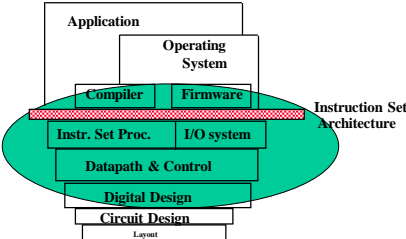# CS/SE 3340
Computer Architecture

Application

Operating System

Compiler | Firmware

Instr. Set Proc. | I/O system

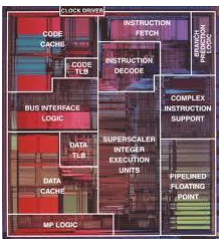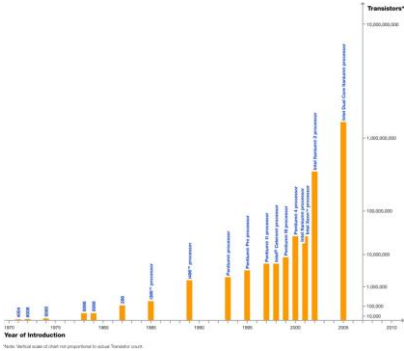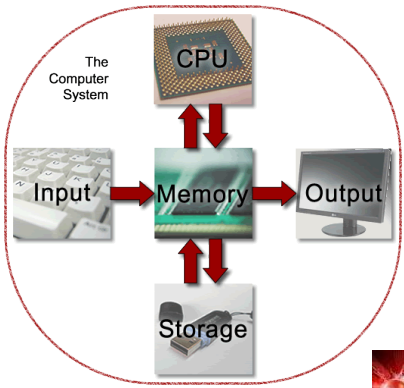Datapath & Control

Digital Design

Circuit Design

Layout

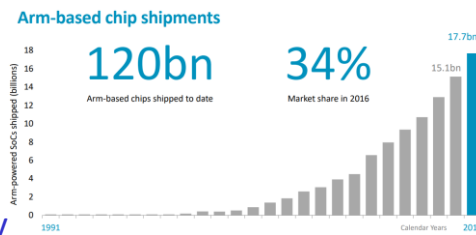Instruction Set Architecture

Introduction to Computer Organization

Adapted from "Computer Organization and Design, 4th Ed." by D. Patterson and J. Hennessy
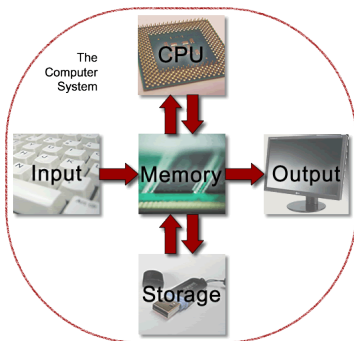
The Computer Revolution

- Progress in computer technology
  - Underpinned by Moore's Law
- Makes novel applications feasible
  - Computers in automobiles
  - Cell phones, tablets
  - Human genome project
  - World Wide Web
  - Search Engines
- Computers are pervasiv
  - **17.7B** ARM chips sold in 2016 (ARM Holdings)

Arm-based chip shipments

120bn
Arm-based chips shipped to date

34%
Market share in 2016

17.7bn

15.1bn

3

Hardware Components

- *Same components for all kinds of computer*
  - Desktop, server, embedded
- *Input/output includes*
  - User-interface devices
    - Display, keyboard, mouse
  - Storage devices
    - Hard disk, CD/DVD, flash
  - Something missing?
    - What about network adapters?

4

Anatomy of a Computer

Output device

Network cable

Input device

Input device
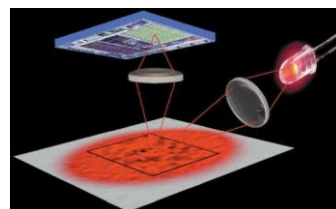
5

Anatomy of a Mouse

- Optical mouse
  - LED illuminates desktop
  - Small low-res camera
  - Basic image processor
    - Looks for x, y movement
  - Buttons & wheel
- Supersedes roller-ball mechanical mouse

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Through the Looking Glass

LCD screen: picture elements (pixels)
  Mirrors content of frame buffer memory

Frame buffer

Raster scan CRT display

Y_0
Y_1

X_0 X_1

Y_0
Y_1

X_0 X_1
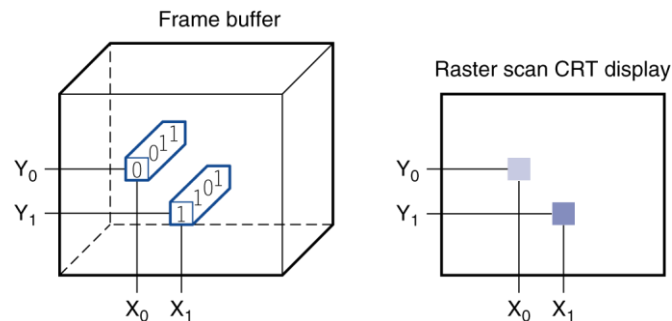
7

A Safe Place for Data

- Volatile main memory
  - Loses instructions and data when power off
- Non-volatile secondary memory
  - Magnetic disk
  - Flash memory
  - Optical disk (CDROM, DVD)

8

4

Opening the Box
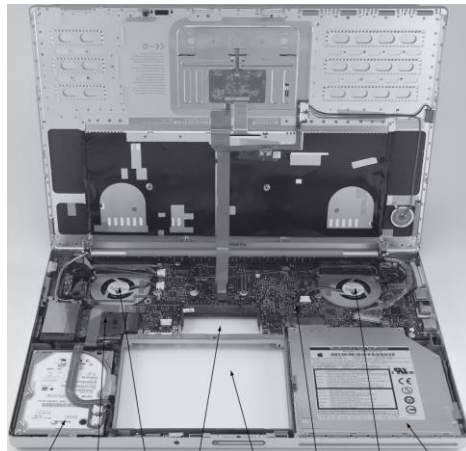
Hard drive Processor Fan with cover Spot for memory DIMMs Spot for battery Motherboard Fan with cover DVD drive

9

Inside the Processor (CPU)

- *Datapath:* performs operations on data
- *Control:* sequences datapath, memory, …
- Cache memory
  - Small fast SRAM memory for immediate access to data

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Inside the Processor

AMD Barcelona: 4 processor cores
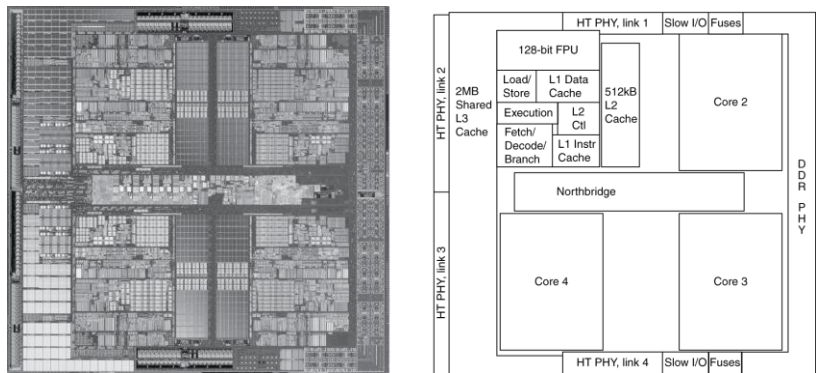
11

Technology Trends

- Electronics technology continues to evolve
  - Increased capacity and performance
  - Reduced cost
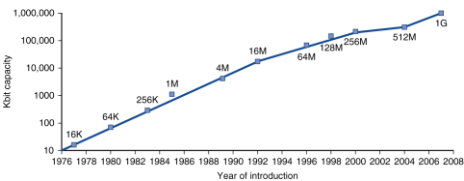
DRAM capacity

Year	Technology	Relative performance/cost
1951	Vacuum tube	1
1965	Transistor	35
1975	Integrated circuit (IC)	900
1995	Very large scale IC (VLSI)	2,400,000
2005	Ultra large scale IC	6,200,000,000

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Moore's Law

Dual Core Itanium
with 1.7B transistors

❑ In 1965, Intel's Gordon Moore
predicted that the number of
transistors that can be integrated on
single chip would double about every
two years

Log Scal

13

Courtesy, Intel ®
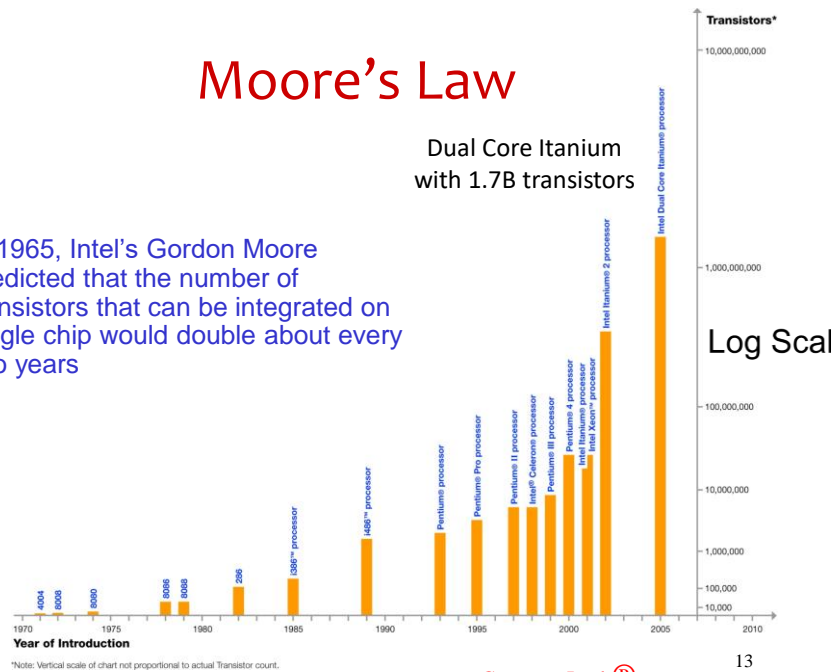
Technology Scaling Road Map

Year	2004	2006	2008	2010	2012
Feature size (nm)	90	65	45	32	22
Capacity (Bills. of Transistor)	2	4	6	16	32

- Fun facts about 22 nm transistors
  - 60 million can fit on the head of a pin
  - You could fit more than 4,000 across the width of a human hair
  - *If car prices had fallen at the same rate as the price of a single transistor has since 1968, a new car today would cost about 0.5 cent!!!*
- 14 nm transistors have been used in VLSI chips since 2014 (Intel's Broadwell Core M processors, Apple's A9)

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International Technology Roadmap for Semiconductors

Some High-level Questions

- How are *data* and *programs* represented in a computer?
  - And how the **hardware** processes data?
- What is the interface between **hardware** an **software**?
  - *The Instruction Set Architecture (ISA)*
- ***What*** determines computer ***performance?*** and **how** it can be improved?
- How hardware designers improve ***performance***?
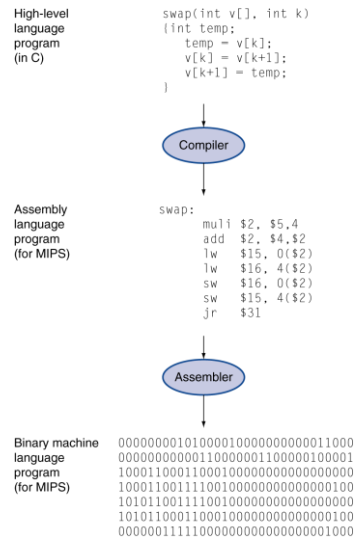 - Faster clock, pipelining, cache, etc...

15

Below Your Program
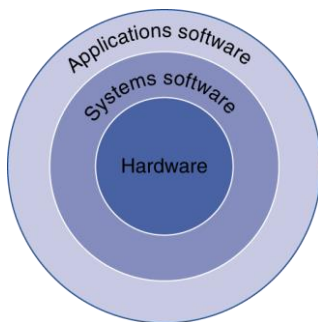
- *Application software*
  - Written in high-level language
- *System software*
  - Compiler: translates HLL code to assembly language or machine code
  - Operating System: service code
    - Handling input/output
    - Managing memory and storage
    - Scheduling tasks & sharing resources
- *Hardware*
  - Processor, memory, I/O controllers

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Levels of Program Code

- *High-level language*
  - Level of abstraction closer to problem domain
  - Provides for productivity and portability
- *Assembly language*
  - Textual representation of instructions
- *Hardware representation*
  - Binary digits (bits)
  - *Encoded* instructions (machine code) and data

High-level language program (in C)

```
swap(int v[], int k)
(int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```

Compiler

Assembly language program (for MIPS)

```
swap:
    muli $2, $5,4
    add  $2, $4,$2
    lw   $15, 0($2)
    lw   $16, 4($2)
    sw   $16, 0($2)
    sw   $15, 4($2)
    jr   $31
```

Assembler

Binary machine language program (for MIPS)

```
00000000101000010000000000011000
00000000000110000001100000100001
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
00000011111000000000000000001000
```

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Understanding Performance

- *Algorithm*
  - Determines number of operations executed
- *Programming language, compiler, architecture*
  - Determine number of machine instructions executed per operation
- *Processor and memory system*
  - Determine how fast instructions are executed
- *I/O system (including OS)*
  - Determines how fast I/O operations are executed

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Abstractions

- *Abstraction* helps us deal with complexity
  - Hide lower-level details
- ***Instruction set architecture (ISA)***
  - The hardware/software interface
- ***Application binary interface***
  - The ISA plus system software interface
- ***Implementation***
  - The details underlying an interface

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Review: Some Basic Definitions

- Kilobyte – 2^{10} or 1,024 bytes
- Megabyte– 2^{20} or 1,048,576 bytes
  - sometimes "rounded" to 10^6 or 1,000,000 bytes
- Gigabyte – 2^{30} or 1,073,741,824 bytes
  - sometimes rounded to 10^9 or 1,000,000,000 bytes
- Terabyte – 2^{40} or 1,099,511,627,776 bytes
  - sometimes rounded to 10^{12} or 1,000,000,000,000 bytes
- Petabyte – 2^{50} or 1024 terabytes
  - sometimes rounded to 10^{15} or 1,000,000,000,000,000 bytes
- Exabyte – 2^{60} or 1024 petabytes
  - Sometimes rounded to 10^{18} or 1,000,000,000,000,000,000 bytes

"All mobile data traffic generated worldwide > 107 <u>exabytes</u> in 2017"
ABI Research – July 2012