Chapter 1

Introduction to computer architecture

In this Chapter

- Digital systems
- Number systems
  - Floating point Representation
- Digital circuits
- Computer organization
- Computer architecture
- Computer security
  - Security through hardware
- Other chapters

Digital Systems

- Computers, iPad, cell phones, digital cameras, etc. created digital revolution, changing ways we:
  - Communicate, work, are entertained, shop
- Digital systems are in everything we see and use
  - Car manufacturing, AI, set-top, boxes, emergency equipment, etc.
  - Heavily used in process control
- Thus, more data is created, processed, stored, transmitted, and accessed
  - Results in demands for more powerful computers
    - Personal computers
    - Large computers used in
      - E-commerce, banking, search engines, research

Impact of Technologies (1)

1. **Impact of innovations in integrated chip (IC) technologies**
   - **Moore's law:**
     - **35% increase in transistor density per year**
     - **40% to 50% increase in transistor count per year**
     - **Has been used as a guide to design each next generation of microprocessors that revolutionized personal computers**
     - **Also resulted in increased power use and heat dissipation**

Digital Systems as Von Neumann machines

- **Computer system that contains**
  - **One or more processors**
    - **Each consisting of one or more *processing cores* (CPUs)**
  - **Memory**
  - **I/O devices**
  - **OS and application programs**
- **Embedded system that is**
  - **A complete system as circuit board or ASIC or FPGA , known as SoC**
    - **Contain CPU(s) and memory**
    - **Dedicated software known as firmware**
  - **May include transmitter/receiver modules**
  - **May include signal conversion modules (converters)**
    - **Analog-to-Digital (A/D)**
    - **Digital-to-Analog (D/A)**
  - **Applications:**
    - **Cell phones, digital camcorder, etc.**
    - **Host device controller interface**
      - E.g., USB

Von Neumann Computer

- **Processing core (CPU) consists of**
  - **Data path that includes**
    - **Digital circuit modules perform computations**
    - **Storage modules store computed data**
  - **Controller that orders data path operations**

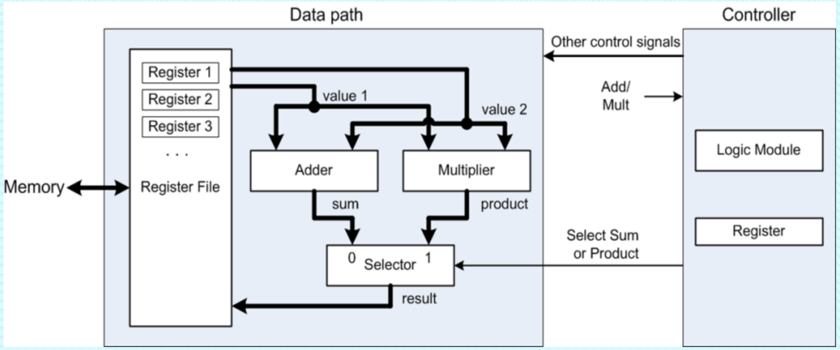

Fig. 1.1

- **As microcomputer that includes**
  - **Multicore processor (s)**
  - **Memory**
  - **Interconnection medium**
  - **I/O devices**
  - **I/O device controller and interface**
  - **Potential for bottleneck between faster processor and slower memory**

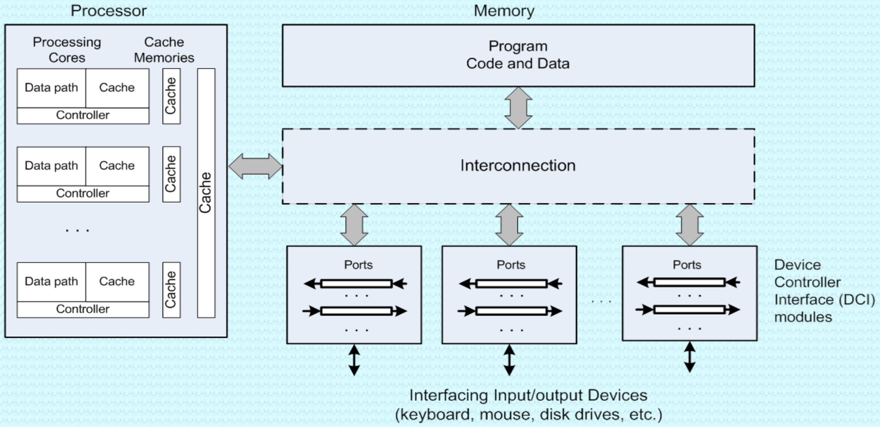

Fig. 1.2

Digital Logic Design (1)

1. Requires logic expressions

- **Example:** f **= ((NOT** a**) AND** b**) OR** c **Eq 1.2**
  - NOT, AND, and OR indicate Boolean logic operators
- **Evaluation**
  - **Suppose a = 0, b = 1, and c = 0**

f = (NOT 0) AND 1) OR 0
= (1 AND 1) OR 0
= 1 OR 0
= 1

What function does f perform?

f is 1 when a, b, c forming a 3-bit number is prime

- **Requirement: Minimal expressions to reduce hardware**

Digital Logic Design (2)

2. **Requires logic gates**
   - **Gates perform logic operations**
   - **Modern gates are built as CMOS circuits**
     - **Complementing MOS transistors reduce power consumption and heat dissipation**
   - **CMOS chips can be fan-cooled when hot**
     - **Thus, enabled personal computers**
     - **Exclusively used today in all types of digital systems**

Digital Logic Design (3)

3. **Require logic circuits**
   - **Logic circuits implement logic expressions**
   - **NAND or NOR are universal gates**
   - **Two types of digital circuits:**
     1. **Combinational: Outputs are generated concurrently**
        - Outputs depend on current inputs only
        - E.g., Adders and selectors
     2. **Sequential: Outputs are generated in sequence (in steps)**
        - Output depends on current inputs as well as previous inputs
        - Uses combinational circuits to generate outputs
        - E.g., registers, counters, and control units

Effect of Increased Power Consumption and Heat Dissipation

- **Examples,**
  - **2 watts for Intel 80386 processor**
  - **130 watts for 3.3 GHz (Giga Hertz) Intel Core i7 processor**
    - **65 times more watts**
- **Problem: Harder to make processors any faster**
  - **Affects computer organization, programming model, and OS**
  - **Current Solutions:**
    - **Divide tasks into subtasks using multithreaded programming**
    - **OS assigns processing cores to perform subtasks**
      - Creates thread-level parallelism
    - **Use multiprocessor systems to perform many independent and dependent tasks faster**
      - Modern Supercomputers for scientific computations
      - Warehouse-scale computers for
        - Interactive applications (Facebook, Google, etc.)
        - Large-scale storage and computing (e.g., cloud computing)

Computer Organization

Specifies implementation details:

- **Circuit and their physical relationship that makeup**
  - **Processing core**
    - **data path organization**
    - **Example: 32-bit Intel vs. AMD processors**
      - Two different data paths but same instruction set
  - **processor,**
  - **memory,**
  - **I/O device controller and interface**
  - **Interconnection of a computer components**
- **Memory organization**
  - **Cache, SDRAM, multi-channel, etc.**

Computer Architecture (1)

Specifies design concepts:

- **Pipelining**
  - **Concept of an assembly line**

Stage 3: Install wheels			Car1	Car2	Car3	. . .
Stage 2: Install doors		Car1	Car2	Car3	. . .	. . .
Stage 1: Install Engine	Car1	Car2	Car3	. . .	. . .	. . .
Time slots (e.g., 10-minutes slots)	1	2	3	4	5	. . .

If each stage is 2 minutes, how many cars built in a year (assume perfect scenario)?

260,000+

  - **E.G., pipelining CPU data path**

Execute			Load r1, B	Load r2, C	Add r3, r1, r2	Store A, r3
Decode		Load r1, B	Load r2, C	Add r3, r1, r2	Store A, r3	. . .
Fetch	Load r1, B	Load r2, C	Add r3, r1, r2	Store A, r3	. . .	. . .
Time (T)	1	2	3	4	5	6

What can go wrong?

Computer Architecture (2)

- **Parallelism**
  - **Single Instruction Multiple Data (SIMD)**
    - **E.g., Intel's Streaming SIMD Extension (SSE) instruction set**
    - **E.g., AMD's 3DNow instruction set**
    - **Also in GPUs**
  - **Instruction level parallelism (ILP)**
    - **Also called Superscalar processor (i.e., processing core)**
    - **E.g., processing cores in Intel Core i7**
  - **Multiple Instructions Multiple Data (MIMD)**
    - **Multicore Processors**
      - E.g., Intel Core i7
    - **Multiprocessor Systems**
      1. *Shared memory*: Processors communicate using memory
      2. *Message passing*: Processors communicate by sending/receiving messages

Computer Security

- **Protecting digital assets (programs and data) from malware attacks**
- **Protecting digital assets from unauthorized access by employees**
- **Affects all**
  - **individuals, government, business organizations**
- **Potable devices also subject to *physical attacks***
- **Application examples**
  - **Secure data storage**
  - **Secure communication**
  - **Secure e-commerce**
  - **Etc.**
- **How hardware can help?**
  - **Hardware more secure than software and disk storage**
  - **Computer security through hardware**
    - **Secure co-processor**
      - E.g., Crypto-processor
    - **Secure processor**
      - Also, supports secure execution
      - Also, guards against physical attacks

Digital Systems

- Digital circuits make logical decisions as True or False logic values
- A voltage range defines each logic value.
  - E.g., 5-volt power source
    - 2.4 to 5V as True
    - 0 to 0.8V as False
  - Lower voltage sources help save power in battery powered devices
- True and False values as 1 and 0 form binary numbers to represent
  - Characters
    - 8-bit, or 256 ASCII codes
    - 16-bit numbers, or over 65,000 Unicodes
  - Pixels to create images
  - Audio and video data
  - Integer and real numbers used in computations

Floating point numbers

- Representation of real numbers in computers is called floating-point (FP) numbers

Biased Exponent		Exponent		Unsigned Fraction	Meaning
Decimal	Binary	Bias = 7	Bias = 8		
0	0000	0	0	0	Represents FP number zero (0.0)
0	0000			≠ 0	Represents a very small FP number called denormal, not typically stored in memory
15	1111			0	Represents infinity (e.g., the result of 1.0 divided by 0.0)
15	1111			≠ 0	Represents an invalid FP number (e.g., the result of computing $\sqrt{-1}$),
1–14	0001–1110	–6 to 7	–7 to 6	Any	Represents a normal FP number

TABLE 1.3 4-Bit Biased Exponent versus Exponent

Remaining Chapters (1)

- Combinational circuits
  - Design methodology for small circuits (Ch2)
    - Circuits with fewer (e.g., ≤ 4) inputs
  - Design methodology for large circuits (Ch3)
    - Circuits with many inputs (e.g., 32-bit Adder)
- Sequential circuits
  - Basic core modules (Ch4)
    - Basic storage elements
  - Design methodology for small circuits (Ch5)
    - Registers, counters, etc.
  - Design methodology for large circuits (Ch6)
    - Data paths and control units

Remaining Chapters (2)

- Memory (Ch7)
  - Memory organization
  - Memory timing
- Processing core (CPU) design, a very complex sequential circuit (Ch8)
  - CPU data path and control
- Microcomputer organization, history and modern designs (Ch9)
  - CPU, memory, I/O device interconnections
  - Device communication
- Memory system (Ch10)
  - Cache memory organization
  - Main memory as physical memory
  - Disk space as virtual memory
- Computer security for computer architects (Ch11), an introduction
  - Threat models
  - HW and SW security models, policies, and mechanisms
  - Trusted computing base as secure co-processor or secure processor

Back Up

Impact of Technologies (2)

2. **Impact of innovations in application developments**
   - **Revolutionizing the way digital systems are designed**
   - **Digital circuits are described in HDL**
   - **CAD tools simulate (validate) HDL descriptions**
   - **CAD tools synthesize (translate) HDL descriptions to circuits**