西安交通大學
XI'AN JIAOTONG UNIVERSITY

第四讲：
程序是如何执行的

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程序是如何执行的?

Related courses

- Programming Language
- Assembly Language
- Compile
- Operating Systems
- Computer Architecture
- And more...
  - Computer Networking
  - Database
  - Discrete Mathematics
  - Data Structure & Algorithm
  - ...

. . .

主要内容

- **计算机程序：设计与编译**
- **程序如何一步步执行：冯诺依曼计算机**
- **操作系统如何管理程序**

计算机程序- hello world!

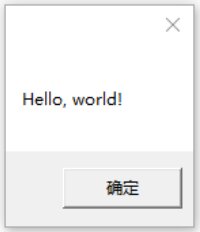
in **JavaScript**

```
<script>
alert("Hello, world!");
</script>
```

Hello, world on web browser

in **VBScript**

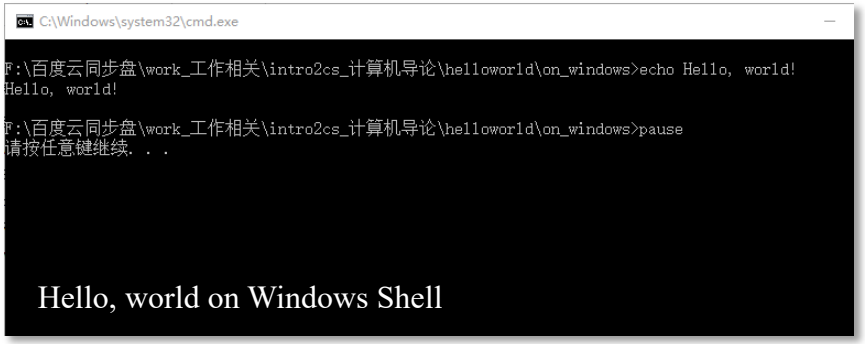
```
MsgBox "Hello, world!"
```



Hello, world on Windows desktop

in **Windows Shell**

```
echo Hello, world!
pause
```



Hello, world on Windows Shell

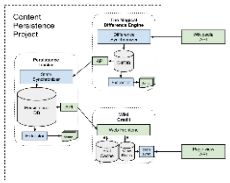
计算机程序- 定义

- A computer program is a **collection of instructions** that performs a specific task when **executed** by a **computer**[1].

Collection Of Instructions

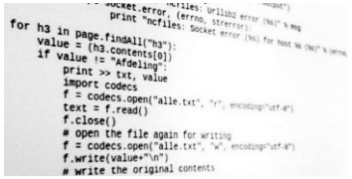
Programming Language

+



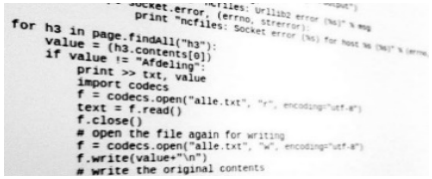
Design

Programming



Source Code

Compile & execute



Source Code

Translate

Native Code / Machine Code

Computer

Hardware

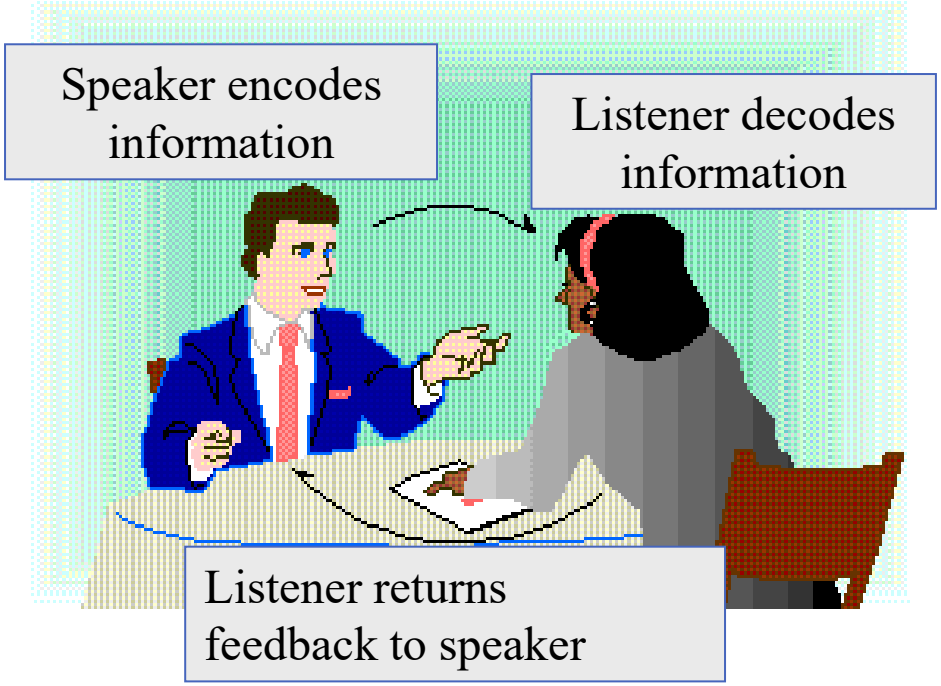
+

Operating System

[1] https://en.wikipedia.org/wiki/Computer_program

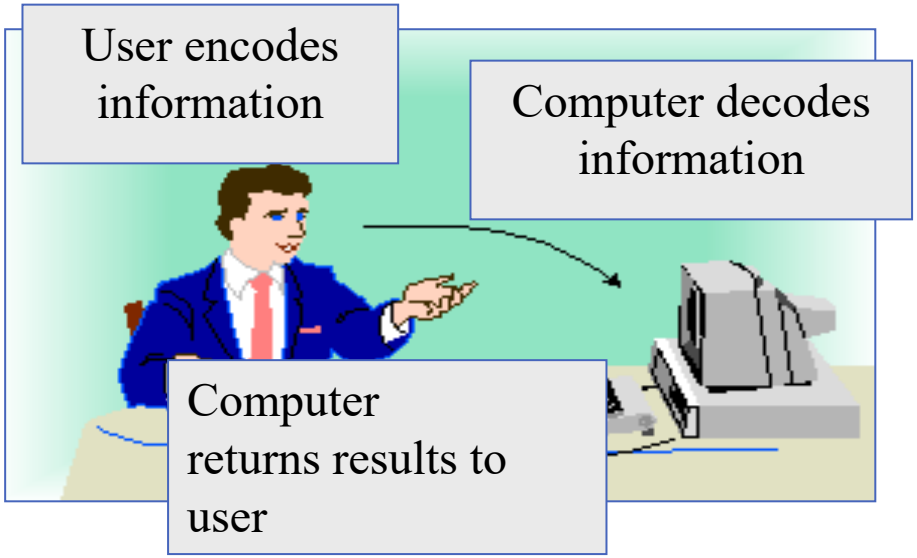
Communication cycle

- One complete unit of communication
  - An idea to be sent
  - An encoder
  - A sender
  - A medium
  - A receiver
  - A decoder
  - A response



程序设计语言

- **Substituting a computer for one of the people in the communication process**
  - Process is basically the same
    - Response may be symbols on the monitor
- **Programming languages bridge the gap between human thought processes and computer binary circuit**



程序设计语言

- Programming Language: A formal computer language or constructed language designed to **communicate instructions to a machine**, particularly a computer[1].

Machine readable

Machine language

Human readable

Compile

Assembly language, FORTRAN, Pascal, C / C++, Java, PHP, Python, Ruby, Perl, MATLAB, Wolfram, Scala, GO, Swift, etc

A picture of books that teaching programming languages and a word cloud of programming language names. There are thousands of programming languages are invented in the history.

[1] https://en.wikipedia.org/wiki/Programming_language

设计一门语言应该考虑哪些问题?

是不是我跟计算机讲什么词，它都能听懂?	是不是我跟计算机说什么格式的数，它都能听懂?	是不是我跟计算机说任何运算符号，它都能听懂?	世界上的逻辑纷繁复杂，要设计多种句式才够用?
计算机语言应该有“关键字”	计算机语言应该定义有限种数据类型。	计算机语言应该定义有限种运算符。	三种句式：顺序、分支、循环

程序设计语言的成分不外四种

Bohm, Corrado; Giuseppe Jacopini. Flow Diagrams, Turing Machines and Languages with Only Two Formation Rules. Communications of the ACM. May 1966, **9** (5): 366–371. doi:10.1145/355592.365646.

程序设计- 数据结构与算法

Design of computer program including 2 levels:

- Data Structure & Algorithm

- **A data structure** is a particular way of organizing and sorting data in a computer so that it can be used efficiently

Related Books

Linear Data Structure

A data structure is said to be linear if its elements form a sequence, or in other words a linear list

- Array
- Stack
- Queue
- Linked List

Non- Linear Data Structure

A non-linear structure is mainly used to represent data containing a hierarchical relationship between elements.

- Tree
- Graph

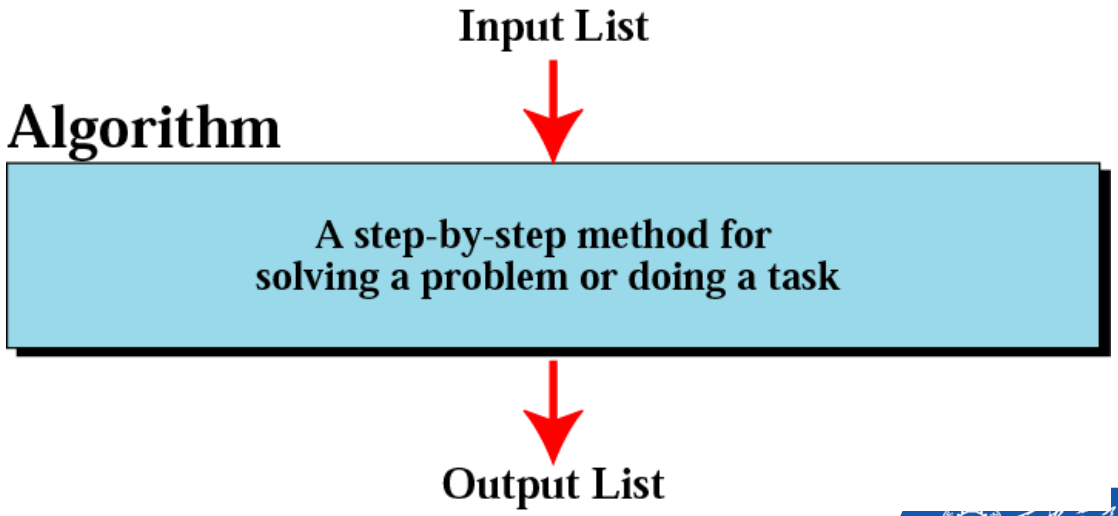
程序设计- 数据结构与算法

Design of computer program including 2 levels:

- Data Structure & Algorithm

Related Books

- It can be defined as a collection of unambiguous executable instructions, whose step by step execution leads to **a predefined goal**, within a finite number of steps.
- **Goal**: Desired input/output relationship.



1 PART

Design: an example

- **Example of Insert Sort**

Input: sequence $\langle a_1, a_2, \ldots, a_n \rangle$ of numbers.

Output: permutation $\langle a'_1, a'_2, \ldots, a'_n \rangle$ such that $a'_1 \le a'_2 \le \cdots \le a'_n$.

Example:

Input: 8 2 4 9 3 6

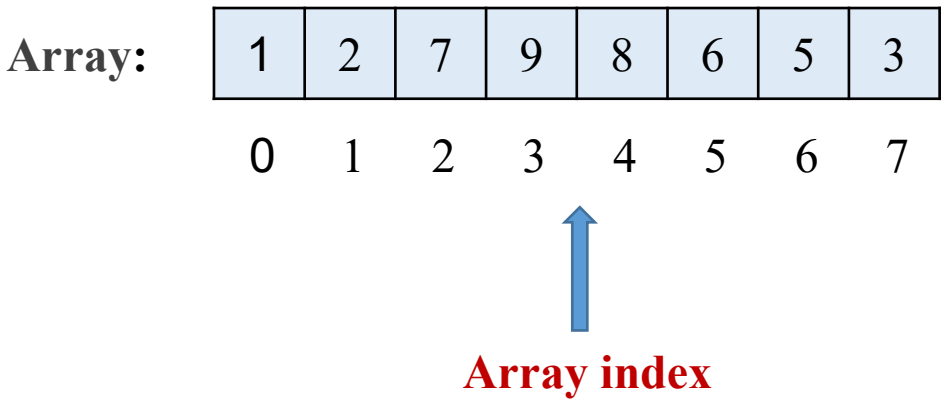
Output: 2 3 4 6 8 9

1 PART

Design: an example

Array

- An array is a data structure consisting of a collection of elements (values or variables), each identified by at least one array index or key
- An array is stored so that the position of each element can be computed from its index tuple by a mathematical formula.



1 PART

Design: an example

- **Example of Insert Sort**

1 PART

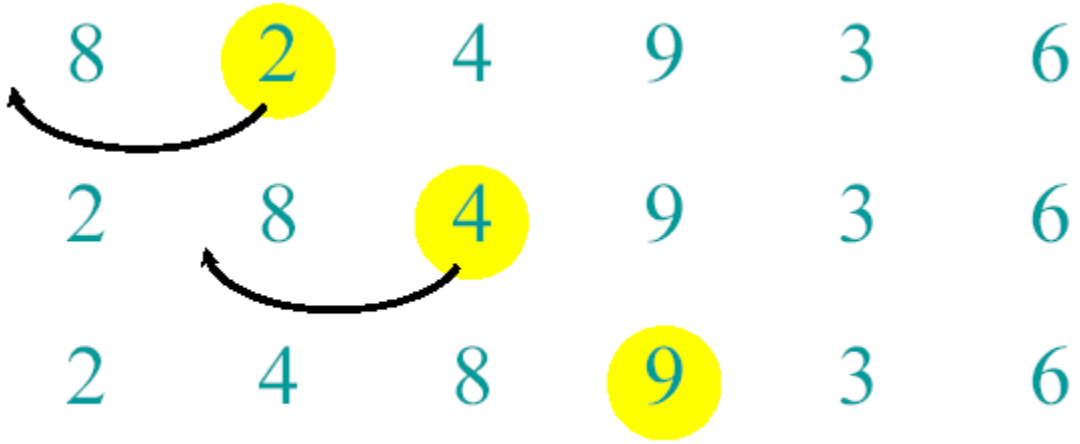
Design: an example

- **Example of Insert Sort**

1 PART

Design: an example

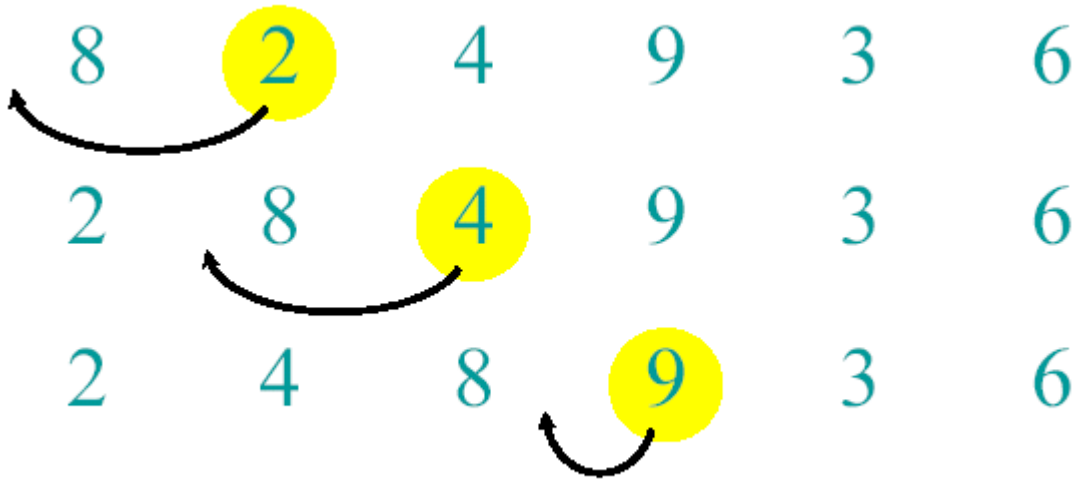
- **Example of Insert Sort**



1 PART

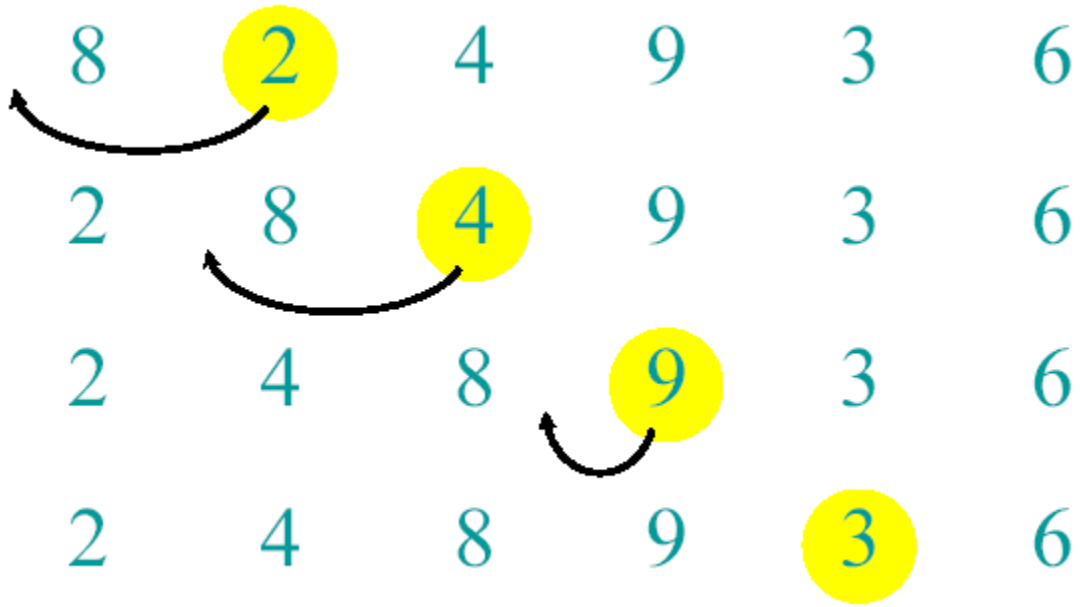
Design: an example

- **Example of Insert Sort**



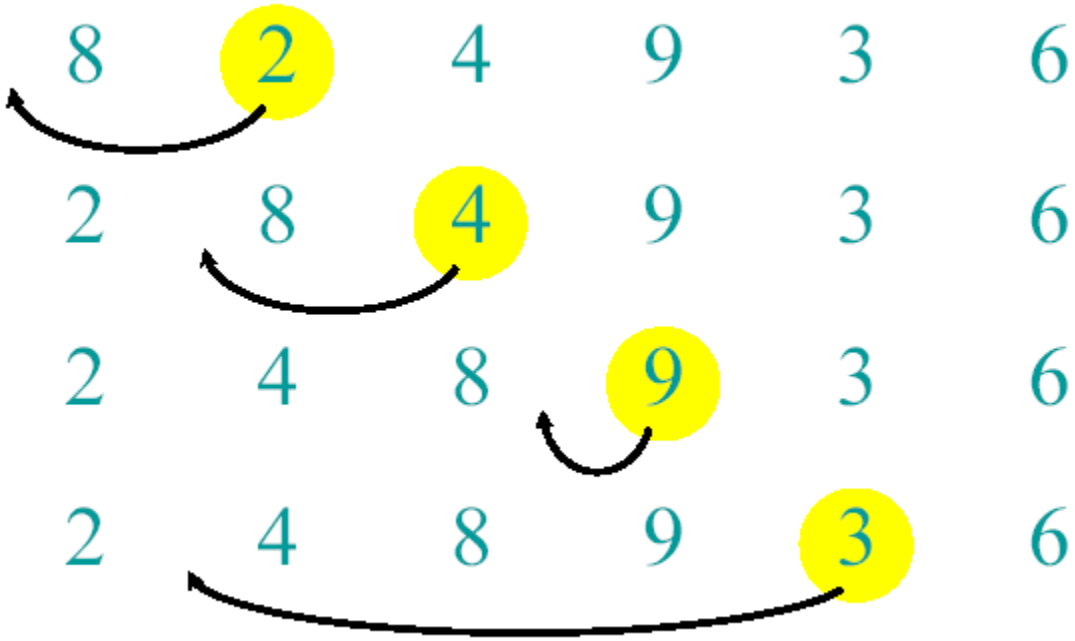
Design: an example

- **Example of Insert Sort**



Design: an example

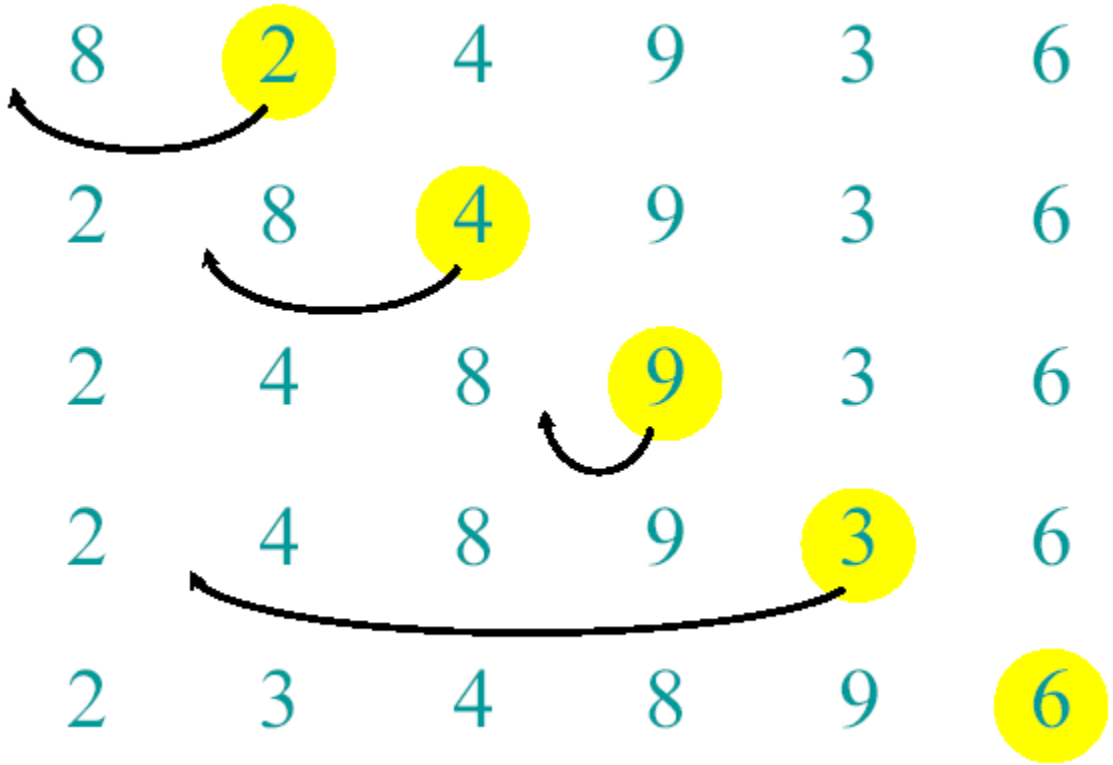
- **Example of Insert Sort**



1 PART

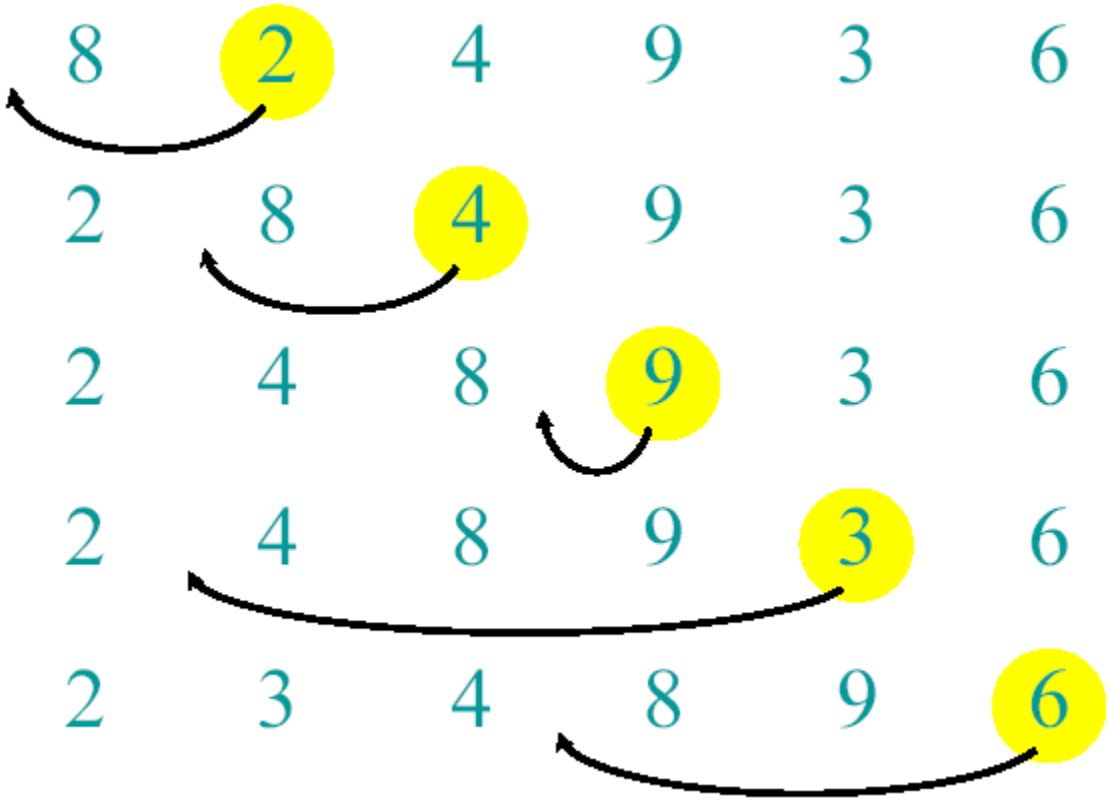
Design: an example

- **Example of Insert Sort**



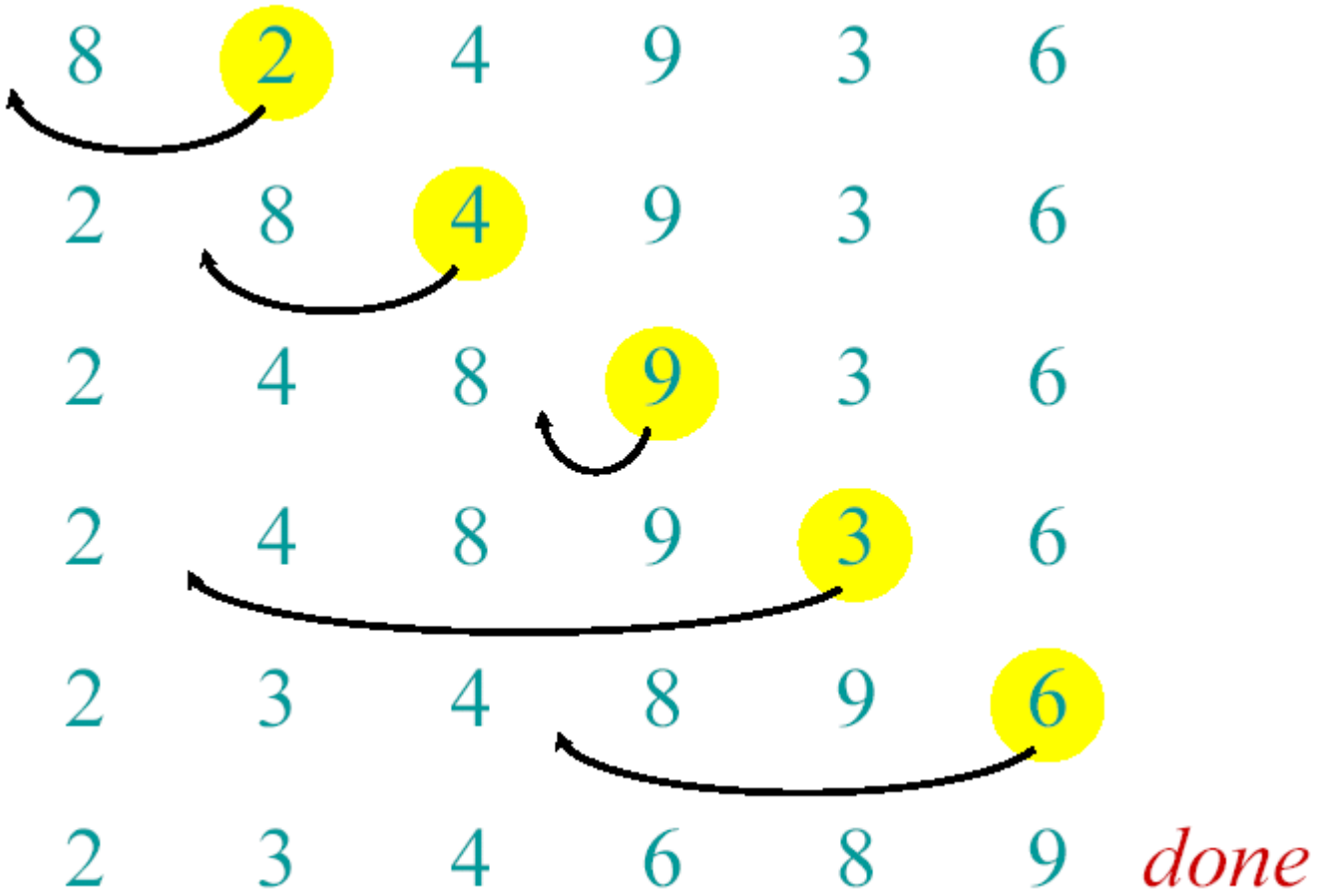
Design: an example

- **Example of Insert Sort**



Design: an example

- **Example of Insert Sort**



1 PART

Design: an example

Example of Insert Sort

A *pseudocode* for insertion sort (INSERTION SORT).

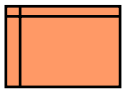
```
INSERTION-SORT(A)
1   for j ← 2 to length [A]
2       do key ← A[ j]
3       ∇ Insert A[j] into the sortted sequence A[1,..., j-1].
4        i ←  j – 1
5        while i > 0 and A[i] > key
6              do A[i+1] ← A[i]
7                    i ← i – 1
8       A[i +1] ←  key
```

6 5 3 1 8 7 2 4

程序设计- 架构设计

- Architecture
- Data Structure & Algorithm

Related Books

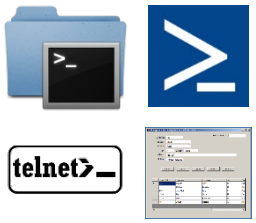


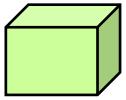
Client (Browser/ Mobile)

Browser

Mobile

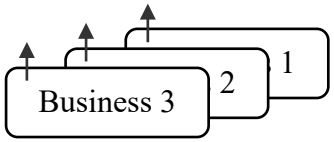
Management





Server

Dynamic



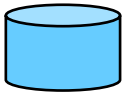
Service-Oriented Architecture

Static

Content Delivery Network

Binary

Text

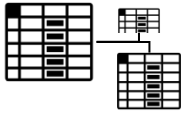


Data

Persistent

Cached

Structured

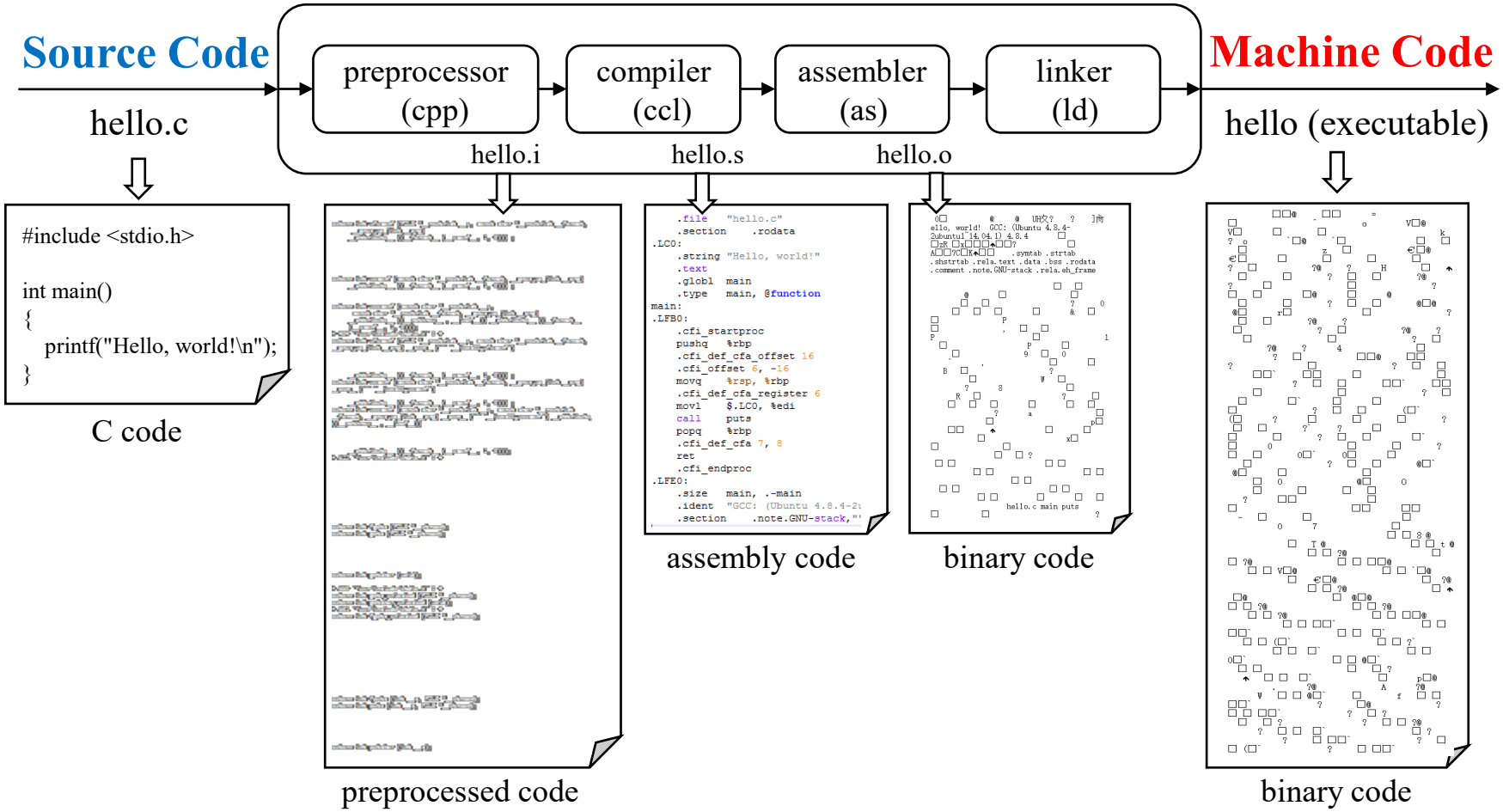


Non-Structured

Semi-Structured

编译

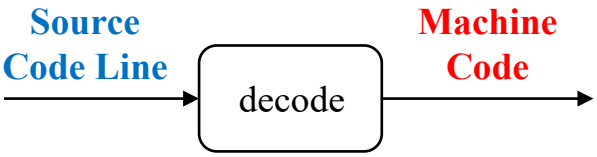
Translate **source code** from a human-readable language into either **machine code** or **object code**.



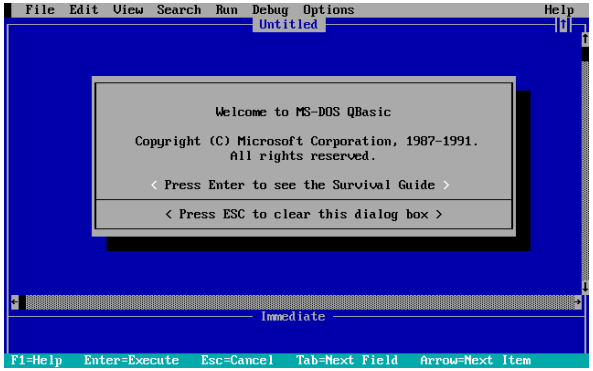
编译- 解释

Execute each line in source code from a programming language immediately, without an intermediate file.

First method

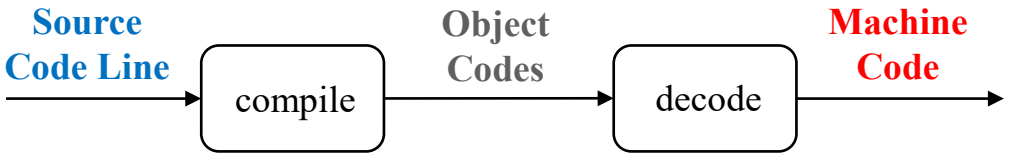


BASIC, APL

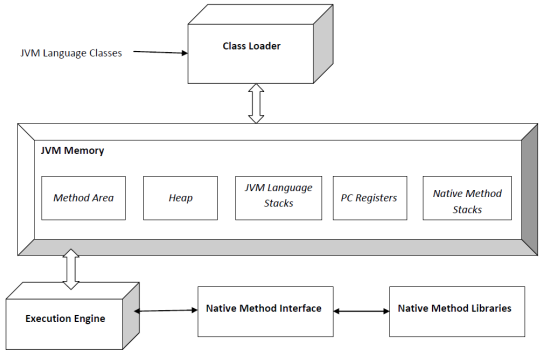


Microsoft QBasic Interface

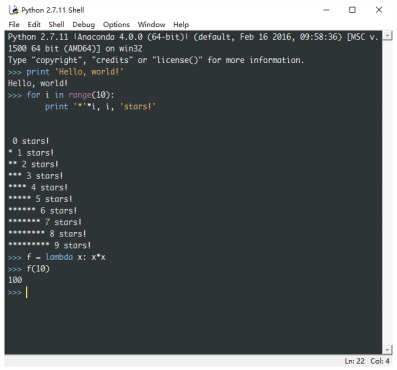
Second method



Java, Python, Ruby, Perl, JavaScript, Go, etc.



Java Virtual Machine Structure



Python IDLE Interpreter

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- 计算机程序：设计与编译
- 程序如何一步步执行：冯诺依曼计算机
- 操作系统如何管理程序

冯诺伊曼计算机

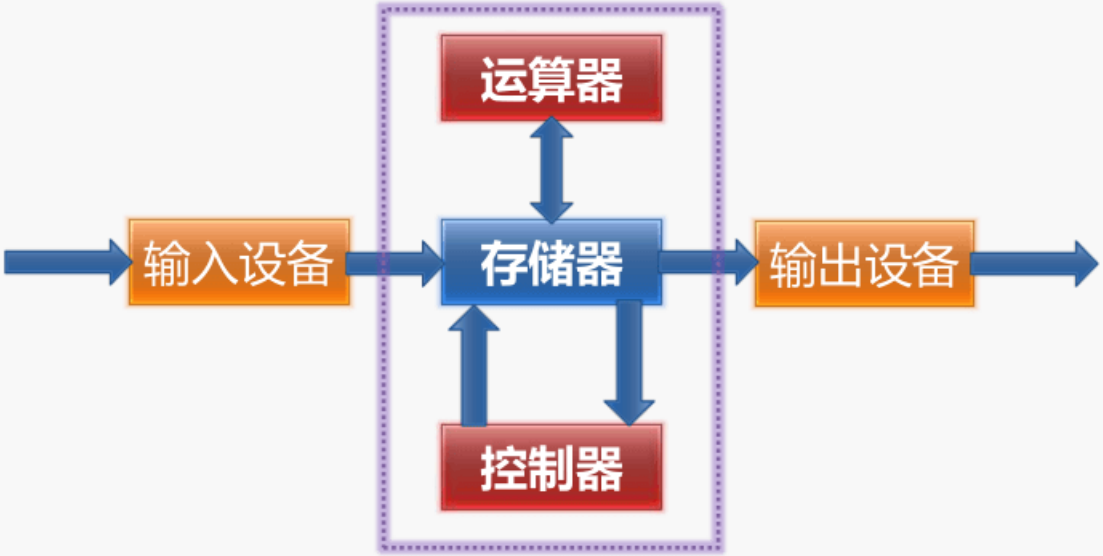
冯·诺依曼结构的要点

① 计算机应由运算器、控制器、存储器、输入设备和输出设备共5个部分组成

② 数据和程序均以二进制代码形式不加区别地存放在存储器中，存放位置由存储器的地址指定

③ 计算机在工作时能够自动地从存储器中取出指令加以执行

④ ……



冯诺伊曼计算机

主存的组织形式

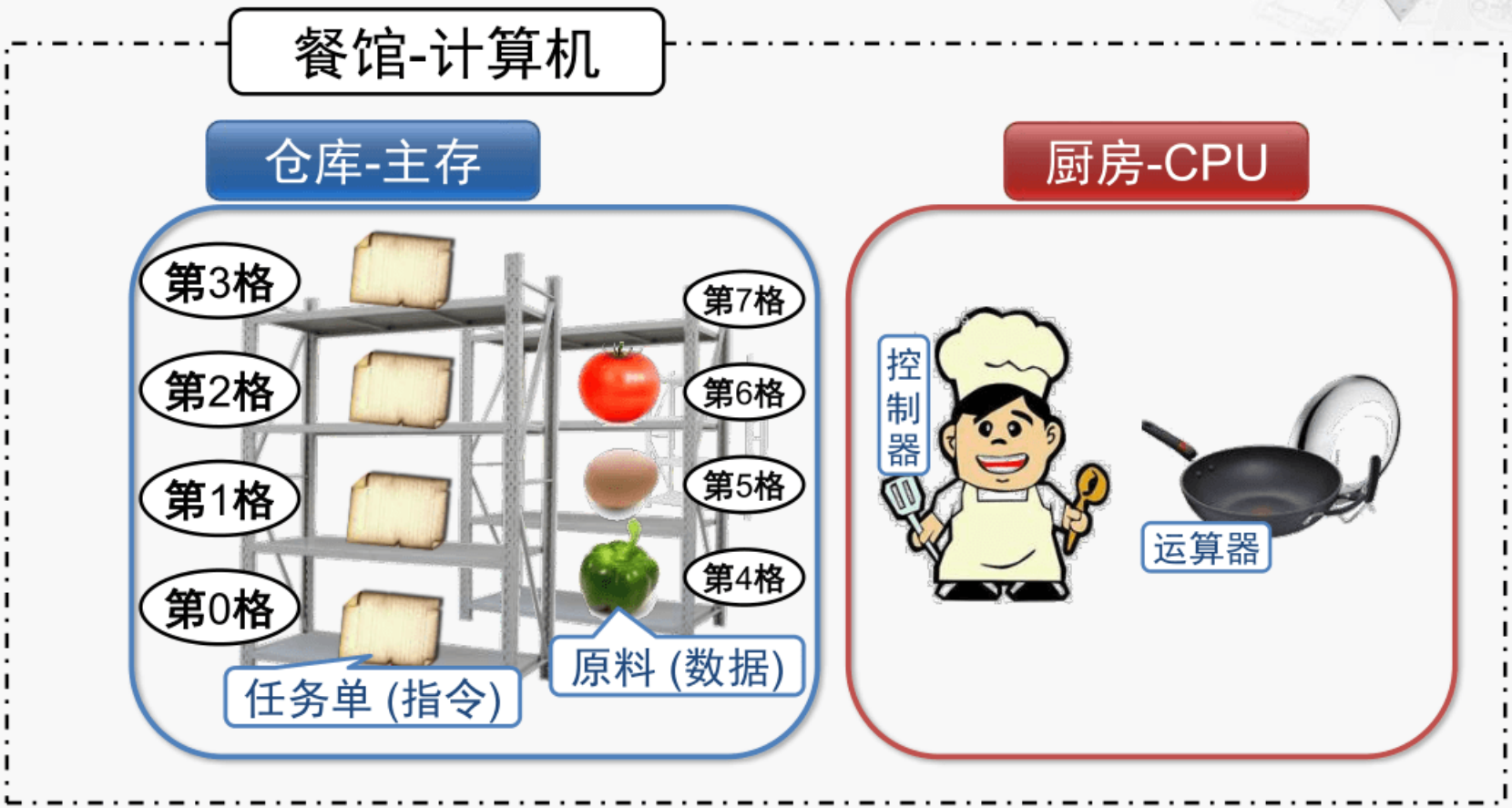
地址：每个存储单元对应的序号

内容：存储单元中存放的信息

地址（二进制）	内容（二进制）
…	……
0011	00001100
0010	00100010
0001	00000000
0000	01101101

冯诺伊曼计算机

冯·诺依曼计算机的类比



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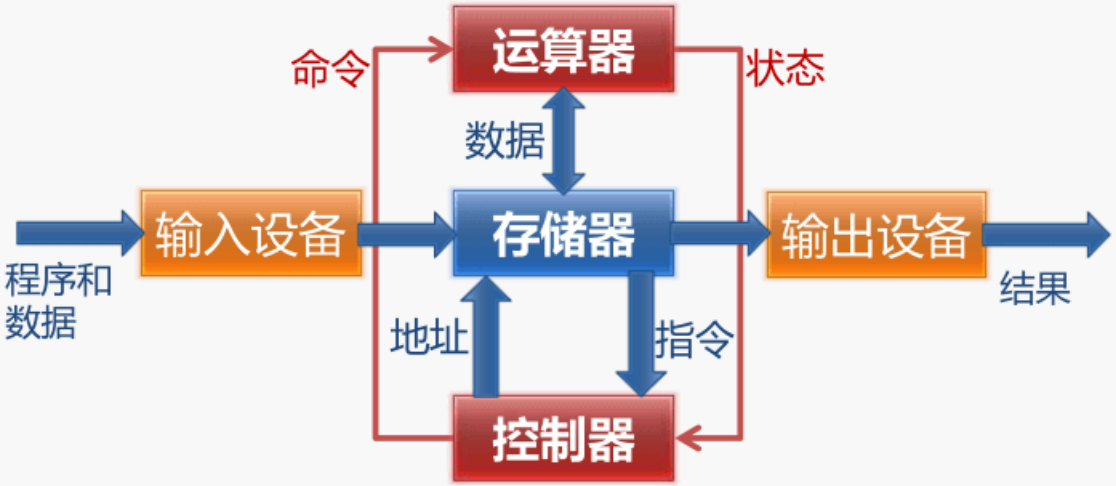
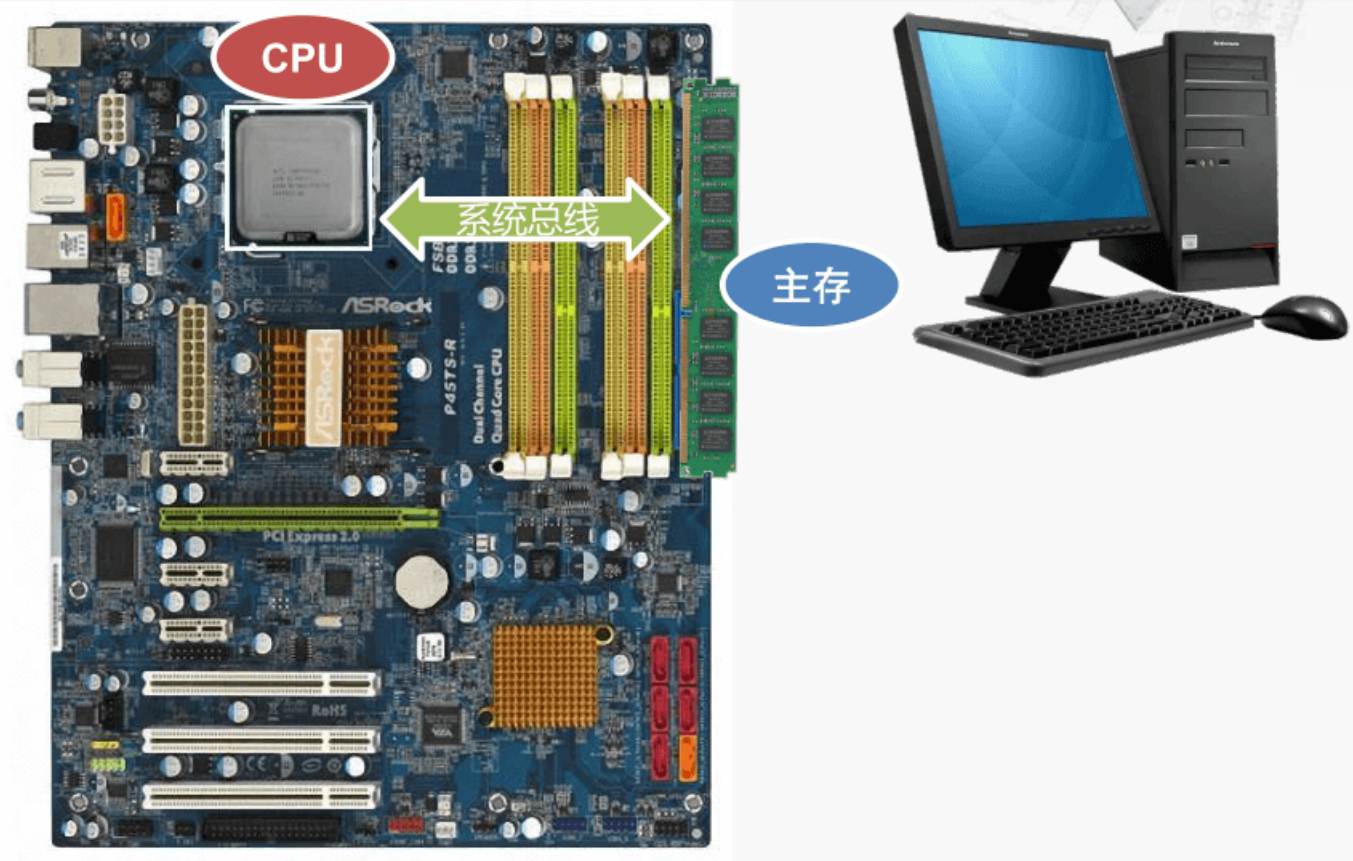


冯诺伊曼计算机

现代个人计算机中的CPU和主存



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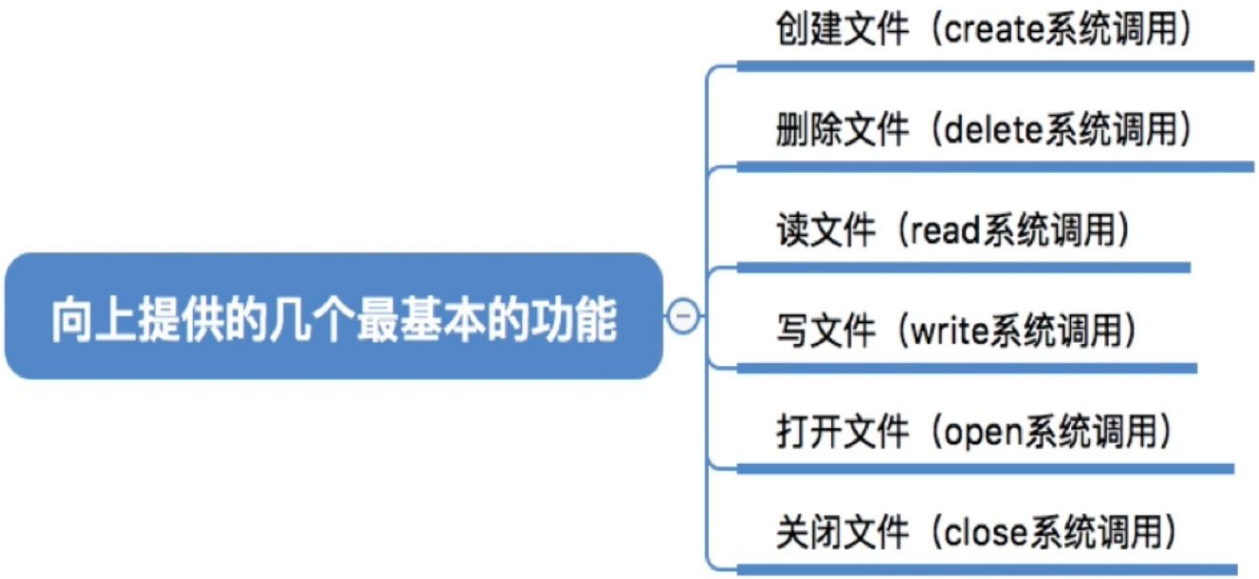
- 程序如何一步步执行：冯诺依曼计算机
- **操作系统如何管理程序**

示例：磁盘管理

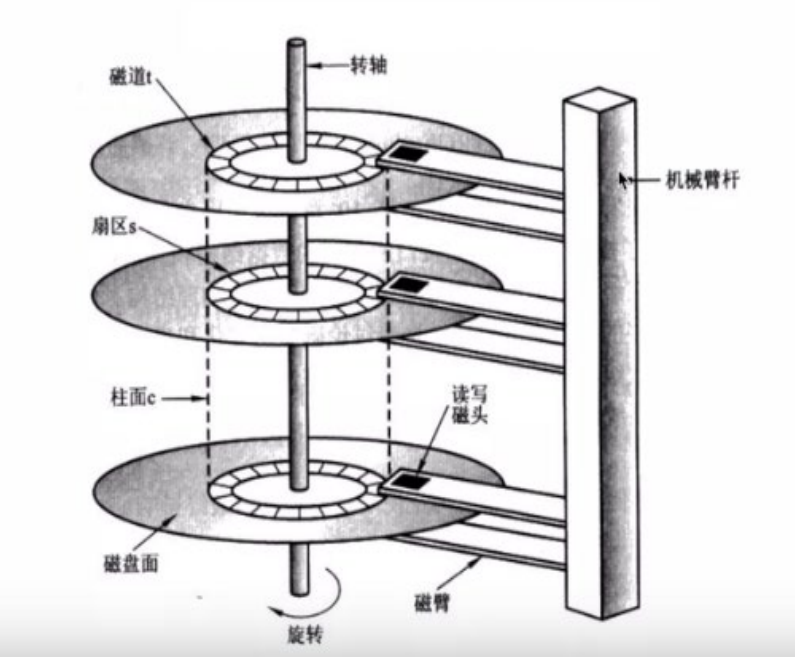
我们平时访问磁盘是如何访问的？

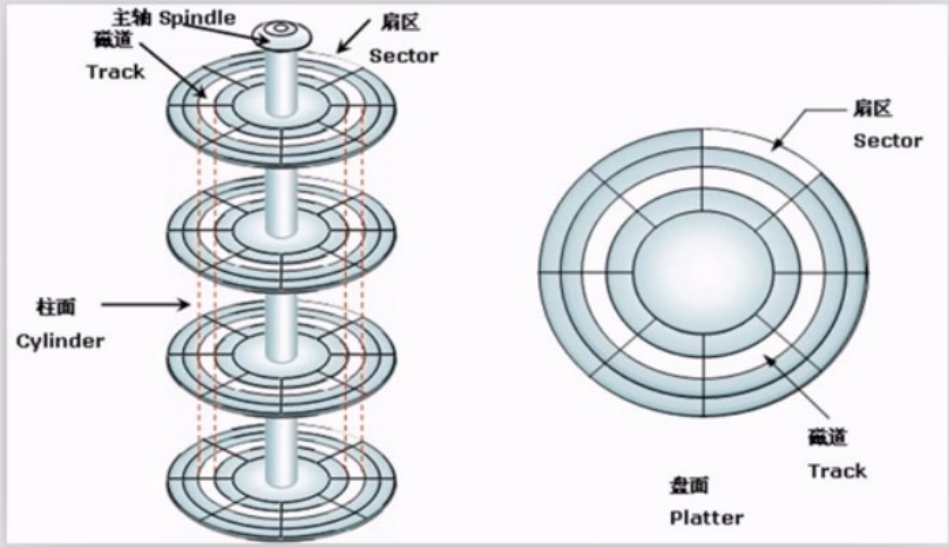
- 文件是最小单元



示例：磁盘管理

（从计算机角度）是如何访问的？





- 按扇区访问：每个扇区，存储一些数据，如512字节。磁头可以按编号寻找对应扇区

示例：磁盘管理

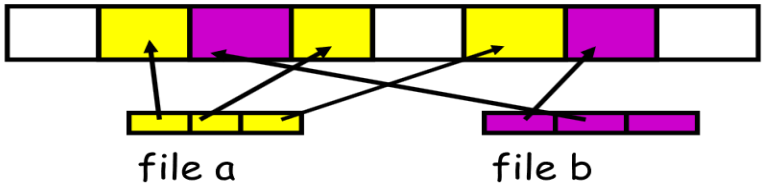
用户使用磁盘如此方便，真实的磁盘使用如此困难，你知道这背后发生了什么吗？

- 操作系统文件管理模块（文件系统）：
  - 文件系统将磁盘空间进行规划和编号处理，这样通过文件名就可以找到具体的数据，而不用关心数据到底是怎么存储的。
  - 两大功能：
    - 以文件名找到对应的磁盘块
    - 持续跟踪空闲空间

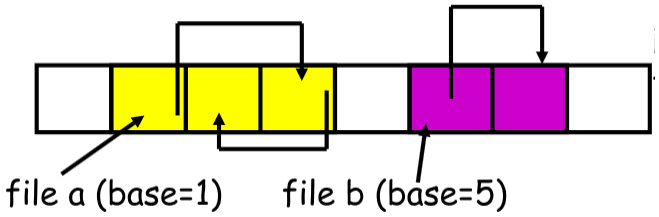
示例：磁盘管理

如何通过文件名找到对应的磁盘块呢？

- 直接索引：采用最最直接的指针方式来索引数据块。



- 间接索引：单个指针指向文件的第一个数据块，每个数据块的末尾存储下一个块地址。



- 他们的优缺点是啥？分层索引又是啥？

示例：磁盘管理

存放索引的数据叫什么？

- 元数据（Data about Data）

这部分元数据需要存储在磁盘中吗？

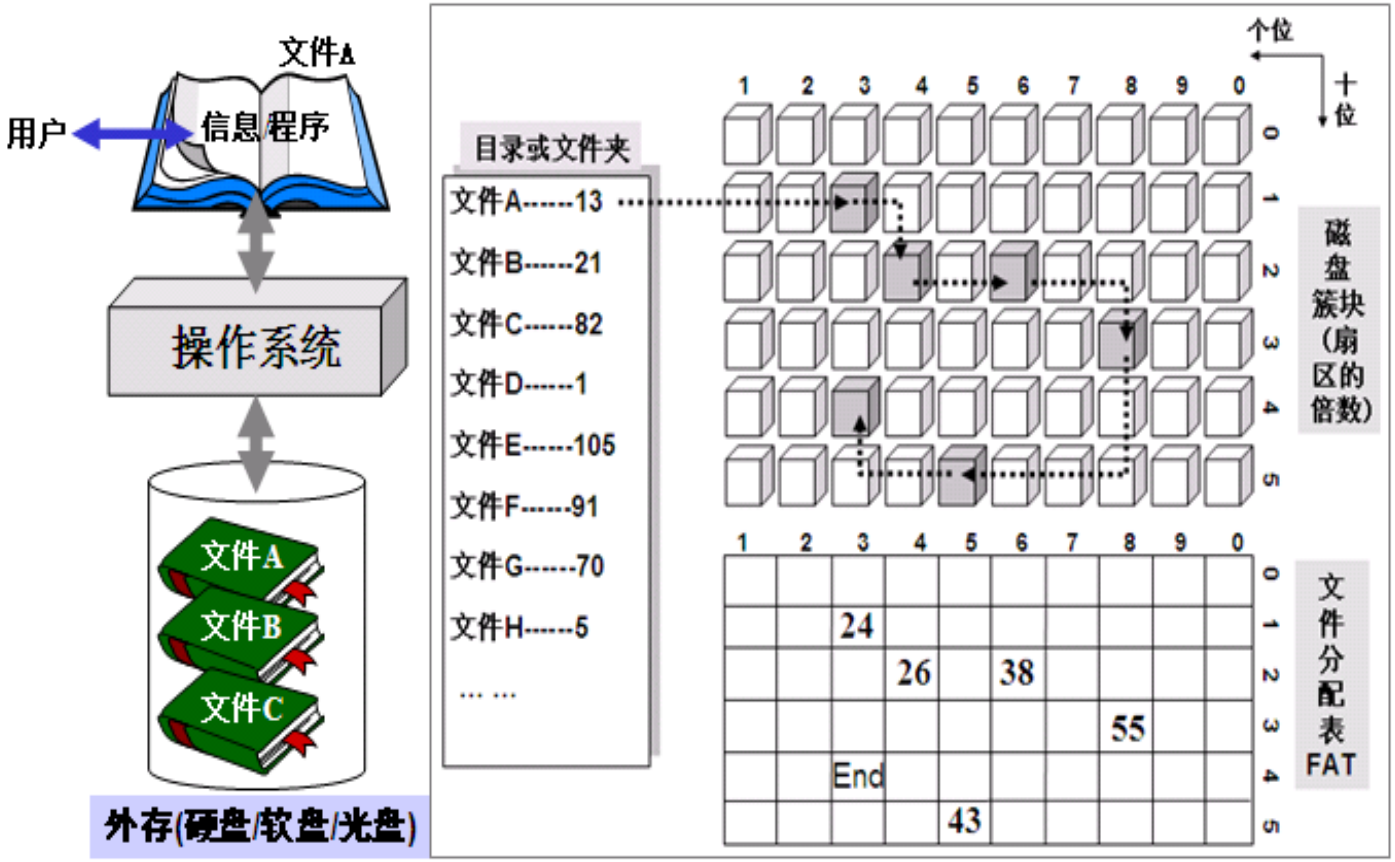
- 需要，要不重启或计算机掉电后，我们就找不到文件对应的磁盘位置了

这部分元数据又该如何索引呢？

- 一般放在规定好的位置（例如磁盘最前面）

示例：磁盘管理

FAT文件系统示例



示例：内存-磁盘分级体系

程序在存储器中，理想存储器应该是什么样子？

- 无限空间
- 零延迟
- 便宜
- 高带宽

示例：内存-磁盘分级体系

现实是什么？

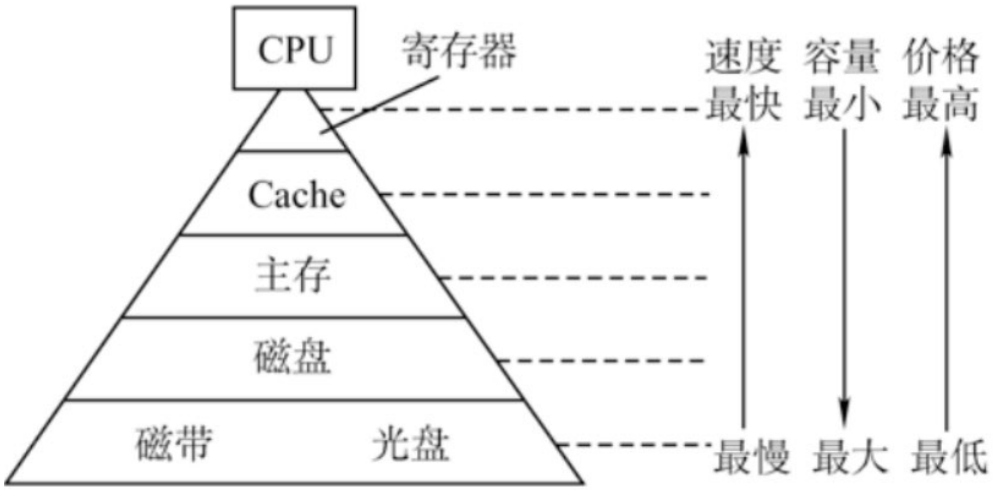
- 速度越高，位价就越高
- 容量越大，速度必越低

存储器	硬件介质	单位成本（美元/MB）	随机访问延时
L1 Cache	SRAM	7	1ns
L2 Cache	SRAM	7	4ns
Memory	DRAM	0.015	100ns
Disk	SSD（NAND）	0.0004	150μs
Disk	HDD	0.00004	10ms

示例：内存-磁盘分级体系

如何同时满足多个理想目标的需求呢？？

- 宿舍衣柜不够大，你们怎么放衣服？



分级存储体系：

相对不容易被访问的内容，放入便宜、容量大、速度慢的存储

相对容易被访问的内容，放在快速、昂贵的存储

同时解决了内存掉电后失效的问题

示例：内存-磁盘分级体系

Memory	DRAM	0.015	100ns
Disk	SSD(NAND)	0.0004	150μs

应用局部性原理的效率计算

- 假设我们现在有100万个字长的数据需要存储
  - 我们将所有数据都放入Disk。现在CPU要访问100万次数据，那么这种情况需用时多少，成本多少？
  - 我们假设CPU的90%访问都集中访问数据中的10%。那么我们设计这样一个结构，将这10%的数据放在Memory，剩下的90%数据继续存放在Disk中。现在CPU同样访问100万次数据，这种情况用时多少，成本多少？
  - 答案：价格贵了4.65倍，速度快了94倍

示例：内存-磁盘分级体系

为什么多级存储体系可以工作呢？

- 程序局部性原理：
  - 程序在执行时呈现出局部性规律，即在一段时间内，整个程序的执行仅限于程序中的某一部分。
  - 时间局部性：
    - 被引用过一次的存储器位置在未来会被多次引用（例如：循环中的变量；被反复调用的函数）
  - 空间局部性：
    - 如果一个存储器的位置被引用，那么将来他附近的位置也会被引用（例如：顺序执行的程序）。

示例：内存-磁盘分级体系

你能举出更多生活中的局部性原理的例子吗？？

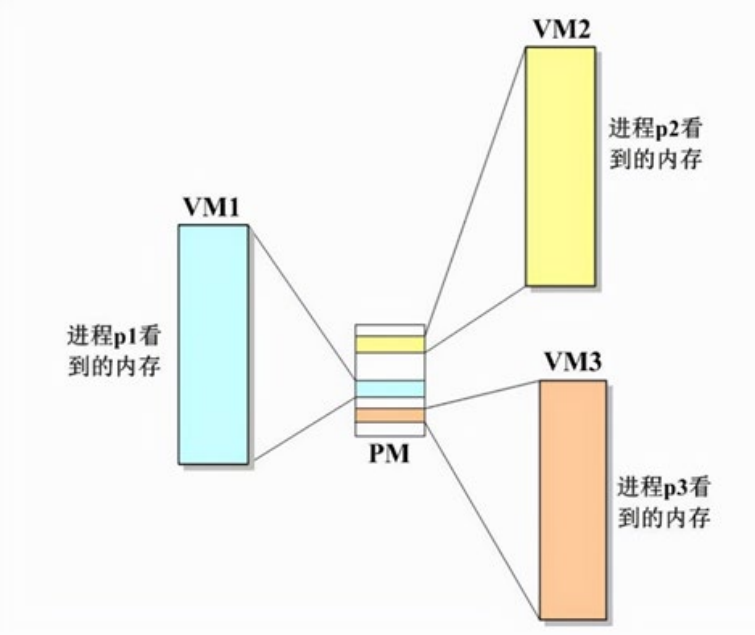
思维启示：

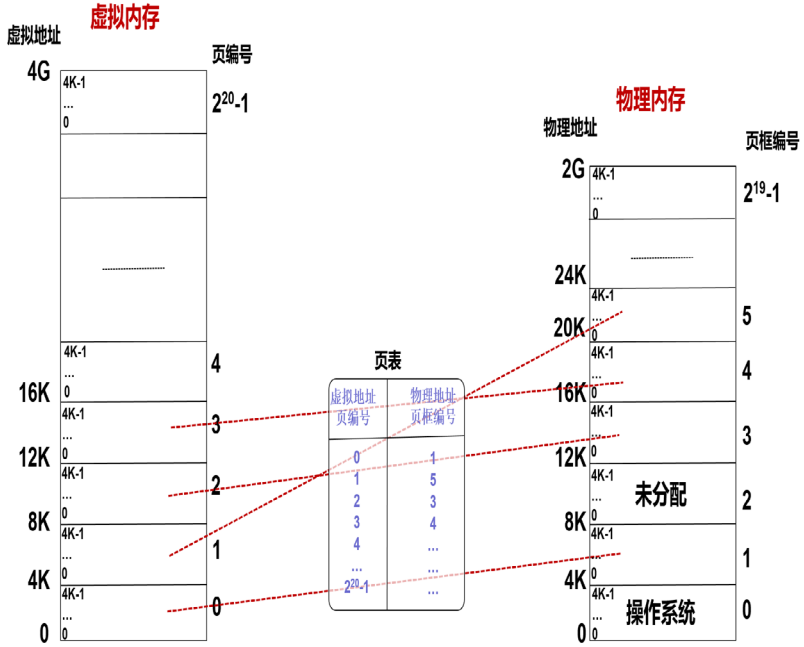
- 1. 计算机是一项系统工程，往往需要各种平衡和折衷（比如价格，性能）。
- 2. 多种资源组合利用往往有更好的效果。

示例：内存管理

内存管理：什么数据会被调入内存？

- 当作业或进程创建后系统会为他们分配内存空间，当结束后内存空间也会被回收。保证个个作业在自己的内存空间内运行，互不干扰。

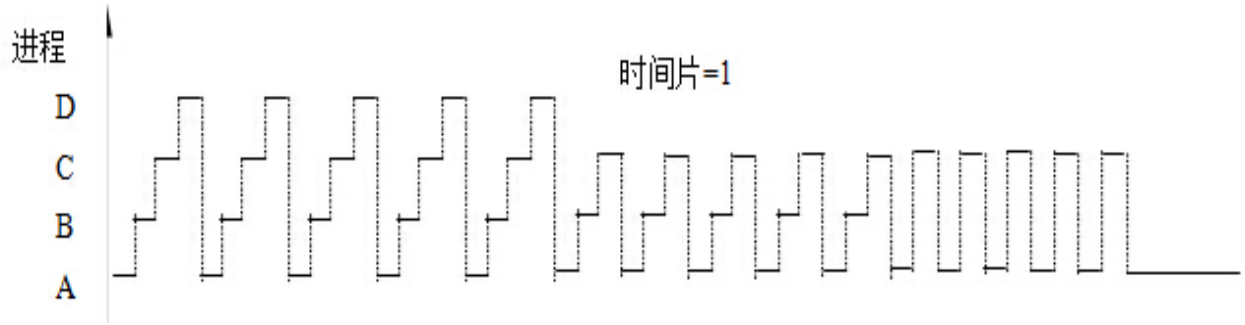




示例：进程调度

进程管理：进程的创建、调度与销毁

- 程序一旦被装入内存执行，就被称之为进程。
- 进程中不只有代码，还有程序计数器的值（代表程序执行到哪里），堆栈段（包括临时数据）和数据段（包括全局变量）等。
- 操作系统根据调度算法，让不同的进程分时、依次执行。



示例：中断管理

中断管理：完成了点击怎么响应

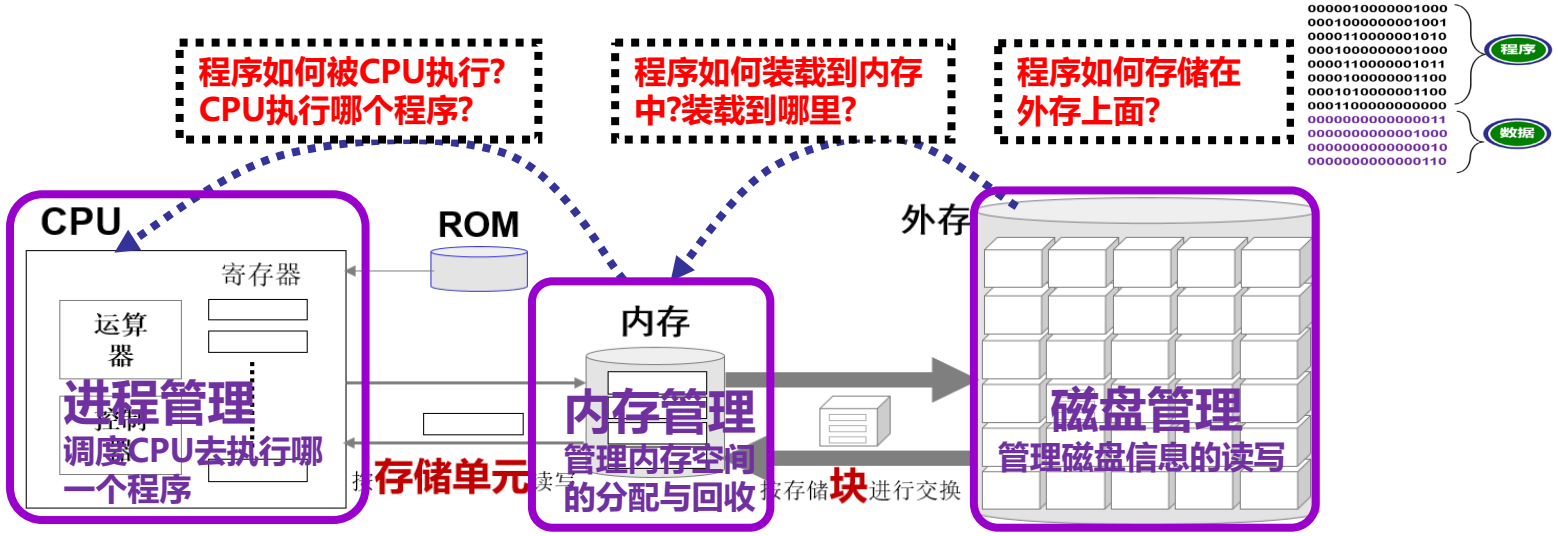
- 当设备收到输入信号时，便通过控制线向CPU发送一个中断信号，当CPU收到中断信号后，再通过中断响应程序进行处理。
- 优点：在I/O设备输入每个数据的过程中，由于无需CPU干预，因而可使CPU与I/O设备并行工作，仅当完成一个数据输入时，才需CPU花费极短的时间去做一些中断处理。

操作系统如何管理程序

根本问题：程序是如何被执行的？

操作系统是一组“管理各种资源以便执行应用程序”的程序

(1)分工。首先独立管理每个部件：磁盘管理、内存管理、进程管理



操作系统如何管理程序

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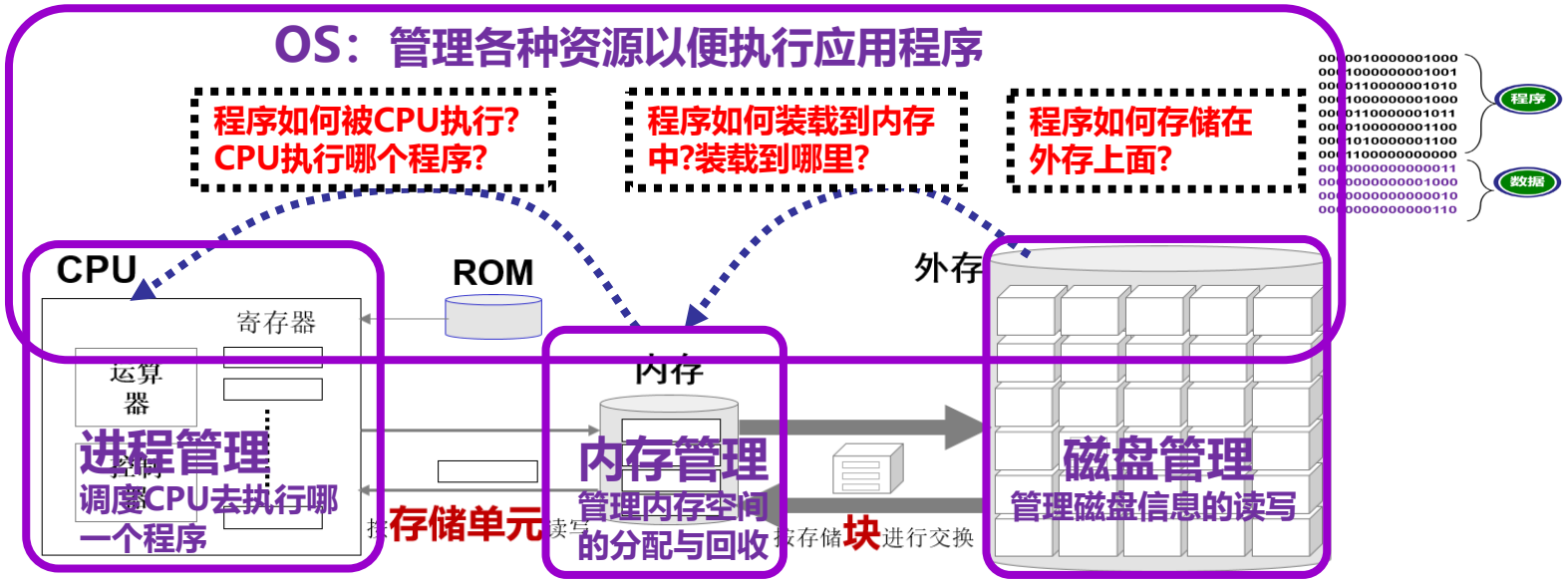
(1)分工。首先独立管理每个部件：磁盘管理、内存管理、进程管理等

(2)合作。各部件合作完成“让CPU执行存储在外存上的程序”



作业（思考、调研）

1. 阅读1966年论文，谈谈自己的理解
2. 从程序员写程序，到用户拿鼠标双击exe文件打开这个程序，这期间都发生了什么？你能运用本堂课知识，详细描述一下吗？
3. 操作系统是程序吗？操作系统管理如何将程序载入内存，那OS自己又是如何被放入计算机内存中的呢？