北京郵電大學
BEIJING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS

Computer Organization and Architecture

Chapter 1

Basic Concepts and Computer Evolution

School of Computer Science（National Pilot Software Engineering School）
AO XIONG (熊翱)
xiongao@bupt.edu.cn

Instructor - associate professor XIONG

Xiong Ao (xiongao@bupt.edu.cn)

Office: 科研楼509

Office hours: 上班时间

Phone number: 13301151068

QQ number: 446226731

WeChat：13301151068

About myself

- 计算机学院网络管理研究中心
- 网络与交换技术全国重点实验室
  - 北邮第一个国家重点实验室，1990年开始建设
  - 第一任主任为陈俊亮院士，现任主任为张平院士
  - 我国第一个智能网系统
  - 我国第一个ITU-T标准
- 研究方向：网络管理与通信软件，网络智能运维，区块链及其应用

About this course

- 《计算机组织与结构》，简称“计组”，是计算机专业的一门重要的基础课
- 计算机专业的核心主干课，在先导与后续课程之间起着承上启下的作用，从事计算机设计、开发、应用与维护等工作的基础
- 包括计算机组成原理和计算机体系架构两个部分
  - 组成原理主要讨论计算机系统的各个组成部分及其工作机制
  - 体系架构研究计算机指令集、I/O机制、寻址技术等等
- 对理解计算机的组成原理，运行机制，对编译器和操作系统的支持等具有重要意义
- 内容非常多

About this course

- 课时安排
  - 总共64学时，其中理论课48学时，实验课16学时，总共4学分
  - 理论课从3-18周，总共16周，我们班国庆节占了1~2次课，所以理论课总共是14~15次课
  - 实验课预计是从11月中开始，连续4周4次实验，每次4个学时
  - 期中考试前7次课，1~8章内容
  - 期中考试后8次课，9~21章内容（9、11不讲）
  - 适当安排复习课

About this course

- 考试安排
  - 期中考试预计在11月初，内容初步定的为1~8章
  - 期末考试预计是在12月底
  - 英文题目，闭卷考试，有一定的中文注解

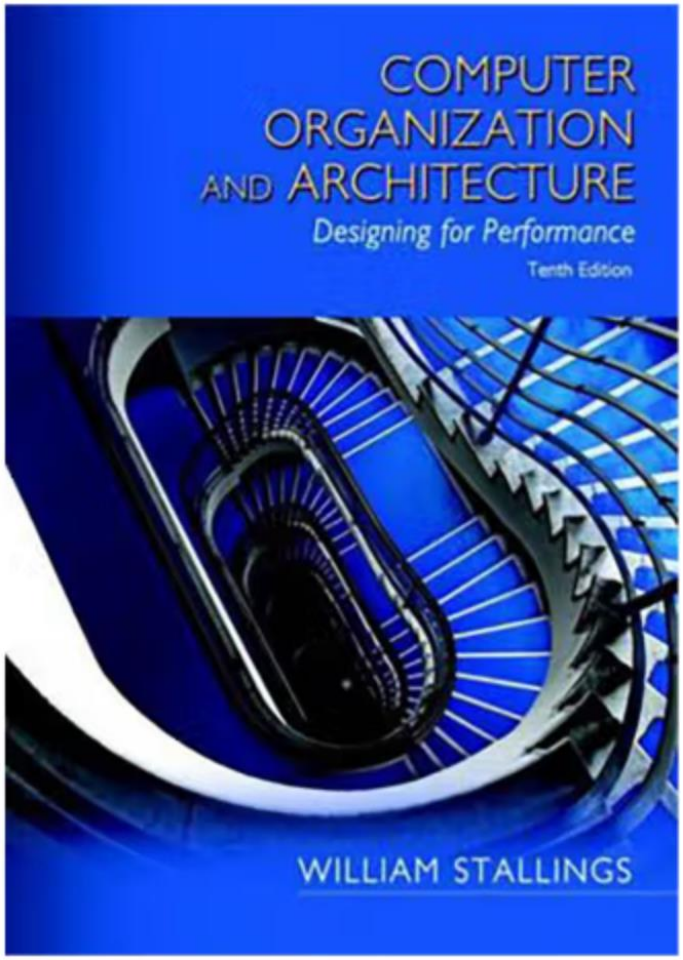
Work Evaluation

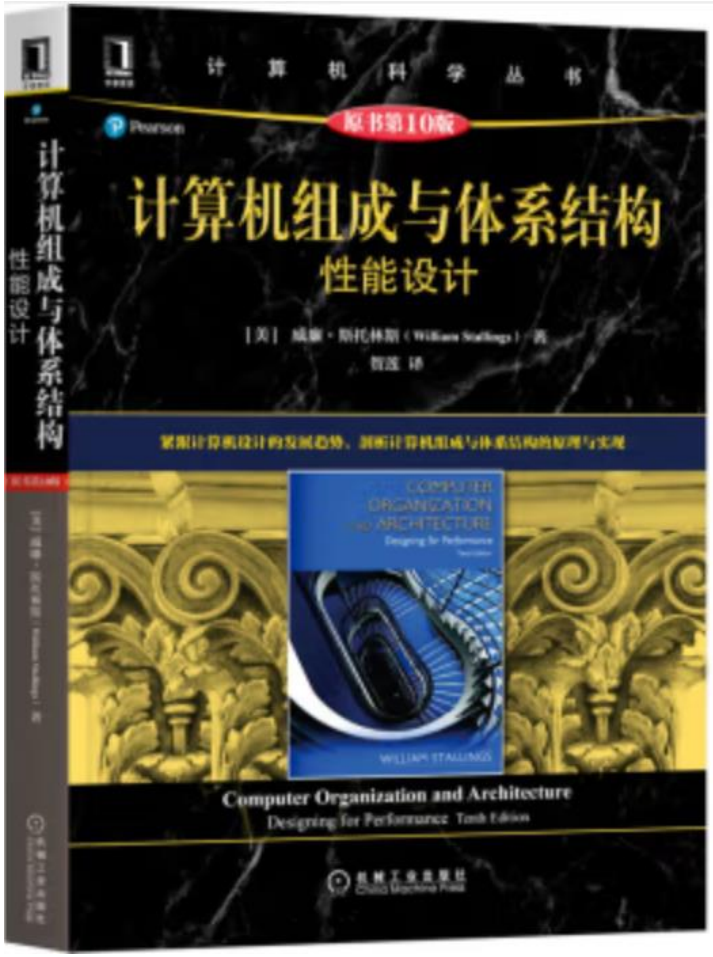
- 总成绩=课堂成绩（期末考试48%+期中成绩12%+平时成绩40%）*75%+课程实验成绩*25%
- 平时成绩包括课堂考勤，作业完成情况等
- 实验成绩包括实验考核、实验报告
- 平时成绩很重要！！

About this course

- 课堂纪律
  - 每节课都需要签到
  - 请假需要有假条，并有辅导员签字
- 作业
  - 本次课的作业，在下次课的前一天晚上交
  - 学委负责收作业
  - 作业中的共性问题会在课堂上讲解

Teaching material 教材





Preface

Let us think about the following questions:

- What is computer? 什么是计算机?
- What types of computer have you seen? 你看过哪些类型的计算机?
- What are the typical characteristics of computer? 计算机的典型特征是什么?
- What are the components of a computer? 计算机有哪些部件?
- How does computer work? 计算机如何工作?
- Why does computer work so fast? 计算机为什么工作这么快?
- What are the key factors that affect the speed of a computer? 哪些因素是影响计算机速度的主要因素?

Preface

In this course, we will study:

- Overview of computer 计算机概述
- Computer system 计算机系统
- Central processing unit 中央处理器
- Control unit 控制器
- Parallel organization 并行组织

Preface

The characteristics of this course:

- core basic course of computer major 计算机专业的核心基础课
- Fundamental 基础
- Abstractness 抽象
- Modularization 模块化
- One of the required subjects for postgraduate entrance examination 研究生入学考试的必修科目之一

Outline

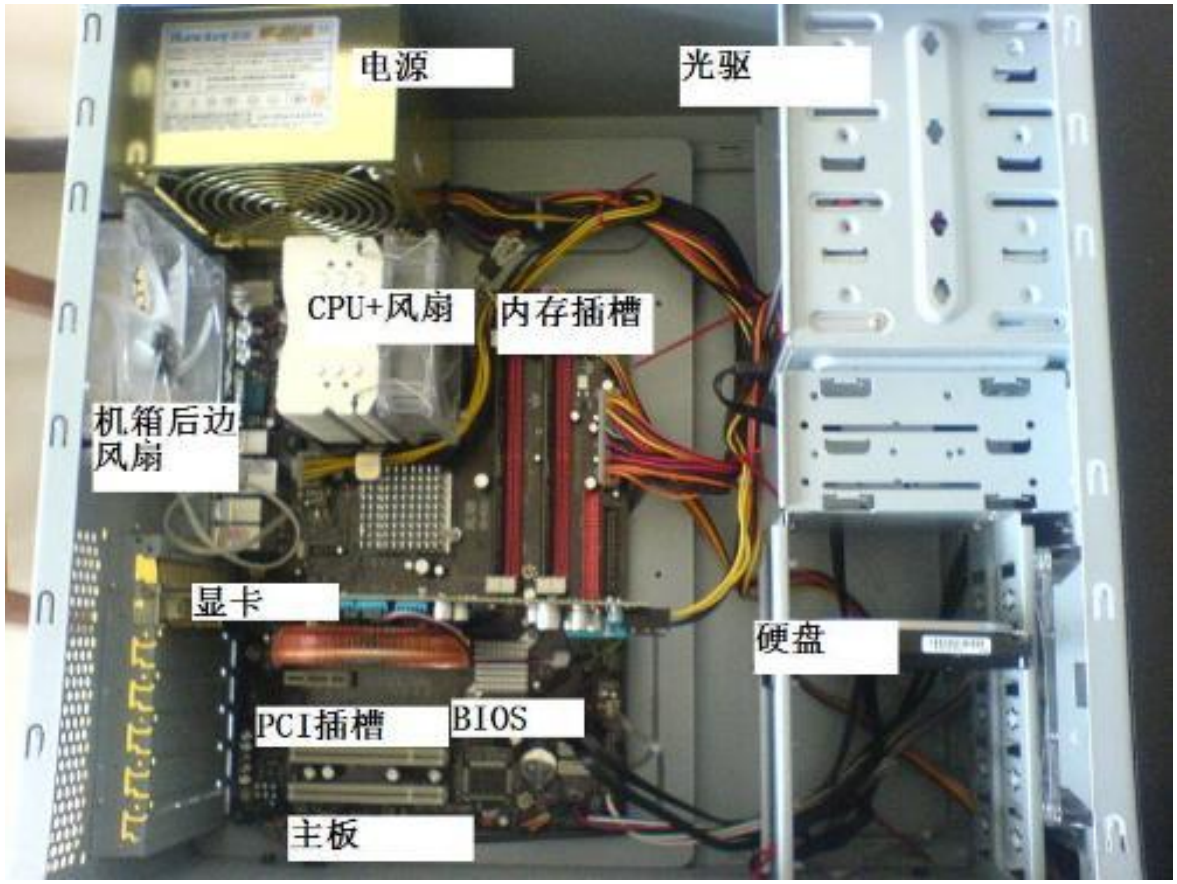
- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

What components does the computer contain?

When you open the computer case, what do you see?

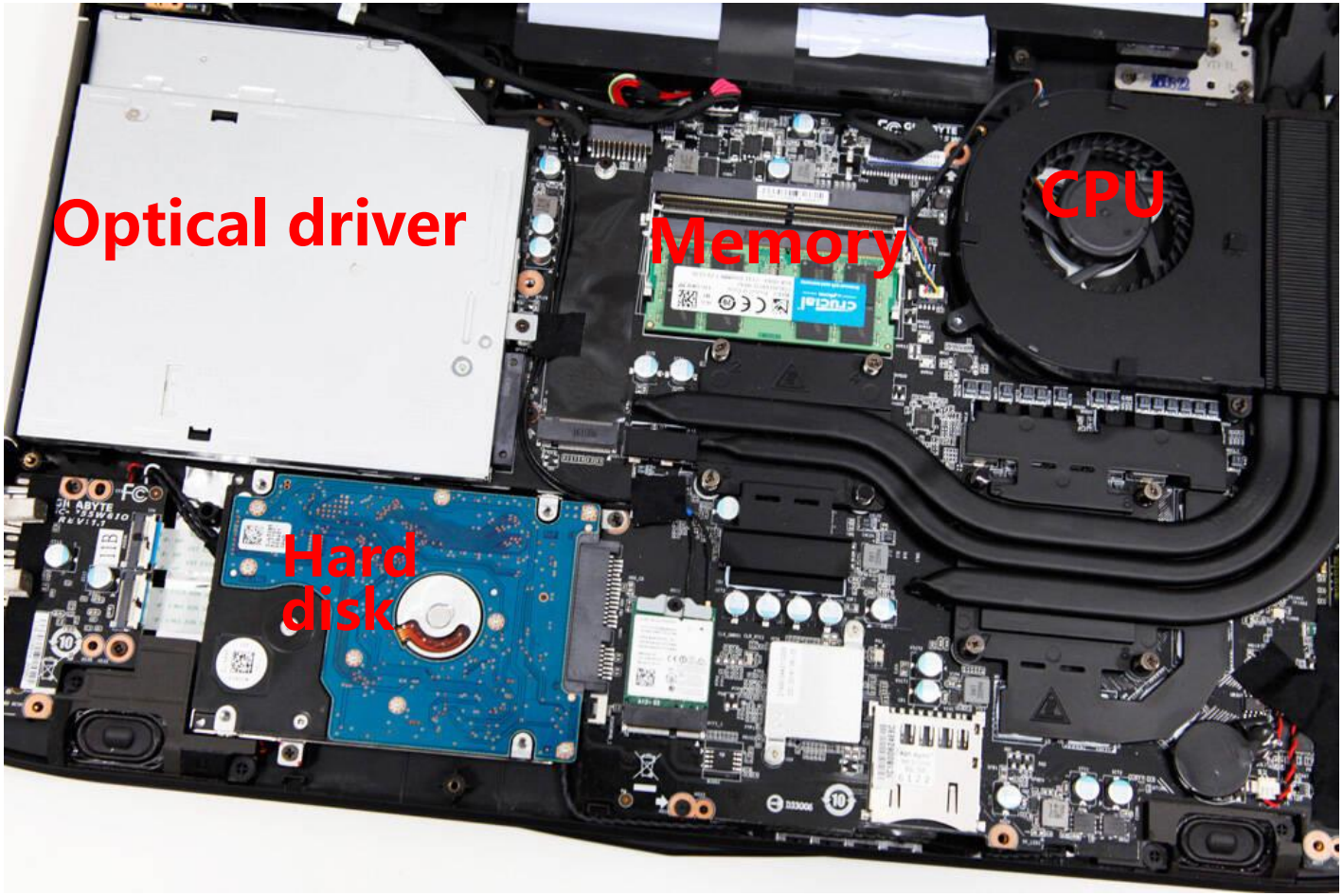
When we open a computer case，...

We can see ……

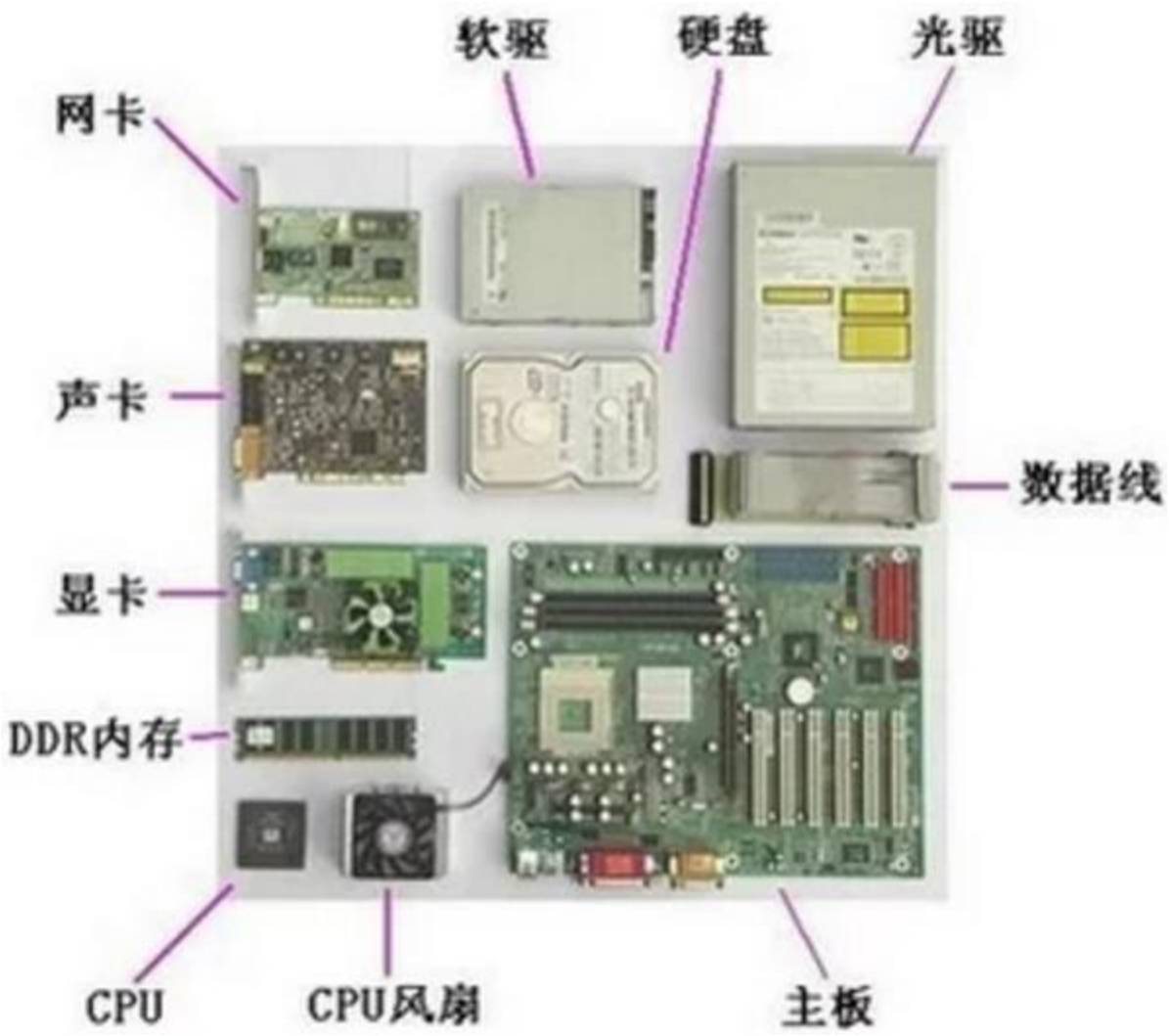


When we open a computer case，...

We can see ……



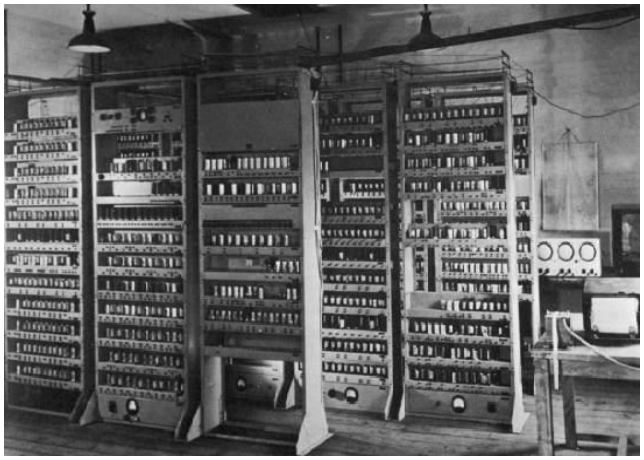
Main parts of the computer 计算机的主要部件



Computing devices then

EDSAC, University of Cambridge, UK, 1949

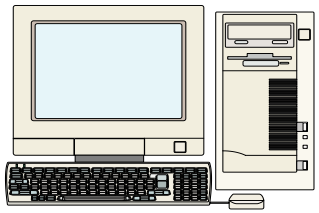
EDSAC： Electronic Delay Storage Automatic Calculator



- First stored program 第一台存储计算机
- About 3000 vacuum tubes， arranged on 12 cabinets, covering an area of 5 × 4 meters
  3000个真空管，排在12个机架上，占地5*4米
- Power consumption 12 kW 功耗12KW
- Consists of five parts: arithmetic unit (ALU), controller, memory, input and output 运算器、控制器，存储器，输入，输出
- About 650 instructions per second 650指令每秒钟

Various computer





Computers have extended to every field of our life！

延伸到日常生活的每一个角落

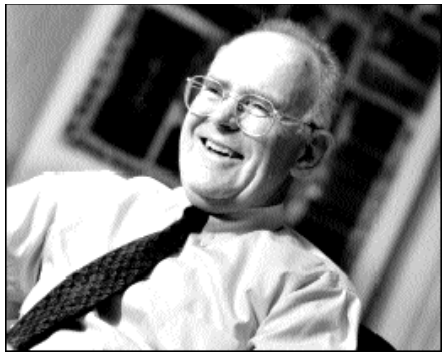
Rapid Change of Underlying Technology 基础技术的快速发展

- With the continuous improvement of the integration of integrated circuits, more components can be packed into chips of the same size 集成电路集成度的不断提高，可以在同样大小的芯片中塞进更多的元器件
- Computers becomes
  - Performance：faster
  - Memory capacity：larger
  - Volume：smaller
- Computer technology
  - Integrated circuit technology
  - Parallel organization

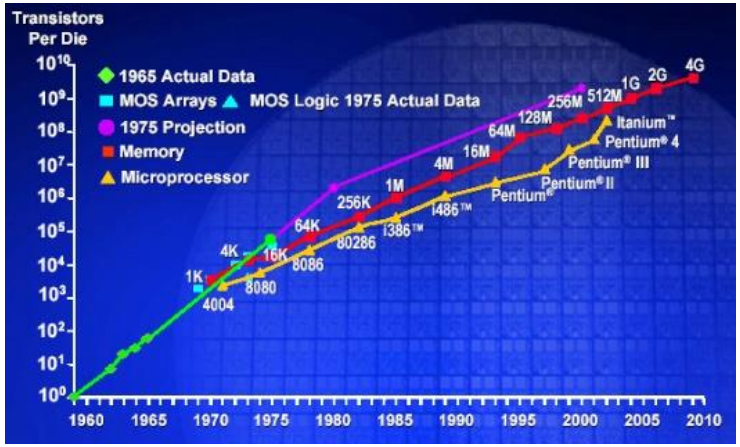
……

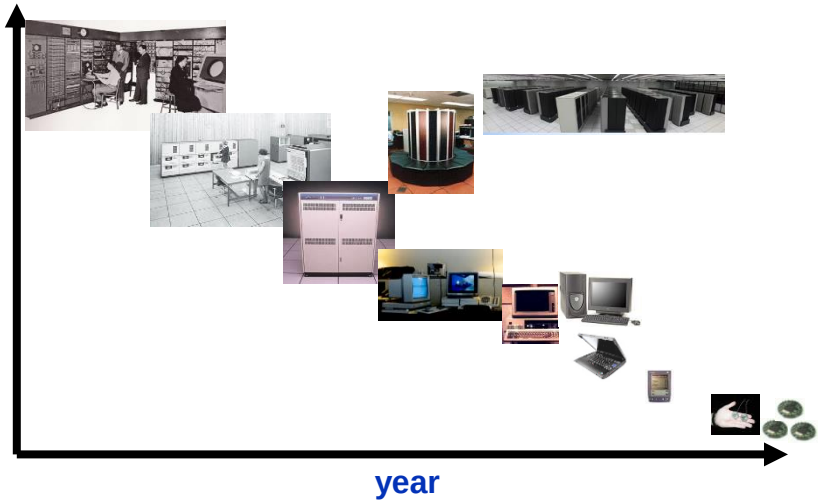
Development trend of computer 计算机发展趋势

- Number of transistor on the chip doubles every certain time 芯片上晶体管的数量每隔一段时间翻一倍
- Processor performance is getting stronger and smaller 处理器性能越来越强，越来越小



Gordon Moore, Electronics, 1965

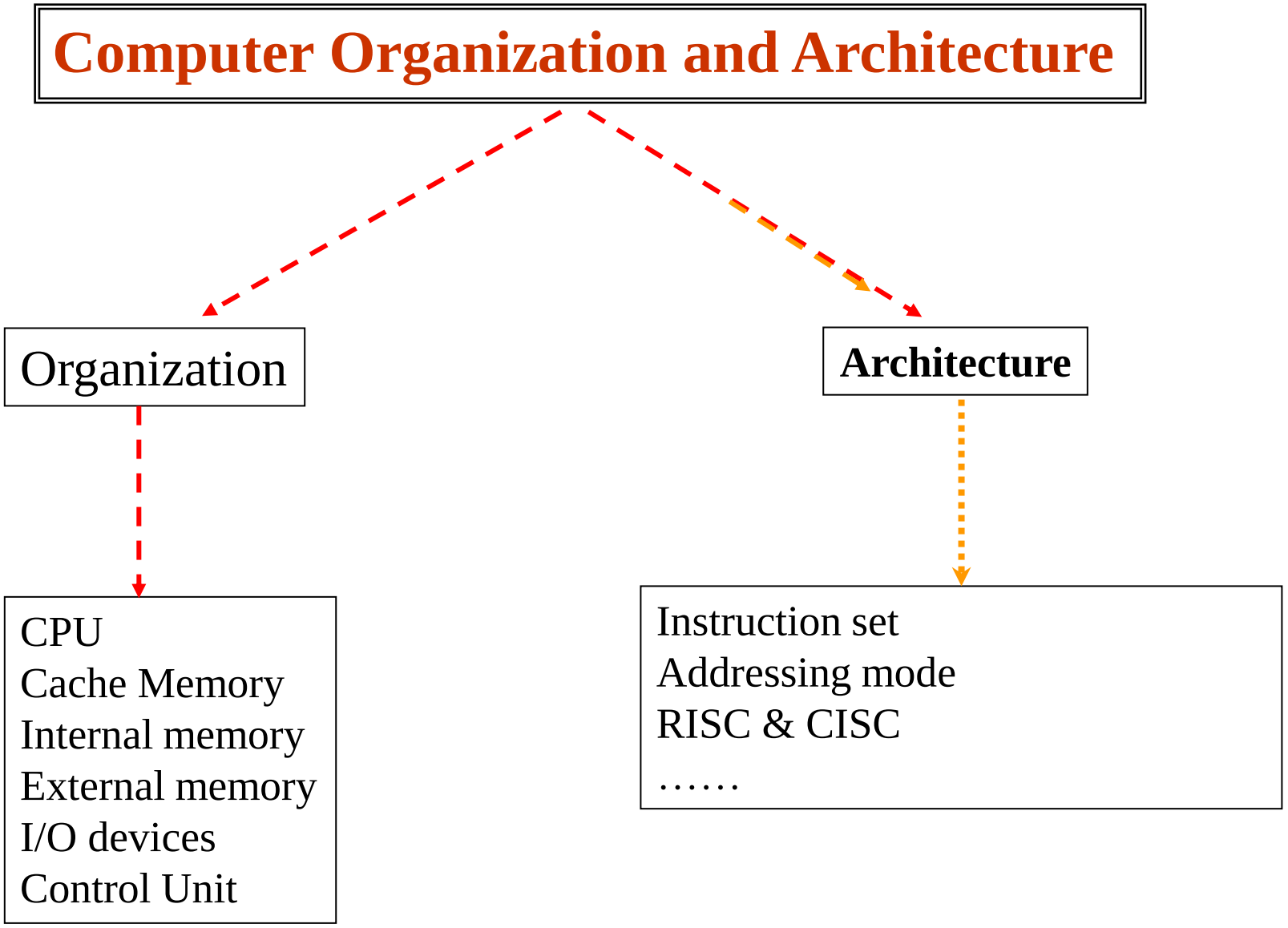




About this course

- Great changes have taken place in the computer field 计算机领域发生了很大的变化
- Computer design becomes more and more complex 设计也越来越复杂
- Basic concepts of computer are still the same 基本概念还是一样
- Basic discussion on the organization and architecture of computers 对计算机的组织和架构进行基础性的讨论
- Help understanding and mastering basic principles of computers 帮助了解和掌握计算机的基本原理

Content of this course



This course is aimed at（1） 课程目标

- Explaining the phenomena of computer architecture and computer design 解释计算机体系结构与计算机设计中的一些现象
  - Knowing the basic instruction cycle and its implication to processing speed 了解基本指令周期及其对处理速度的影响
- Studying the "key" problems 研究一些关键问题
  - CPU & memory bottleneck CPU和存储器的瓶颈
  - CPU & I/O devices problems CPU和I/O设备的问题

This course is aimed at (2) 课程目标

- Studying how the "performance" could be improved 研究如何提高性能
  - example : CPU-memory : cache memory 比如，通过cache缓存来解决CPU和存储器中的问题
- How could we improve execution speed with other techniques ? 研究如何通过其他技术提高执行速度
  - Example : pipelining 比如：流水机制

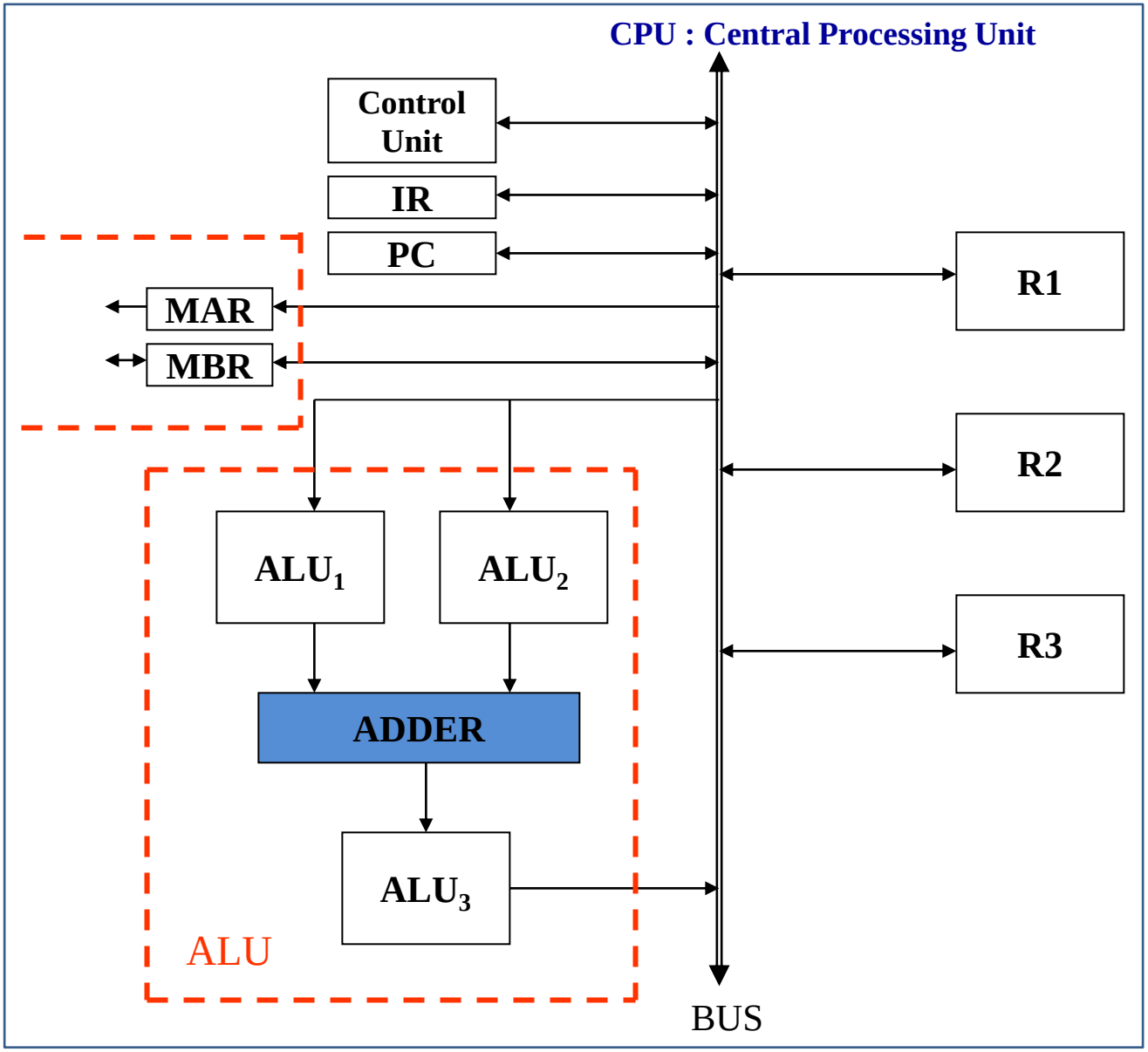
Example：How does computer work? 计算机如何工作?

- How does a basic instruction execute in CPU? 在CPU中，一条基本指令如何执行？

Example：Add R1, R2

(add content of R1 and content of R2, place result in R1)

Composition of CPU CPU的组成部分



Execution steps of Add R1,R2

Add R1, R2

The "possible" micro-execution steps are : 可能的微执行步骤

a. $ALU_1 \leftarrow [R1]$ {content of R1 is moved to ALU_1}

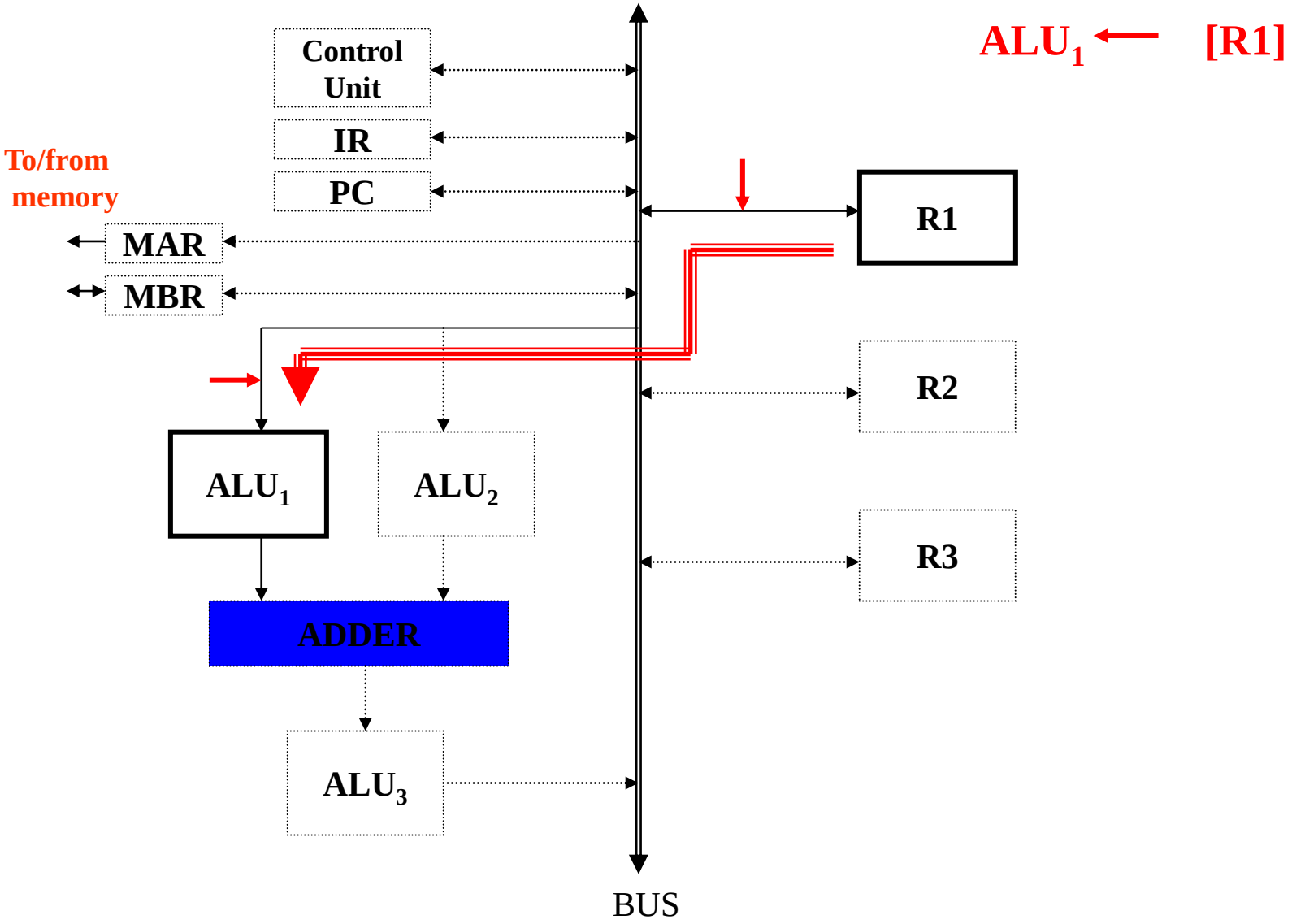
b. $ALU_2 \leftarrow [R2]$ {content of R2 is moved to ALU_2}

c. ADD {content of $ALU_1 + ALU_2 = ALU_3$}

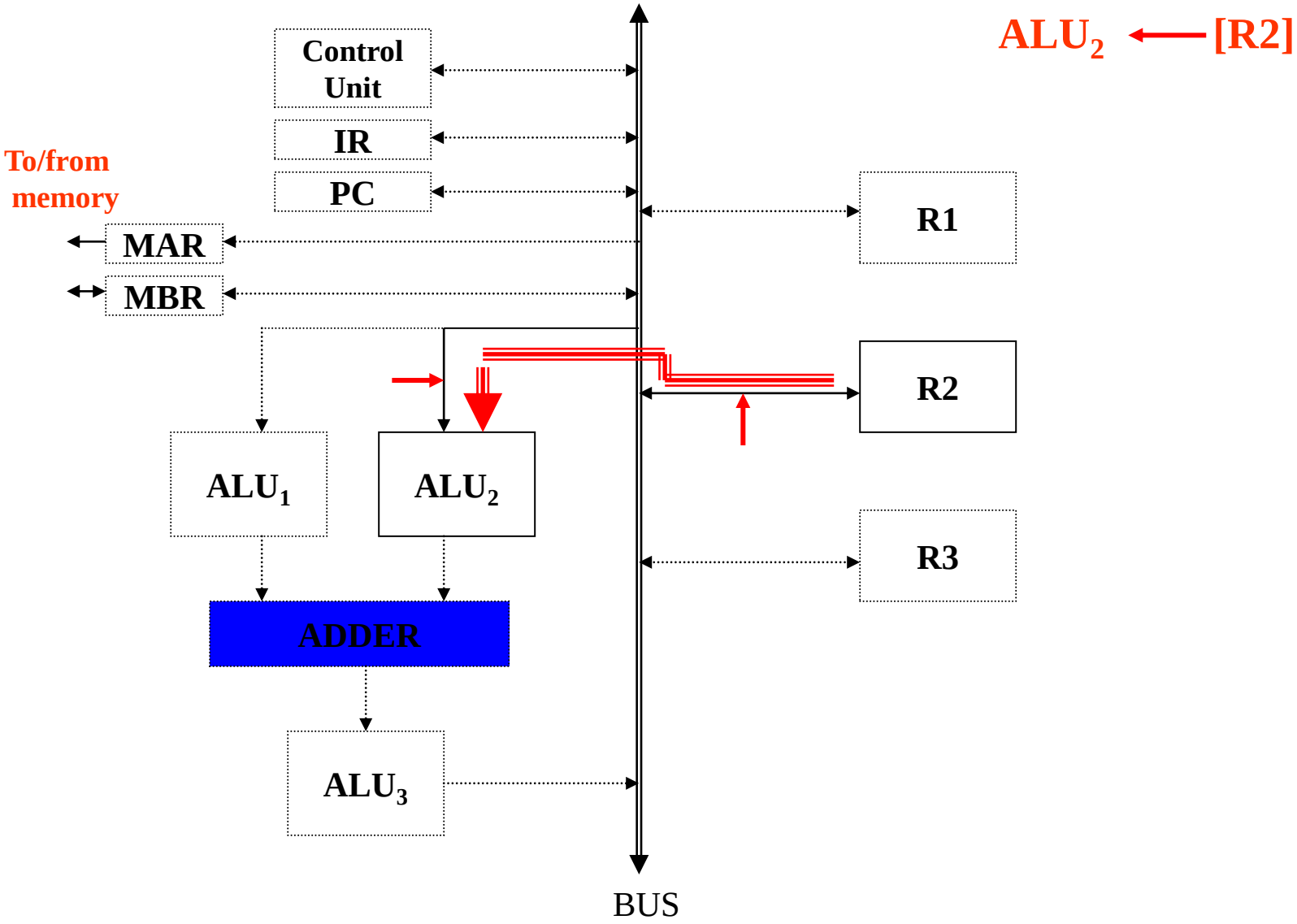
d. $R1 \leftarrow [ALU_3]$ {Result of addition is moved to R1}

If, each micro-step is executed in "one" clock-cycle, then this Add instruction needs 4 clock-cycles 假如每个微步骤的执行需要**1**个时钟周期，则该**Add**指令需要**4**个时钟周期

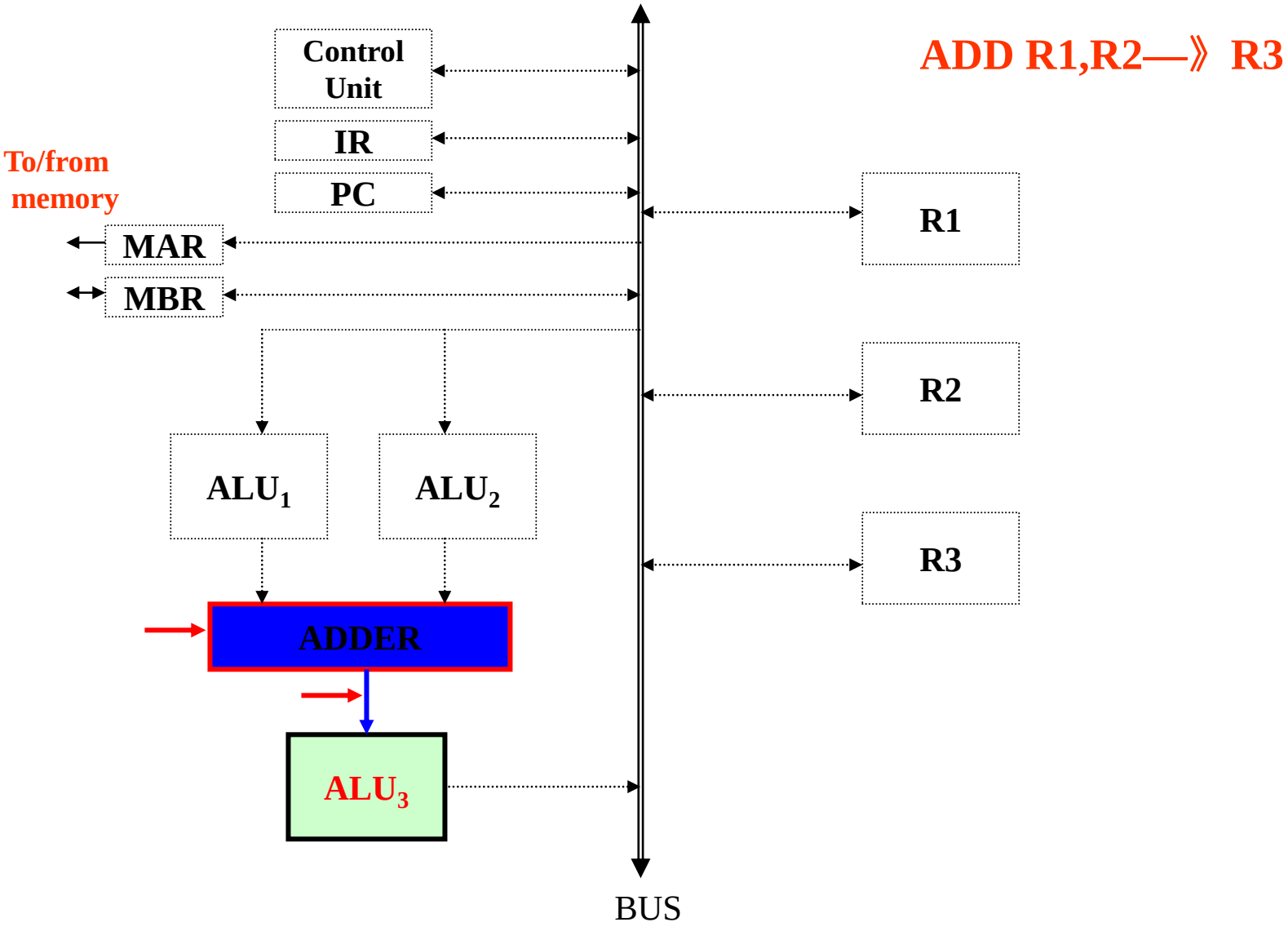
Execution steps of Add - step1



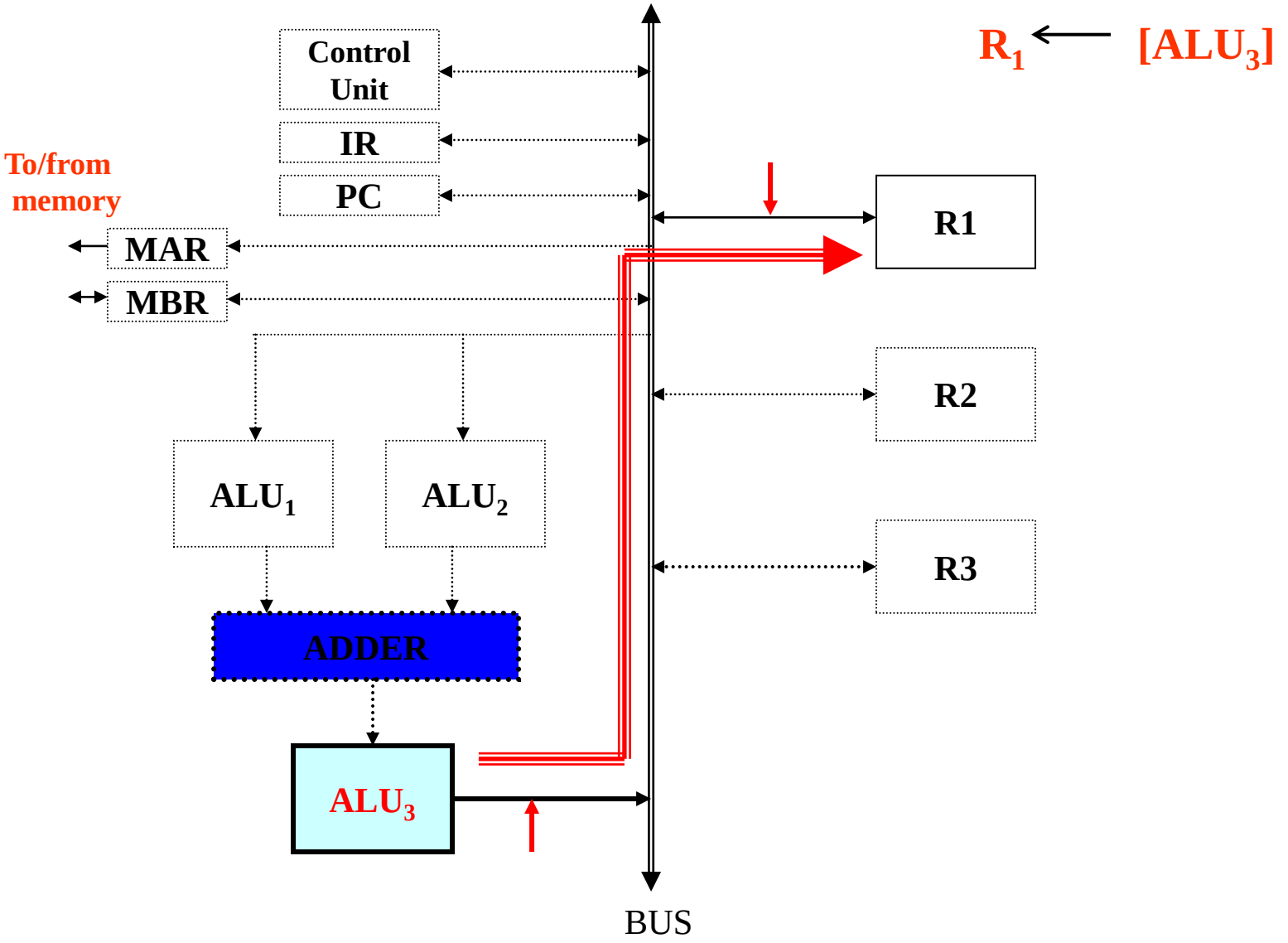
Execution steps of Add - step2



Execution steps of Add - step3



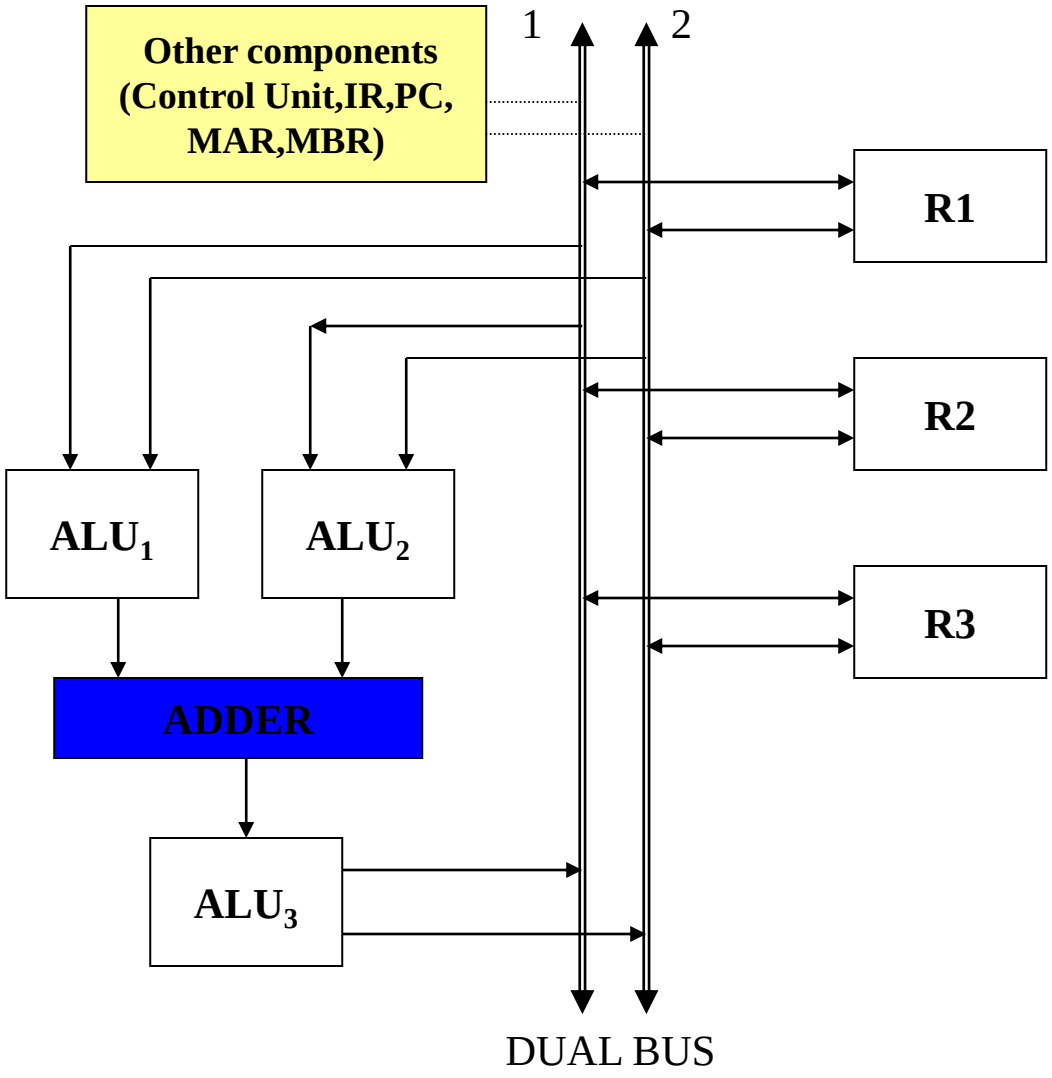
Execution steps of Add - step4



How to reduce execution time? 如何减少执行时间?

- Need 4 clock-cycles 需要4个时钟周期
- Data transfer takes 75% of the time 数据传输占了75%的时间
- With single bus, it is slow, since in each "clock" only one transfer could be executed 对于单总线，速度很慢，因为在每个时钟周期内只能执行一次传输
- Is there any other way to "improve" the speed? 有没有其他方法可以“提高”速度？
- Dual bus processor may be faster 双总线处理器可能更快
- Additional processor cost 额外处理器成本

Dual bus processor 双总线处理器



1. ALU1 ← [R1] (bus1)
   ALU2 ← [R2] (bus2)
2. ADD
3. R1 ← [ALU3] (bus1)

Only 3 clocks cycles needed, 25% faster

How about this :

1. ALU1 ← [R1] (bus1)
   ALU2 ← [R2] (bus2)
   ADD
2. R1 ← [ALU3] (bus1)

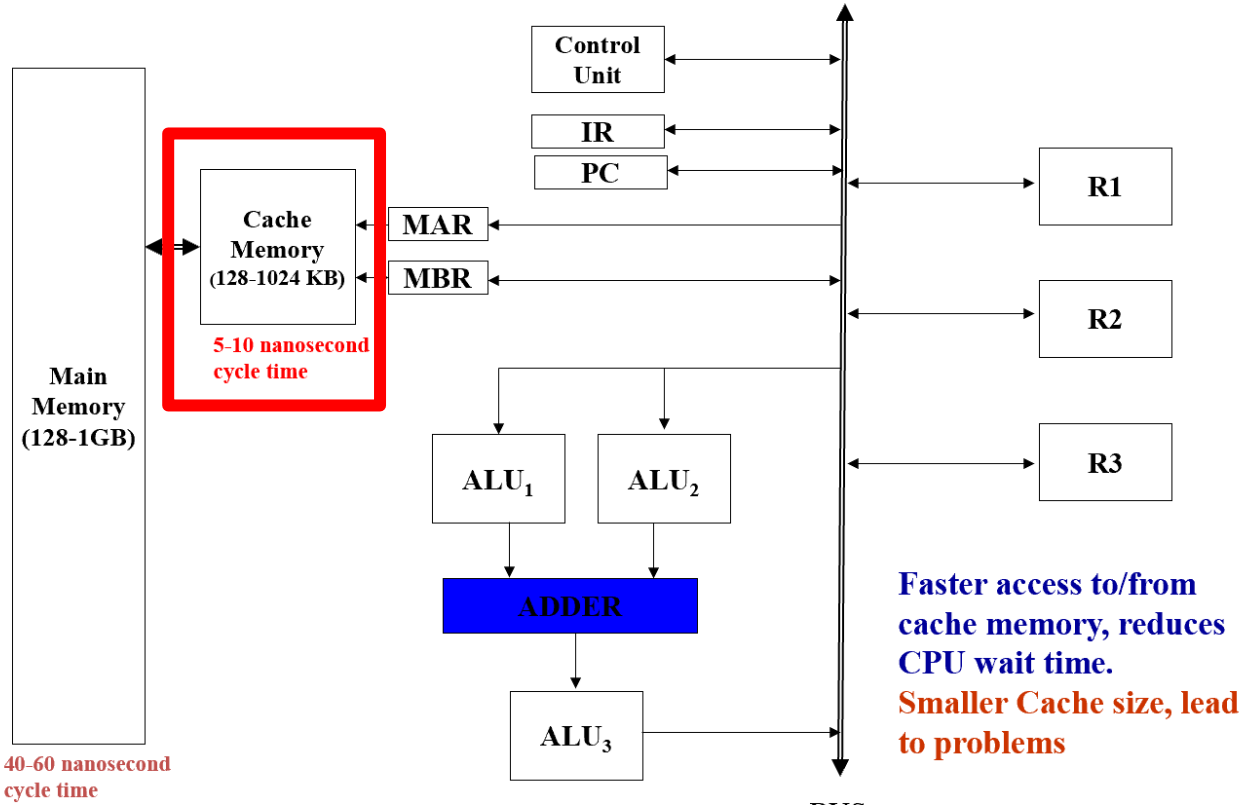
Only 2 clocks cycles needed, 50% faster

Problem:

- For CPU with > 1 GHz clock，it can transfer 16/32/64 bit data or instruction (from one CPU unit to another) in **less than one nanosecond** 对于时钟频率超过1 Ghz的CPU，可以在不到1纳秒的时间内从一个单元到另一个单元传输16/32/64位数据或指令
- Memory unit/system, transfers 16/32/64 bit data or instruction in 40 to 60 nanoseconds (for memory with 40-60 nanosecond cycle time) 存储器单元/系统，在40到60纳秒内传输16/32/64位数据或指令（对于具有40-60纳秒周期时间的存储器）
- **CPU has to wait more than 50 CPU clocks**, waiting for data/instruction from memory to be available CPU必须等待超过50个CPU时钟，等待来自内存的数据/指令可用

How to solve the problem? 如何解决?

- We can overcome (partly) the CPU-Memory bottleneck by inserting cache memory between CPU and Main Memory. How? 我们可以通过在CPU和主内存之间插入高速缓存来部分克服CPU和内存之间的瓶颈



Other way to improve speed

- Is there any other way to improve instruction execution speed (increasing performance)? **Pipelining** 有没有其他方法可以提高指令执行速度（提高性能）？流水线
- Are these improvements need extra cost? (**cost vs performance issue**) 这些改进是否需要额外成本？(性价比问题)
- Balance is the key issue 平衡是关键

Main content of this course

- PART ONE：OVERVIEW 概论
- PART TWO：THE COMPUTER SYSTEM 计算机系统
- PART THREE：ARITHMETIC AND LOGIC 算术与逻辑
- PART FOUR：THE CENTRAL PROCESSING UNIT 中央处理器
- PART FIVE：PARALLEL ORGANIZATION 并行组织
- PART SIX：THE CONTROL UNIT 控制器

Part one：Overview

- Basic Concepts and Computer Evolution
- Performance Issues

Part two：The computer system

- Top Level View of Computer Function and Interconnection
- Cache Memory
- Internal Memory
- External Memory
- Input/Output
- Operating Systems Support

Part three：Arithmetic and Logic

- Number Systems (pass)
- Computer Arithmetic
- Digital Logic (pass)

Part four：The central processing unit

- Instruction Sets: Characteristics and Functions
- Instruction Sets: Addressing Modes and Formats
- Processor Structure and Function
- Reduced Instruction Set Computers
- Instruction-Level Parallelism and Superscalar Processors

Part five：parallel organization

- Parallel Processing
- Multicore Computers
- General-Purpose Graphic Processing Units

Part six：The control unit

- Control Unit Operation
- Microprogrammed Control

Outline

- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

In this course, we will learn:

- What parts does the computer consist of? 计算机是由哪几部分组成的
- How does each part work? 每个部分是如何工作的
- How are these parts connected? 这些部分是如何连接在一起的
- What are the key factors affecting computer performance? 哪些是影响计算机性能的关键因素
- What methods are used to improve the performance of the computer? 采用哪些方法去提高计算机的性能

Example

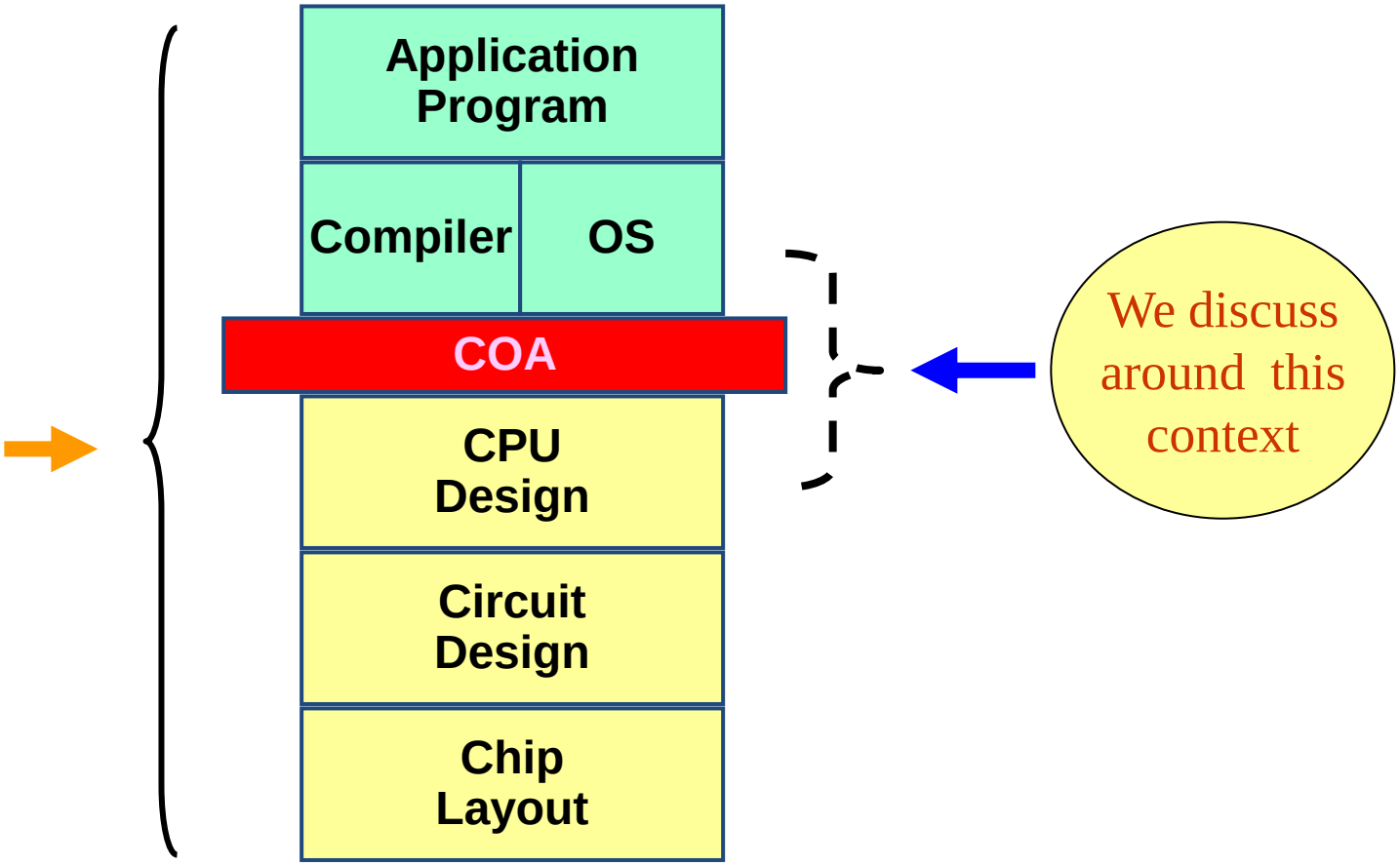
- Balance 平衡
  - Inserting cache memory 增加cache
  - Selection of the number of registers: not only enough, but also not too many 选择合适的寄存器数量
  - cost vs performance 成本和性能
- Parallel 并行
  - Internal of CPU: pipeline, superscalar CPU内部：流水线，超标量
  - On chip: multicore 片上：多核
  - Internal of machine: SMP,NUMA 机器内部：对称多处理，NUMA
  - Multi-machine: cluster 多机器：集群

After this course, we will know

- We are able to analyze the inter relation among design of instructions, its implementation in a processor and the performance issues. 我们能够分析指令设计、指令在处理器中的实现以及性能问题之间的内在关系
- Learn about the computer design and organization issues——hardware of a computer. 学习计算机设计和组织问题，也就是计算机硬件

What is the context of this course?

Layers of computer functions or subsystems



Outline

- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

Architecture 架构

- Architecture is those attributes visible to the programmer 架构是程序员可以看到的属性
  - Instruction set , number of bits used for data representation, I/O mechanisms, addressing techniques. 指令集、用于数据表示的位数、I/O机制、寻址技术
  - e.g. Is there a multiply instruction? 例如，是否提供乘法指令
  - How best is memory handled by the OS? 操作系统如何最好地处理内存

Organization 组织

- Organization is how features are implemented 组织是功能实现的方式
  - Control signals, interfaces, memory technology. 控制信号、接口、存储器技术
  - e.g. Is there a hardware multiply unit or is it done by repeated addition? 是否有硬件乘法单元或通过重复加法完成
  - What type of non-volatile memory is used to store the BIOS? 什么类型的非易失性内存用于存储BIOS

Importance of the distinction 重要的区别

- A family of computer models: All with the same architecture but with differences in organization 系列计算机：具有相同的体系结构，但在组织上有所不同
  - The different models in the family have different price and performance characteristics 系列中的不同型号具有不同的价格和性能特点
  - The organization of a particular architecture changing with changing technology 某个体系结构的计算机，它的组织随着技术的变化而变化
    - e.g. IBM System/370

Example

- All Intel x86 family share the same basic architecture 所有Intel x86系列共享相同的基本体系结构
- The IBM System/370 family share the same basic architecture IBM System/370系列具有相同的基本体系结构
- This gives code compatibility at least backwards 这使代码至少向后兼容
- Organization differs between different versions 不同版本的机器，组织结构不同

Organization and Hardware 组织和硬件

- Operation units and their interconnection to realize structural specifications 实现结构规范的操作单元及其相互连接
  - Internal CPU，including Arithmetic, logic, branch, data transfer are implemented CPU内部的设计，包括算术，逻辑，分支，数据传输的实现等
  - Memory system 存储系统
  - Bus structure 总线结构
- Hardware used to refer to specific of a machine 硬件一般指的是机器的特定组成部分
  - Detailed logic design 详细的逻辑设计
  - Packaging technology of machine 机器的封装技术

Outline

- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

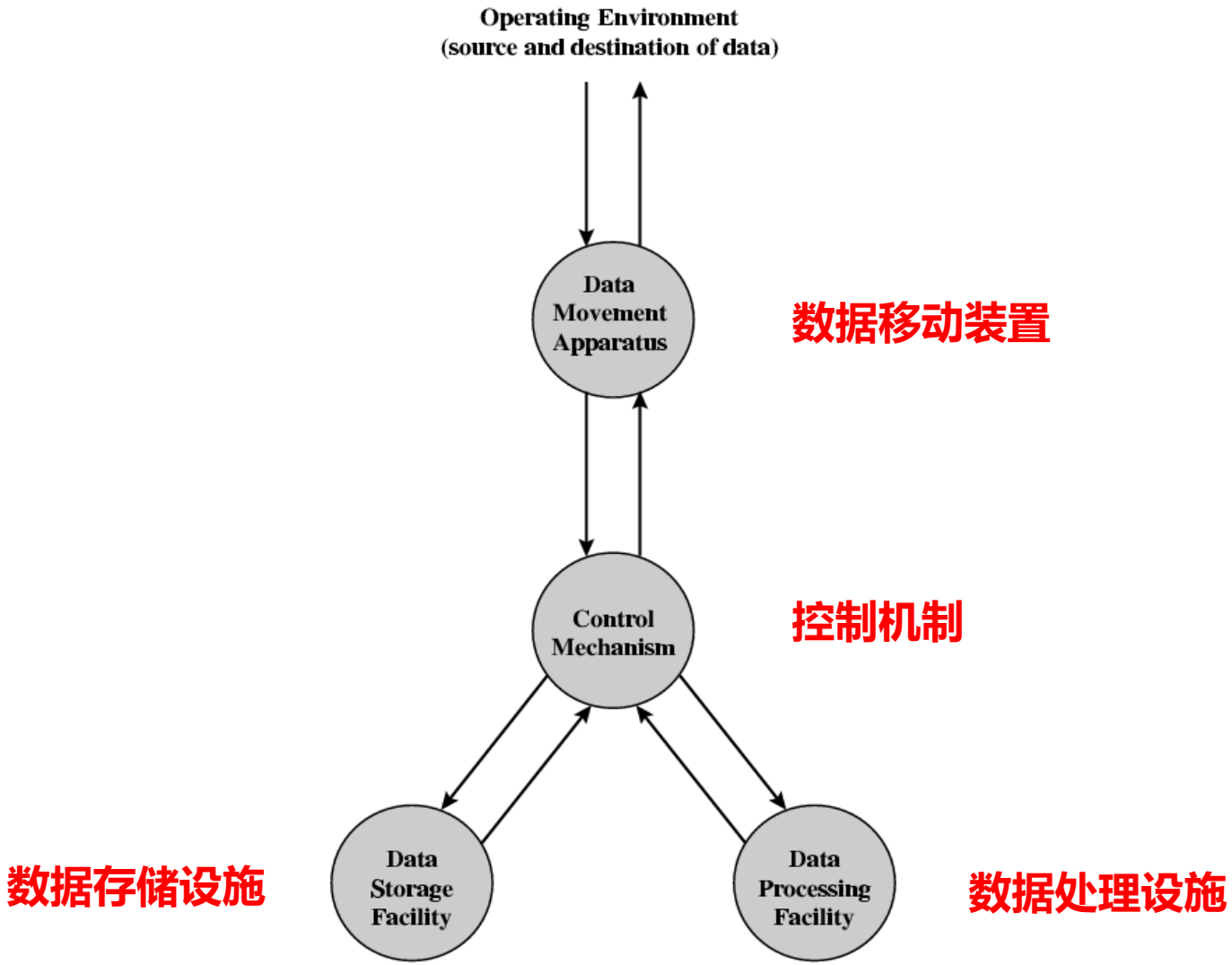
Structure & Function 结构和功能

- Structure is the way in which components relate to each other 结构是组件之间相互关联的方式
- Function is the operation of individual components as part of the structure 功能是单个组件作为结构的一部分能够完成的操作

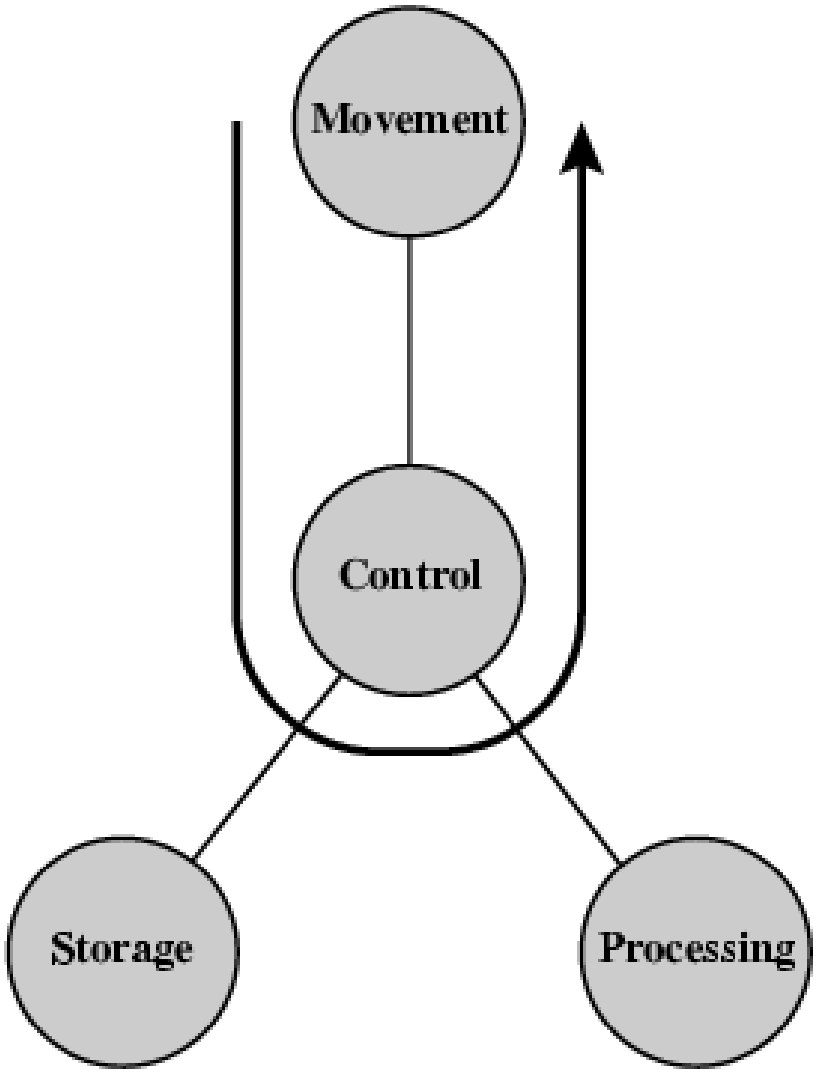
Function 功能

- All computer functions are:
  - Data processing 数据处理
  - Data storage 数据存储
  - Data movement 数据移动
  - Control 控制

Function View 功能视角



Operation type 1 — data movement 数据移动



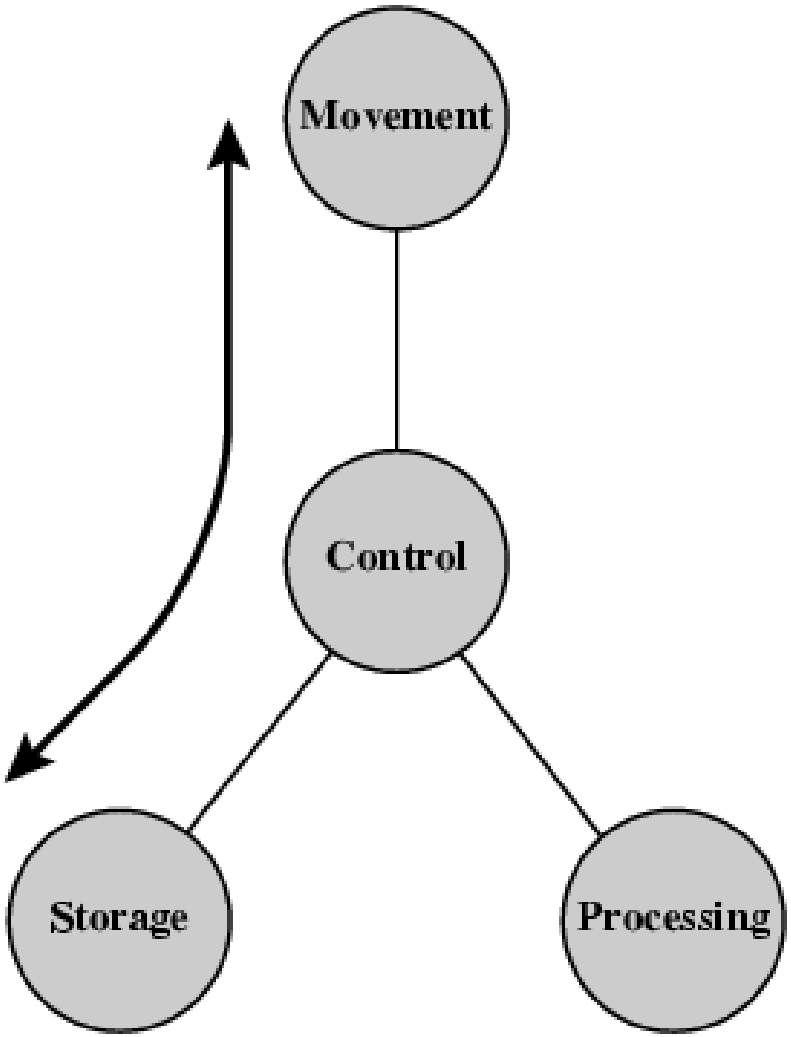
移动

控制

存储

处理

Operation type 2 — storage 存储



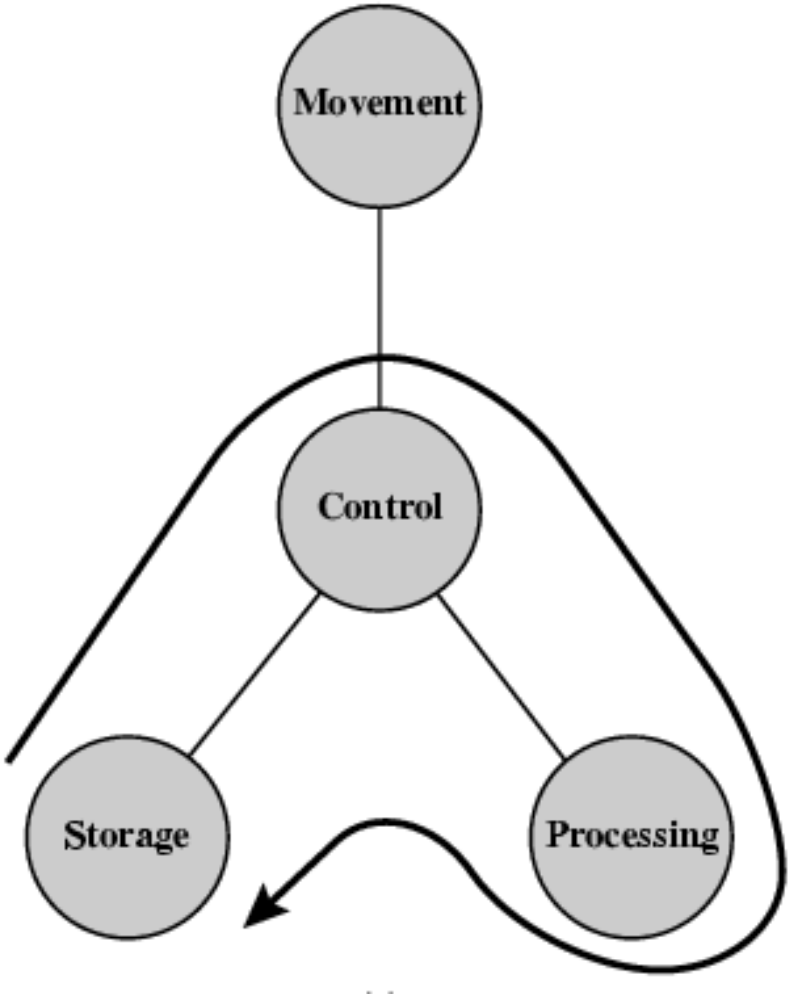
移动

控制

存储

处理

Operation type 3 — processing from/to storage



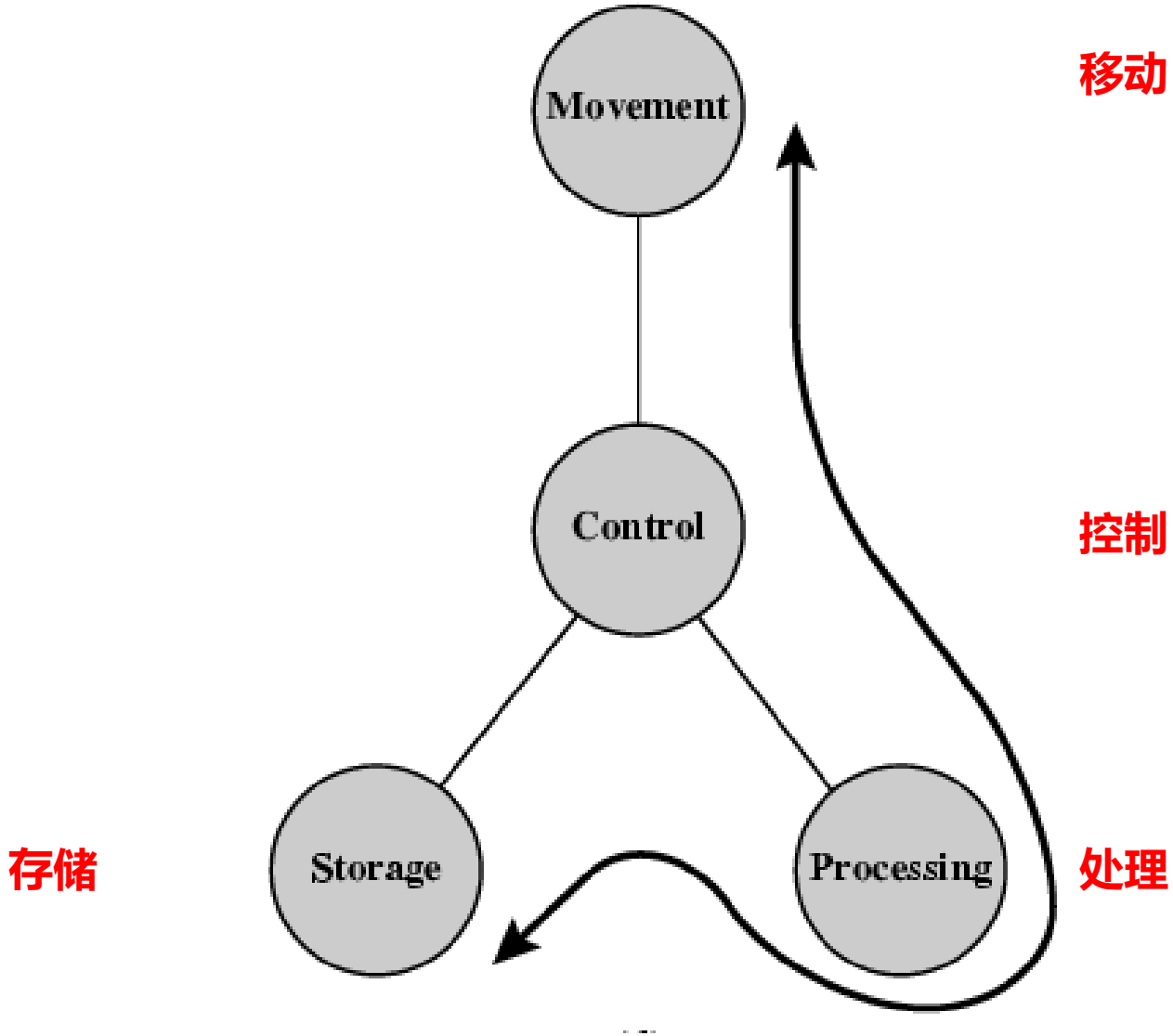
移动

控制

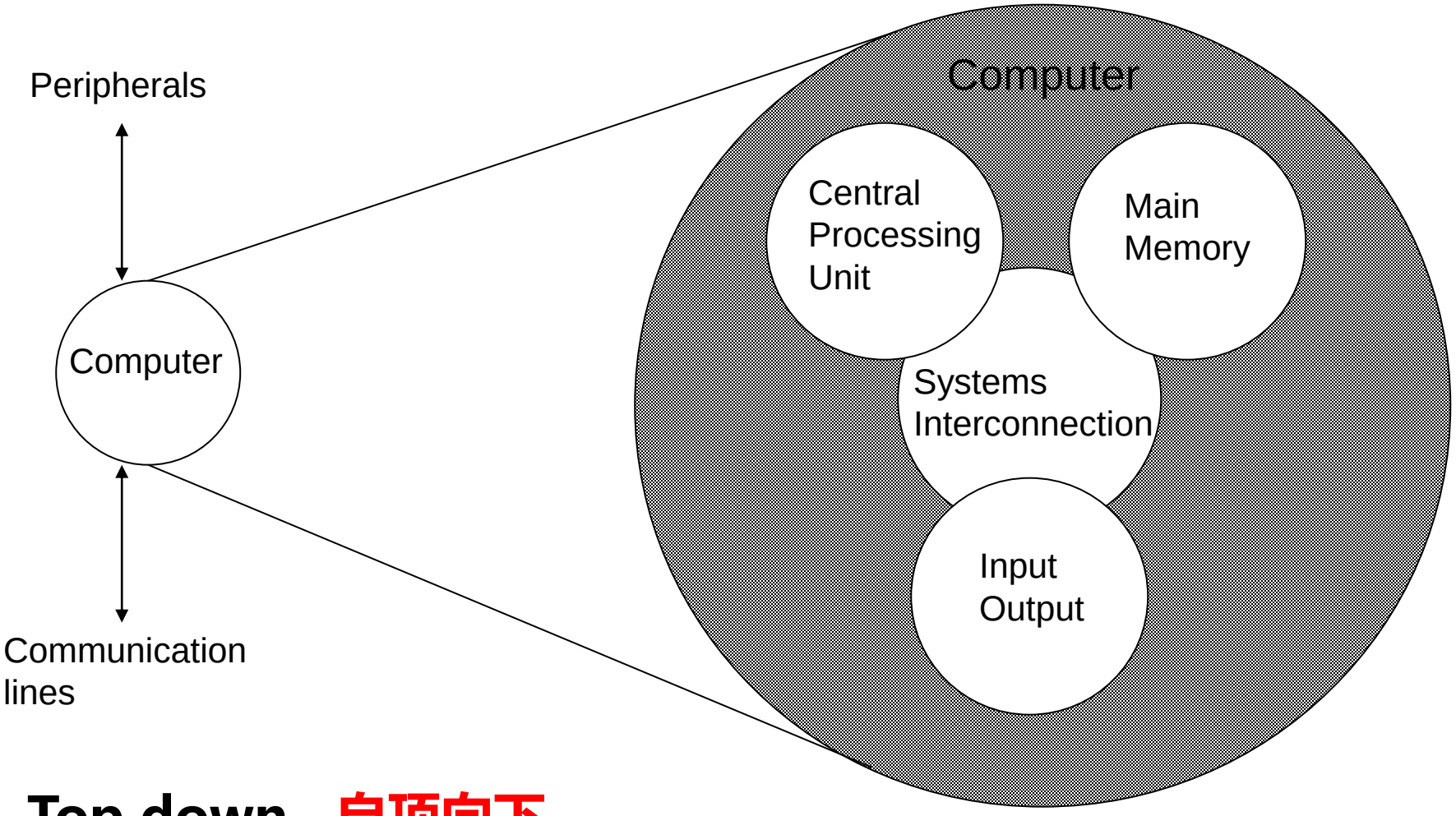
存储

处理

Operation type 4 — processing from storage to I/O

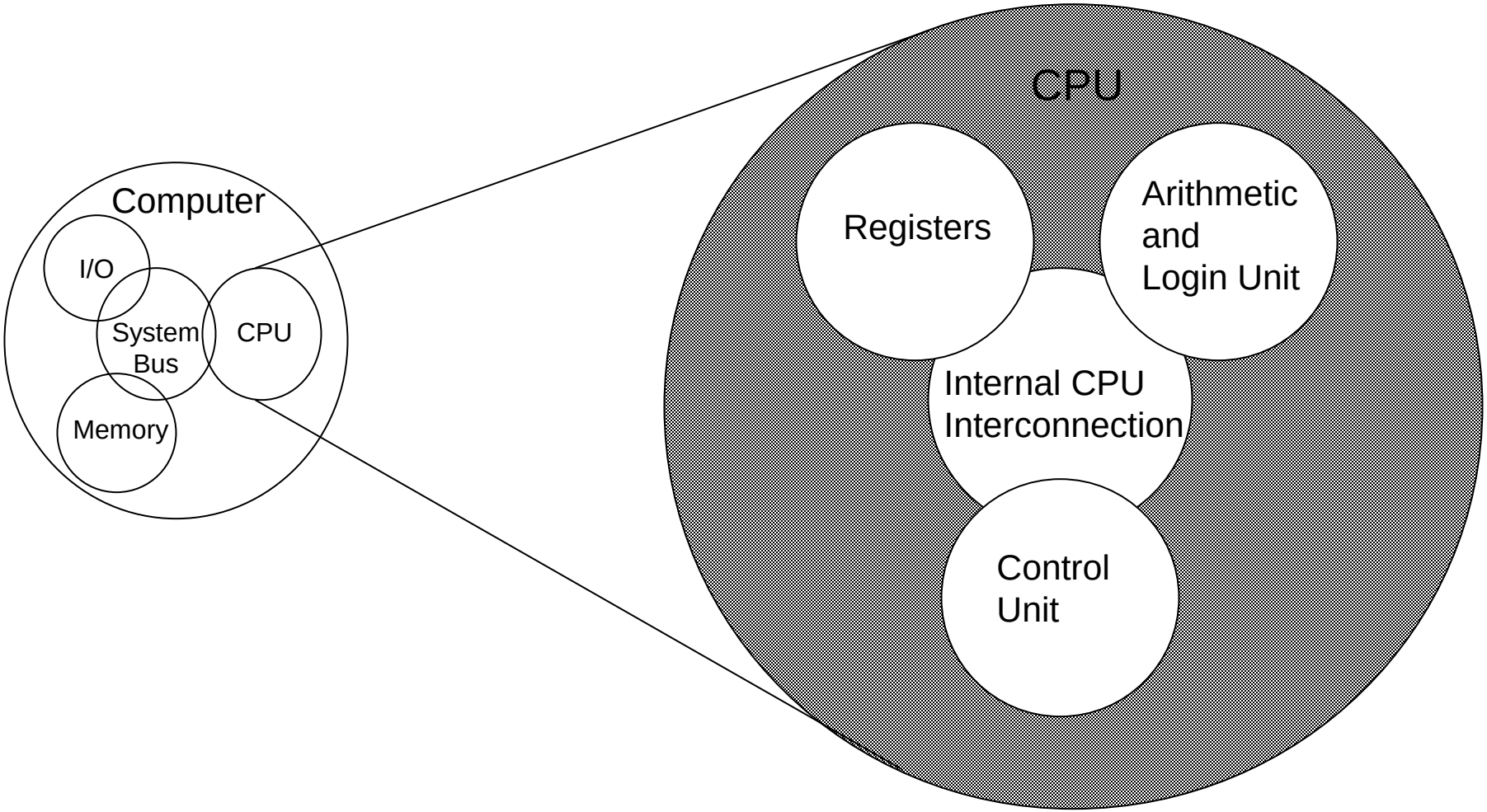


Structure - Top level 结构：顶层

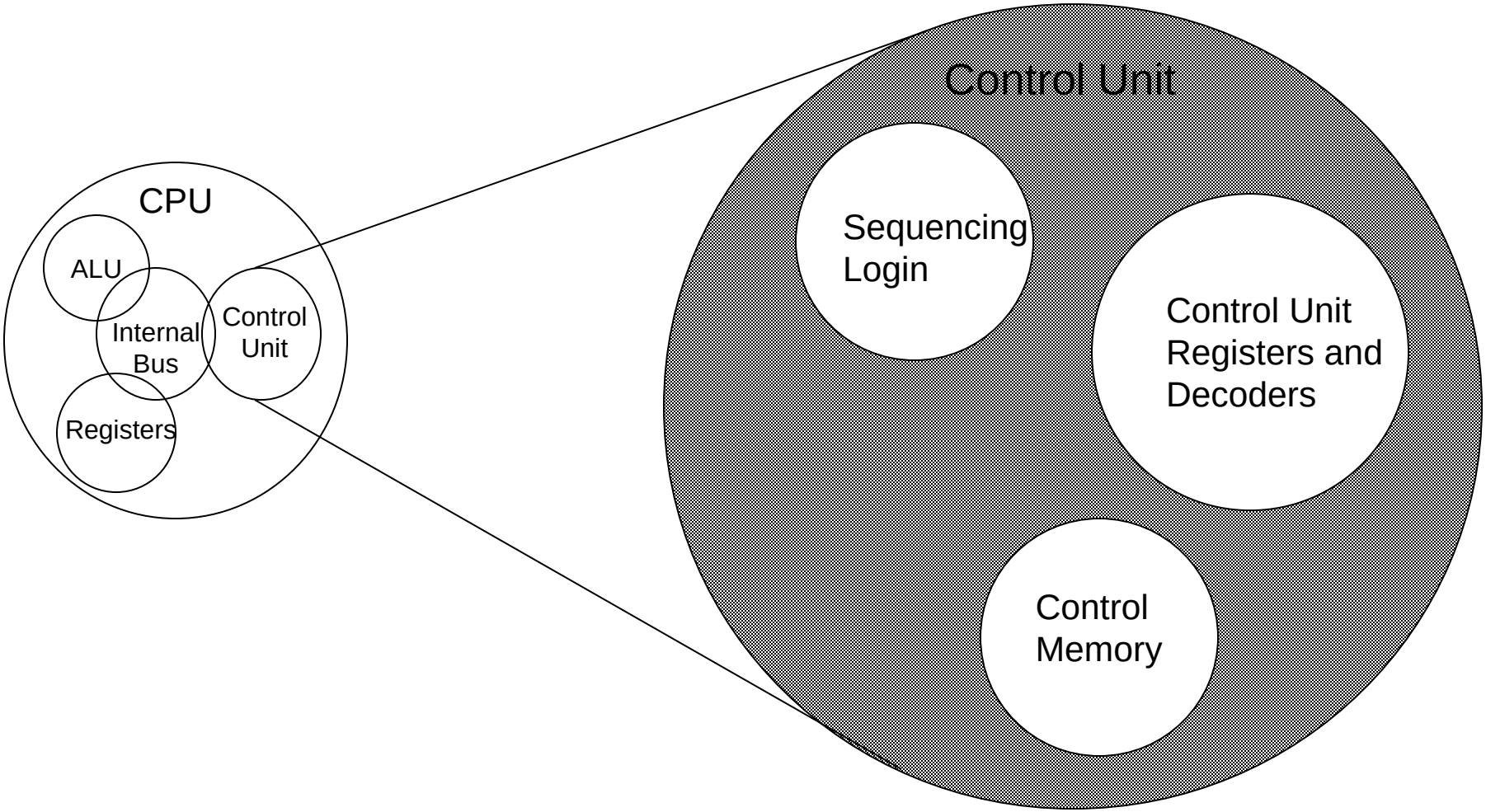


Top down 自顶向下

Structure - CPU



Structure – Control Unit



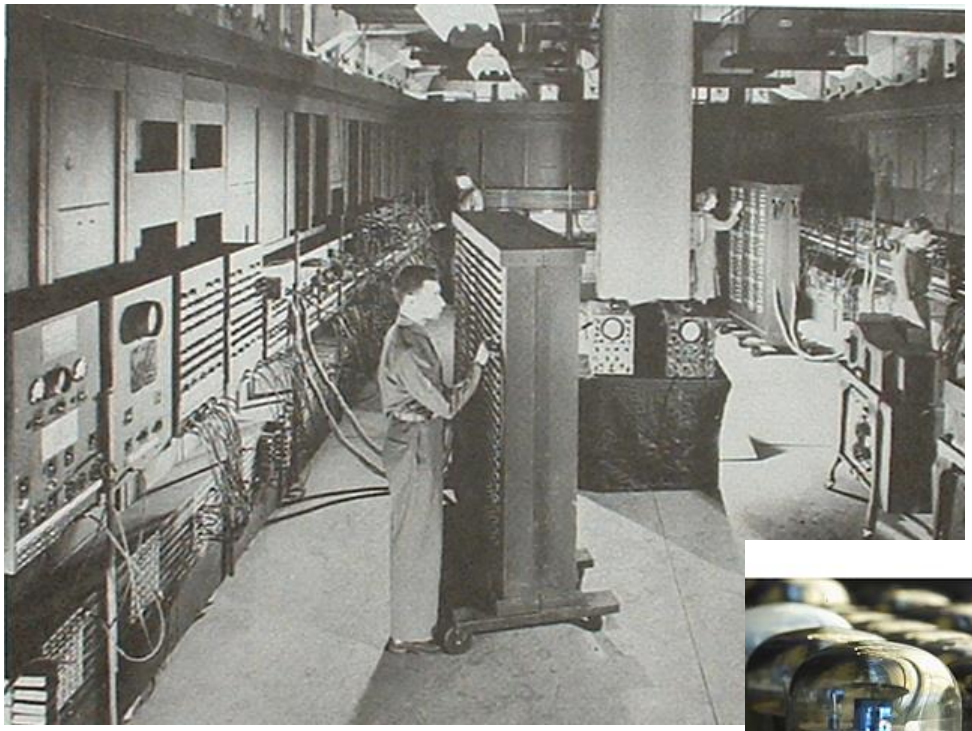
Outline

- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

ENIAC – the first computer 第一台计算机

- ENIAC，Electronic Numerical Integrator And Computer，电子数字积分器和计算器
- For war purposes, to compute the ballistic trajectory 战争用途，计算弹道轨迹
- Started in 1943, finished in 1946 (too late for war purpose) 1943年开始，到1946年完成
- In university of Pennsylvania，By Professor John Mauchly and his student John P Eckert，Use Vacuum Tubes 宾州大学教授莫克利和他的学生艾克特用真空管建造
- Weighted 30 tons, consumes 140kw of electric power, 1500 square feet of space, only 5000 addition per second 重30吨，消耗140kw电力，占1500平方英尺，每秒5000次加法
- As milestone of science development, used until 1995 科学发展的里程碑

Main component - Vacuum Tubes 主要部件-真空管

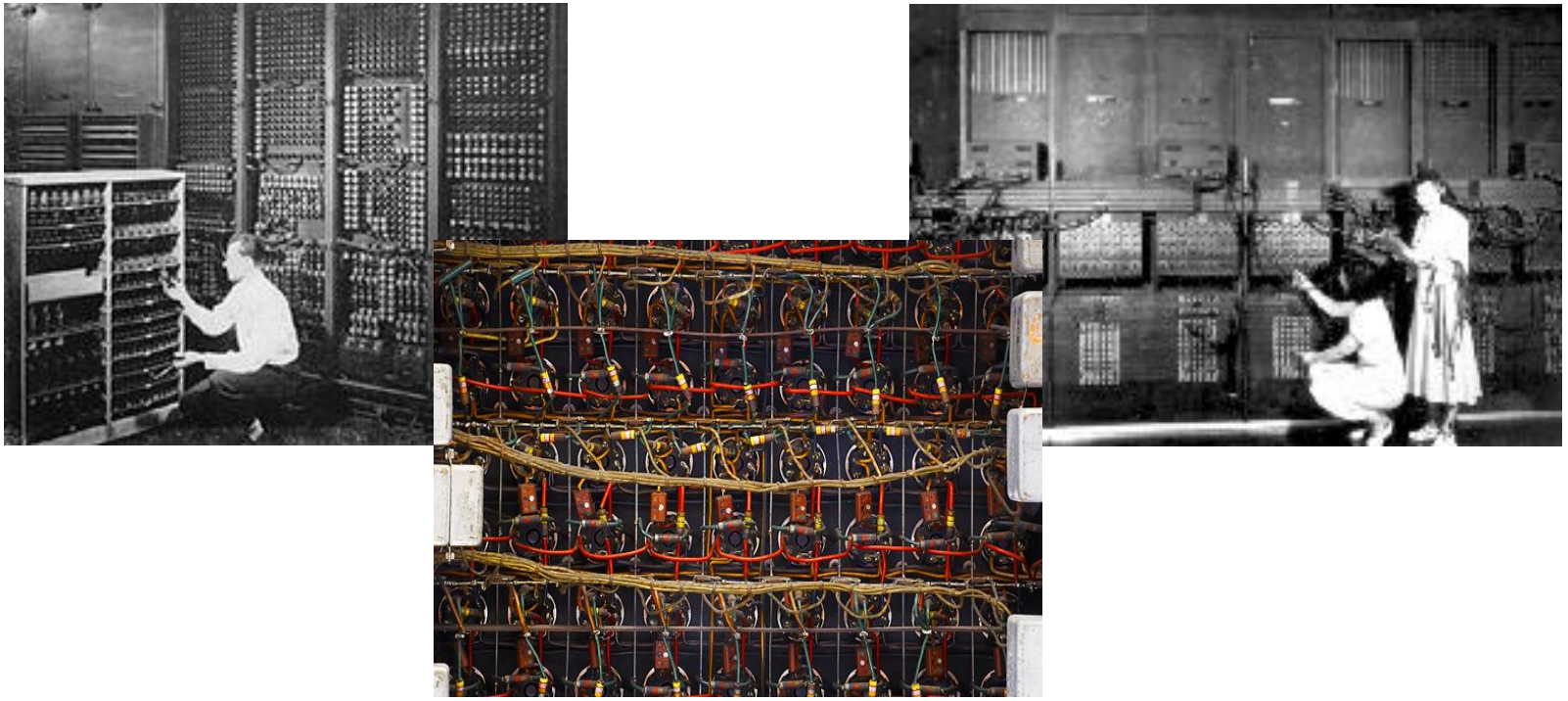


Detail of ENIAC

- Decimal，not binary 采用十进制，而不是二进制
- 10 vacuum tubes represent each digit, at any time only one vacuum tube was in the ON state 10个真空管表示1个十进制数字，任何时候只有1个真空管处于on的状态
- 20 accumulators of 10-digit decimal number 20个10位10进制数的累加器
- 5000 additions per second 5000次加法每秒
- Programmed manually by switches 通过插拔实现人工编程
- No microprocessors 没有微处理器
- No memory 没有存储器

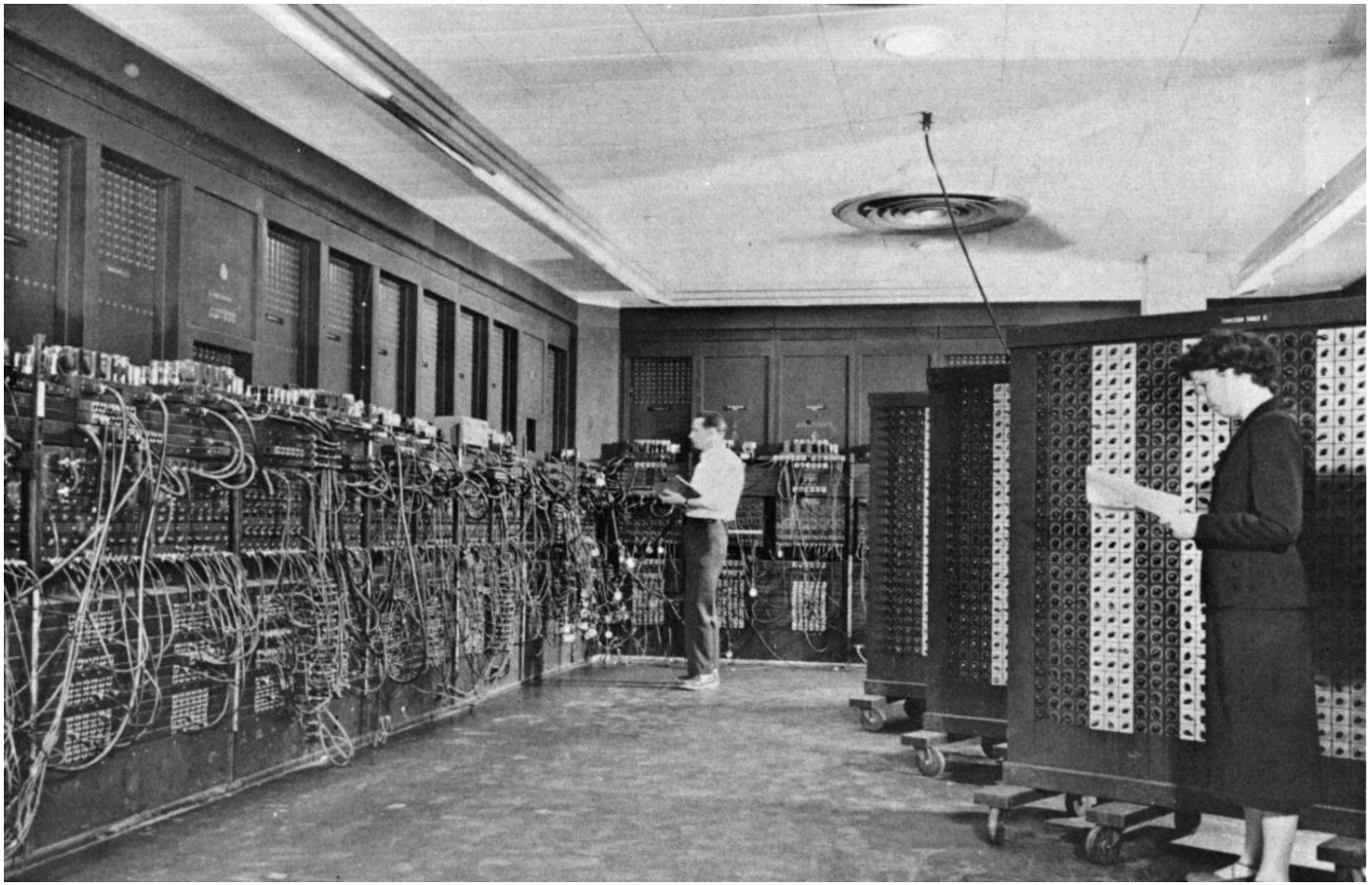
Main shortcoming of ENIAC ENIAC的缺点

- No memory 没有存储器
- The task of entering and altering programs was extremely tedious 输入和修改程序非常麻烦



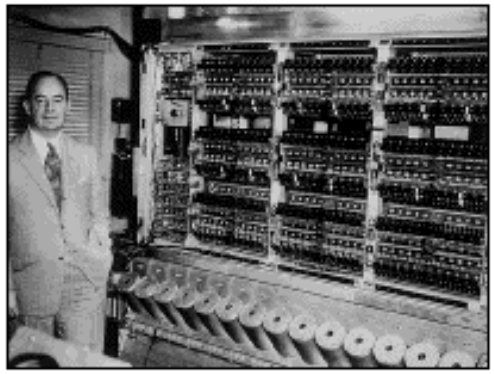
Detail of ENIAC

Changing the program could take days!



How to overcome this problem? 如何处理?

- The stored-program concept had been proposed 存储程序概念的提出
  - John von Neumann 冯.诺依曼
  - Alan Turing 阿兰.图灵
  - First publication of the idea was in 1945 proposal by von Neumann for EDVAC 1945年首次由冯诺依曼在EDVAC中提出存储程序



John von Neumann

Alan Turing

John von Neumann 冯诺依曼

- American mathematician, Hungarian origin, Jewish, 1903-1957. He moved to the United States in 1933 and is one of the six tenured professors in the Institute of higher studies of Princeton University 美国数学家，匈牙利裔，犹太人，1903-1957年。他于1933年移居美国，是普林斯顿大学高等研究所六位终身教授之一
- Basic mathematics (including operator theory, measure theory, set theory, algebraic geometry, ergodic theory, etc.), quantum mechanics, computer science and engineering, game theory, etc 基础数学（包括算子论、测度论、集合论、代数几何、遍历论等）、量子力学、计算机科学与工程、博弈论等
- Because of its pioneering contribution in the field of computer and game theory, it is praised as "father of computer" and "father of game theory" by later generations 由于其在计算机和博弈论领域的开创性贡献，被后人誉为“计算机之父”和“博弈论之父”

John von Neumann 冯诺依曼

- In 1945, he completed the first draft of the report on EDVAC (electronic discrete variable automatic computer) 1945年完成了EDVAC（电子离散变量自动计算机）报告的初稿
  - Summarized the ideas of early computer theory and provided a logical framework for modern computer theory 总结了早期计算机理论的思想，并为现代计算机理论提供了逻辑框架
  - "birth certificate" of modern computer 现代计算机的“出生证明”
  - Current computer is still called the von Neumann machine 现在的计算机仍然被称为冯·诺依曼机器
- Completed "computer and brain" and "self breeding automata theory", is the embryonic form of "artificial intelligence" field 完成了“计算机与大脑”和“自我繁殖自动机理论”，是“人工智能”领域的雏形

Alan Turing 阿兰.图灵

- Born in London on June 23, 1912, he committed suicide in 1954 他于1912年6月23日出生于伦敦，1954年自杀
- Turing's scientific achievements in science 图灵的科学成就
  - mathematical logic and computer science, constitute the basis of modern computer technology 数理逻辑和计算机科学，构成了现代计算机技术的基础
  - computability theory 可计算性理论
  - decision problem 决策问题
  - Computer 计算机
  - artificial intelligence 人工智能
  - mathematical biology 数学生物学
  - Turing experiment 图灵实验等

Alan Turing 阿兰.图灵

- In May 1936, submitted a paper entitled "on the application of digital computing in solving difficult problems" 1936年5月，提交了一篇题为“数字计算在解决难题中的应用”的论文
  - described a kind of machine that can assist mathematical research 描述了一种可以辅助数学研究的机器
  - later called "Turing machine “ 后来被称为“图灵机”
- In the autumn of 1939, worked for government to decipher the enemy code 1939年秋，为政府工作，破译敌方密码
- In 1945, engage in the logic design and specific development of “automatic computer” (ACE). 1945年，他开始从事“自动计算机”（ACE）的逻辑设计和具体开发

Alan Turing 阿兰.图灵

- In October 1950, Turing published his paper “can machines think?”. This epoch-making work won Turing the laurel of “father of artificial intelligence”. 1950年10月，图灵发表了他的论文《机器能思考吗？》。这项划时代的工作为图灵赢得了“人工智能之父”的桂冠。
- The American Computer Association (ACM) established the annual Turing prize in 1966 to honor those who have made outstanding contributions in computer science. 美国计算机协会（ACM）于1966年设立了年度图灵奖，以表彰那些在计算机科学领域做出杰出贡献的人
- The Turing prize is known as the "Nobel Prize in computer science". 图灵奖被称为“诺贝尔计算机科学奖”

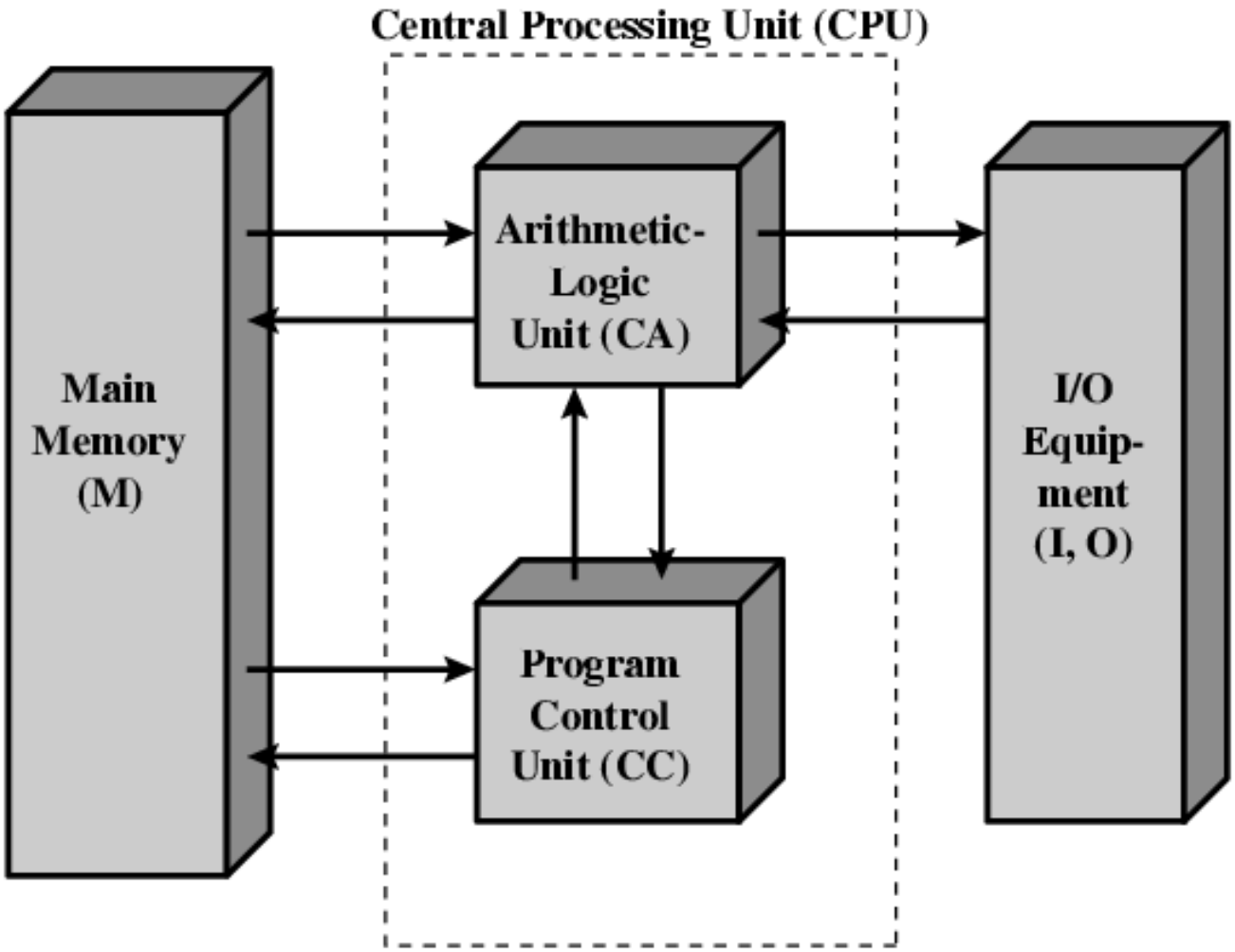
Characteristics of Stored Program concept 存储程序概念的特征

- A main memory, which stores both data and instructions 存储数据和指令的主存储器
- Binary numbers for both data and instructions 数据和指令均为二进制数
- An arithmetic-logic unit performs the basic operations 算术逻辑单元执行基本运算
- The data and instructions are stored in the memory, selected by addresses 数据和指令存储在内存中，由地址进行选择
- The proper sequencing of the operation is controlled by a control unit 操作顺序由控制单元控制

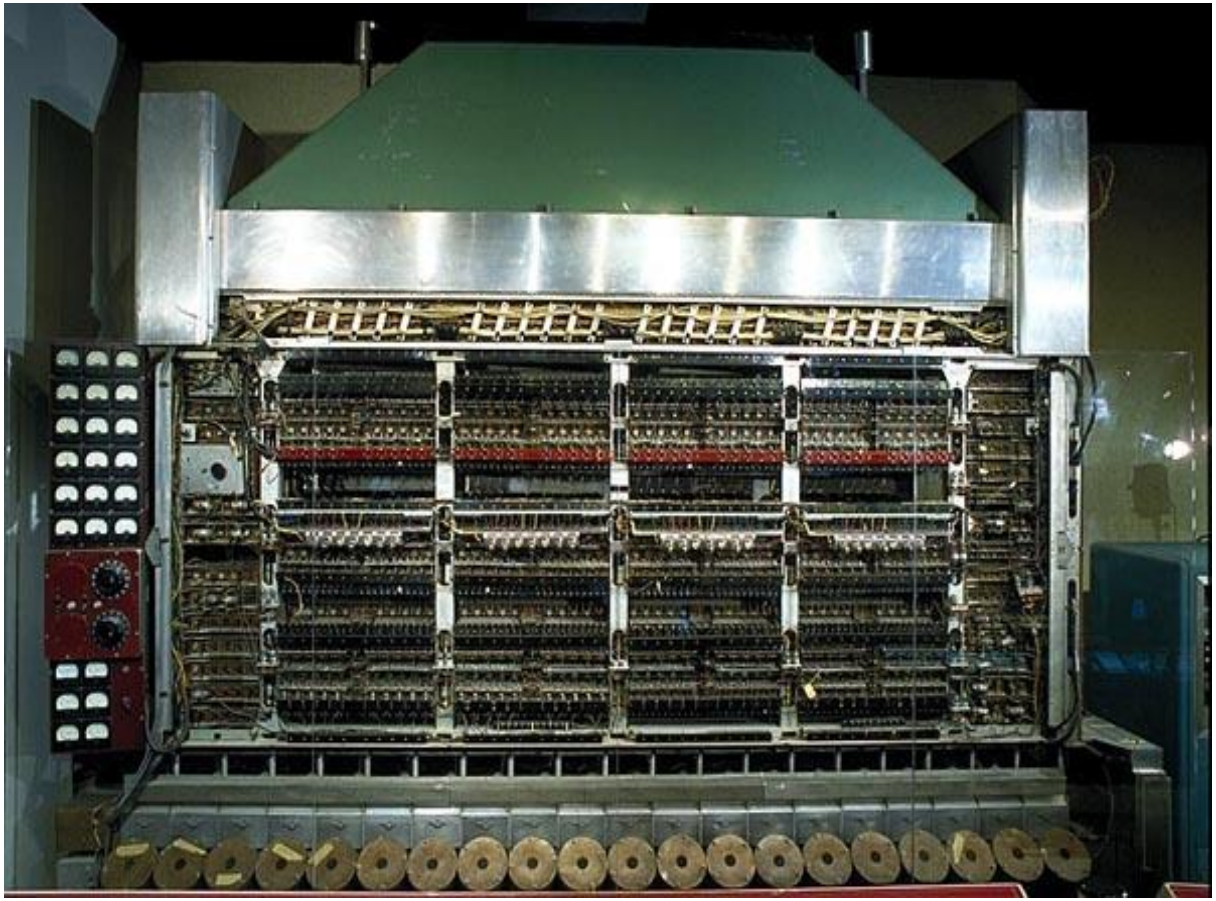
The von Neumann Machine 冯诺依曼机

- IAS（Institute of Advanced Studies）,started in 1946 1946年开始设计IAS计算机
- 5 functional units 包括五个功能单元
  - ALU, memory, control unit, input devices, output devices
- NOT Completed until 1952 1952年完成
- Until now, most computers are still structured based on this concept 直到现在，大部分计算机还是基于这个概念

Structure of von Neumann Machine (IAS)

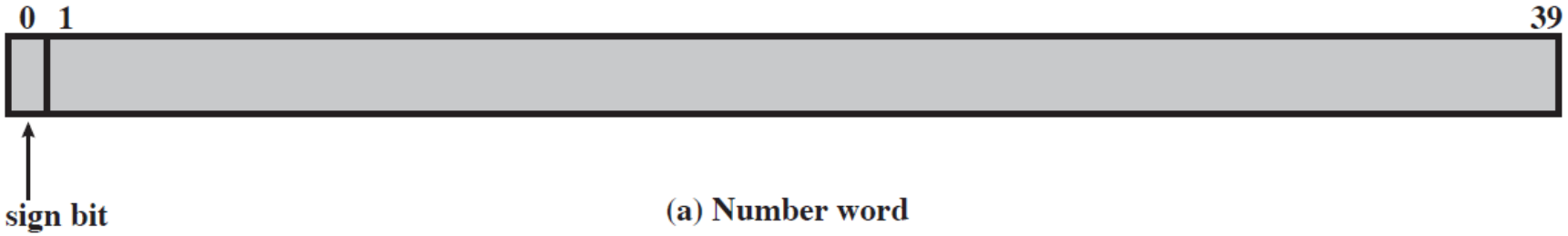


IAS computer



Details of IAS – 1　IAS的细节1

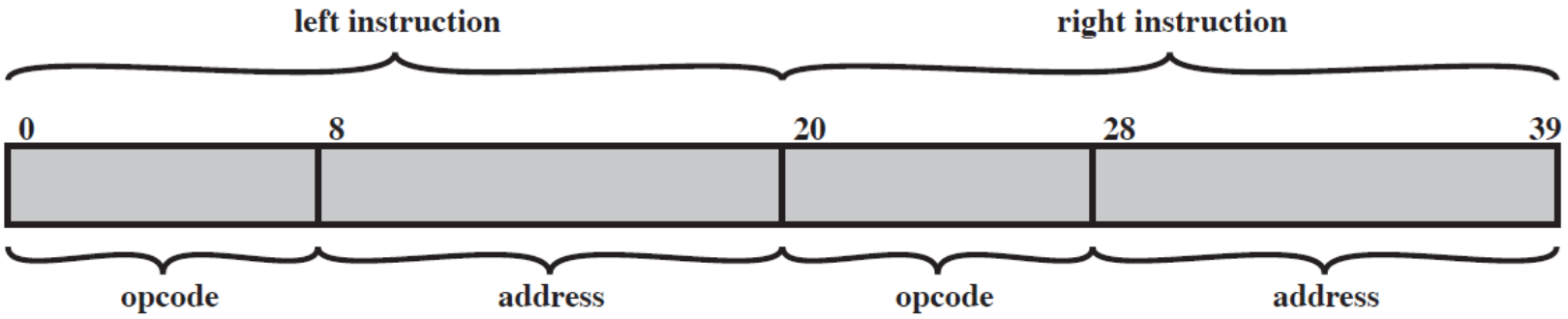
- IAS: Institute for Advanced Studies, Princeton　普林斯顿高级研究院
- Memory: 1000 x 40 bit words in binary number　存储器：1000个40位字
- Both data and instructions are stored there　数据和指令都存在存储器中
- Each number is represented by a sign bit and a 39-bit value　每个字包括一个符号位和39位的数值



(a) Number word

Details of IAS – 2 IAS的细节2

- A word may also contain two 20-bit instructions 1个字可能包含2个20位的指令
  - an 8-bit operation code 8位的操作码
  - a 12-bit address 12位的地址



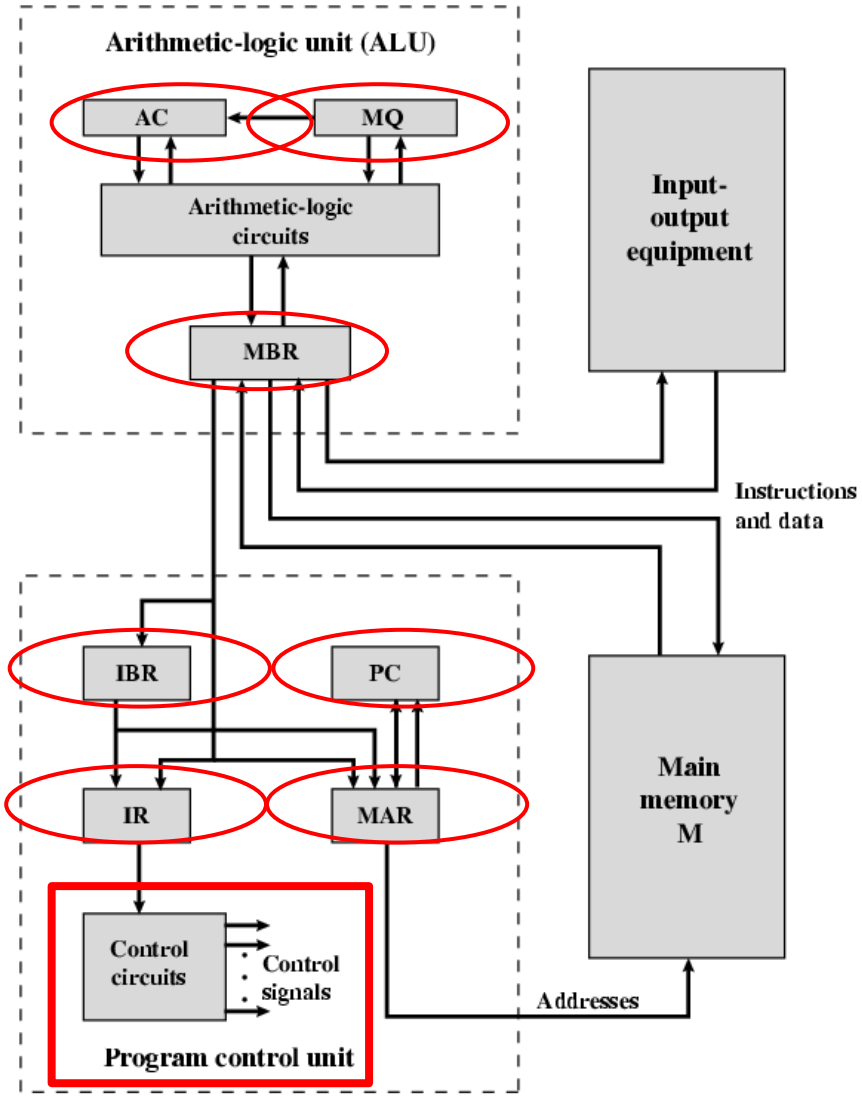
(b) Instruction word

Registers of IAS IAS的寄存器

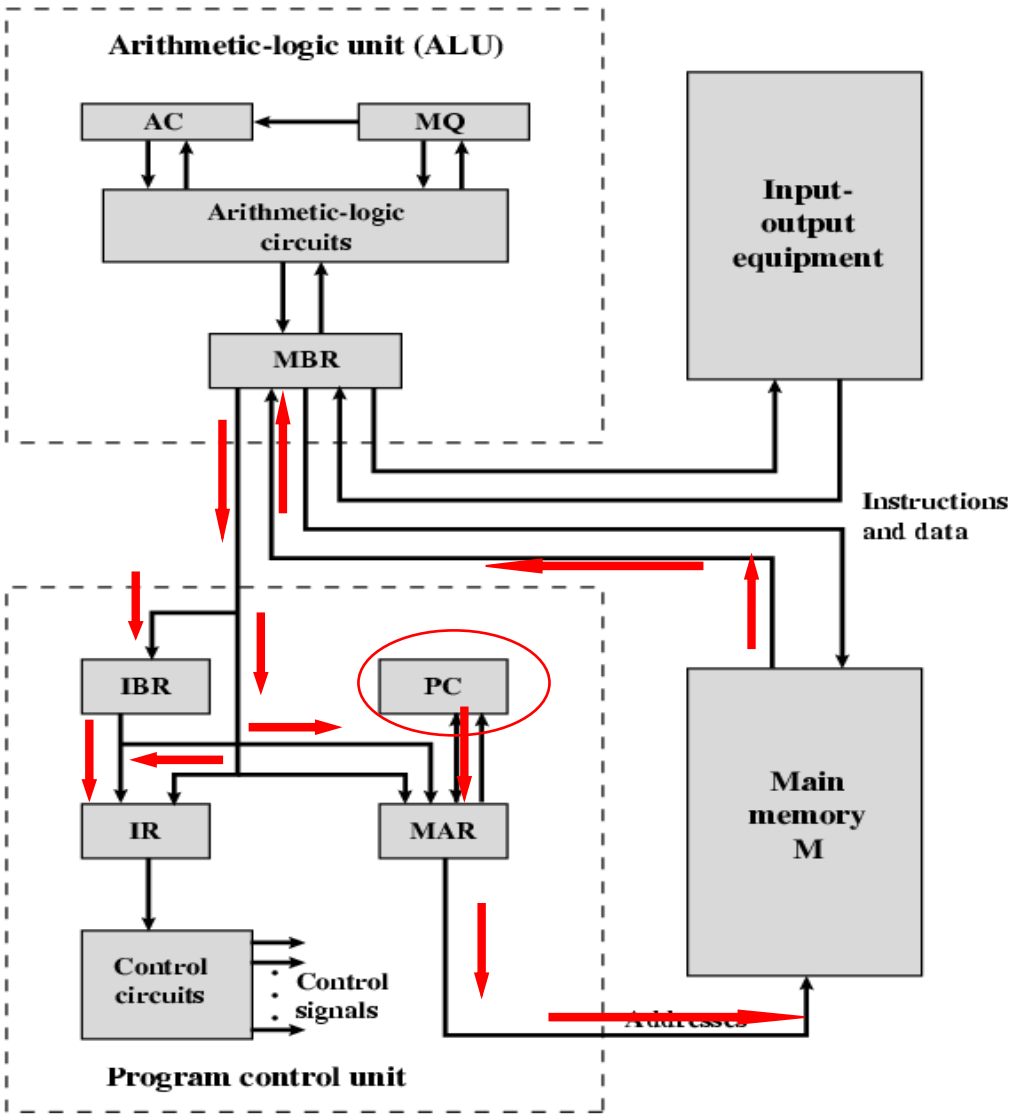
- Memory Buffer Register 存储器缓冲寄存器
- Memory Address Register 存储器地址寄存器
- Instruction Register 指令寄存器
- Instruction Buffer Register 指令缓冲寄存器
- Program Counter 程序计数器
- Accumulator 加法器，累加器
- Multiplier Quotient 乘商寄存器

IAS control unit IAS的控制单元

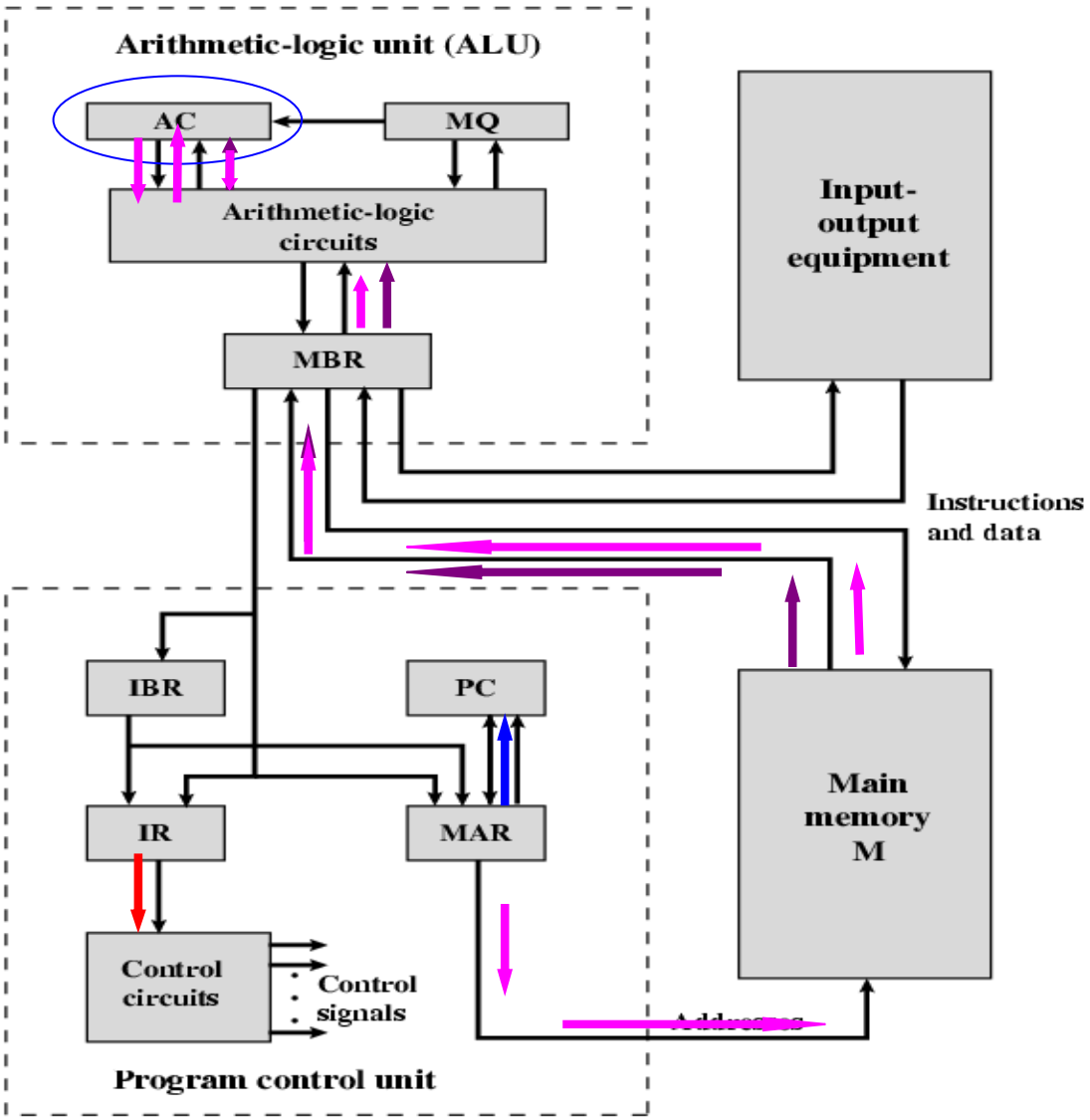
- The control unit operates the IAS by fetching instructions from memory and executing them one at a time 控制单元通过从内存中提取指令并一次执行一条指令来操作IAS



Fetch cycle 取指周期



Execute cycle 执行周期



Instruction types 指令类型

- Data transfer 数据传送
  - Memory – ALU registers 存储器-ALU寄存器
  - Register – Register 寄存器-寄存器
- Unconditional branch 无条件分支
- Conditional branch 条件分支
- Arithmetic 算术运算
- Address modify 地址修改

Commercial Computers 商用计算机

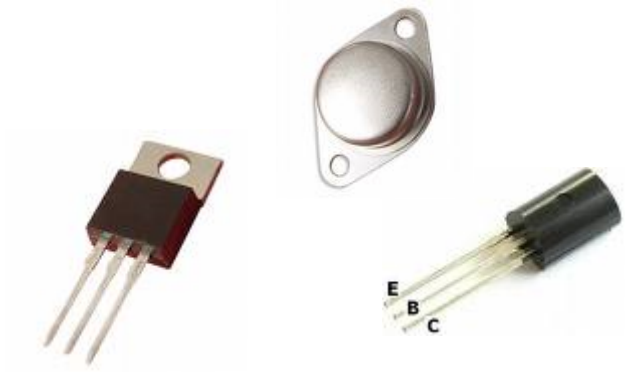
- Eckert-Mauchly Computer Corporation 艾克特-莫克利计算机公司
  - In 1947,Eckert and Mauchly formed the corporation 1947年成立
  - UNIVAC I：first commercial computer
  - UNIVAC II：backward compatible 向后兼容
  - As a department of Sperry-Rand Corporation SR公司的一个部门
- IBM
  - The major manufacturer of punched-card processing equipment then 穿孔卡处理设备的主要制造商

IBM

- Punched-card processing equipment 打孔卡处理设备
- 1953 - the 701 1953年推出701
  - IBM’s first stored program computer IBM的第一台存储程序计算机
  - Scientific calculations 科学计算
- 1955 - the 702 1955年推出702
  - Business applications 商业应用
- Lead to 700/7000 series 700/7000系列计算机
- Made IBM the dominant computer manufacturer IBM成为占主要地位的计算机制造商

Second generation : transistors 第二代：晶体管

- Replaced vacuum tubes 代替真空管
  - Invented 1947 at Bell Labs 1947年贝尔实验室发明
  - Smaller 体积小
  - Cheaper 价格便宜
  - Less heat dissipation 发热少
  - Made from Silicon 由硅制造



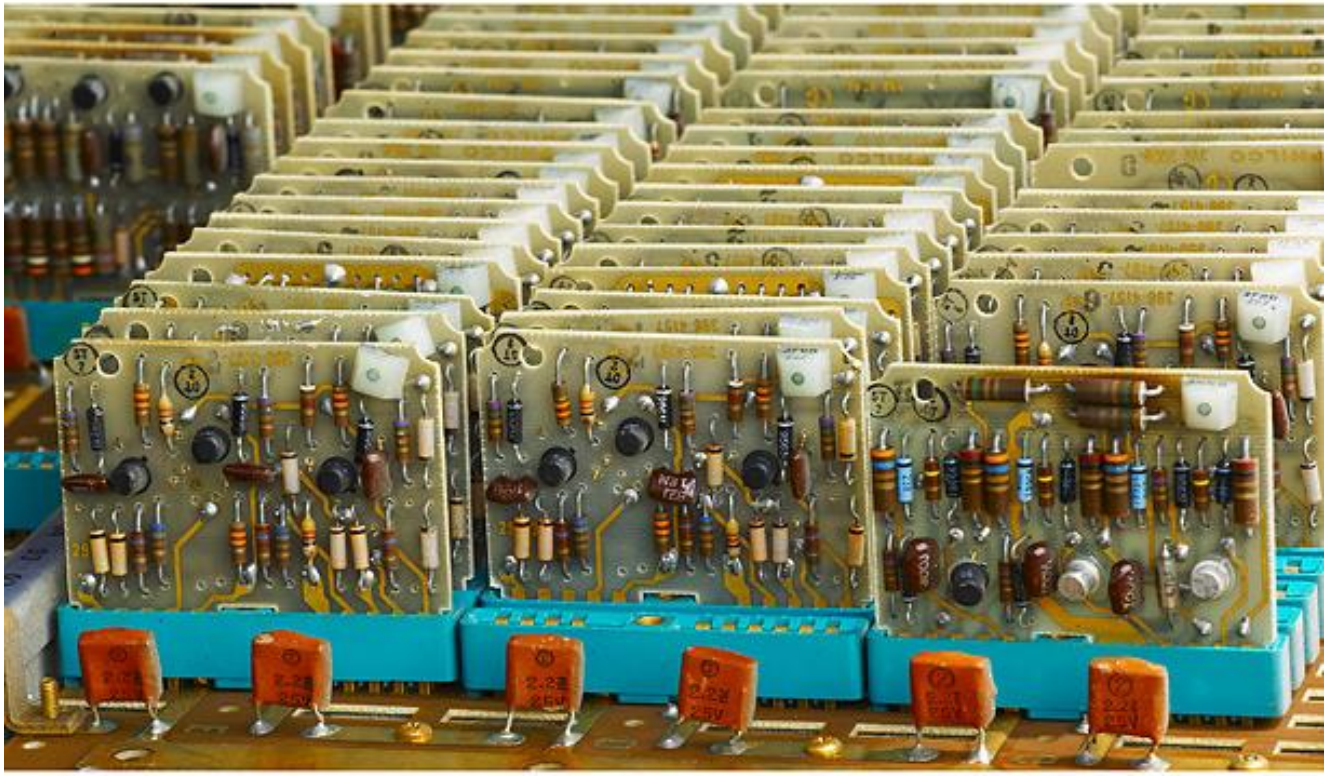
- This results 导致
  - More complex arithmetic, logic units, control units 更复杂的算术、逻辑单元和控制单元
  - More powerful, more complex control 运算能力更强，控制更复杂
  - High-level language, system software 高级语言，系统软件

Transistor based computer 基于晶体管的计算机

- Second generation machines 第二代计算机
- NCR & RCA produced small transistor NCR和RCA生产小型晶体管机器
- IBM 7000 series IBM7000系列
  - 7090:1960
  - 7094:the lase member of the 7000 series 7000系列最后一个型号
    - Data Channel 数据通道
    - Multiplexer 多路复用器
- DEC（Digital Equipment Corporation 美国数字设备公司， Alpha 芯片）- 1957
  - Produced PDP-1

Example of transistor board 晶体管电路板

- **Philco 212 Transistor Boards, 1962**



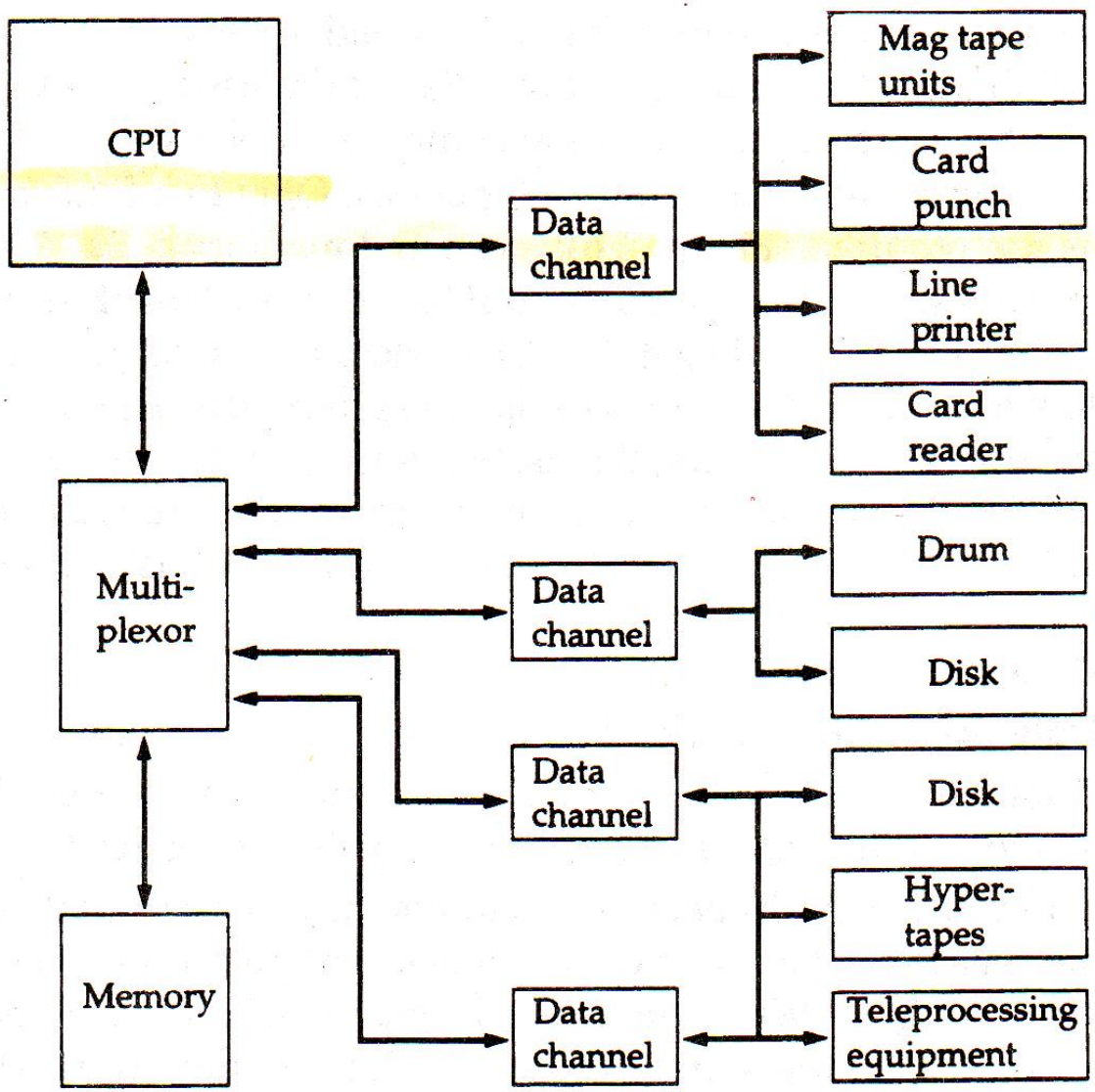
IBM 7094

- IBM 7094 is a representative of the second generation

  7094是典型的二代机

- It is a central-switched architecture 具有中心交换架构
- It uses data channels and multiplexor 使用数据通道和复用器
  - A data channel is an independent I/O module with its own processor and its own instruction set 数据通道是一个独立的I/O模块，具有自己的处理器和指令集
  - Multiplexor is the central termination point for data channels, the CPU, and memory 多路复用器是数据通道、CPU和内存的中心终结点

Configuration of 7094

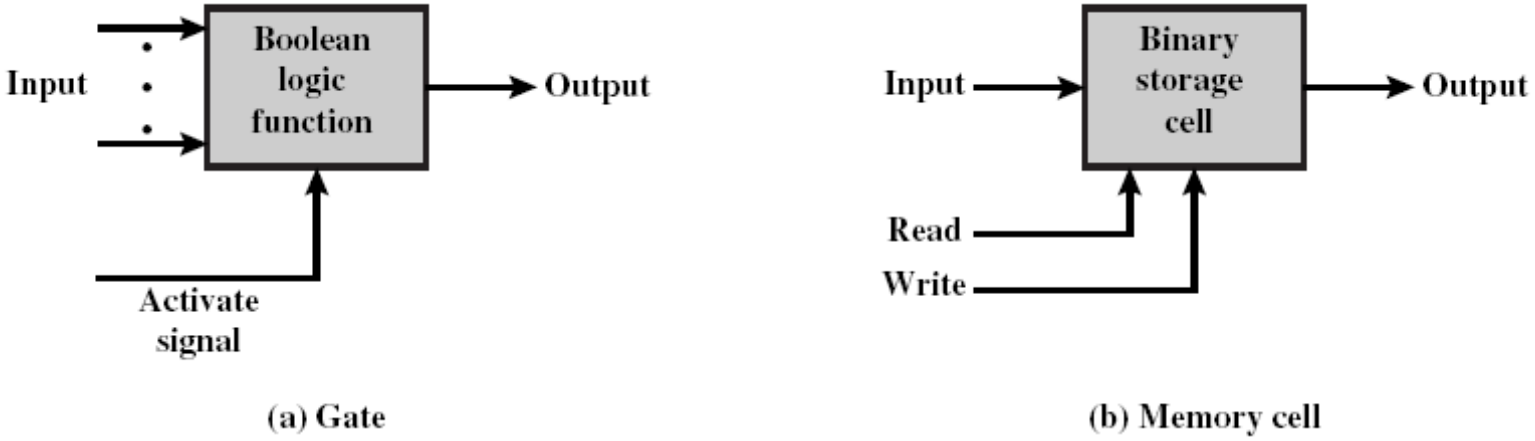


Shortcoming of transistor and development 晶体管的缺点和发展

- Shortcoming of transistor 晶体管的缺点
  - Discrete components were manufactured separately 分立元件单独制造
  - The entire manufacturing process, from transistor to circuit board, was expensive and cumbersome 从晶体管到电路板的整个制造过程既昂贵又繁琐
- Development: Microelectronics 发展：微电子
  - The invention of the integrated circuit in 1958 1958年集成电路的发明
  - The third generation of computers 第三代计算机

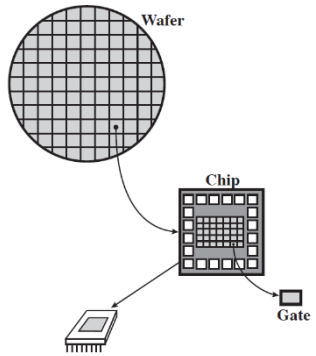
Microelectronics 微电子

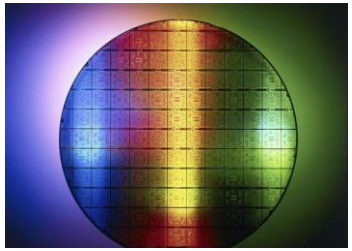
- From the view of microelectronics , a computer consists of 从微电子的角度来看，计算机由这些组成
  - Gates 门
  - memory cells 存储位元
  - interconnections among these elements 这些元素的连接



Microelectronics 微电子

- Transistors, resistors, and conductors can be made by semiconductor 晶体管、电阻, 和导体可以用半导体制造
- The whole circuit is mounted on a very small silicon chip instead of an equivalent circuit made of discrete components 整个电路安装在一个非常小的硅芯片上，而不是由分立元件构成的等效电路
- A silicon wafer is divided into several chips, each chip contains exactly the same circuit 硅片(硅晶圆）被分成几个芯片，每个芯片包含完全相同的电路





Moore’s Law 摩尔定律

Pronounced in 1965 by Gordon Moore- cofounder of Intel

Chap. 1

Development of the Number of Transistors/Chip

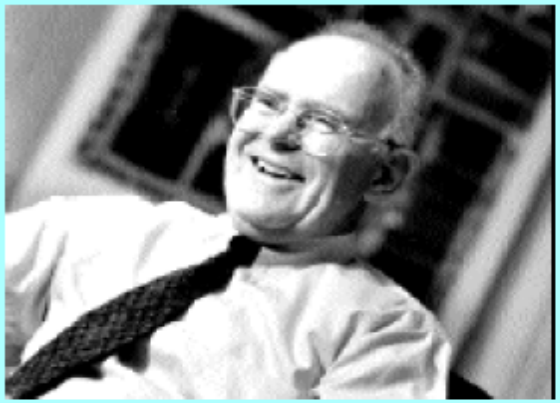
Gordon Moore (one of the founders of Intel) predicted 1965:
The number of transistors on a semiconductor chip doubles approximately every 18 months.

(or increases ten-fold approximately every 5 years)

➔ Moore‘s Law

$$N = a * 10^{1/5 * t}$$

Microprocessors get smaller, more compact and faster and faster!



31

Moore’s Law 摩尔定律

- Some facts revealed by Moore ‘s law 摩尔定律揭示的几个事实
  - Cost of a chip has remained almost unchanged: the cost of computer has fallen 芯片的成本几乎没有变化：计算机的成本下降了
  - Higher packing density means shorter electrical paths, giving higher speed 更高的封装密度意味着更短的电子路径，提供更高的速度
  - Smaller size making it more convenient to place in a variety of environments 尺寸更小，便于放置在各种环境中
  - Reduced power and cooling requirements 降低电源和冷却要求
  - Fewer interconnections increases reliability 更少的互连增加了可靠性

The computer family concept 计算机系列的概念

- The characteristics of a computer family are 系列机的特征
  - Similar or identical instruction set 相似或完全相同的指令集
  - Similar or identical operating system 相似或完全相同的操作系统
  - Increasing speed 更高的速度
  - Increasing number of I/O ports 更多的IO端口
  - Increasing memory size 更大的存储器容量
  - Increasing cost 更高的成本

IBM System/360

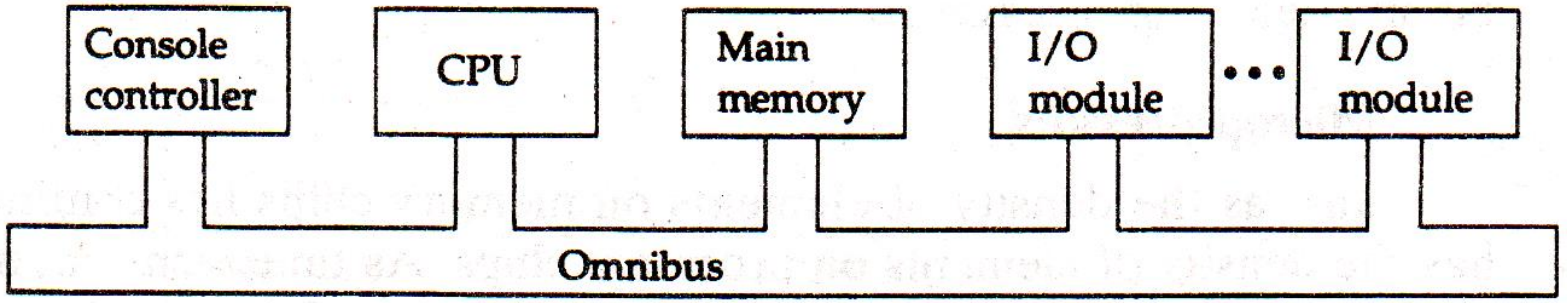
- By 1964, IBM announced System/360 family, this was the industry ‘s first planned family of computers. 1964年，IBM宣布推出System/360系列，这是业界第一个计算机系列
  - The family covered a wide range of performance and cost 该系列产品涵盖了广泛的性能和成本
  - A program written can be executed by all models of the family, with only a difference in the speed 编写的程序可由该系列的所有型号执行，但速度不同
  - The customer can start with lower model and upgrade to the higher when it is needed 客户可以从较低型号开始，并在需要时升级到较高型号

DEC PDP-8

- In the same year(1964), Digital Equipment Corporation (DEC) announced PDP-8 1964年，DEC公司开发了PDP-8
  - Small
  - Lower cost
- These features enabled another manufacturer to purchase a PDP-8 and integrate it into a different system for resale 允许其他厂家购买PDP-8，然后集成到其他系统进行销售
  - These manufacturers came to be known as original equipment manufacturers (OEMs) 这些制造商称为OEM

Detail of DEC PDP-8

- Later models used the bus structure consists of 96 signal lines to carry control, address, and data signals 后期型号使用了总线结构，包括96个信号线携带控制、地址和数据信号
- The architecture is highly flexible, allowing modules to be plugged into the bus to create various configurations 这种结构很灵活，允许模块插入总线来得到不同的配置



Generations of computer

- Vacuum tube :1946-1957 真空管
- Transistor : 1958-1964 晶体管
- Small scale integration : 1965 on 小规模集成电路
  - Up to 100 devices on a chip
- Medium scale integration : to 1971 中规模集成电路
  - 100-3,000 devices on a chip
- Large scale integration : 1971-1977 大规模集成电路
  - 3,000 - 100,000 devices on a chip
- Very large scale integration : 1978 -1991 超大规模集成电路
  - 100,000 - 100,000,000 devices on a chip
- Ultra large scale integration : 1991 – now 巨大规模集成电路
  - Over 100,000,000 devices on a chip

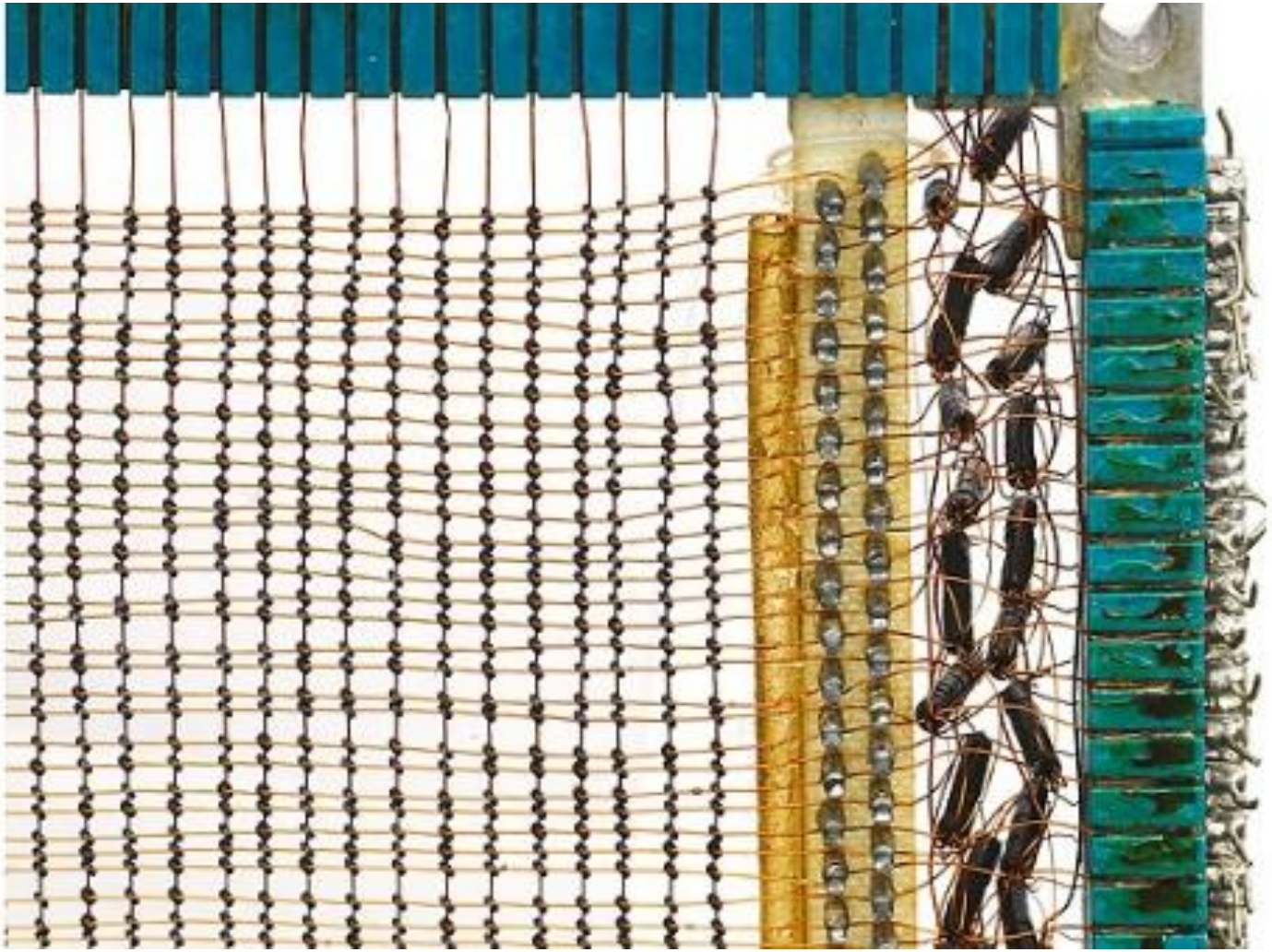
Technology Change 技术的改变

- Hardware
  - Vacuum tubes: Electron emitting devices 真空管：电子发射装置
  - Transistors: On-off switches controlled by electricity 晶体管：由电控制的开关
  - Integrated Circuits(IC/ Chips): Combines thousands of transistors 集成电路（IC/芯片）：集成了数千个晶体
  - Very Large-Scale Integration(VLSI): Combines millions of transistors 超大规模集成电路：集成了数百万个晶体管
- Software
  - Machine language: Zeros and ones 机器语言：0和1
  - Assembly language: Mnemonics 汇编语言：助记符
  - High-Level Languages: English-like 高级语言：和英语类似

Core Memory 磁芯存储器

- In the 1950s and 1960s, most computer memory was constructed from tiny rings of ferromagnetic material, each about a sixteenth of an inch in diameter. 在20世纪50年代和60年代，大多数计算机内存是由微小的铁磁性材料环构成的，每个环的直径约为十六分之一英寸
- Core Memory: Cores are rings of ferrite suspended in a grid of wires 磁芯存储器：磁芯是铁氧体环，悬挂在一排导线中
- A charge to a point on the grid magnetizes the ring in a clockwise or counter-clockwise direction, which corresponds to a one or a zero: one bit 对栅极上某一点的电荷以顺时针或逆时针方向磁化环，这对应于1或0:1位
- Able to retain information when the electricity is turned off because it holds its state 断电的情况下，能够保留信息
- fast （1us）but expensive, destructive readout 速度快，读只需要1微秒，但是价格昂贵，并且是破坏性的，需要重写

Core Memory 磁芯存储器



Semiconductor Memory 半导体存储器

- 1970 – semiconductor memory: higher density(about the size of a single core, could hold 256 bits of memory; non-destructive and much faster than core but more expensive 1970年，半导体存储器：密度更高（约为单磁芯大小，可容纳256位存储器；非破坏性，比磁芯快得多，70ns），价格更高
- 1974 – the price per bit of semiconductor memory dropped below the price per bit of core memory. – since then, the cost continue decreasing, the density continue increasing. 1974年，半导体存储器的每比特价格低于磁芯存储器的每比特价格。之后，成本持续下降，密度持续增加
- 13 generations.：The capacity of a single chip has changed from 1K, 4K, 16K, 64K, 256K, 1M, 4M, 16M, 64M, 256M, 1G and 4G. Now a single memory can reach 128G 经历了13代的发展，单个芯片的容量从1K，4K，16K，64K，256K，1M，4M，16M，64M，256M，1G，4G，现在单个存储能达到128G，甚至更大

Resulting New Developments – Microprocessors 微处理器

- Just as the density of elements on memory chips has continued to rise, so has the density of elements on processor chips 正如内存芯片上的元素密度不断上升一样，处理器芯片上的元素密度也在不断上升
- As time went on, more and more elements were places on each chip 随着时间的推移，越来越多的元素被放置在每个芯片上
- The first microprocessor is Intel 4004 第一个微处理器是英特尔4004
- The next major advance was the Intel 8008, which appeared in 1972. It is the first 8-bit microprocessor 下一个重大进步是英特尔8008，它出现在1972年。它是第一款8位微处理器
- The first general-purpose microprocessor was Intel 8080, which appeared in 1974. It is a central processor designed for general-purpose microcomputer. It is faster, richer instruction sets, and has stronger addressing capabilities 第一个通用微处理器是英特尔8080，它出现在1974年。它是为通用微型计算机设计的中央处理器。它速度更快，指令集更丰富，寻址能力更强

Outline

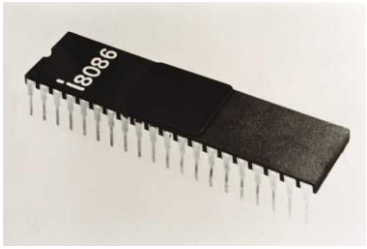
- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

Intel

- 1971 - 4004
  - First microprocessor 第一个微处理器
  - All CPU components on a single chip 所有的组件在一个芯片上
  - 4 bit
- Followed in 1972 by 8008
  - 8 bit
  - Both designed for specific applications 专用
- 1974 - 8080
  - Intel’s first general purpose microprocessor 第一代通用处理器
  - 8 bit data path
  - Used in first personal computer – Altair 第一个个人计算机

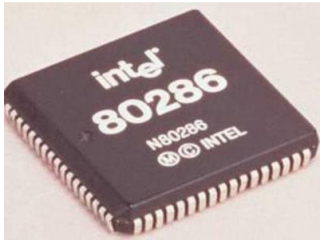
Intel x86

- 8086 – 5MHz – 29,000 transistors
  - much more powerful
  - 16 bit
  - instruction cache, prefetch few instructions 指令cache
  - 8088 (8 bit external bus) used in first IBM PC 8088处理器用在第一台IBM PC



Intel x86

- 80286
  - 16 Mbyte memory addressable
  - up from 1Mb



- 80386
  - 32 bit
  - Support for multitasking

- 80486
  - sophisticated powerful cache and instruction pipelining 复杂的cache和指令流水线
  - Built-in maths co-processor 内置数学协处理器

Intel x86

- Pentium
  - Superscalar 超标量
  - Multiple instructions executed in parallel 多个指令并行处理
- Pentium Pro
  - Increased superscalar organization 增强的超标量组织
  - Aggressive register renaming 主动寄存器重命名
  - branch prediction 分支预测
  - data flow analysis 数字流分析
  - speculative execution 决策执行

Intel x86

- Pentium II
  - MMX technology 多媒体加速技术
  - graphics, video & audio processing 图形、视频和语音处理

- Pentium III
  - Additional floating point instructions for 3D graphics 3D图形浮点处理指令

- Pentium 4
  - Further floating point and multimedia enhancements 进一步的浮点和多媒体增强功能

Intel x86

- Core
  - First x86 with dual core 第一代x86双核处理器
- Core 2
  - 64 bit architecture 64位架构
- Core 2 Quad – 3GHz – 820 million transistors
  - Four processors on chip 单芯片4个处理器
- i7、i5、i3……
- x86 architecture dominant outside embedded systems 除嵌入式系统之外x86占统治地位
- Instruction set architecture evolved with backwards compatibility 指令集基于后向兼容进行发展

ARM Evolution ARM的发展

- ARM： Advanced RISC Machine
- Designed by ARM Inc., Cambridge, England
- Licensed to manufacturers 给制造商授权
- High speed, low power consumption 高速，低功耗
- PDAs, hand held games, phones PDA，手持游戏机，手机
  - E.g. iPod, iPhone
- Acorn produced ARM1 & ARM2 in 1985 and ARM3 in 1989
- Acorn, VLSI and Apple Computer founded ARM Ltd.

ARM products

- Cortex-a/cortex-a50：application processors，such as smartphones，eBook readers，digital TV and home gateways，etc. Cortex-a/cortex-a50：应用服务器，主要用于智能手机、电子书阅读器，数字电视，家庭网关等
- Cortex-r ：real-time applications，such as automotive braking systems, mass storage controllers, networking and printing devices, etc. Cortex-r，实时应用，主要用于汽车制动系统，大容量存储控制器，网络和打印设备等
- cortex-m：microcontroller domain，such as IoT devices, wireless sensor, automotive body electronics, etc. Cortex-m：微控制器领域，例如物联网设备，无线传感器，汽车车身电子设备等

Outline

- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

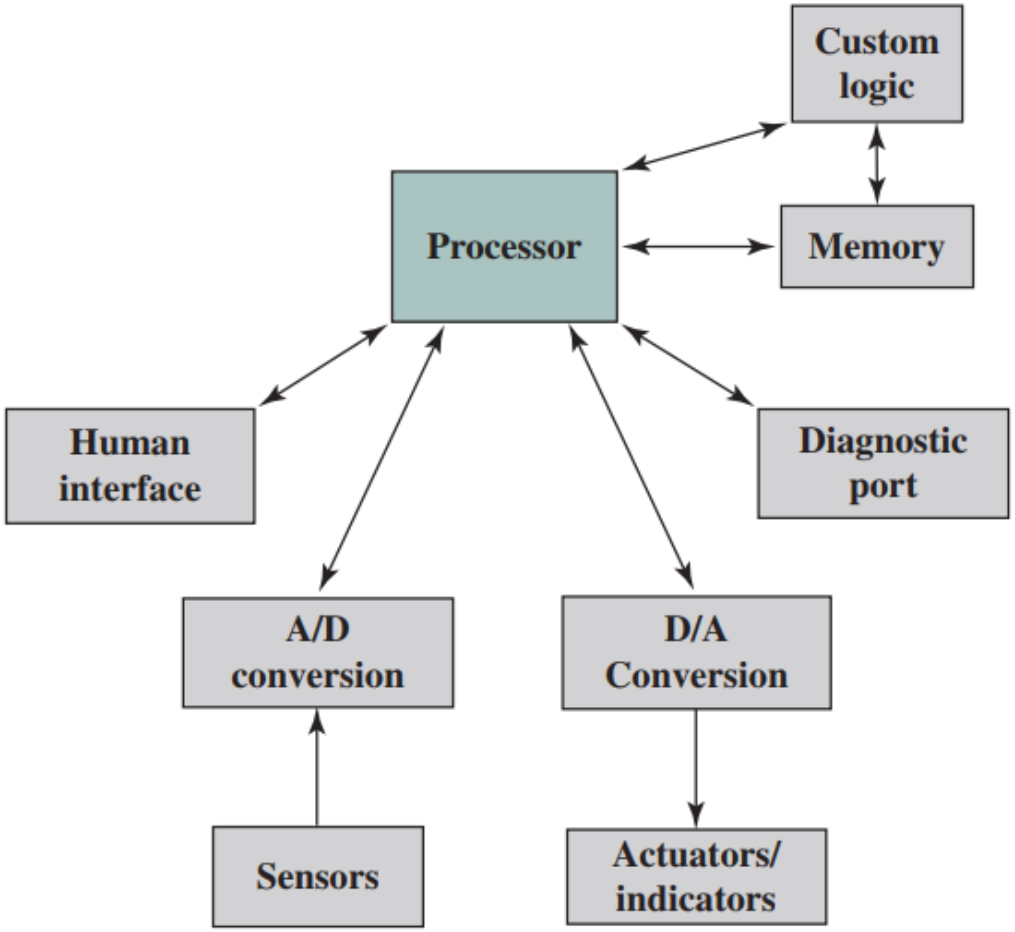
What is embedded system? 什么是嵌入是系统

- An embedded system is a special-purpose computer system designed to perform one or a few dedicated functions, often with real-time computing constraints 嵌入式系统是一种特殊用途的计算机系统，设计用于执行一个或几个专用功能，通常具有实时计算限制
- It is usually *embedded* as part of a complete device including hardware and mechanical parts 通常作为完整设备的一部分嵌入，包括硬件和机械部件
- Complexity varies from low, with a single microcontroller chip, to very high with multiple units, peripherals and networks mounted inside a large enclosure 复杂度从单个微控制器芯片到大型机箱内安装多个处理单元、外围设备和网络

Requirements of embedded system 嵌入式系统的要求

- Different sizes 不同的尺寸要求
  - Different constraints, optimization, reuse 不同的限制、优化和重用
- Different requirements 不同的要求
  - Safety, reliability, real-time, flexibility, legislation 安全性，可靠性，实时性，扩展性，法规性
  - Lifespan 生命值
  - Environmental conditions 环境条件
  - Static v dynamic loads 静态或动态负载
  - Slow to fast speeds 速度从慢到快
  - Computation v I/O intensive 计算密集型或I/O密集型

Possible organization 可能的组织结构



Outline

- Introduction of Computer and this course 计算机和本课程的介绍
- Why Study Computer Organization and Architecture? 为什么要学习计算机组织与架构?
- Organization and Architecture 组织与架构
- Structure and Function 结构与功能
- A Brief History of Computers 计算机发展史
- Intel x86 and ARM processor families x86和ARM处理器家族
- Embedded System 嵌入式系统
- Cloud Computing 云计算

What is Cloud Computing? 什么是云计算

- In a narrow sense, cloud computing is a network that provides resources, where users can access the resources on the "cloud" at any time, use them according to demand, and can be seen as infinitely scalable, paying according to usage 狭义上，云计算就是一种提供资源的网络，使用者可以随时获取“云”上的资源，按需求量使用，并且可以看成是无限扩展的，按使用量付费
- In a broad sense, cloud computing is a service related to information technology, software, and the Internet. This computing resource sharing pool is called “cloud”. Cloud computing gathers many computing resources and achieves automated management through software 广义上，云计算是与信息技术、软件、互联网相关的一种服务，这种计算资源共享服务叫做“云”，云计算把许多计算资源集合起来，通过软件实现自动化管理

Characteristics 特点

Cloud computing has strong scalability, coordinating a large amount of computing resources, storage resources, and network resources together. Users can access unlimited resources through the network and can expand at any time 云计算具有很强的扩展性，将大量计算资源、存储资源和网络资源协调在一起，通过网络获取到无限的资源，并且可以随时进行扩展

- Virtualization technology 虚拟化技术
- Dynamically scalable 动态可扩展
- On demand requests and usage 按需请求和使用
- High flexibility 灵活性高
- High reliability 可靠性高
- High cost-effectiveness 性价比高

Categories of Cloud Computing 云计算的类别

- By scope of use 按使用范围
  - Public Cloud 公有云
  - Private Cloud 私有云
- By purpose 按用途
  - Storage Cloud 存储云
  - Financial Cloud 金融云
  - Education Cloud 教育云
  - Medical Cloud 医疗云

Services types of cloud computing 云计算的服务类型

- IaaS: Provide users with virtualized computing resources, such as virtual machines, storage, networks, and operating systems. IaaS：向用户提供虚拟化计算资源，如虚拟机、存储、网络和操作系统
- PaaS: Provides an on-demand development environment and components for developing, testing, and managing software applications. PaaS：为开发、测试和管理软件应用程序提供按需开发的环境和组件
- SaaS: Provides on-demand applications through the internet, allowing users to directly use software provided by service providers. SaaS：通过互联网提供按需付费的应用程序，用户直接使用服务提供商提供的软件

Core technology of cloud computing 云计算的核心技术

- Virtualization 虚拟化
- Distributed file system 分布式文件系统
- Distributed database 分布式数据库
- Resource Management Technology 资源管理技术
- Energy consumption management technology 能耗管理技术
- Network and Information Security 网络和信息安全

Important terminology 重要术语

- Bit is a binary digit that can have value 0 or 1
- A byte is defined as 8 bits
- A word is a set of bits constituting the smallest unit of addressable memory
- A kilobyte is 2^{10} bytes (1024 bytes)
- A megabyte or a meg is 2^{20} bytes
- A gigabyte is 2^{30} bytes

Key terms

Computer	Computer Organization	Computer Architecture	Family of Computer models
Hierarchical System	Structure	Function	Peripheral
Data Processing	Data Storage	Data Movement	Control
Central Processing Unit	Main Memory	I/O	System Interconnection
Control Unit	Arithmetic and Logic Unit	Registers	CPU Interconnection

Key terms

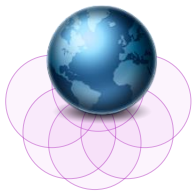
Accumulator (AC)	Execute cycle	Main memory	microprocessor	bus structure
Arithmetic and logic unit (ALU)	Input/output (I/O)	MAR	multiplexor	central-switched architecture
chip	IBR	MBR	mainframe computers	PC
Data channel	IR	backward compatible	OEM	multiple cores
Fetch cycle	IC	Von Neumann machine	Program control unit	Upward compatible

Summary and Question

- 小结
  - 课程介绍
  - 组织与架构，结构与功能
  - 计算机发展历史
  - X86和ARM简介
  - 嵌入式简介
  - 云计算概念
- 问题
  - 问题1：组织与架构的区别
  - 问题2：计算机的代是以什么作为依据？

Assignment

- Review Questions:
  - 1.1，1.2，1.3，1.6，1.7，1.8



谢谢大家！