CG3207

Computer Architecture

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What is a (Micro)-Computer ?
What is a (Micro)-Processor ?

- Micro-, Mini-, "*Right-size*", Super- ➔ have to be rapidly redefined as the years go by.
- No hard definitions.
  - Computer ➔ loosely speaking, generally refers to a system containing a processor + memories (primary and/or secondary) + I/O devices.
  - Processor ➔ loosely speaking, generally refers to the computing part of the computer.
  - But today, exceptions appear more than the rules – so it may be meaningless trying to differentiate.
- A PC is only one type of computer.
  - In fact many little processors/computers lie within the PC box.
    - The main processor (Intel Pentium, AMD Thunderbird for example)
    - The graphics processor,
    - The processor in the hard-disk, keyboard, mouse, ethernet card, and many others. – Easily 10-20 depending on your PC configuration.

What is a Processor ?

- It processes an algorithm.
  - Example: find the average series of numbers, 8 at a time.
    - Method 1
      - Read in all 8 numbers together
      - Add: $K_0=N_0+N_1$, $K_1=N_2+N_3$, $K_2=N_4+N_5$, $K_3=N_6+N_7$
      - Add $L_0=K_0+K_1$, $L_1=K_2+K_3$
      - Add $M=L_0+L_1$
      - Divide M by 8.
    - Method 2
      - The "Computer" way. Write a program loop.
  - Different structure of implementation – different architecture
- Processing using
  - Hardwired mode – Application Specific Processor (ASP)
    - Normally referred as ASIC
  - Interpreted mode – General Purpose Processor
    - Normally referred as processor
  - Programmable hardwired components – Application Domain Specific Processor (ADSP)
    - Comes different names such as DSP, Image Processor, etc.

What is a Processor ?

- Types of processors
  - General Purpose Processors
  - Application Domain Specific Processors
  - Application Specific Processors
- General Purpose Processors
  - Targeted at general algorithms → implies the algorithm can be changed after the processor is built.
  - Uses an interpreted mode
    - Means has a bunch of instructions that comprehensive enough to perform all the computations required in all digital algorithms.
    - To execute a particular algorithm, the various instructions are called in some specific sequence.
  - Typically sequential → typically there is only one instance for each instruction. Therefore cannot do things in parallel. (*but it is changing*)
  - So it is "slow".
    - Besides sequential, also needs to fetch instruction, decode and then execute.

What is a Processor ?

- Application Domain Specific Processors
  - Examples are DSPs
  - Targeted at a certain domain of applications.
    - Eg: implementation of filtering or some signal processing algorithms.
    - Typically require to perform a multiple and accumulate operation.
      - Such operations are "hardwired" so that the operation can be done quickly.
    - Programmability of the special functions are normally provided – so that the chip is good for a range of applications and not just one only.
      - Some form of instructions is present.
- Application Specific Processors
  - Very often refers to as ASIC
  - Target only for one application
    - Eg: Real-time MPEG2 encoder
- The bulk of discussions will be targeted towards programmable processors.

What is so interesting about a General Purpose Processor?

- Stored program concept.
  - Hardware is fixed:
    - Functional components
    - A set of fundamental instructions
  - Rearrangement of the instructions (a program) solve different problems!
  - Divided the solution into hardware and software
    - Gives rise to great flexibility
    - Can do changes anytime – almost essential as logic become more complex.
  - Can amortized the expensive setup cost for hardware over more units – as there is little customization needed.
- However
  - Inefficient as processing unit may not be well suited to solution space.
    - Has to provide complete set of processing components and yet some may not be used. Multiple instances may be needed on other cases.
  - Slow – sequential, not parallel.

Module Learning Outcome

- Able to explain the working principles behind the broad spectrum of processors, computing machines and their application to the solutions of modern day problems.
- Able to critically consider and analyse the issues involved in the architectural design of the digital processors and computing machines.
- Able to critically consider and analyse the trade-off in the application of the processor in a wide spectrum of engineering problems.
- Able to design a simple processor using hardware descriptive languages and to demonstrate a working design on an FPGA.

Module Structure

- Lectures, tutorials and 3-person group project.
- Project: 65% of final marks
  - The design of a microprocessor and its implementation on a Xilinx FPGA board
- Final written examination: 30% of final marks
  - Consisting of 40 multiple choice questions relating to critical analysis.
- Class formative online exercises after every chapter: 5%

Scope

- Introduction
- Logic design of a microprocessor
- Supporting tools
- High Performance Processor Design Techniques
- Memory organisation
- Multiprocessor
- More on Hardware Design Techniques

- References:
  - *Computer System Architecture, Mano, M.M., 3rd ed, Prentice Hall.*
  - *Computer Architecture, Baron, R.J. and Higbie, L., Addison Wesley.*
  - *Lecture notes.*

Introduction

- Computer Architecture
- Historical Perspectives
- A Classification of Computer Architectures
- Measuring the Quality of a Computer Architecture
- Factors Influencing the Success of a Computer Architecture
- System Performance

Computer Architecture

- Refers to the design of their instruction set hardware components and system organization
- 2 major parts
  - Instruction Set Architecture (ISA) specifies a computer's behavioral characteristics.
    - The specifications that determine how machine-language programmers will interact with the computer.
      - How it is controlled?
      - What is available to be controlled?
    - A computer is generally viewed in terms of its ISA
  - Hardware System Architecture (HSA) :
    - The specification of the computer's major hardware subsystems, e.g., CPU and I/O system.
    - HSA specifies a computer's structural characteristics and efficiency.
- An implementation of an ISA
  - Architecture vs implementation

Historical Perspectives

- First generation computers (1945 - 1955)
  - Technologies: Vacuum tubes
  - Major architectural innovations: Stored program computer
  - Examples:
    - ABC (Atanasoff-Berry Computer)
    - ENIAC (Electronic Numerical Integrator and Calculator)
    - EDVAC (Electronic Discrete Variable Computer)
    - EDSAC (Electronic Delay Storage Automatic Calculator) : The first stored program computer (von Neumann machine)
    - IAS (Princeton's Institute of Advanced Studies)
- Second generation computers (1955 - 1965)
  - Technologies: Transistors and magnetic-core memory,
  - Examples:
    - TX-0, TX-2 (Transistor eXperimental computer)
    - PDP-1, PDP-8 (Programmed Data Processor)
    - IBM 7090, 7094
    - CDC 6600 (Control Data Corporation)

Historical Perspectives

- Third generation computers (1965- 1980)
  - Technologies: Integrated circuits, solid-state or magnetic-
  - core memory, batch-processing operating systems,
  - multiprogramming operating systems
  - Major architectural innovations:
    - Computer-family architecture
    - Microprogramming control units
    - Execution-stack architecture
    - Hardware support for high-level programming language
    - Pipelining and multiple arithmetic units in CPU
    - Highly parallel computer
    - Cache memory
  - Examples:
    - IBM System/360-370, DEC PDP-11, ILLIAC IV, CRAY-1

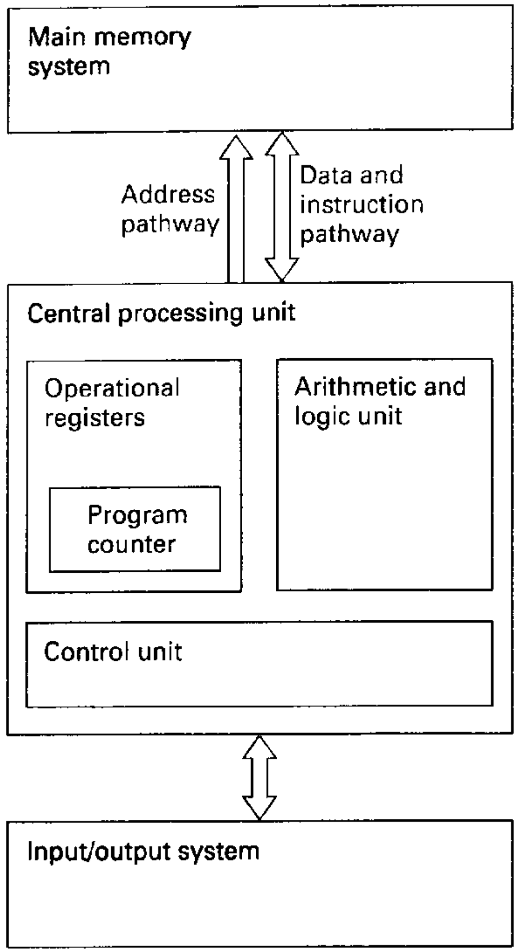
Historical Perspectives

- Fourth generation computers (1980-)
  - Technologies:
    - VLSI, solid-state memory,
    - time-sharing operating systems,
    - virtual memory,
    - support for many high-level programming languages
  - Major architectural innovations:
    - Reduced-instruction-set computers
    - multiprocessor computers
    - Dataflow architecture
  - Examples:
    - Personal computers
    - Workstations
    - Mainframes
    - Supercomputers

A Classification of Computer Architectures

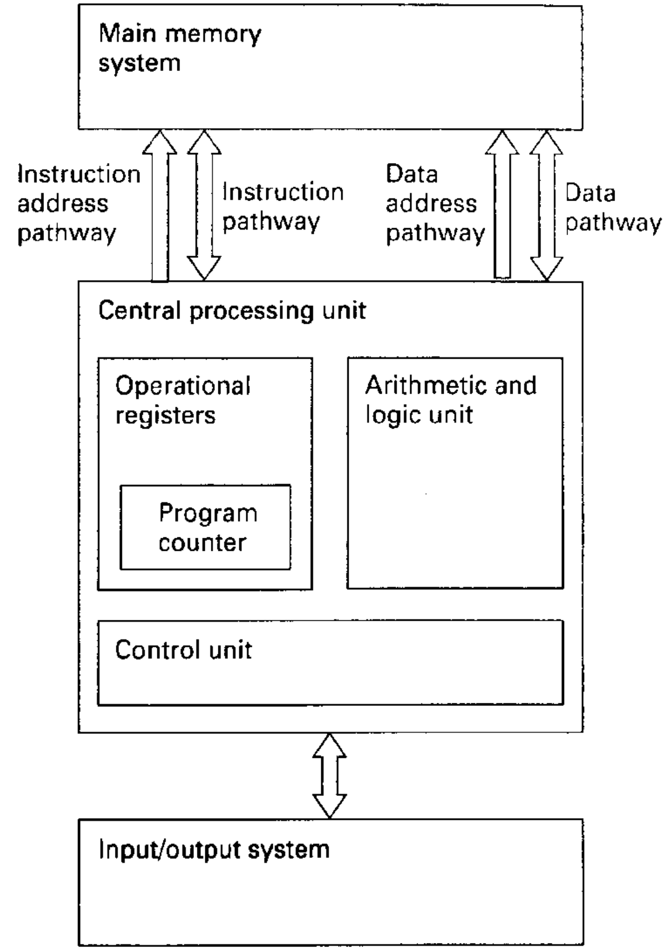
- Von Neumann Machines
  - a CPU,
  - a main-memory system,
  - an I/O system.
- It is a stored-program computer.
- It carries out instructions sequentially.
- It has a single path between the main memory system and the control unit of the CPU.

- Harvard: different path for data and instructions



a.

Von Neumann

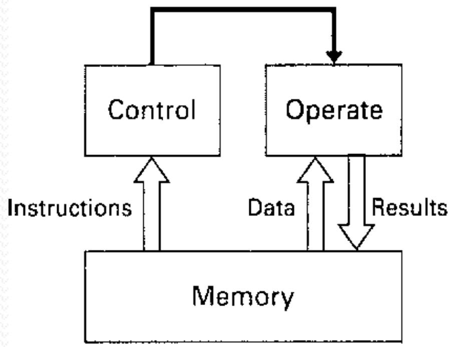


b.

Harvard Architecture

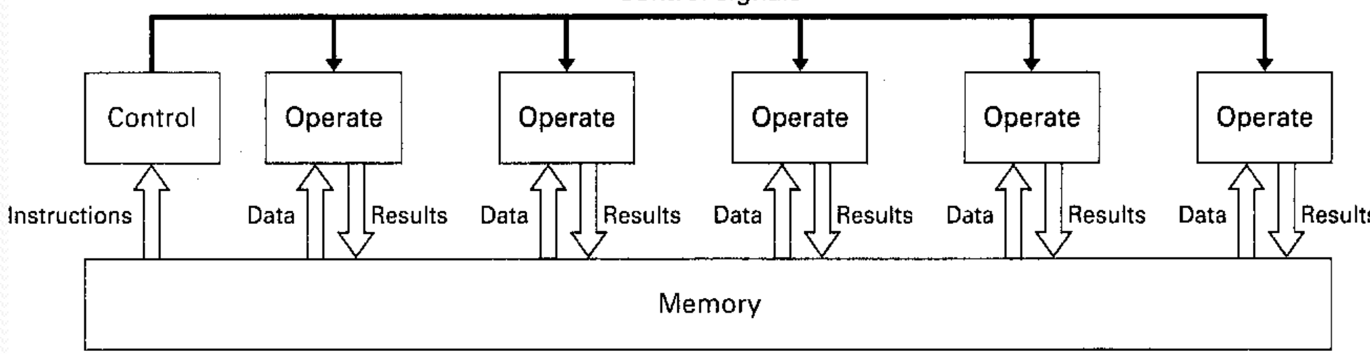
Flynn's classification

- A) Single Instruction stream, single data stream (SISD)
- B) Single Instruction stream, multiple data stream (SIMD)
- C) Multiple Instruction stream, multiple data stream (MIMD)
- D) Multiple Instruction stream, single data stream (MISD)



(a)

Von Neumann



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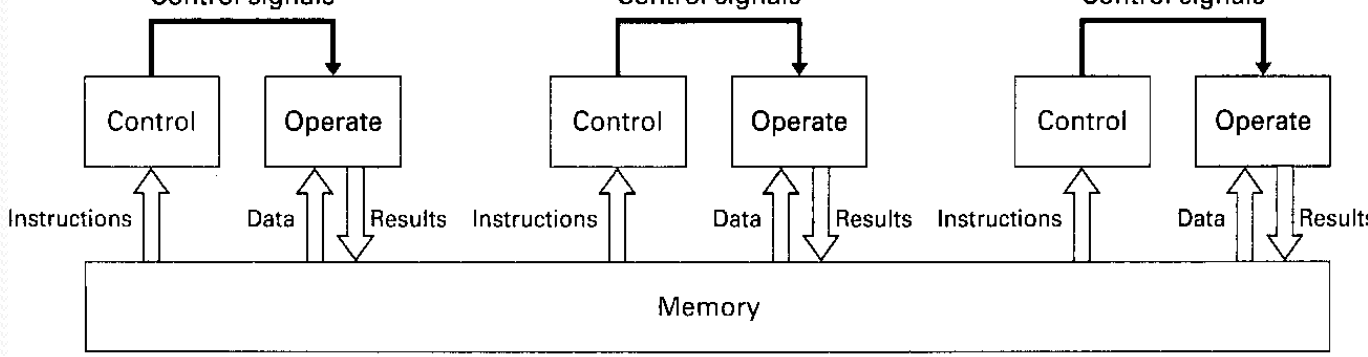

(c)

References Materials for Bed time Reading

- Intel IA32 Software Developer Volume 1 on Basic Architecture – available from Intel website. + others
  - http://support.intel.com/design/mobile/documentation.htm#manuals

- **Great Microprocessors of the Past and Present**
  - http://www.cpushack.com/CPU/cpu.html#tableofcontents