

CS202: COMPUTER ORGANIZATION

Lecture 1

Course Introduction

Course Introduction

- Today's topics:
 - ◆ Why computer organization is important
 - ◆ Course information
 - ◆ Background and computer abstraction

Why to Learn Computer Organization?

- Embarrassing if you are a student in CS and can't make sense of the following terms: DRAM, pipelining, cache hierarchies, I/O, virtual memory, ...
- Embarrassing if you are a student in CS and can't decide which processor to buy: 3 GHz P4 or 2.5 GHz Athlon (this course helps us reason about performance/power), ...
- First step for chip designers, compiler/ OS writers
- Knowledge of the hardware will help you write better programs

Must a Programmer Care about Hardware?

- Must know how to reason about program performance and energy
- CPU Performance: if we understand how CPU process data, we can enhance the computation efficiency
- Memory management: if we understand how/where data is placed, we can help ensure that relevant data is nearby
- Thread management: if we understand how threads interact, we can write smarter multi-threaded programs
- I/O management

What you have learned?

- Binary numbers
- Read and write basic C/Java programs
- Understand the steps in compiling and executing a program
- Digital Circuit, Logic design:
 - ◆ Logical equations, schematic diagrams
 - ◆ Combinational vs. sequential logic
 - ◆ Finite state machines (FSMs)

What you will learn?

■ Major content

- ◆ Basic parts of a computer (processor, memory, disk, etc.)
- ◆ Principles of computer architecture: CPU datapath and control unit design
- ◆ Assembly language programming in MIPS
- ◆ Memory hierarchies and design
- ◆ I/O organization and design

■ Course goals

- ◆ To learn the organizational structures that determine the capabilities and performance of computer systems
- ◆ To understand the interactions between the computer's architecture and its software
- ◆ To understand cost performance trade-offs

Key Topics

- Introduction (Chapter 1)

- ◆ Basic terms
- ◆ Moore's Law, power wall
- ◆ Core ideas in computer architecture



- Processors (Chapter 2-4)

汇编

- ◆ Assembly language (Chapter 2)
- ◆ Computer arithmetic (Chapter 3)
- ◆ Pipelining (Chapter 4)

CPU Design

- Memory (Chapter 5)

- Parallel Processors (Chapter 6)

The content is useful and important

- Computer organization principles are everywhere
 - ◆ Embedded computer vs. general-purpose computers:
 - Cellphone, Digital Camera, MP3 music player, Industrial process control
- Complex system design
 - ◆ How to partition a problem
 - ◆ Functional Spec → Control & Datapath → Physical implementation
 - ◆ Modern ^{computer aided design} CAD tools
- Both EEs and CSEs need this information in almost all jobs

Course Information

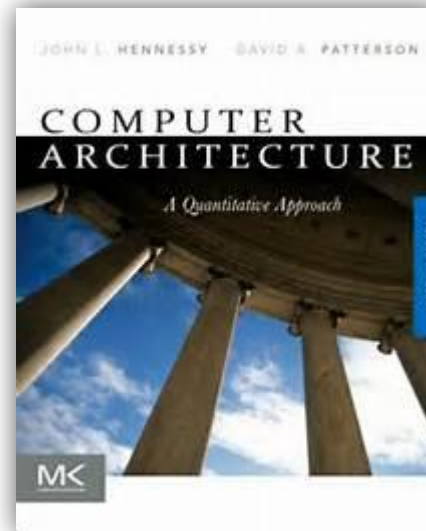
- Course Materials:
 - ◆ Blackboard system: Computer Organization (H) Spring 2023
- QQ group: 650796339
- Lectures:
 - ◆ Monday 10:20-12:10 (3rd Teaching Building 301)
- Instructor:
 - ◆ Prof. Jin Zhang (zhangj4@sustech.edu.cn)
 - ◆ Office: 414, CoE South
 - ◆ Office hour: Tuesday 10:00-12:00
- Lab:
 - ◆ Wei Wang (wangw6@sustech.edu.cn)
 - ◆ Office: 111 CoE South
 - ◆ Office hour: Tuesday 14:00-16:00



群名称: CS214-计组-2023s
群 号: 650796339

Course Information

- Textbook: Computer Organization and Design – the HW/SW Interface, Patterson and Hennessy, 5th edition
- Reference book: Computer Architecture - a quantitative approach, Hennessy and Patterson, 5th edition



Patterson and Hennessy



- Turing award 2017

For pioneering a systematic, quantitative approach to the design and evaluation of **computer architectures** with enduring impact on the **microprocessor industry**.



David A. Patterson
Professor of UC Berkeley
Distinguished Engineer at Google



John L. Hennessy
President of Stanford University
Chairman of Alphabet

Recommended Reading

- Code: The Hidden Language of Computer Hardware and Software, Charles Petzold, 2000. 《编码的奥秘》, 《编码——隐匿在计算机软硬件背后》
- Computer Systems: A Programmer's Perspective, R. E. Bryant, D. R. O'Hallaron, 3rd Edition, Pearson, 2015. 《深入理解计算机系统》

Other Readings

- ❖ 《浪潮之巅》《数学之美》吴军
- ❖ 《创新者：一群技术狂人和鬼才程序员如何改变世界》
沃尔特·艾萨克森（《史蒂夫·乔布斯传》、《爱因斯坦传》、《本杰明·富兰克林传》）
- ❖ 《沸腾十五年》《沸腾新十年》林军 《激荡四十年》
- ❖ 《图灵和ACM图灵奖》
- ❖ 《黑客与画家》硅谷创业之父Paul Graham
- ❖ 《人月神话》《信息简史》
- ❖ KK三部曲 《失控》《科技想要什么》《必然》

Course Information

- Assessment:

- ◆ Theoretical part:

- Final exam (~30%)
 - Midterm exam (~30%)
 - Assignments (~5%) 4次作业
 - Attendance and Interaction (~5%)

- ◆ Lab part (~30%)

- Please Submit on time

- ◆ all the assignments and reports should be submitted in the Sakai system, late submission will not be accepted in the system.

Rules about Plagiarism

- No Plagiarism is allowed
 - ◆ If plagiarism on homework or project is found for the first time, **the plagiaristic part is graded as 0** and warning is given to the students
 - ◆ If plagiarism is found for the second time, **the course is graded as 0**
 - ◆ For lab/project report, any sentence that is copied from other paper or article **should cite the original source** as the reference, otherwise, the report is considered as plagiarism
- Submit the commitment letter on Blackboard system before homework #1

Tips for Attending the Lecture

- To get the best use of lecture
 - ◆ interactive
 - ◆ ask whenever you have question, interrupt whenever you want
 - ◆ ask immediately after the class if you are shy
 - ◆ give me suggestions and feedback frequently
- Get the main idea in class, read the details after class

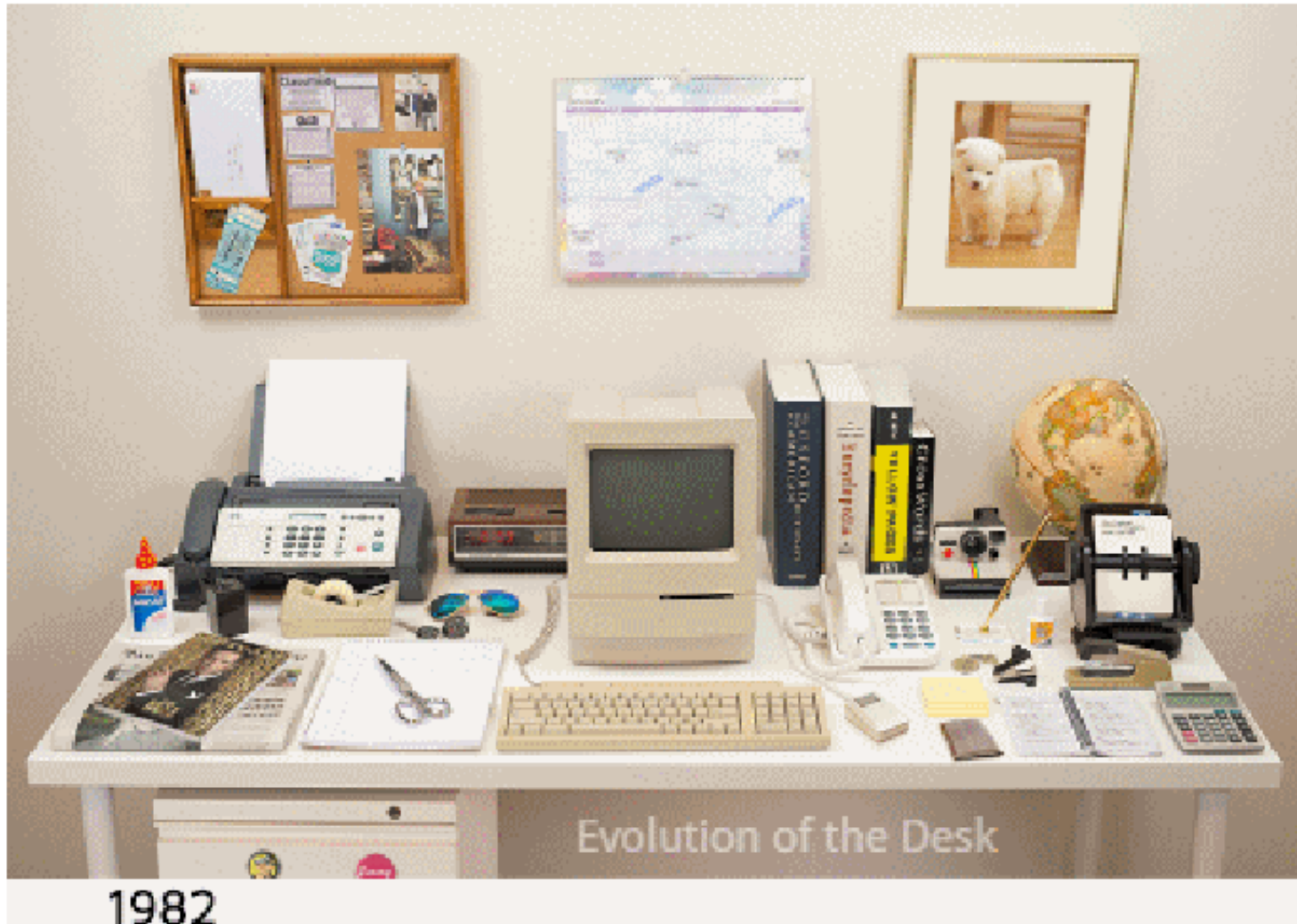
10 Interventions that Changed World

- ❑ 1. Internet
- ❑ 2. Computer
- ❑ 3. Light Bulb
- ❑ 4. Automobile
- ❑ 5. Steam Engine
- ❑ 6. Telephone
- ❑ 7. Refrigeration
- ❑ 8. Printing Press
- ❑ 9. Wheel
- ❑ 10. The Plow



Source: <http://www.geniusstuff.com>

Evolution of the Desk (1980-2015)



Evolution of the Desk (1980-2015)



Source: http://www.360doc.com/content/14/0919/20/5052258_410779481.shtml

Various Forms of Computers



Classes of Computers

- Personal computers
 - ◆ General purpose, variety of software
 - ◆ Subject to cost/performance tradeoff
- Server computers
 - ◆ Network based
 - ◆ High capacity, performance, reliability
 - ◆ Range from small servers to building sized

Classes of Computers

- Supercomputers
 - ◆ High-end scientific and engineering calculations
 - ◆ Highest capability but represent a small fraction of the overall computer market
- Embedded computers
 - ◆ Hidden as components of systems
 - ◆ Stringent power/performance/cost constraints

Evolvment of Computers

Petaflop

Teraflop

Gigaflop

每秒完成几次浮点运算

Flop: float point operation

K M G ...?



The PostPC Era

- Cloud computing 共享
 - ◆ Warehouse Scale Computers (WSC)
 - ◆ Software as a Service (SaaS)
 - ◆ Portion of software run on a Personal Mobile Device and a portion run in the Cloud
 - ◆ Amazon and Google
- Data centers
 - ◆ Millions of computers connected by off-the-shelf networking devices

Google Data Centers

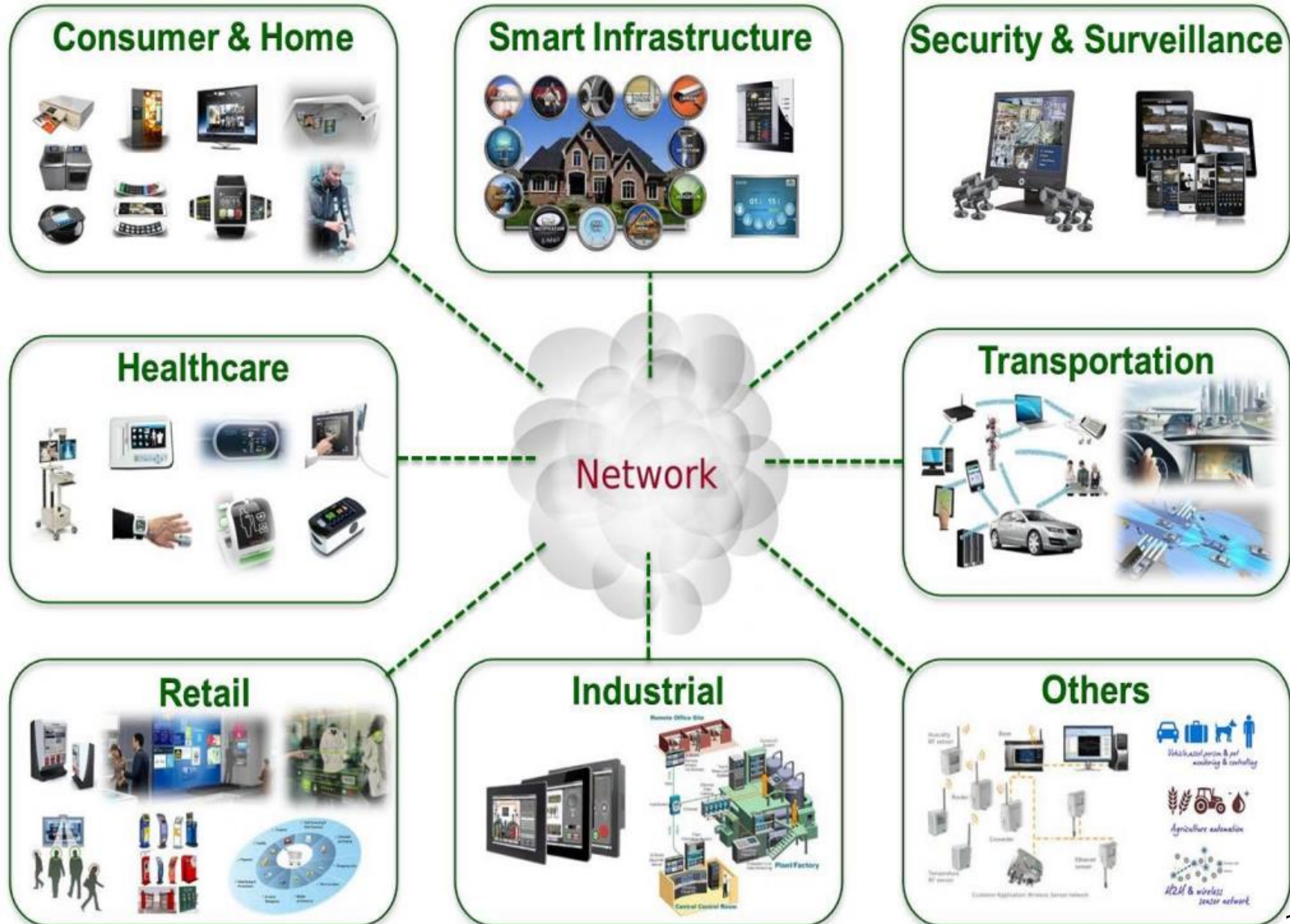


The PostPC Era

- Personal Mobile Device (PMD)
 - ◆ Battery operated
 - ◆ Connects to the Internet
 - ◆ Hundreds of dollars
 - ◆ Smart phones, tablets, electronic glasses



Internet of Things

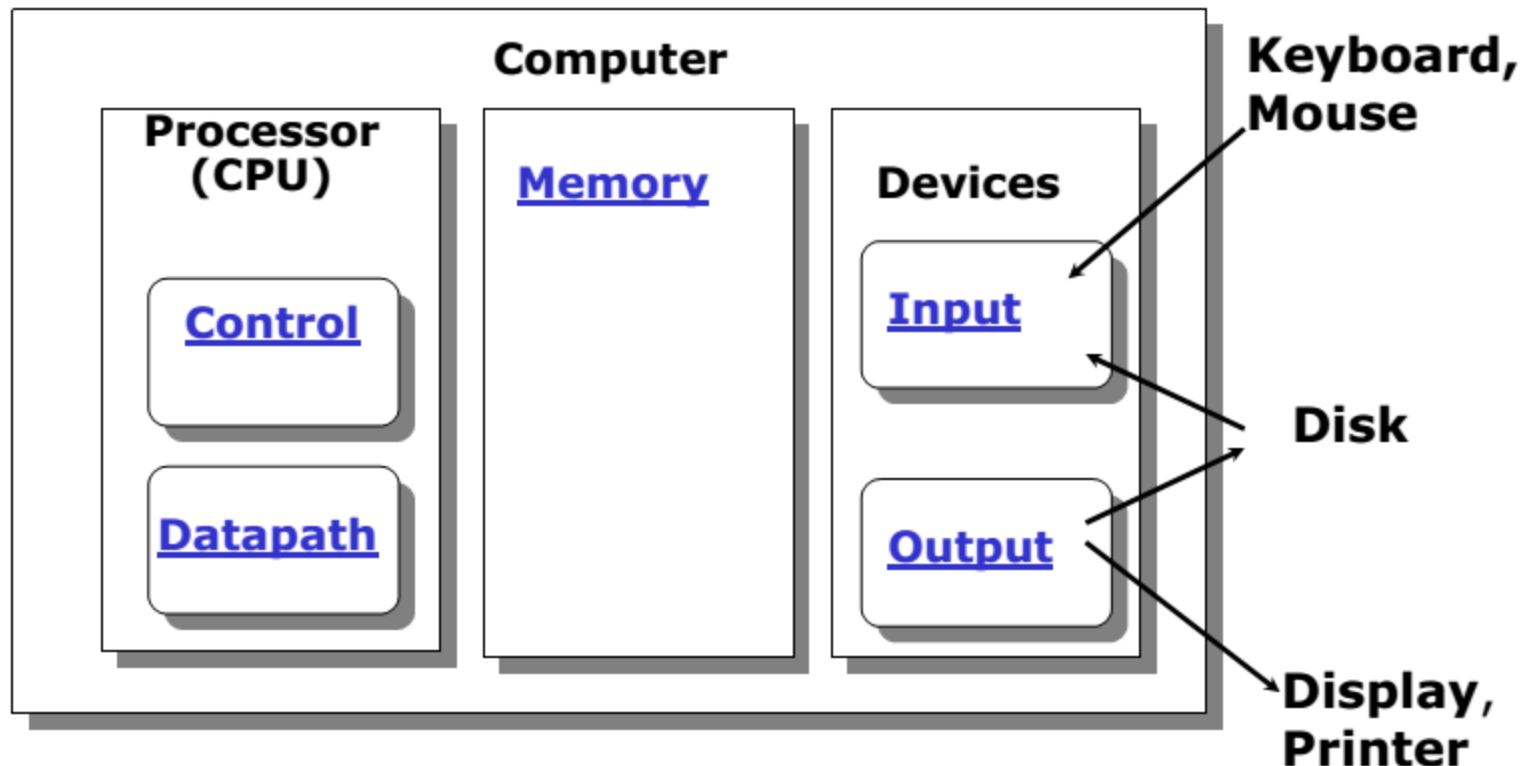


New Computer Architecture for AI era

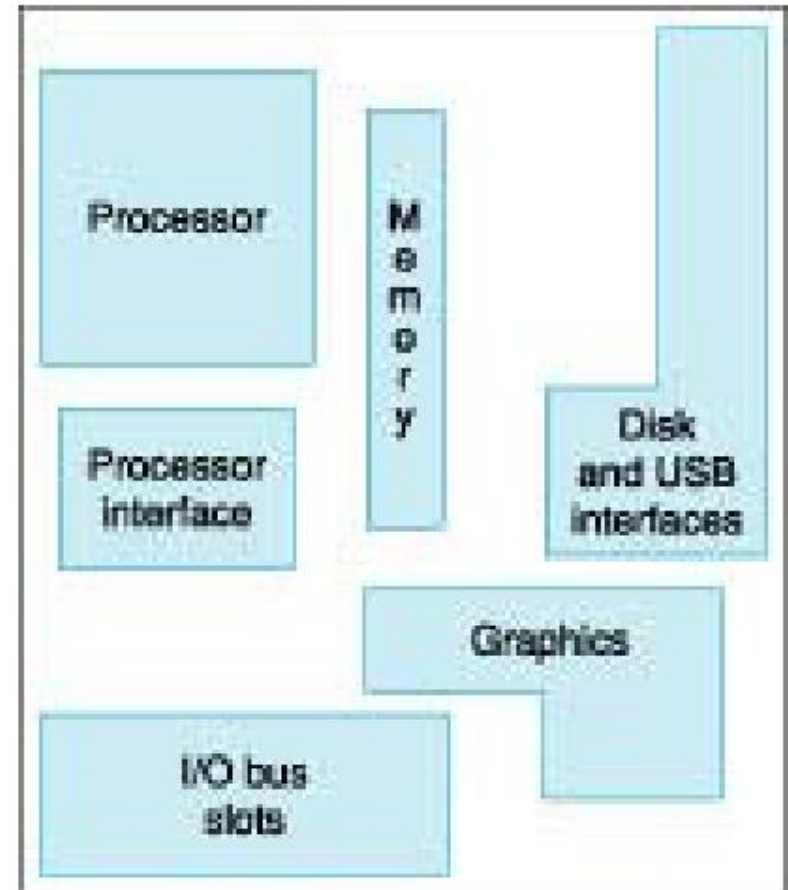
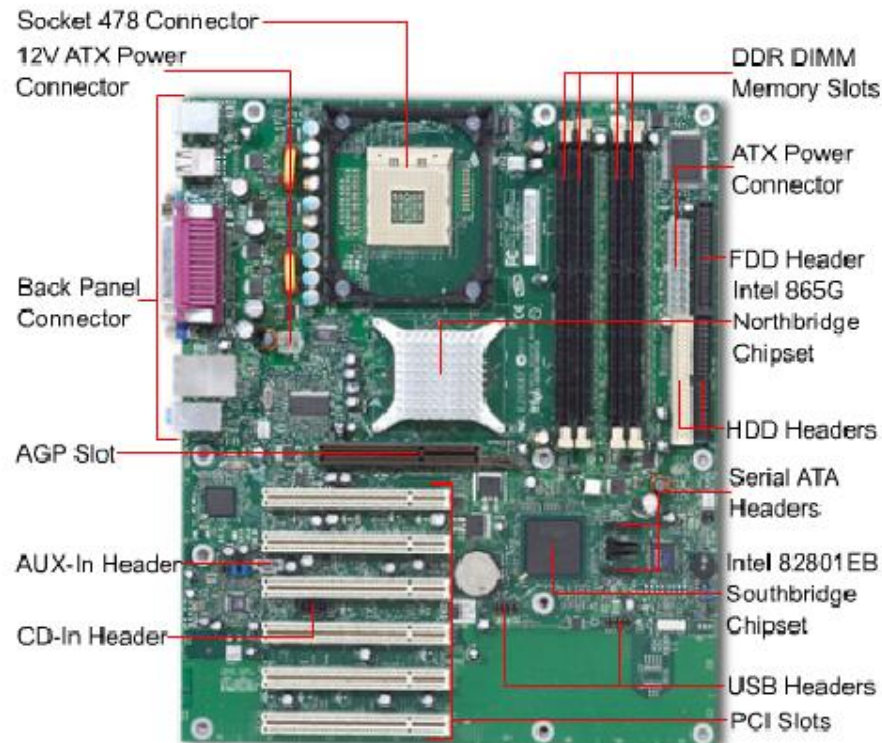
- AI and big data requires new computer architecture
 - ◆ More Suitable for deep learning
 - ◆ High requirement on parallel
 - ◆ Low energy
- From CPU to GPU, TPU...
- AI chips on smartphone
- Dozens of companies dive in this area:
 - ◆ Google, NVIDIA, 华为、地平线、寒武纪、深鉴
 - ◆ Nobody knows who will win

Components of a Computer

- Same components for all kinds of computer:
 - ◆ Input Device, Output Device, Memory, Processor (Control, Datapath)



PC motherboard



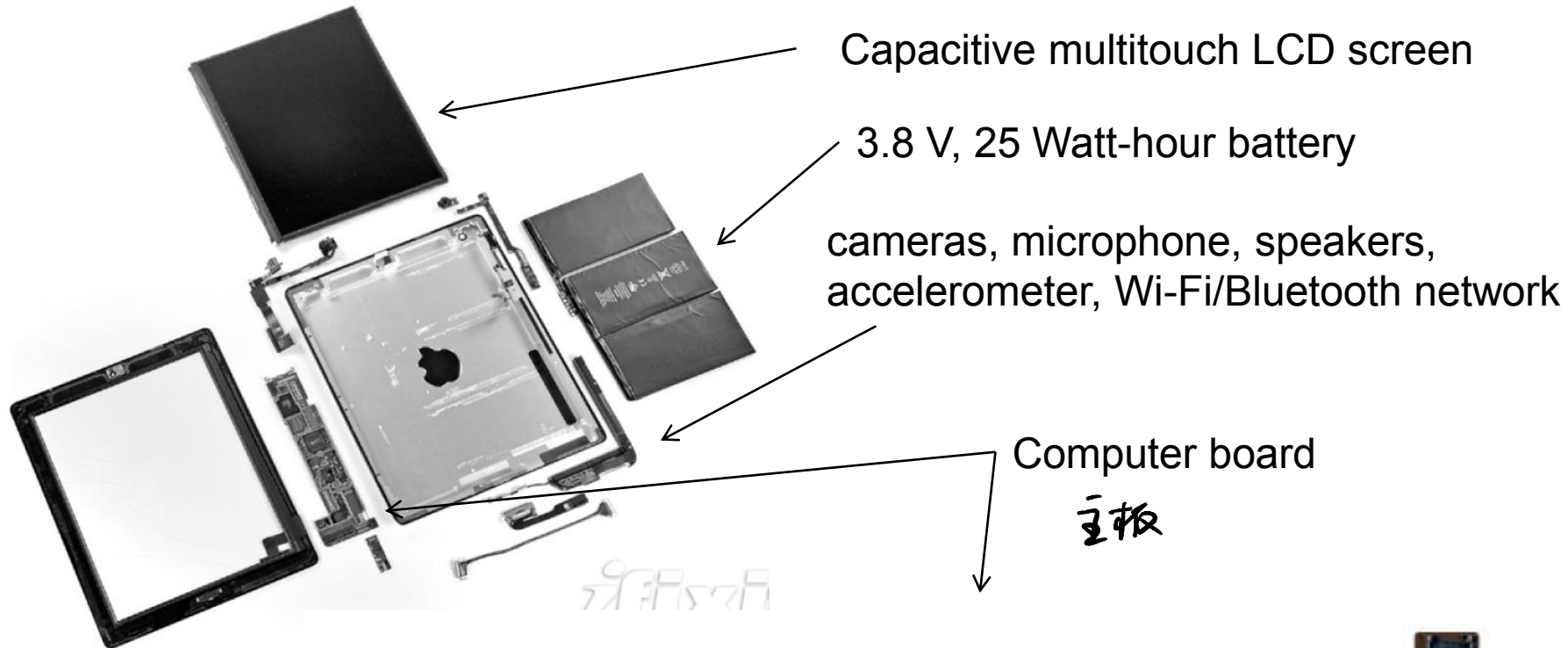
Courtesy: www.tigerdirect.com

Let's break up an iPad

- LCD (liquid crystal display)
 - ◆ A matrix of pixels:
 $1024 * 768 * 24$ bits (8 bit for one color)
- Touchscreen
 - ◆ Replace keyboard and mouse in PostPC device
 - ◆ Capacitive screen, which allows multiple touches simultaneously



Opening the Box

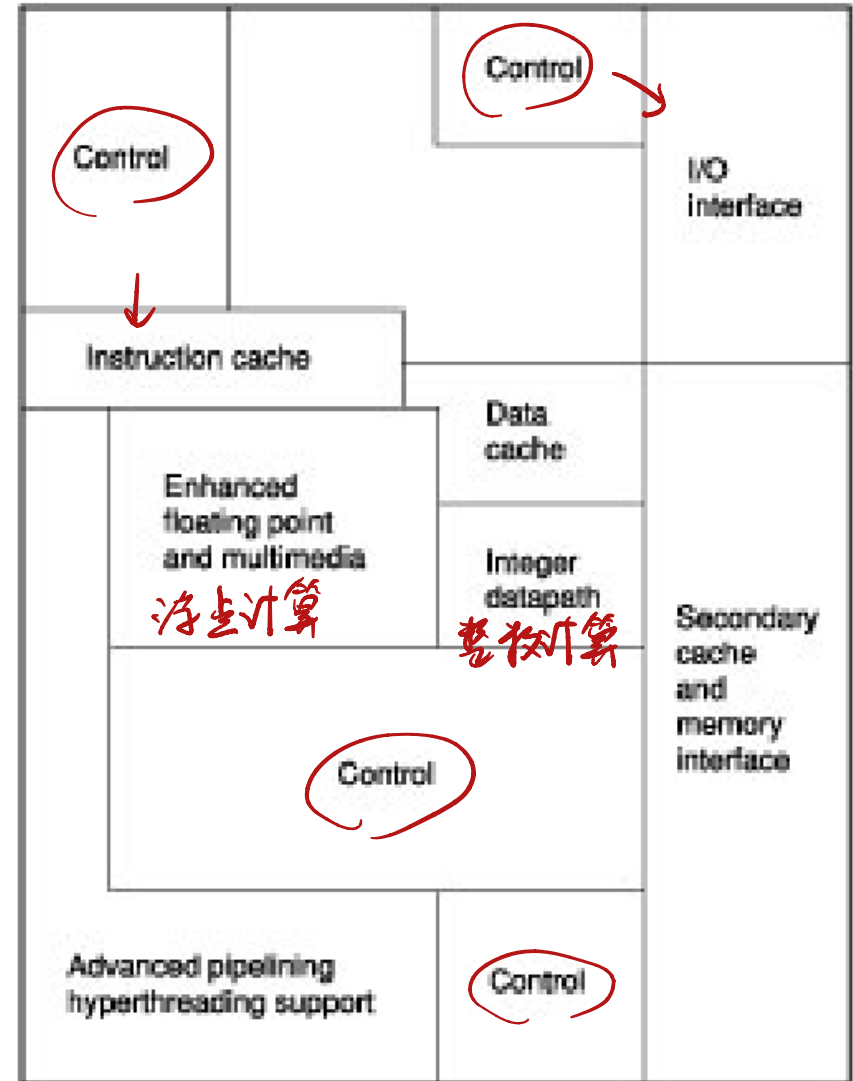
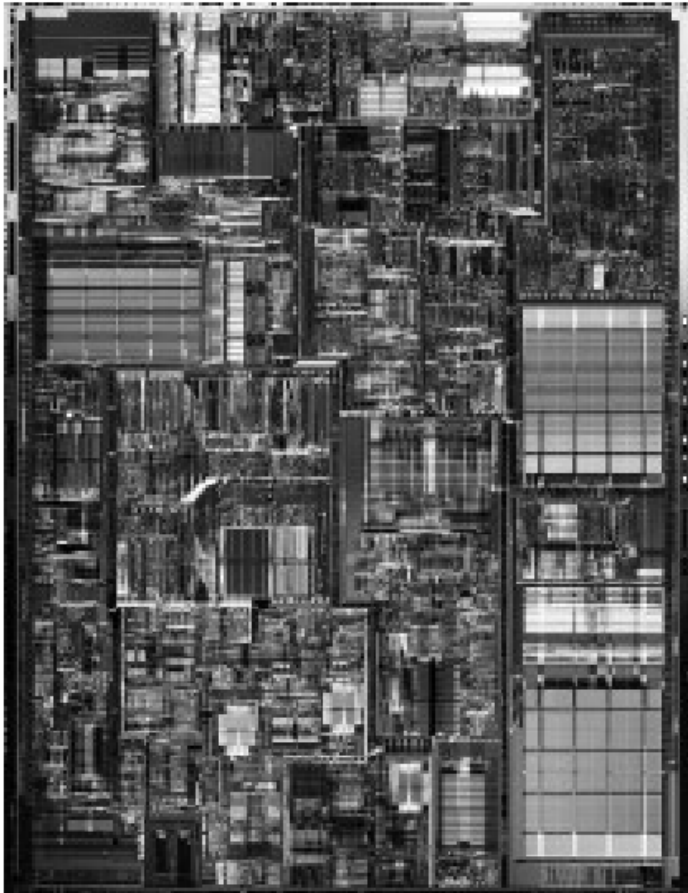


Chips: integrated circuit
PCB board: traditional circuit

Components of the iPad

- Input device: touch screen, camera, microphone, network
- Output device: LCD, speaker, network
- Memory: flash memory, main memory
- Central processor unit (CPU):
 - ◆ A5 processor

Inside the Processor



Inside the Processor

- Apple A5



Inside the Processor (CPU)

- Datapath: performs operations on data
- Control: control the sequence of datapath, memory, I/O
- Cache memory
 - ◆ Small fast SRAM memory for immediate access to data

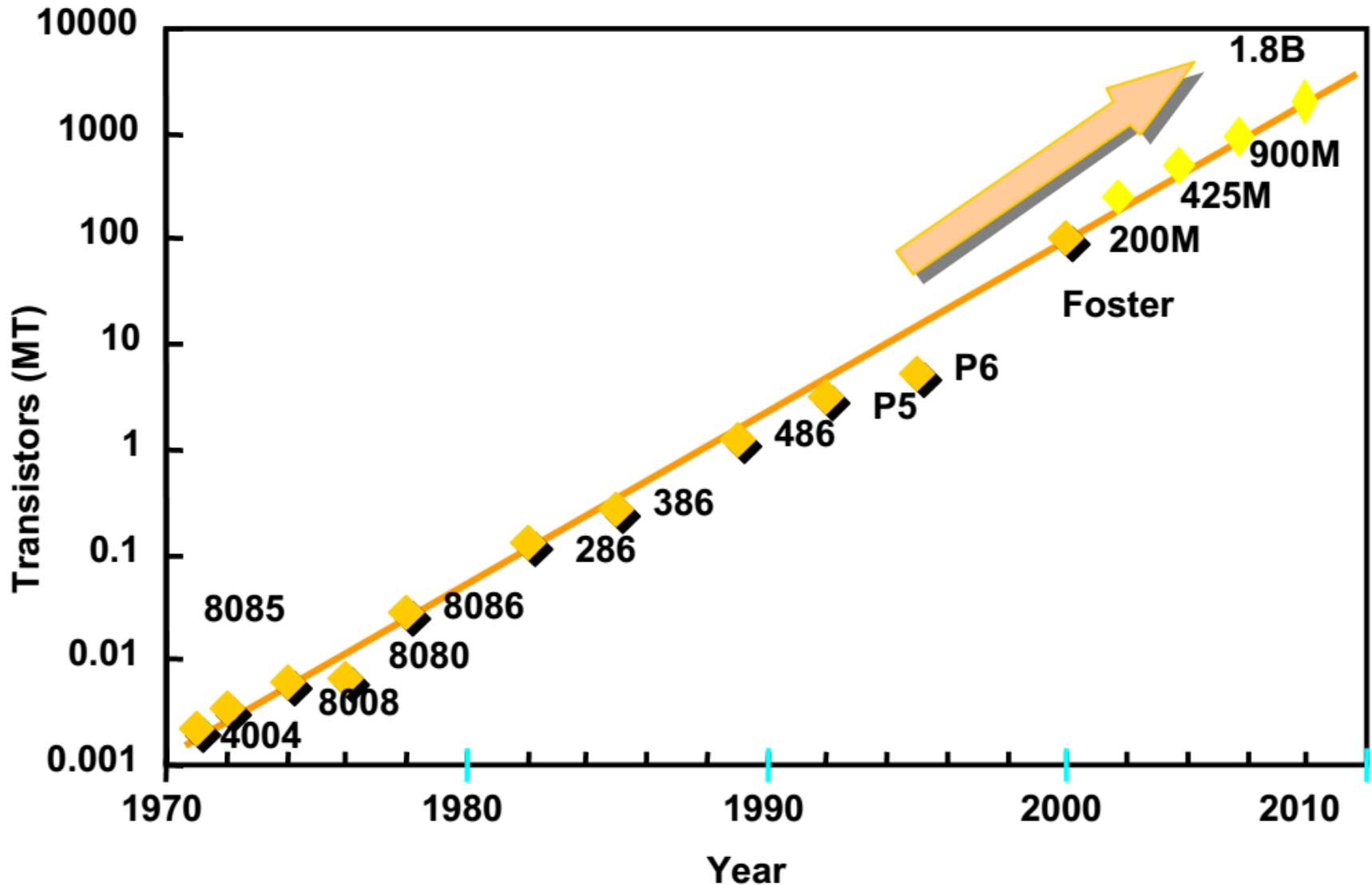
Technologies for Processors and Memory

- Processors
- Memory
- I/O

Micro Processor Advances-Moore's Law

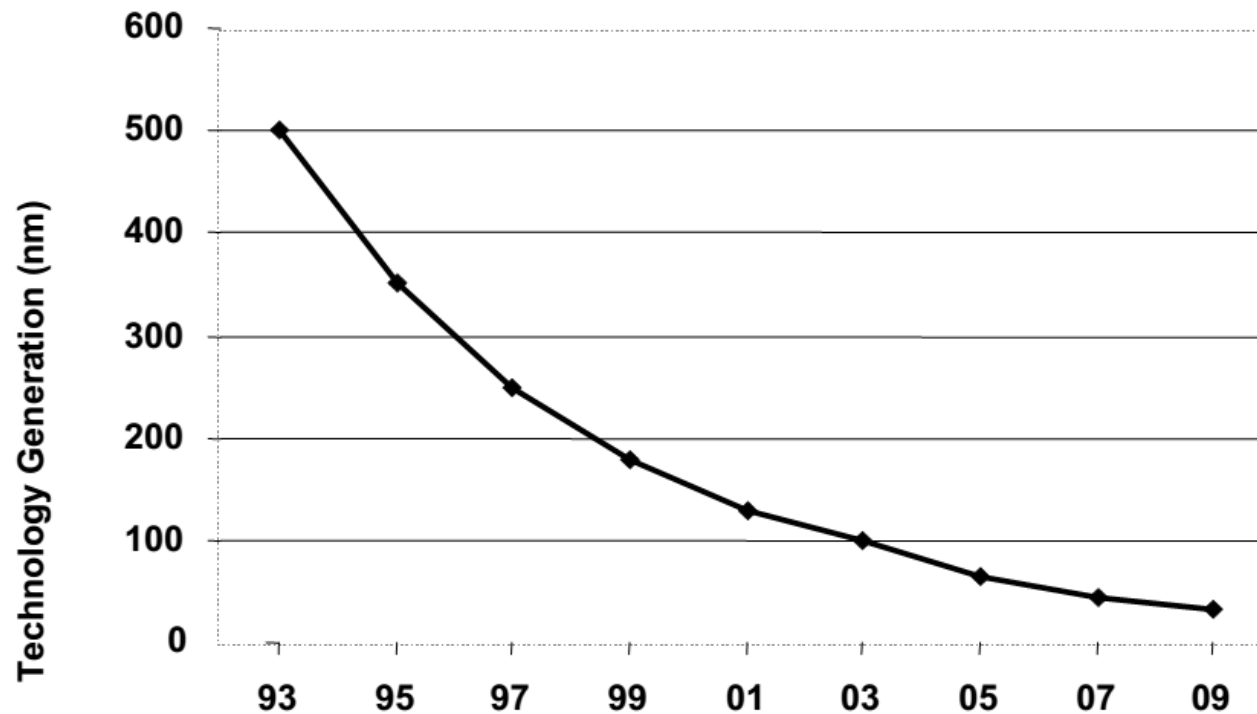
- In 1965, Gordon Moore made a prediction
 - ◆ ^{# CPU ~~transistor~~} The number of transistors that can be integrated on a die would double every 18 to 24 months
- Amazingly visionary – million transistor/chip barrier was crossed in the 1980's
 - ◆ 2300 transistors, 1 MHz clock (Intel 4004) – 1971
 - ◆ 16 Million transistors (Ultra Sparc III)
 - ◆ 42 Million transistors, 2 GHz clock (Intel Xeon) – 2001
 - ◆ 55 Million transistors, 3 GHz, 130nm technology, 250mm² die (Intel Pentium 4) – 2004
 - ◆ 140 Million transistor (HP PA-8500)
 - ◆ 1.8 Billion transistors (Itanium II)

Moore's Law



How is that possible?

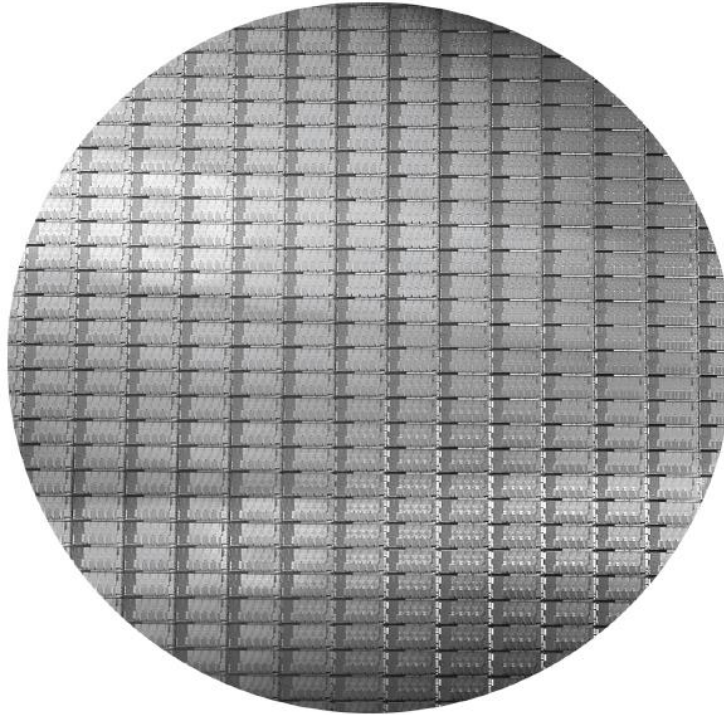
- Scale the transistor channel length



Feature size scaling to reduce die size

Intel Core i7 Wafer

晶元



- 300mm wafer, 280 chips, 32nm technology
- Each chip is 20.7 x 10.5 mm
- Latest i7-1160G7, Q3'20, 10 nm SuperFin, 4.40 GHz 4 Core
- Apple M1: 5nm, 16 billion transistors, 8-core, 3.2GHz

主频: 时钟频率

Processor Technology Trends

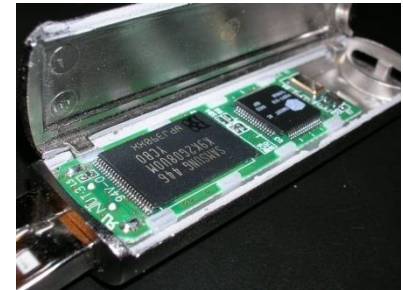
- Shrinking of transistor sizes: 250nm (1997) → 130nm (2002) → 70nm (2008) → 35nm (2014)

晶体管

- Transistor density increases by 35% per year and die size increases by 10-20% per year... functionality improvements!
- Transistor speed improves linearly with size (complex equation involving voltages, resistances, capacitances)
- Wire delays do not scale down at the same rate as transistor delays

Storage

- Volatile main memory *掉电丢失* *SRAM, DRAM*
 - ◆ Loses instructions and data when power off
- Non-volatile secondary memory *disk* *磁盘*
 - ◆ Magnetic disk
 - ◆ Flash memory
 - ◆ Optical disk (CDROM, DVD)



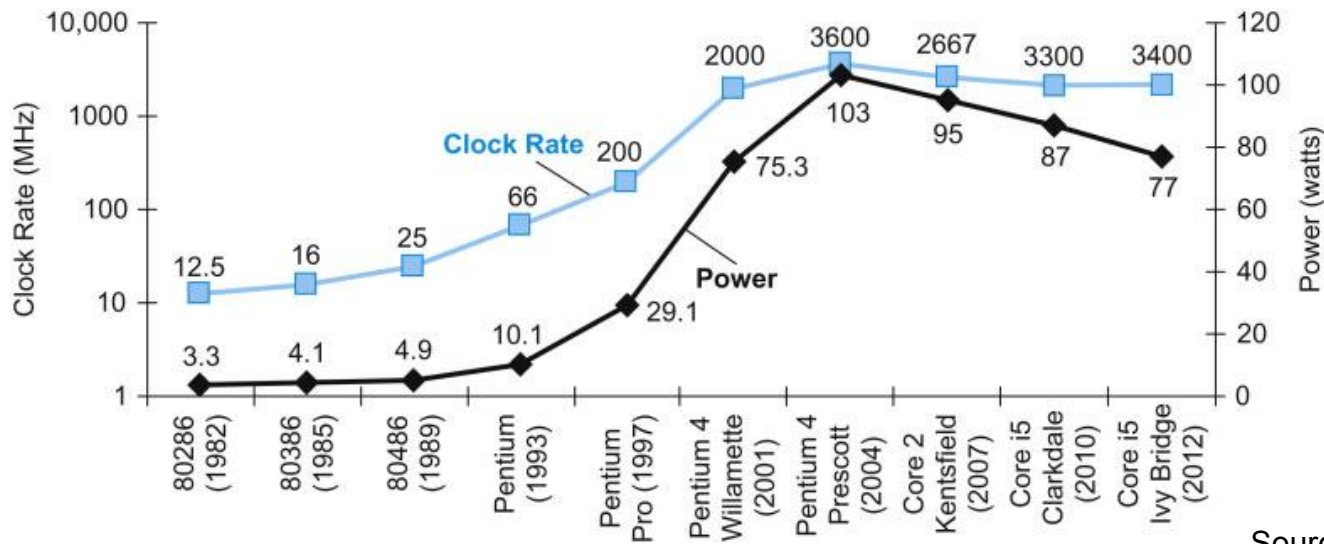
Memory and I/O Technology Trends

- DRAM density increases by 40-60% per year, latency has reduced by 33% in 10 years (the memory wall!), bandwidth improves twice as fast as latency decreases
- Disk density improves by 100% every year, latency improvement similar to DRAM
- Networks: primary focus on bandwidth; 10Mb → 100Mb in 10 years; 100Mb → 1Gb in 5 years

Power Consumption Trends

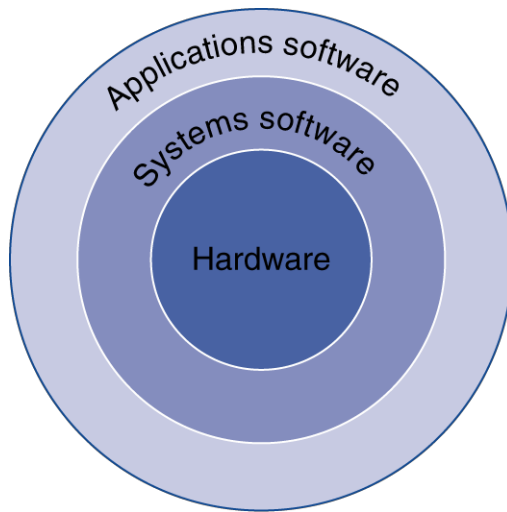
- $P \propto \frac{1}{2} CV^2$
 \propto activity x capacitance x voltage² x frequency

Handwritten notes: %时间以f工作, 电容, reduce, recognize state
- Voltage and frequency are somewhat constant now, while capacitance per transistor is decreasing and number of transistors (activity) is increasing
- Leakage power is also rising (function of #trans and voltage)



Source: H&P Textbook

Between Your Program and Hardware



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

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 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)

```
000000001010000100000000000011000
000000000000110000001100000100001
100011000110001000000000000000000
100011001111001000000000000000100
101011001111001000000000000000000
101011000110001000000000000000100
00000011111000000000000000001000
```

Eight Great Ideas

- Design for *Moore's Law*
- Use *abstraction* to simplify design
- Make the *common case fast*
- Performance *via parallelism*
- Performance *via pipelining*
- Performance *via prediction*
- *Hierarchy* of memories
- *Dependability* via redundancy

