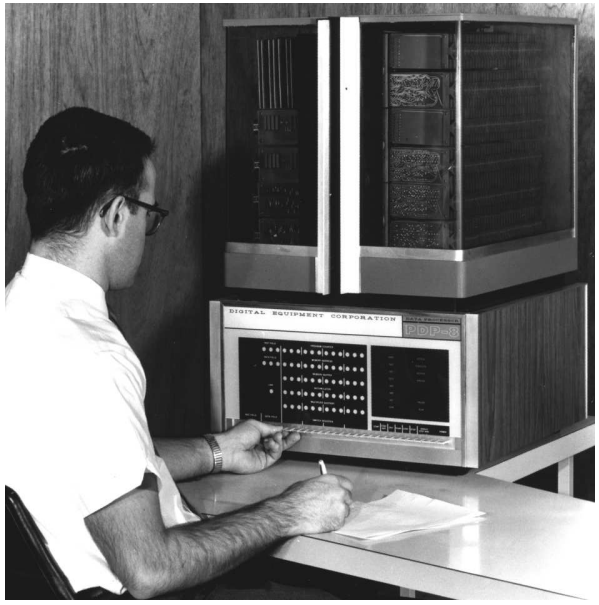
Though the Zuse Z3 was the first operational stored-program computer, SSEM and EDSAC were world's first operational electronic stored-program computers.

Implementing Computers: Mainframes

IBM System/360 (1967)

Implementing Computers: Minicomputers

PDP I (1960)



PDP 8 (1965)

Implementing Computers: Microprocessors

Instead of being a little mainframe, the PC is, in fact, more like an incredibly big chip. – Robert X. Cringely

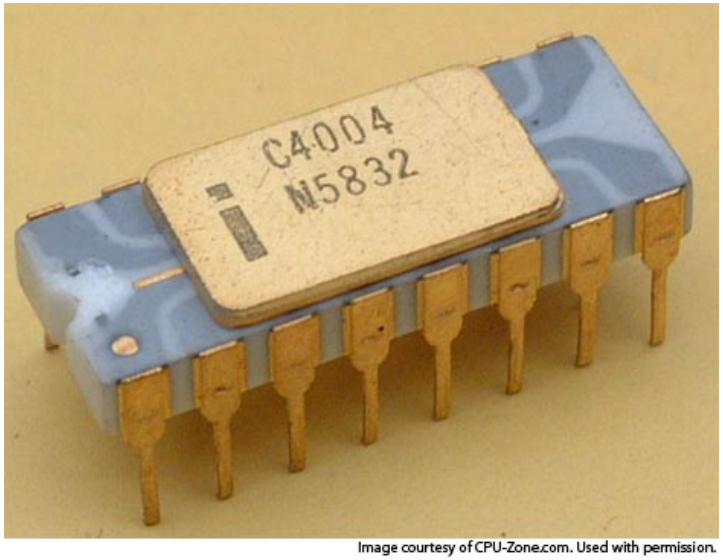


Image courtesy of CPU-Zone.com. Used with permission.

The microprocessor was invented by Ted Hoff in 1971.

Implementing Computers: Microcomputers

IBM PC (1981) [$2880]

Apple Macintosh (1984) [$2500]

Implementing Computers: Microcomputers (Cont'd)

First Portable Personal Computer: Osborne I (1981) [$1795]

Implementing Computers: Microcomputers (Cont'd)

- First true "laptop" PCs (GRiD Compass 1101 (1982) [$8K]; see above left) appear in 1980s, *cf.*, portable "desktop" PCs like the Osborne I; expense of display and memory technologies limits market severely.
- Laptops finally surpass desktops in sales in 2008.

Implementing Computers: Microcomputers (Cont'd)

- Hand-held personal computing appears first as Personal Digital Assistants (PDAs) in early 1990s.
- Early PDAs (Palm Pilot, Newton) were typically too expensive and based on technologies of limited user interest, *e.g.*, handwriting recognition.

- Second-generation PDAs achieve success among business and government users when combined with basic secure messaging abilities, *e.g.*, Blackberry (1999).

Implementing Computers: Microcomputers (Cont'd)

- The convergence of hand-held multimedia-enabled computing and communication technology has resulted in tablet computers and smartphones; the former is preferable for screen size and the latter for device size.

Implementing Computers: Embedded Computing

Implementing Computers: Supercomputers

IBM Blue Gene/P (2007) [164K processor cores]

Implementing Computers: Non-Von Neumann Architectures

CM-2 (1987)

DWAVE 2000Q (2017)

Based on massively parallel instruction execution by multiple processors (CM-2) or quantum entanglement (DWAVE 2000Q).

. . . And If You Liked This . . .

- MUN Computer Science courses on this area:
  - COMP 2003: Computer Architecture
  - COMP 4723: Introduction to Microprocessors
- MUN Computer Science professors teaching courses / doing research in in this area:
  - Vinicius Prado da Fonseca