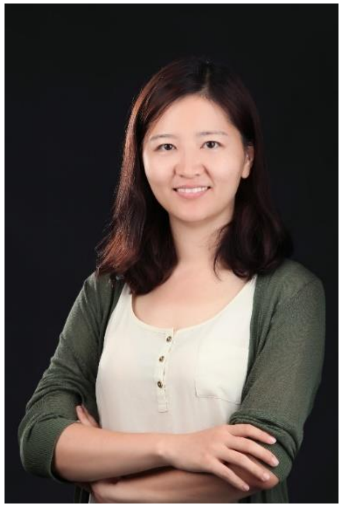
CS202: COMPUTER ORGANIZATION

Lecture 1

Course Introduction

张 进



- 2000年-2004年，清华大学电子系学士
- 2004年-2006年，清华大学电子系硕士
- 2006年-2009年，香港科技大学计算机系博士
- 2009年-2014年，香港科技大学计算机系研究助理教授
- 2014年至今，南方科技大学计算机系助理教授、副教授/博士生导师

研究方向：移动计算，智能物联网，无线感知，可穿戴设备与移动健康

- ➢ 在IOTJ、TWC、TMC、TPDS、Mobicom、Infocom、MobiHoc、ICDCS等国际顶级期刊会议发表论文90余篇
- ➢ 近五年承担和参与国家、广东省和深圳市科研项目10余项，包括：国家自然科学基金（青年，面上），科技部重点研发计划，广东省重点实验室，广东省普通高校重点实验室，广东省创新团队，深圳市工程实验室、深圳市学科布局项目
- ➢ 带领的研究团队：研究助理教授1名、博士10名、硕士6名、工程师2名、本科生20余名

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)
  - Assembly language (Chapter 2)
  - Computer arithmetic (Chapter 3)
  - Pipelining (Chapter 4)
- 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 CAD tools
- Both EEs and CSEs need this information in almost all jobs

Course Information

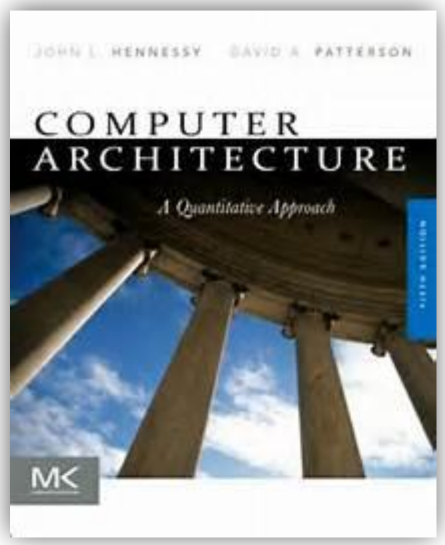
- Course Materials:
  - Blackboard system: Computer Organization Spring 2023
- QQ group: 622311135
- Lectures:
  - Monday 14:00-15:50 (Business School 101)
- Instructor:
  - Prof. Jin Zhang (zhangj4@sustech.edu.cn)
  - Office: 414, CoE South
  - Office hour: Tuesday 10:00-12:00
- Lab:
  - Wei Wang (wangw6@sustech.edu.cn)
  - Office: 111 CoE South
  - Office hour: Tuesday 14:00-16:00

群名称：CS202-2023s-Eng
群　号：622311135

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

COMPUTER ORGANIZATION AND DESIGN
THE HARDWARE/SOFTWARE INTERFACE
DAVID A. PATTERSON
JOHN L. HENNESSY
MK



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%)
    - 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 cites 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. Stream 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

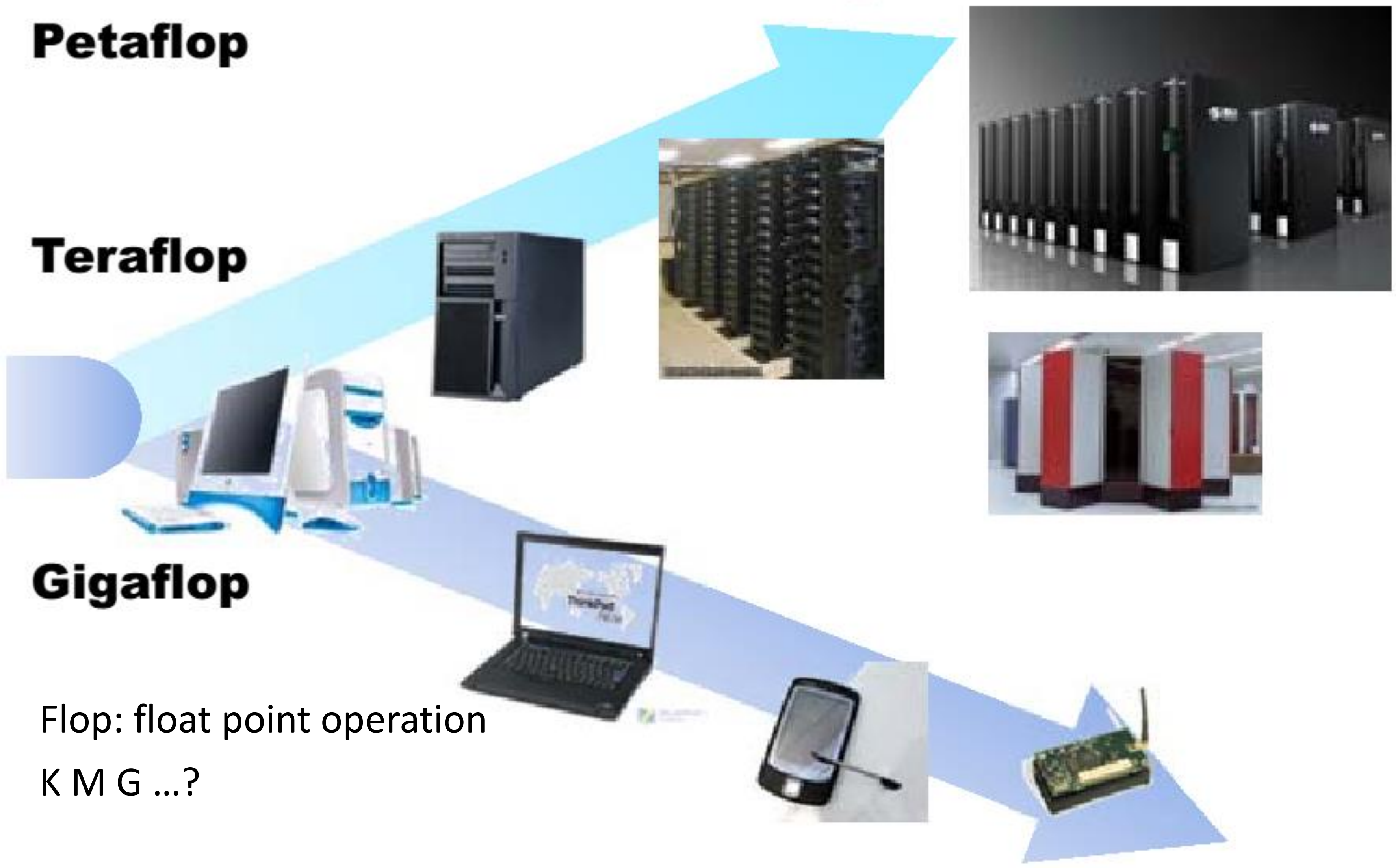
Classes of Computers

- 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

Evolvement of Computers



Flop: float point operation

K M G …?

The PostPC Era

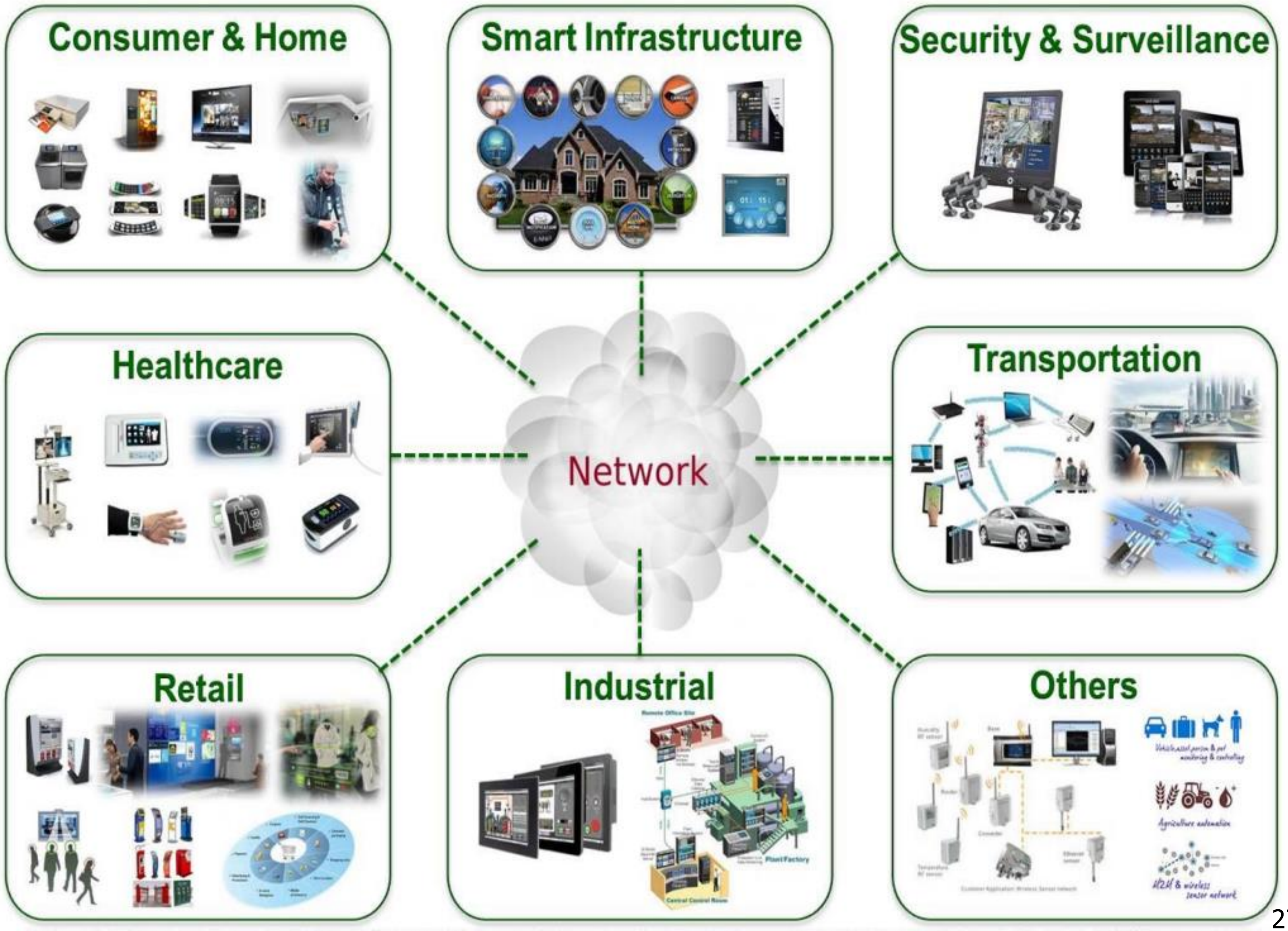
- Cloud computing
  - Warehouse Scale Computers (WSC)
  - Software as a Service (SaaS)
  - Portion of software run on a Personal Mobile Device and a portion run in the Cloud
  - Amazon and Google
- Data centers
  - Millions of computers connected by off-the-shelf networking devices

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

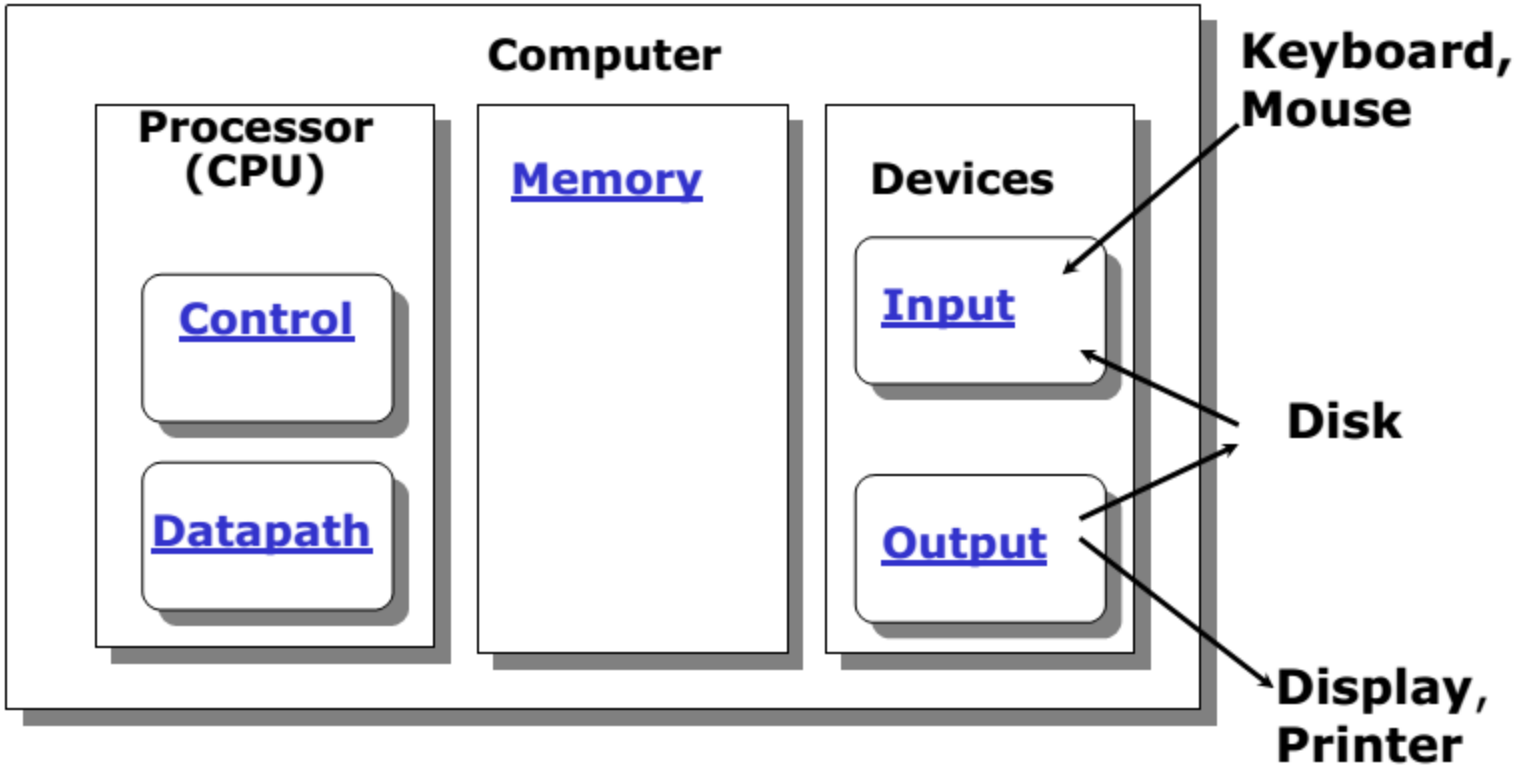


New Computer Architecture for AI era

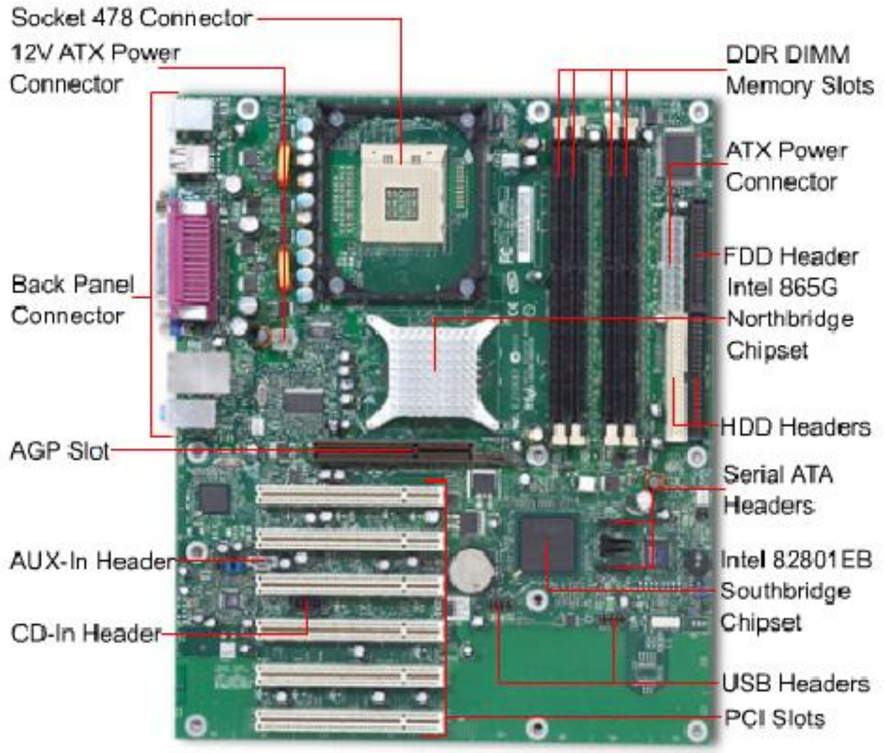
- AI and big data requires new computer architecture
  - More Suitable for deep learning
  - High requirement on parallel
  - Low energy
- From CPU to GPU, TPU…
- AI chips on smartphone
- Dozens of companies dive in this area:
  - Google, NVIDIA, 华为、地平线、寒武纪、深鉴
  - Nobody knows who will win

Components of a Computer

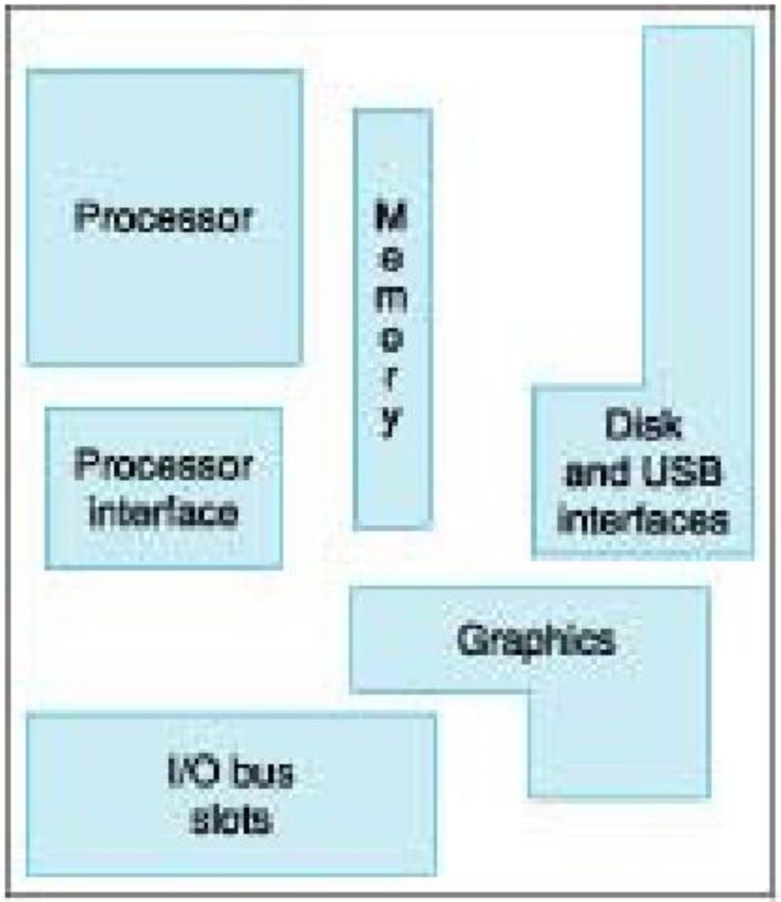
- Same components for all kinds of computer:
  - Input Device, Output Device, Memory, Processor (Control, Datapath)



PC motherboard

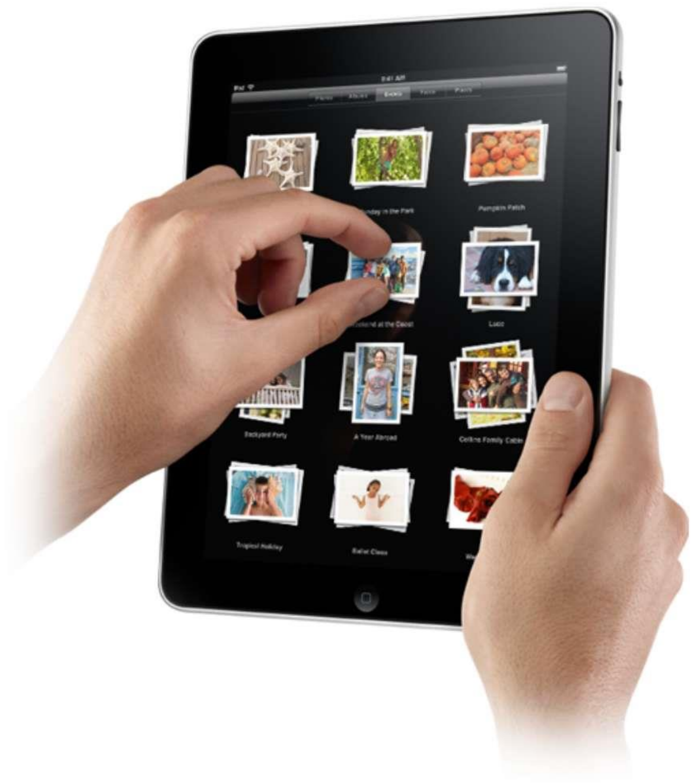


Courtesy: www.tigerdirect.com

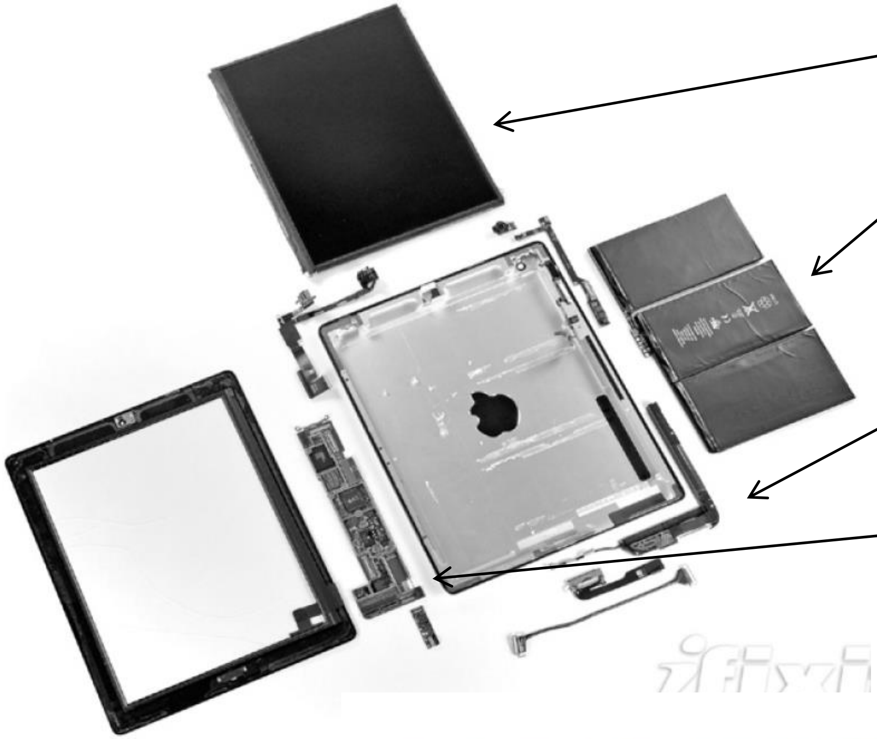


Let’s break up an iPad

- 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



Capacitive multitouch LCD screen

3.8 V, 25 Watt-hour battery

cameras, microphone, speakers, accelerometer, Wi-Fi/Bluetooth network

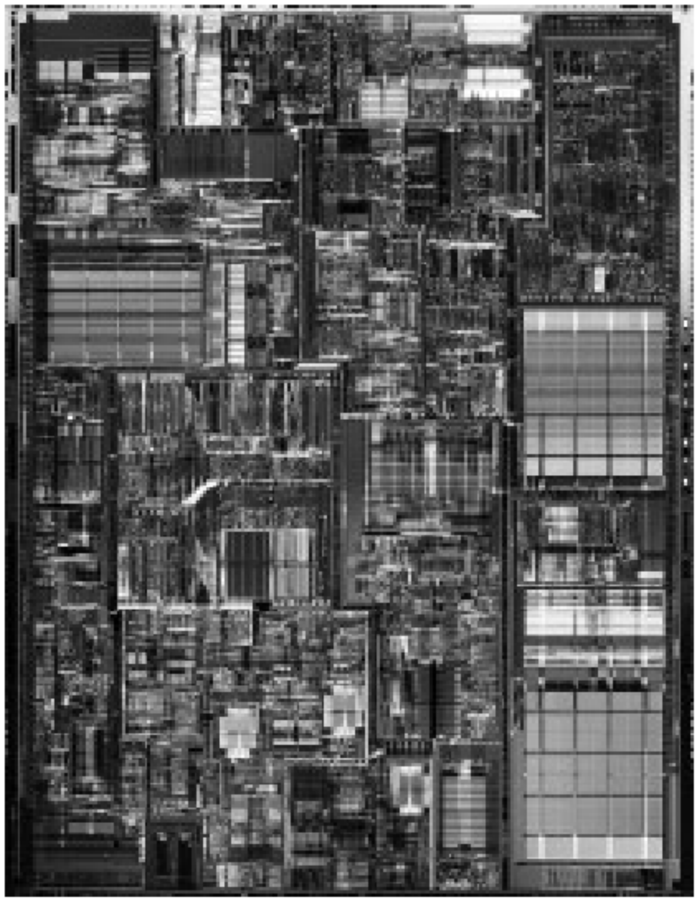
Computer board

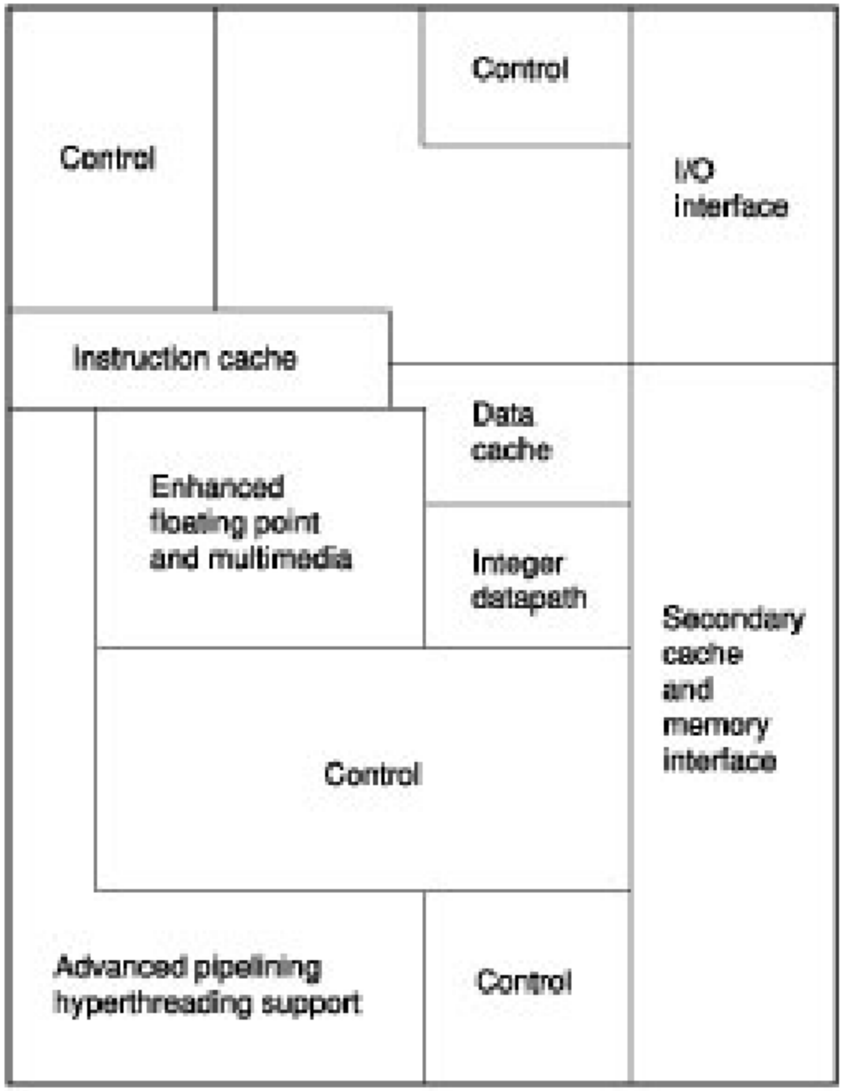
Chips: integrated circuit
PCB board: traditional circuit

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

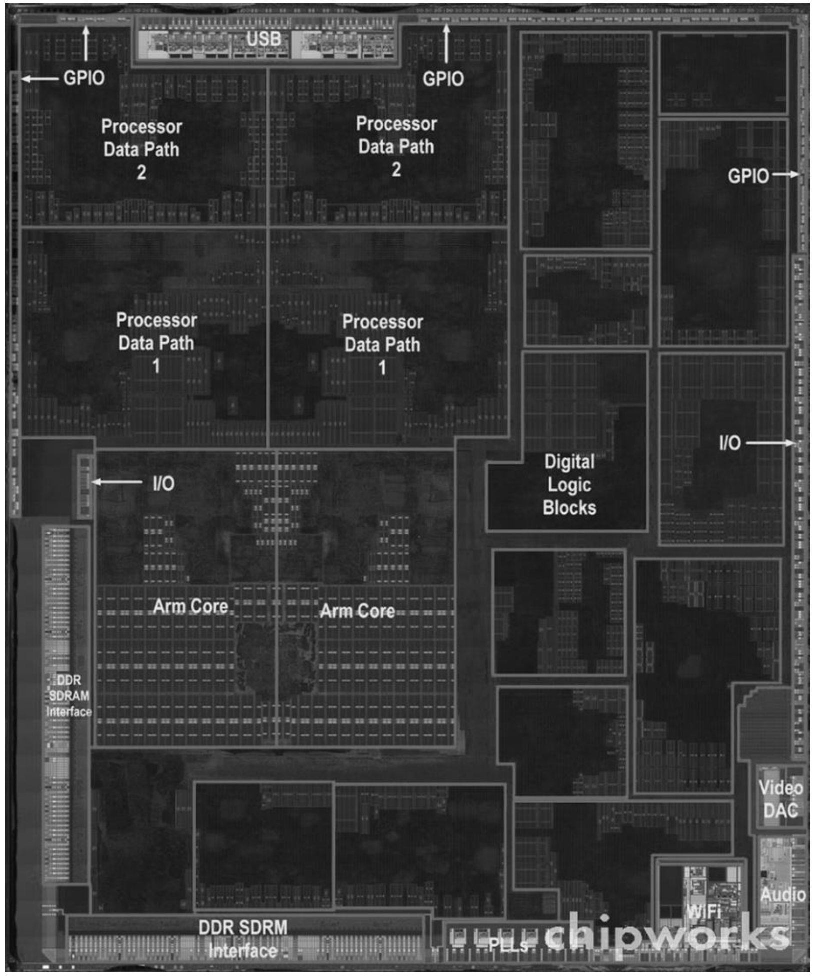
Inside the Processor




Control
Control
I/O interface
Instruction cache
Data cache
Enhanced floating point and multimedia
Integer datapath
Secondary cache and memory interface
Control
Advanced pipelining hyperthreading support
Control

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

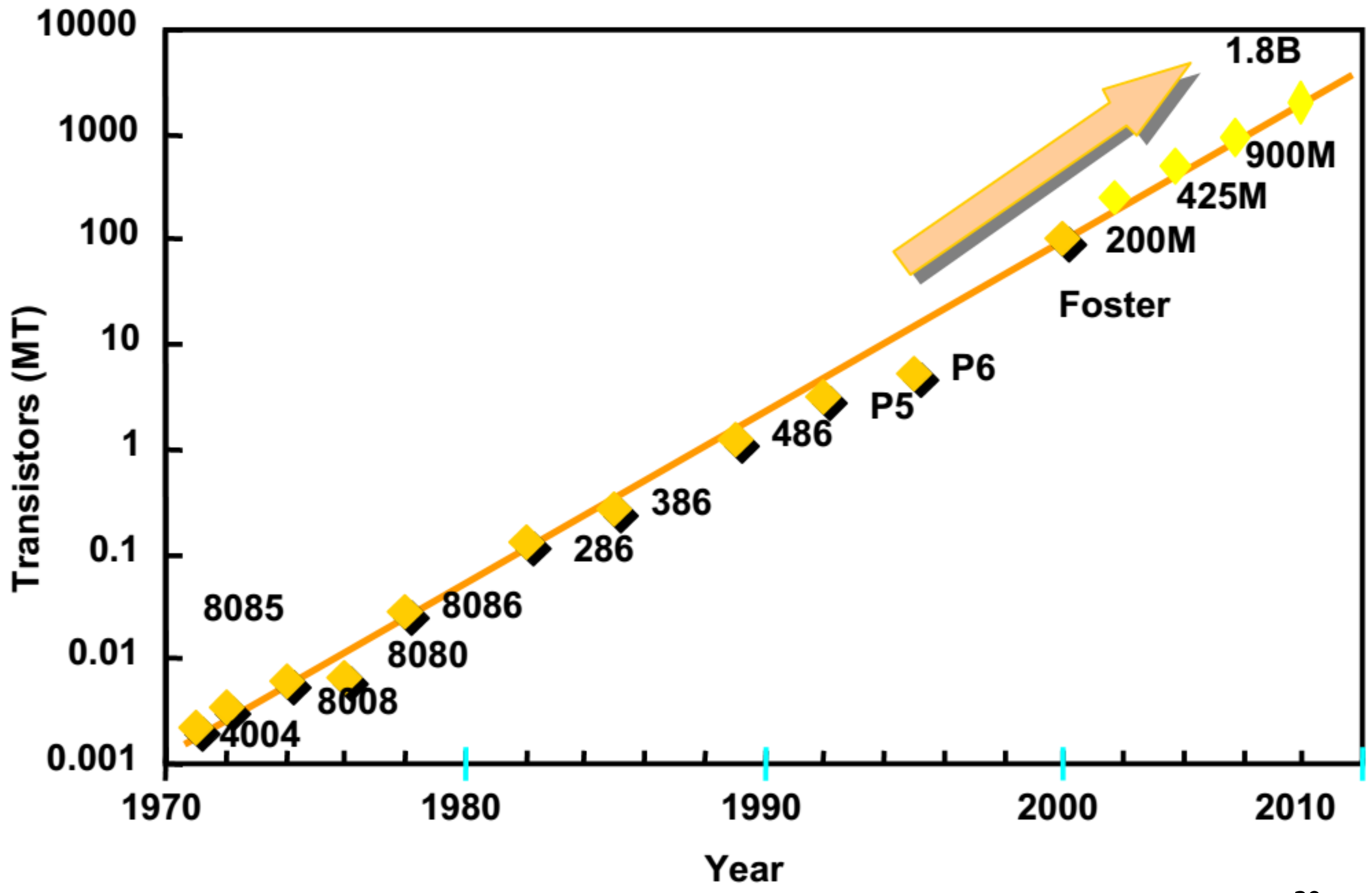
Technologies for Processors and Memory

- Processors
- Memory
- I/O

Micro Processor Advances-Moore’s Law

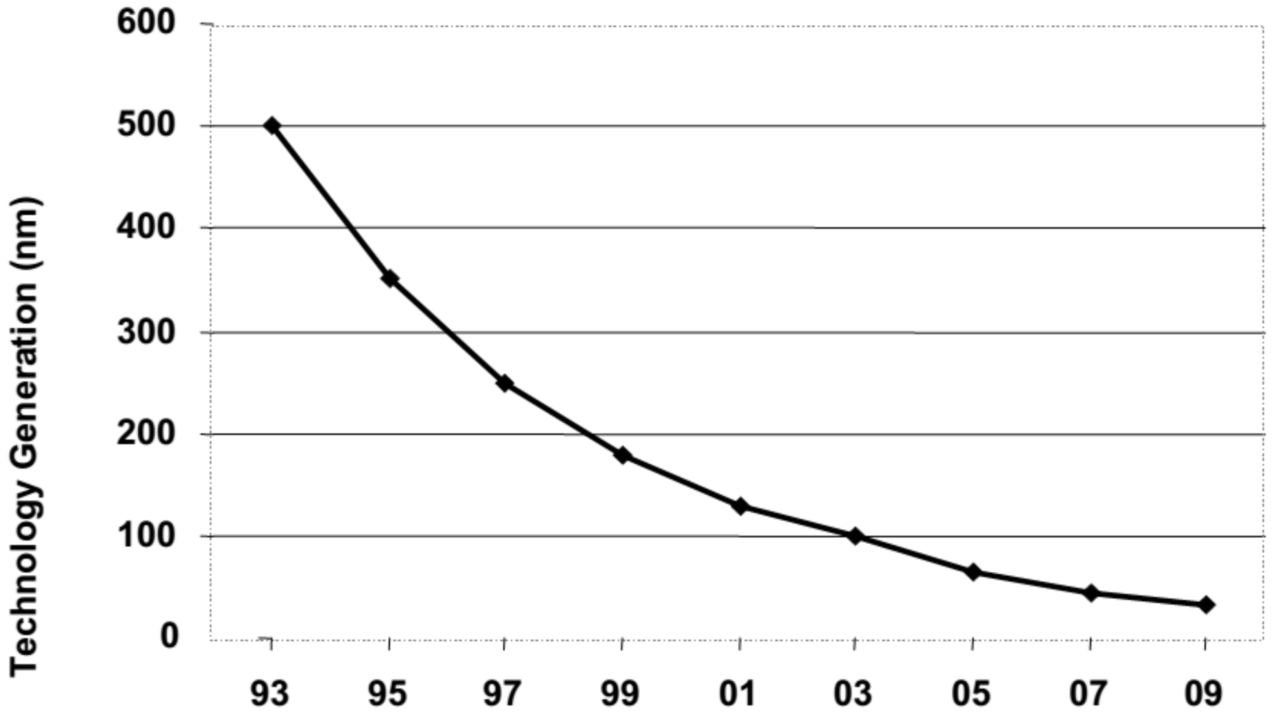
- In 1965, Gordon Moore made a prediction
  - **The number of transistors that can be integrated on a die would double every 18 to 24 months**
- Amazingly visionary – million transistor/chip barrier was crossed in the 1980’s
  - 2300 transistors, 1 MHz clock (Intel 4004) – 1971
  - 16 Million transistors (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


10000
1000
100
10
1
0.1
0.01
0.001
Transistors (MT)
1970
1980
1990
2000
2010
Year
1.8B
900M
425M
200M
Foster
P6
P5
486
386
286
8086
8085
8080
8008
4004

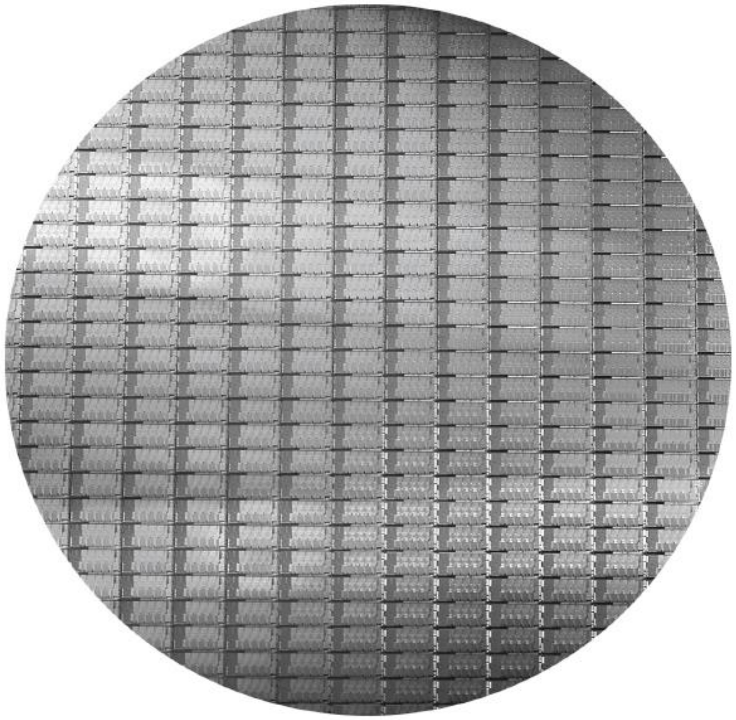
How is that possible?

- Scale the transistor channel length



Feature size scaling to reduce die size

Intel Core i7 Wafer



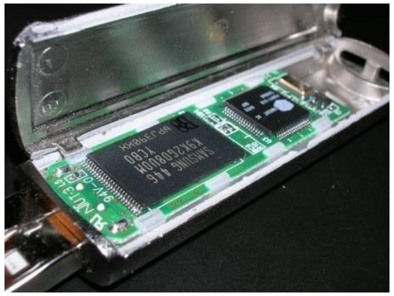
- 300mm wafer, 280 chips, 32nm technology
- Each chip is 20.7 x 10.5 mm
- Latest i7-1160G7, Q3’20, 10 nm SuperFin, 4.40 GHz 4 Core
- Apple M1: 5nm, 16 billion transistors, 8-core, 3.2GHz

Processor Technology Trends

- Shrinking of transistor sizes: 250nm (1997) → 130nm (2002) → 70nm (2008) → 35nm (2014)
- 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
  - Loses instructions and data when power off
- Non-volatile secondary memory
  - Magnetic disk
  - Flash memory
  - Optical disk (CDROM, DVD)



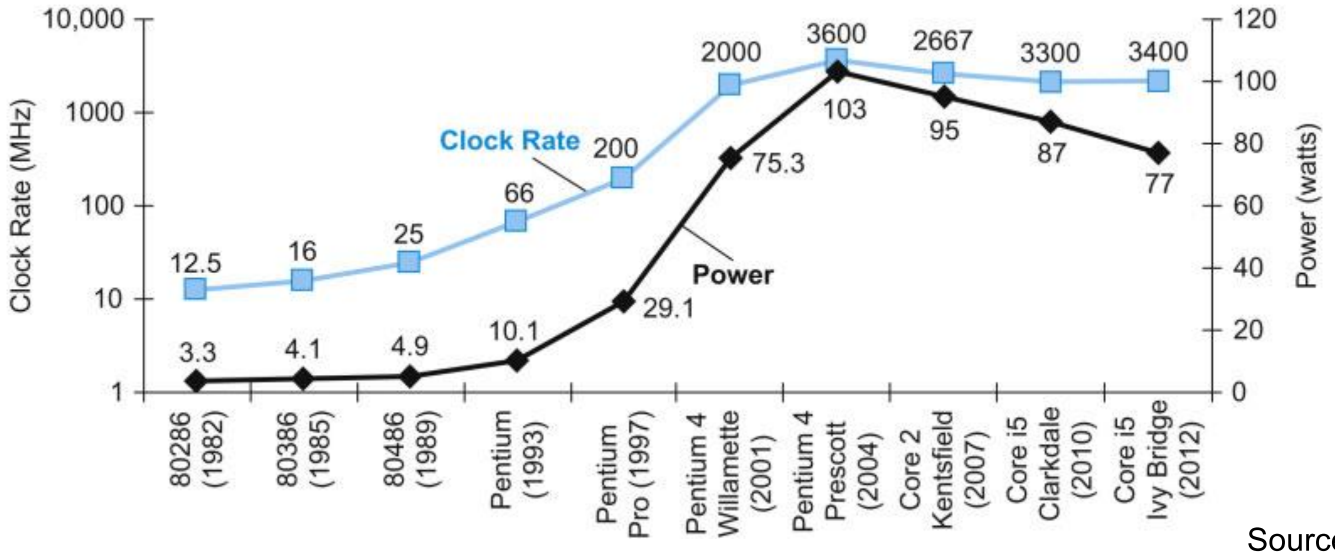
Memory and I/O Technology Trends

- 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

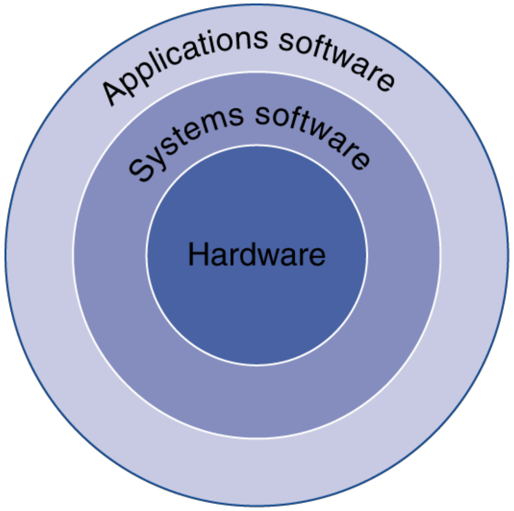
- Dyn power ∝ activity x capacitance x voltage2 x frequency
- Voltage and frequency are somewhat constant now,

  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

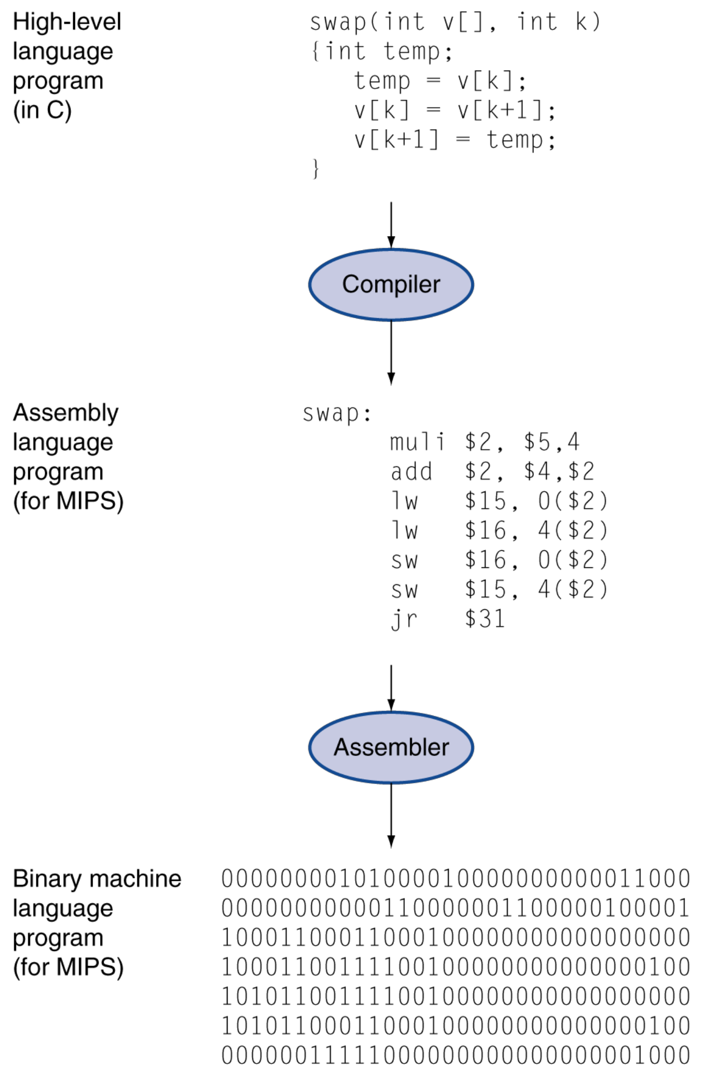
Between Your Program and Hardware



- 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)
Compiler
Assembly language program (for MIPS)
Assembler
Binary machine language program (for MIPS)

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

```
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
```

```
00000000101000010000000000011000
00000000000110000001100000100001
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
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

As when we use ifelse statement, we can improve the speed by predicting the statement that will be run using the probability that usually the statement will be run.