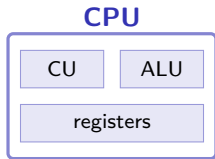


Processor Fundamentals

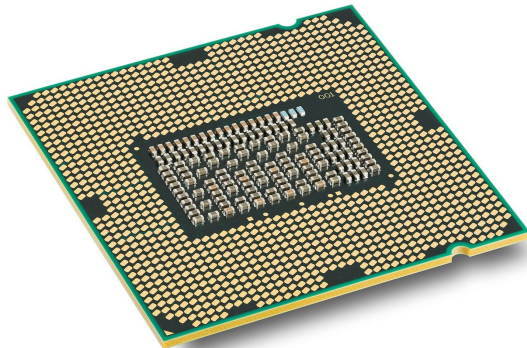
AS Computer Science ■ Topic 4

A-Level Computer Science



What we will cover

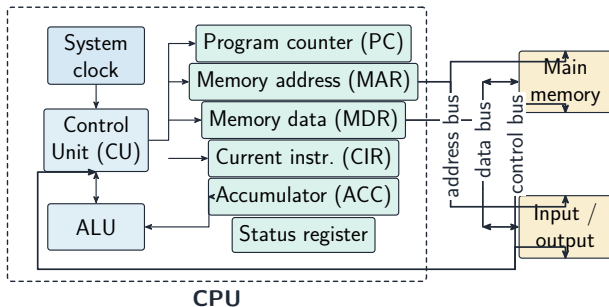
- 1 Von Neumann & the CPU
- 2 Buses & performance
- 3 Fetch-execute & interrupts
- 4 Assembly & addressing
- 5 Binary shifts & masking
- 6 Recap



1

Von Neumann and the CPU

Von Neumann architecture



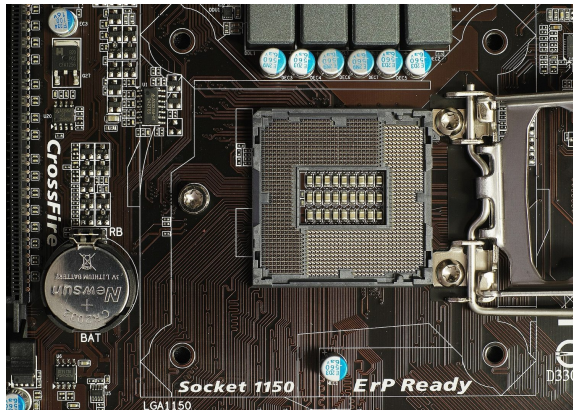
One **single memory** holds both program and data – the **stored program** 存储程序.

- CPU fetches and runs one instruction at a time
- change the program $\Rightarrow$ change behaviour, no rewiring
- instructions run **in order** unless a branch changes the flow

The CPU's main parts

- **ALU** 算术逻辑单元 – arithmetic & logic
- **control unit** 控制单元 – decodes, sends control signals
- **clock** 时钟频率 – keeps the CPU in step
- **registers** 寄存器 – tiny, very fast stores, including the **general-purpose registers** 通用寄存器 for temporary values

All of it sits inside one small chip.



Special-purpose registers

Six **special purpose registers** 专用寄存器 do the work of the fetch–execute cycle:

PC

program counter: next instruction's address

MAR

memory address register: address being accessed

MDR

memory data register: data to/from memory

CIR

current instruction register: what is being decoded

ACC

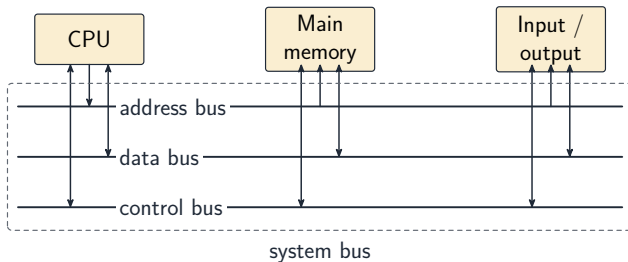
accumulator: the value the ALU works on

Status

status register: flags
– carry, zero, negative

Data moves are written as register transfers, e.g. $\text{MAR} \leftarrow [\text{PC}]$.

The system buses



- **address bus** 地址总线 – address, **one-way**
- **data bus** 数据总线 – data, two-way
- **control bus** 控制总线 – signals, two-way

Three sets of parallel wires. An n -bit address bus reaches 2^n locations.

What actually makes a computer faster

clock speed

时钟频率
pulses per second, e.g. 3.8 GHz

cores

核心
a multi-core CPU runs several threads at once

word size

字长
32- or 64-bit: how much the CPU handles at once

cache memory

高速缓存
a closer, faster store than the immediate access store
立即存取存储器

amount of RAM

随机存取存储器
too little and the OS must page to disk

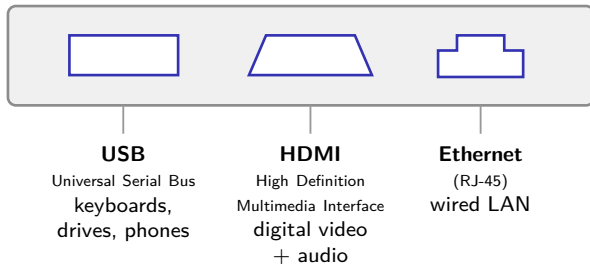
secondary storage

辅助存储器
an SSD loads programs far faster than an HDD

Each instruction takes a fixed number of clock cycles. Match the specs to the **workload**: a quad-core beats a dual-core on parallel work, but higher per-core speed wins on single-threaded work.

Ports connect the peripherals

A **port** 端口 is a physical socket for a **peripheral** 外围设备. Different ports carry different signals, so an HDMI cable will not fit a USB socket.

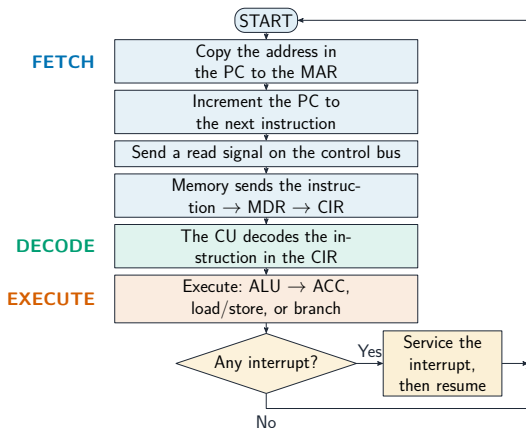


Also on the case: **VGA** (older *analogue* video) and audio jacks. **USB-C** is unusual – it carries video, data *and* power.

2

Fetch-execute and interrupts

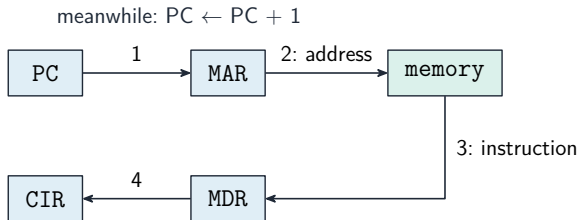
The fetch-execute cycle



- **fetch**: PC → MAR, increment PC, read → MDR → CIR
- **decode**: the CU reads the instruction
- **execute**: ALU / load-store / branch

Then check for interrupts and repeat.

The register transfers in a fetch



1 $MAR \leftarrow [PC]$

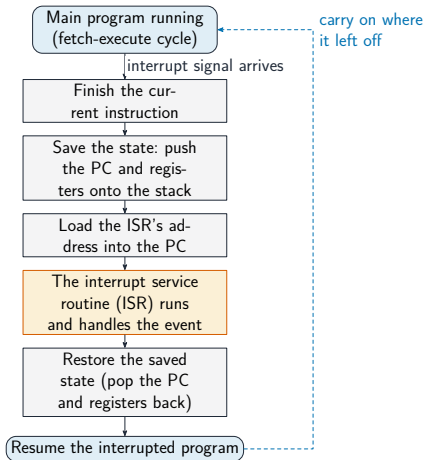
2 $PC \leftarrow [PC] + 1$

3 read signal on control bus

4 $MDR \leftarrow [memory]$

5 $CIR \leftarrow [MDR]$

Interrupts



An **interrupt** 中断 pauses the cycle for an urgent event:

- 1 finish the current instruction
- 2 save the state (PC, registers)
- 3 run the **ISR** 中断服务程序
- 4 restore and carry on

Interrupts, and what the CU decodes

decode

the CU decodes the instruction in the CIR – **what operation**, and **which operands or addresses**

an interrupt 中断

a signal that **pauses** the normal cycle so the CPU can handle an urgent event – a key press, a packet arriving, a hardware fault

what happens

the current registers are saved, and the **interrupt service routine 中断服务程序** runs

then

the saved state is restored and the interrupted program continues as if nothing happened

priorities

a higher-priority interrupt can interrupt a lower one; equal ones queue

why it matters

the system responds **without the CPU constantly checking devices** – and it is how the OS multitasks

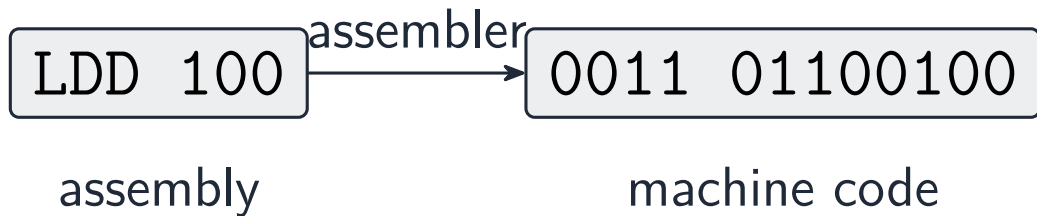
Polling wastes cycles asking “anything yet?”. An interrupt lets the device speak, which is why every modern system uses them.

3

Assembly and addressing

Assembly and machine code

The **processor** 处理器 runs **machine code** 机器码 (bit patterns). **Assembly language** 汇编语言 is readable, one line per instruction, using **mnemonics** 助记符 (LDD, ADD, JMP). A **two-pass assembler** 两遍汇编器: pass 1 builds a **symbol table** 符号表 of **labels** 标签; pass 2 generates code (handling forward references).



The instruction set, and the two-pass assembler

data movement

LDD, LDM, LDI, LDX, STO, MOV

arithmetic

ADD, SUB, INC, DEC

logic and shifts

AND, OR, XOR, LSL, LSR – and a **cyclic shift** 循环移位, where the bit leaving one end re-enters the other

comparison and jumps

CMP, JMP, JPE, JPN

the assembler's job

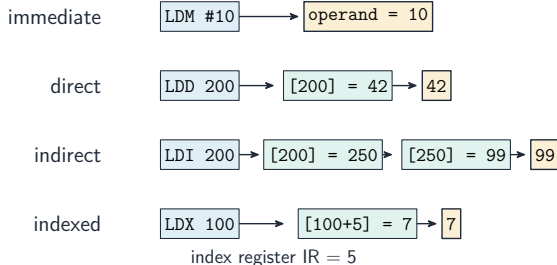
translate mnemonics to machine code, resolving labels to addresses

why two passes

to handle **forward references** 前向引用 – a jump to a label that is defined **later** in the source

Pass one builds the symbol table; pass two writes the code. One pass alone cannot know an address it has not yet reached.

Addressing modes



How the CPU finds the operand:

- **immediate addressing** 立即寻址: the operand *is* the value
- **direct addressing** 直接寻址: the value at that address
- **indirect addressing** 间接寻址: the address of an address
- **indexed addressing** 变址寻址: address + an index register
- **relative addressing** 相对寻址: an offset from the current position

Worked example: trace the program

```
LDD 200  
ADD 201  
STO 202
```

[200] = 5

[201] = 7

[202] = ?

LDD load ■ ADD add ■ STO store

after...	ACC	[202]
LDD 200	5	–
ADD 201	12	–
STO 202	12	12

A **trace table** 跟踪表 records every register after **each** instruction – exactly what exam trace questions ask for.

4

Binary shifts and masking

Binary shifts

A **logical shift** 逻辑移位 fills with 0:

- left by 1 = $\times 2$
- right by 1 = $\div 2$ (integer)

An **arithmetic** right shift keeps the sign bit.

LSL #1 00001011 $\longrightarrow$ 00010110 $\times 2$ (0 in on the right)

LSR #1 00001011 $\longrightarrow$ 00000101 $\div 2$ (0 in on the left)

ASR #1 10110100 $\longrightarrow$ 11011010 sign bit kept (stays negative)

Logical vs arithmetic right shift

Both move every bit one place to the right. They differ only in **what enters on the left** — and that single bit decides whether a negative number survives.

start

1	1	1	1	0	0	0	0
---	---	---	---	---	---	---	---

 = 240 unsigned, -16 signed

LSR #1

0	1	1	1	1	0	0	0
---	---	---	---	---	---	---	---

 = 120 halves the **unsigned** value

ASR #1

1	1	1	1	1	0	0	0
---	---	---	---	---	---	---	---

 = -8 halves the **signed** value

The two results differ in **one bit** — the one that entered on the left. **LSR** always brings in a 0; **ASR** copies the sign bit, so a negative number stays negative and $-16 \div 2$ comes out right.

ASR copies the **sign bit**, so a negative number stays negative.

Bit masking

One **bit** 位 per signal; use a **mask** 掩码:

- **set**: OR a 1 in that bit
- **clear**: AND a 0 in that bit
- **toggle**: XOR a 1 in that bit

set bit 2

$$\begin{array}{r} 01001000 \\ \text{OR } 00000100 \\ \hline = 01001100 \end{array}$$

clear bit 6

$$\begin{array}{r} 01001000 \\ \text{AND } 10111111 \\ \hline = 00001000 \end{array}$$

toggle bit 3

$$\begin{array}{r} 01001000 \\ \text{XOR } 00001000 \\ \hline = 01000000 \end{array}$$

Bit masking: the three operations

test bit n

R AND the mask, then check whether the result is **non-zero**

set bit n

R OR the mask – ones in the mask force ones in the result

clear bit n

R AND the *inverted* mask – zeros force zeros, ones leave the rest alone

flip bit n

R XOR the mask

building a mask

a 1 in the position you care about and 0 everywhere else – 00001000 for bit 3

where it is used

monitoring and control: one byte can carry eight independent sensor or actuator states

Each operation is chosen for what it leaves *unchanged*. AND clears, OR sets, XOR flips – and in every case the other bits survive.

Worked example – four addressing modes

Memory: location 200=250, 250=99,
105=7. **The index register holds 5. What is
in the accumulator after each instruction?**

- LDM #200 – **immediate**: the operand *is* the number. Accumulator = **200**.
- LDD 200 – **direct**: go to location 200 and take what is there. = **250**.
- LDI 200 – **indirect**: location 200 holds 250, which is another *address*, so go on to 250. = **99**.
- LDX 100 – **indexed**: add the index register, $100 + 5 = 105$, and read location 105. = **7**.

Count the hops: immediate none, direct one, indirect two, indexed one after an addition.

Exam tips

- Learn the **fetch-execute cycle** in register-transfer terms (PC, MAR, MDR, CIR, ACC) and what increments the PC.
- Name each register's job; the **address bus is one-way**, the data bus is two-way.
- Distinguish the **addressing modes** (immediate, direct, indirect, indexed) – a frequent question.
- Explain how clock speed, number of cores, cache size and word length affect **performance**.
- For a **binary shift**, state whether it is logical or arithmetic; a left shift multiplies by 2, a right shift divides by 2.

5

Recap

Topic 4 – key takeaways

1

Von Neumann

one memory for program & data

2

Buses

address (one-way), data, control

3

Cycle

fetch → decode → execute;
interrupts pause it

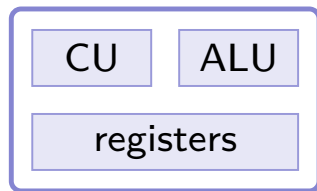
4

Assembly

mnemonics; addressing modes;
shifts & masks

Check yourself

- 1 Which register holds the next instruction's address?
- 2 Which bus is one-way?
- 3 What does an interrupt make the CPU do first?
- 4 00000110 after LSL #1 – value?



Answers 1. the PC 2. the address bus 3. finish the current instruction, then save state 4. $00001100 = 12$