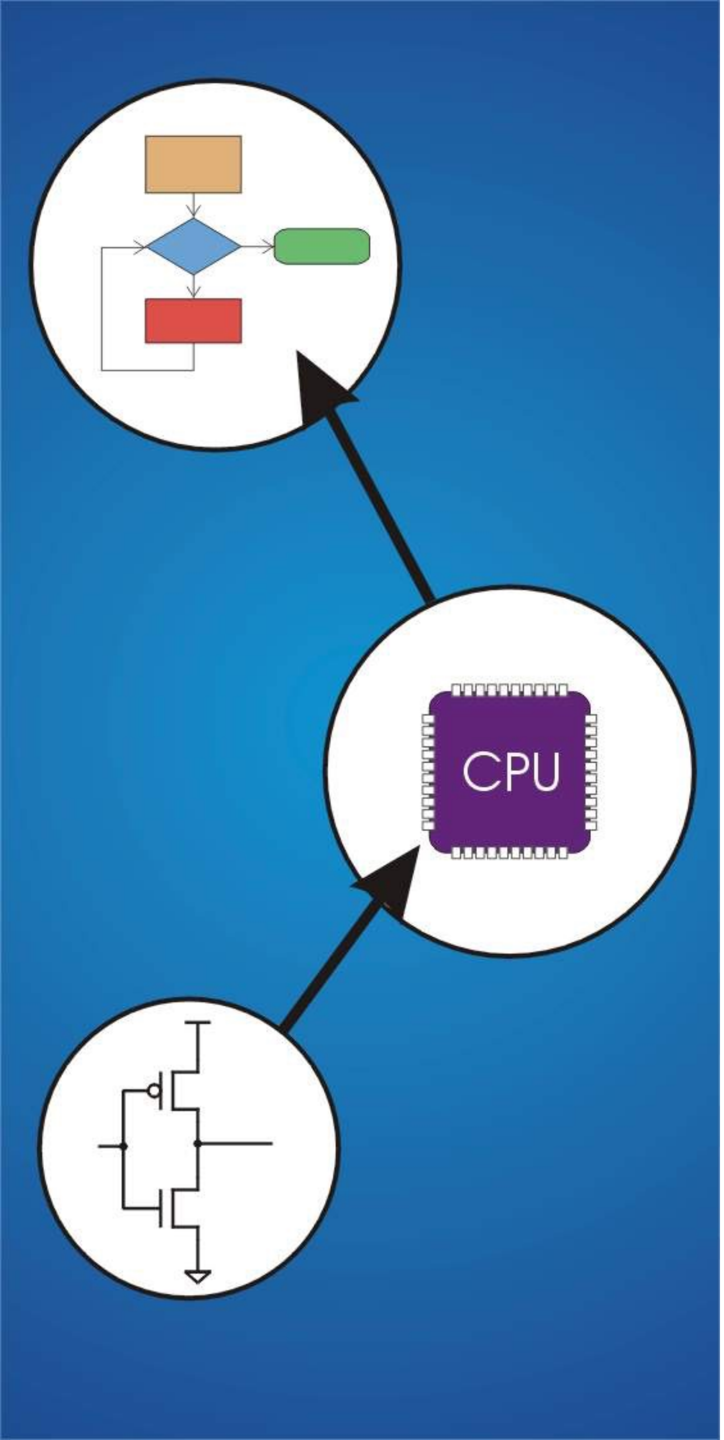


Chapter 1
Welcome Aboard

Introduction to the World of Computing

Computer: electronic genius?

- NO! Electronic idiot!
- Does exactly what we tell it to, nothing more.

Goal of the course:

You will be able to write programs in C
and understand what's going on underneath.

Approach:

Build understanding from the bottom up.

Atoms/Electrons ➨ Transistors ➨ Gates ➨ Processor ➨ Instructions ➨ C Programming

Two Recurring Themes

Abstraction

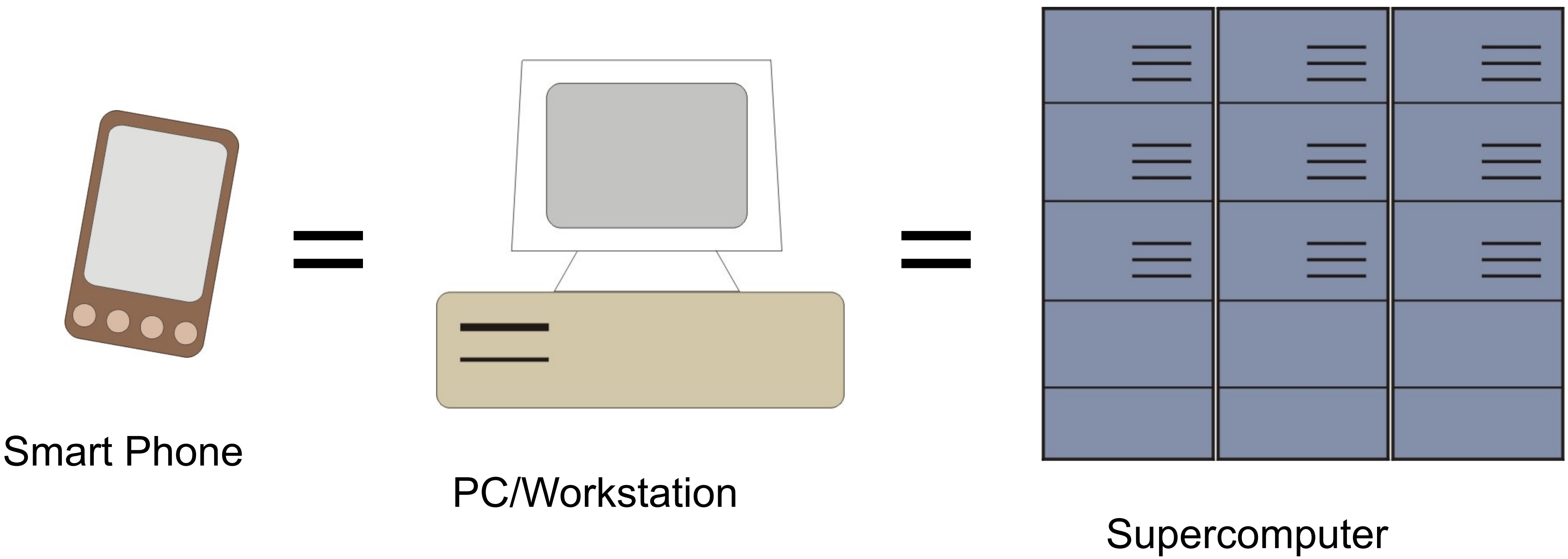
- Productivity enhancer – don't need to worry about details…
  Can drive a car without knowing how
  the internal combustion engine works.
- …until something goes wrong!
  Where's the dipstick? What's a spark plug?
- Important to understand the components and
  how they work together.

Hardware vs. Software

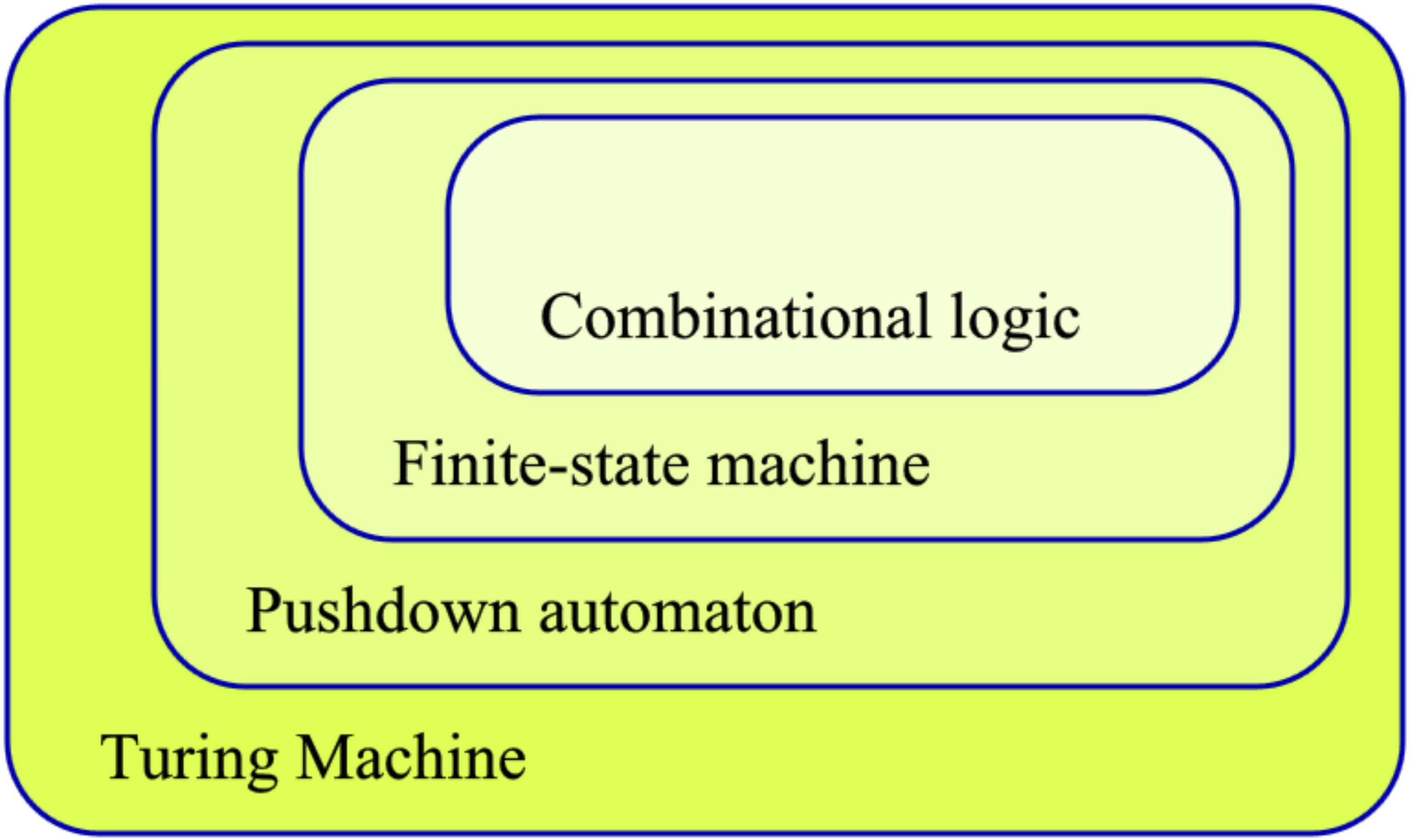
- It's not either/or – both are components of a computer system.
- Even if you specialize in one,
  you should understand capabilities and limitations of both.

Big Idea #1: Universal Computing Device

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



Automata Theory



Source: https://en.wikipedia.org/wiki/Pushdown_automaton

Language Hierarchy

- **Language accepted by Finite-state machine (example)**

  $L = \{1^n : n = 2k+1, k > 0\}$

- **Language accepted by Pushdown automation (example)**

  $L = \{1^n 0^n : n > 0\}$

- **Language accepted by Turing machine (example)**

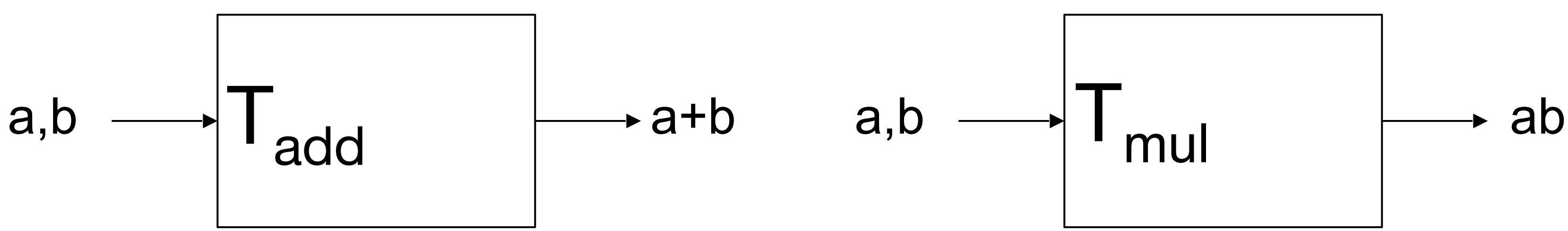
  $L = \{1^n 0^n 1^n : n > 0\}$

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

Turing machine that multiplies

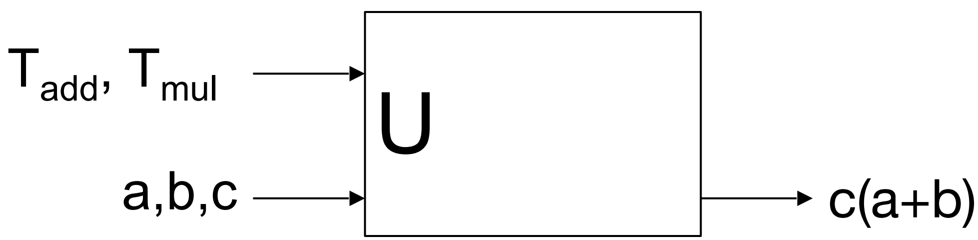
For more info about Turing machines, see http://www.wikipedia.org/wiki/Turing_machine/

For more about Alan Turing, see http://www.turing.org.uk/turing/

Universal Turing Machine

A machine that can implement all Turing machines -- this is also a Turing machine!

- **inputs: data, plus a description of computation (other TMs)**



Universal Turing Machine

U is <u>programmable</u> – so is a computer!

- **instructions are part of the input data**
- **a computer can emulate a Universal Turing Machine**

A computer is a universal computing device.

Halting Problem

- **Halting Problem**
  - **the problem of determining, from a description of an arbitrary computer program (i.e., Turing machine) and an input, whether the program will finish running (i.e., halts) or continue to run forever**
- **Halting problem is undecidable (not Turing machine solvable)**
  - **Proof sketch**

$$h(i,x) = \begin{cases} 1 & \text{if program } i \text{ halts on input } x \\ 0 & \text{otherwise} \end{cases}$$

$$g(i) = \begin{cases} 0 & \text{if } h(i,i) = 0 \\ \text{undefined} & \text{otherwise (i.e., runs forever)} \end{cases}$$

Let *e* is a program that computes *g*. What happen for *g(e)*?

From Theory to Practice

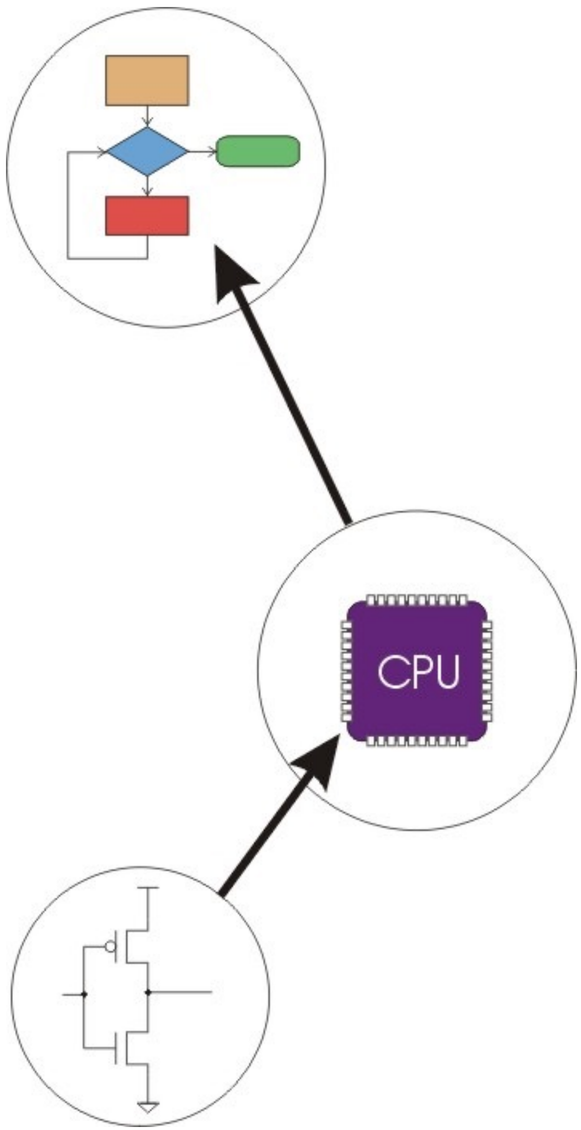
In theory, computer can *compute* anything that's possible to compute

- **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



Problems

Algorithms

Language

Instruction Set Architecture

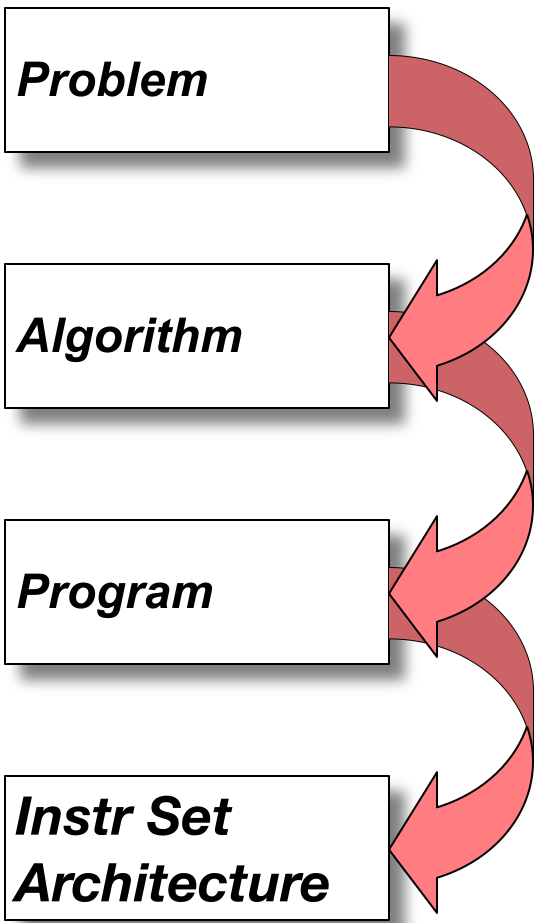
Microarchitecture

Circuits

Devices

How do we solve a problem using a computer?

A systematic sequence of transformations between layers of abstraction.

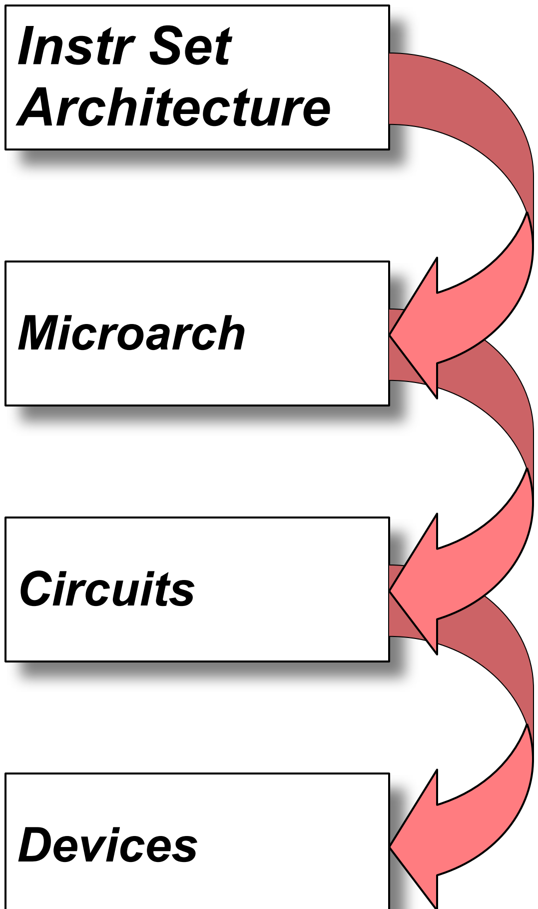


Software Design:
choose algorithms and data structures

Programming:
use language to express design

Compiling/Interpreting:
convert language to
machine instructions

Deeper and Deeper…



Processor Design:
choose structures to implement ISA

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

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

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

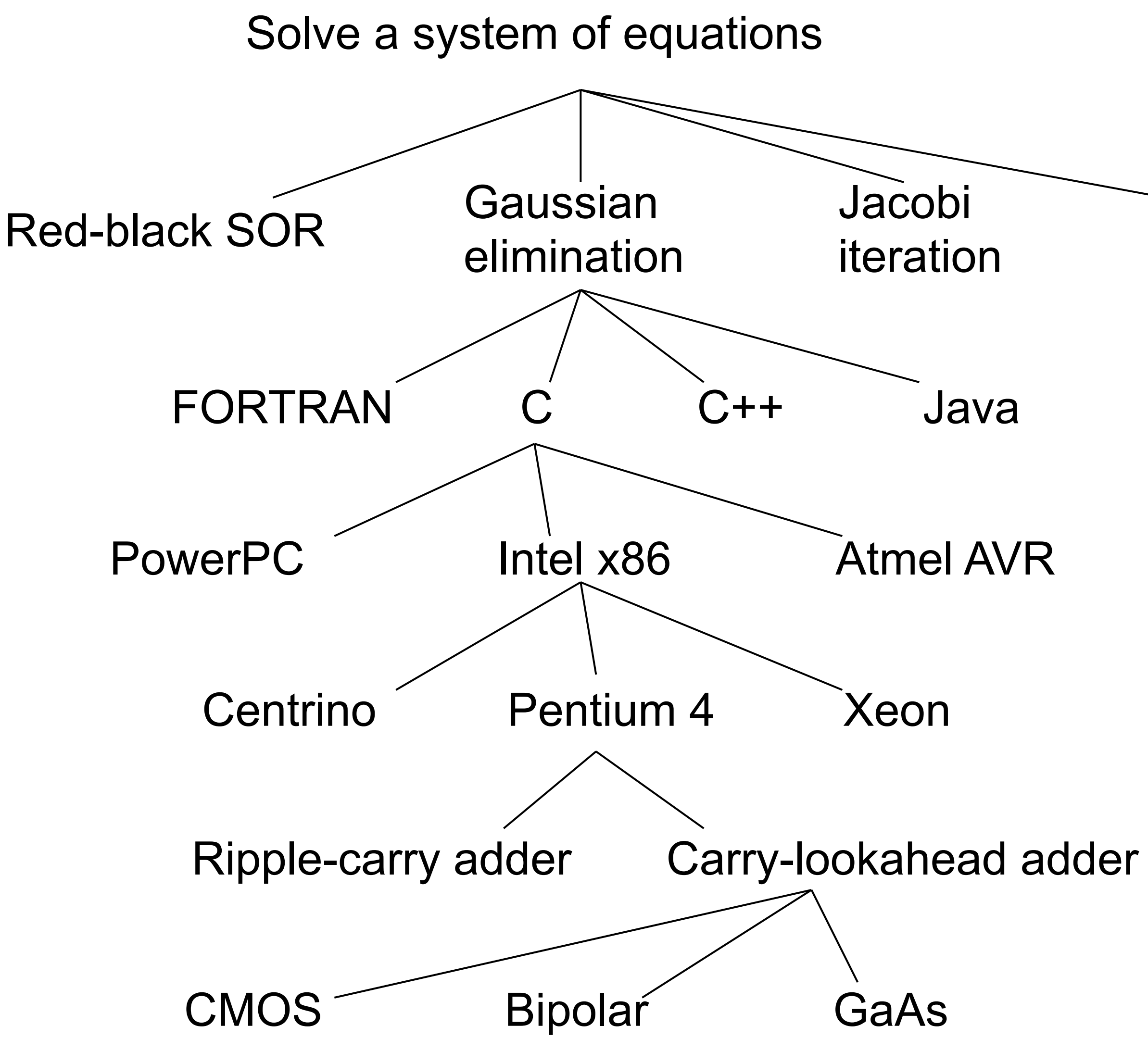
Logic Circuits

- 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



Tradeoffs:
cost
performance
power
(etc.)

Course Outline

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?

C Programming
- How do we write programs in C?
- How do we implement high-level programming constructs?