Chapter 1
Welcome Aboard

Slides based on set prepared by
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Computer System: Layers of Abstraction

Application Program
Algorithms
Language
Instruction Set Architecture
(and I/O Interfaces)
Microarchitecture
Circuits
Devices

Software
Hardware
Big Idea #1: Universal Computing Device

All computers, given enough time and memory, are capable of computing exactly the same things.
Turing Machine

Mathematical model of a device that can perform any computation – Alan Turing (1937)

- ability to read/write symbols on an infinite “tape”
- state transitions, based on current state and symbol

Every computation can be performed by some Turing machine. (Turing’s thesis)

Turing machine that adds

\[
T_{\text{add}} : \quad \text{a,b} \rightarrow a+b
\]

Turing machine that multiplies

\[
T_{\text{mul}} : \quad \text{a,b} \rightarrow ab
\]
Universal Turing Machine

Turing described a Turing machine that could implement all other Turing machines.

- inputs: data, plus a description of computation (Turing machine)

\[ T_{\text{add}}, T_{\text{mul}} \rightarrow U \rightarrow a, b, c \rightarrow c(a+b) \]

Therefore, a computer is a universal computing device!
From Theory to Practice

In theory, computer can compute anything that’s possible to compute
  • given enough memory and time

In practice, solving problems involves computing under constraints.
  • time
    ➢ weather forecast, next frame of animation, ...
  • cost
    ➢ cell phone, automotive engine controller, ...
  • power
    ➢ cell phone, handheld video game, ...
Big Idea #2: Transformations Between Layers

How do we solve a problem using a computer?
A systematic sequence of transformations between layers of abstraction.

- **Problem**
- **Algorithm**
- **Program**
- **Instr Set Architecture**

**Software Design:**
choose algorithms and data structures

**Programming:**
use language to express design

**Compiling/Interpreting:**
convert language to machine instructions
Deeper and Deeper…

**Instr Set Architecture**

**Processor Design:**
choose structures to implement ISA

**Microarch**

**Logic/Circuit Design:**
 gates and low-level circuits to implement components

**Circuits**

**Process Engineering & Fabrication:**
develop and manufacture lowest-level components

**Devices**
Descriptions of Each Level

Problem Statement
• stated using "natural language"
• may be ambiguous, imprecise

Algorithm
• step-by-step procedure, guaranteed to finish
• definiteness, effective computability, finiteness

Program
• express the algorithm using a computer language
• high-level language, low-level language

Instruction Set Architecture (ISA)
• specifies the set of instructions the computer can perform
• data types, addressing mode
Descriptions of Each Level (cont.)

Microarchitecture
• detailed organization of a processor implementation
• different implementations of a single ISA

Logic Circuits
• combine basic operations to realize microarchitecture
• many different ways to implement a single function (e.g., addition)

Devices
• properties of materials, manufacturability
Many Choices at Each Level

Solve a system of equations

- Red-black SOR
- Gaussian elimination
- Jacobi iteration
- Multigrid

Tradeoffs:
- cost
- performance
- power
(etc.)
What’s Next

Bits and Bytes
• How do we represent information using electrical signals?

Digital Logic
• How do we build circuits to process information?

Processor and Instruction Set
• How do we build a processor out of logic elements?
• What operations (instructions) will we implement?

Assembly Language Programming
• How do we use processor instructions to implement algorithms?
• How do we write modular, reusable code? (subroutines)

I/O, Traps, and Interrupts
• How does processor communicate with outside world?