Computer Hardware

BCS1110

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📅 Week 1 Lecture

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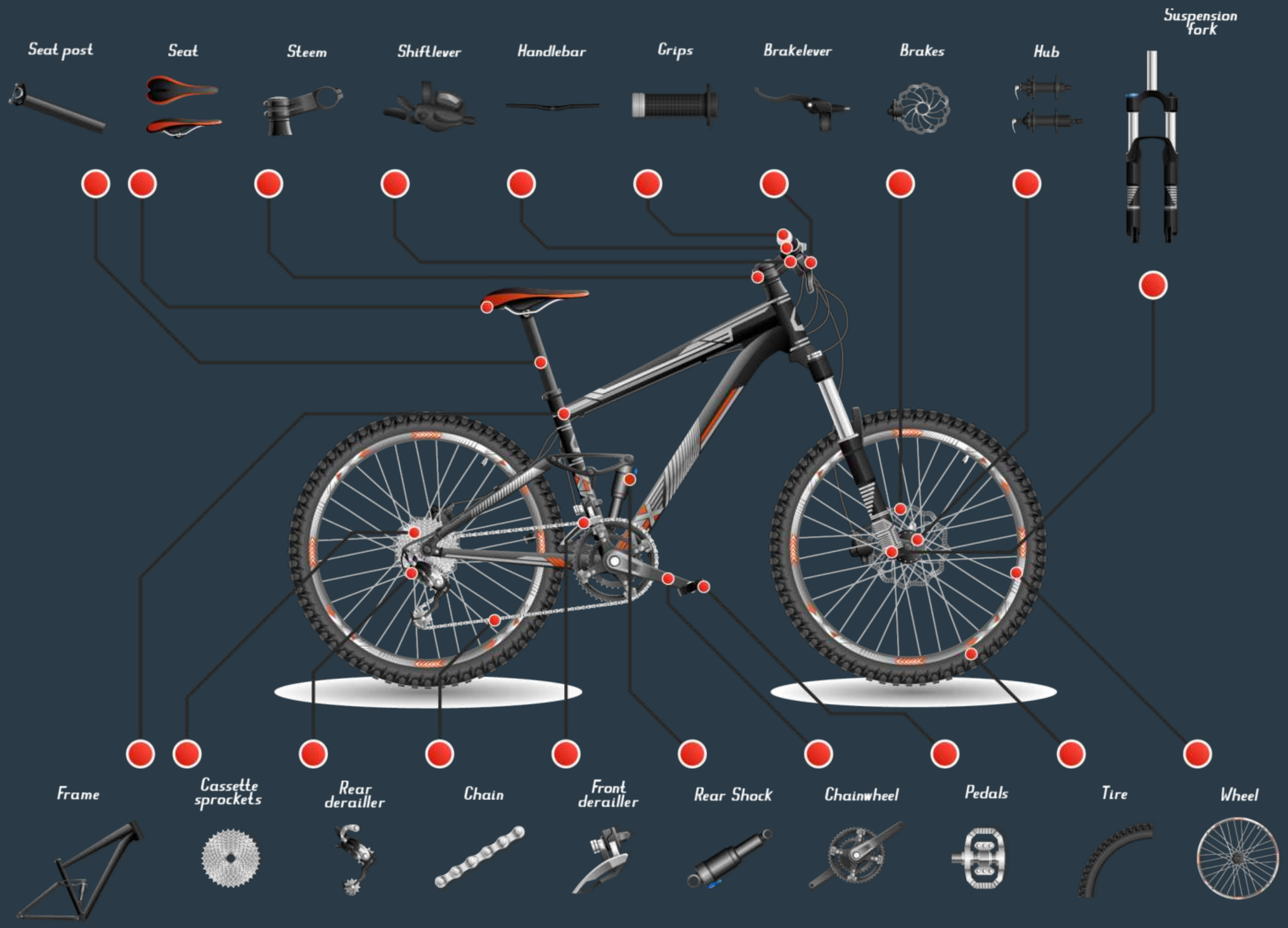
📍 EPD150 MSM Conference Hall

Plan for today

- Building blocks of a computer
- Abstraction in Hardware
- Arithmetic Logic Unit
- Computing Hardware Overview

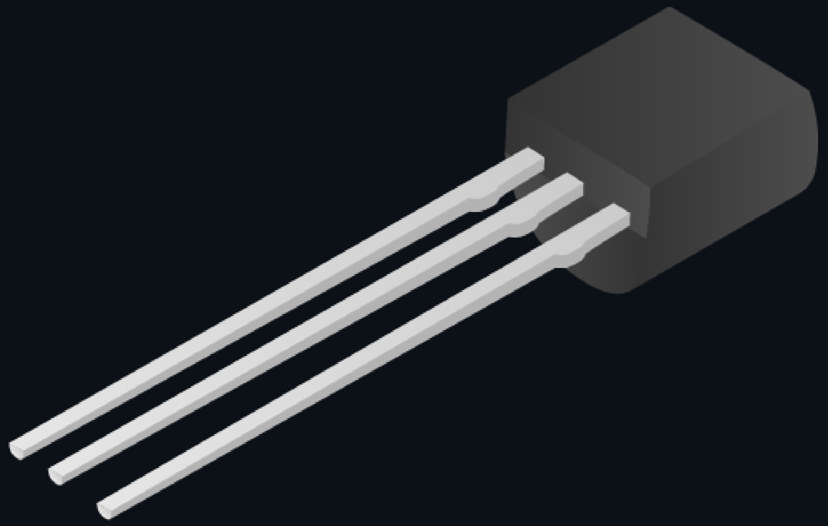

Seat post
Seat
Steem
Shiftlever
Handlebar
Grips
Brakelever
Brakes
Hub
Suspension fork
Frame
Cassette sprockets
Rear derailler
Chain
Front derailler
Rear Shock
Chainwheel
Pedals
Tire
Wheel

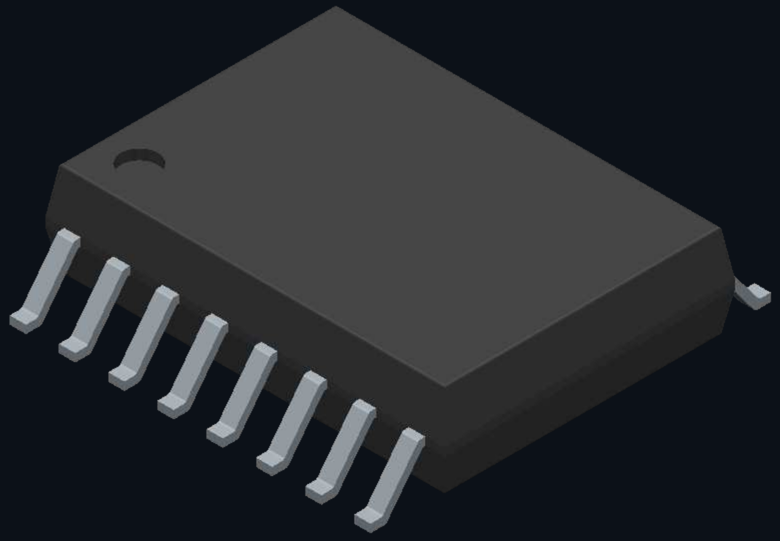
Roller Chain

Building blocks of a computer

Part 1/4

Computers are constructed using individual **transistors**, which form **circuits** that enable various operations and logic

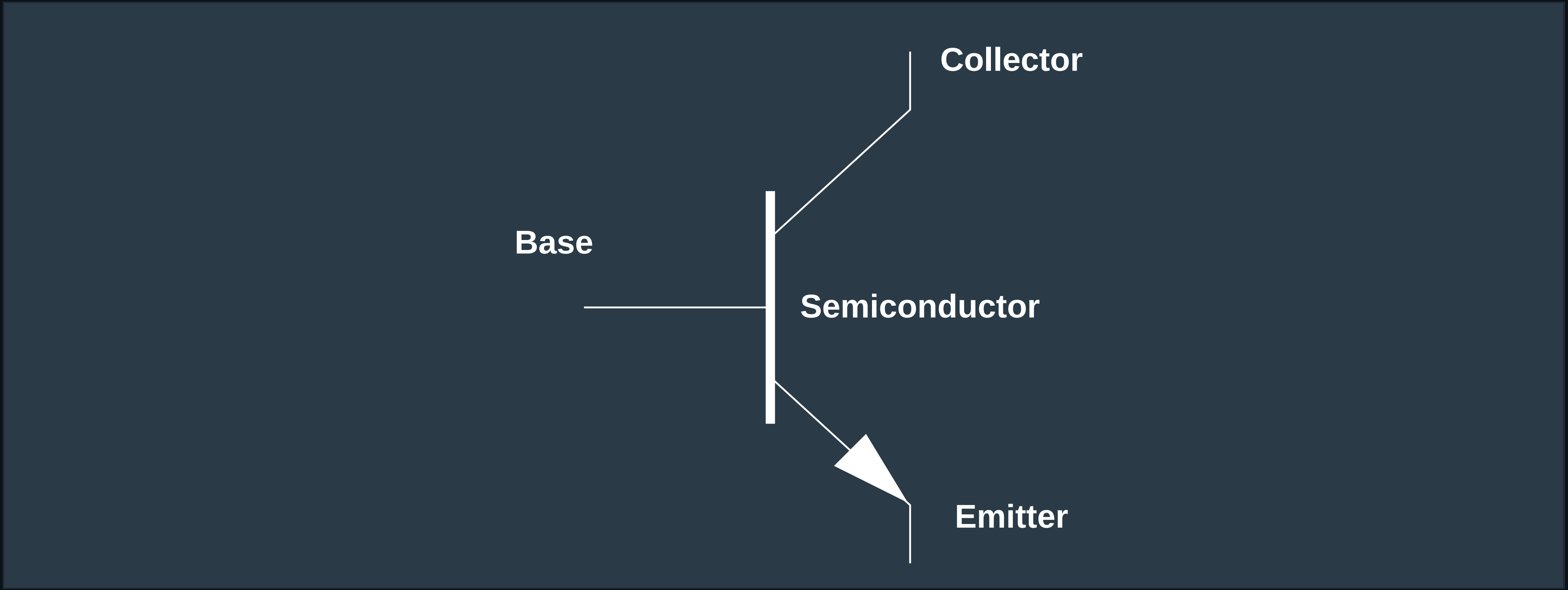




Transistors

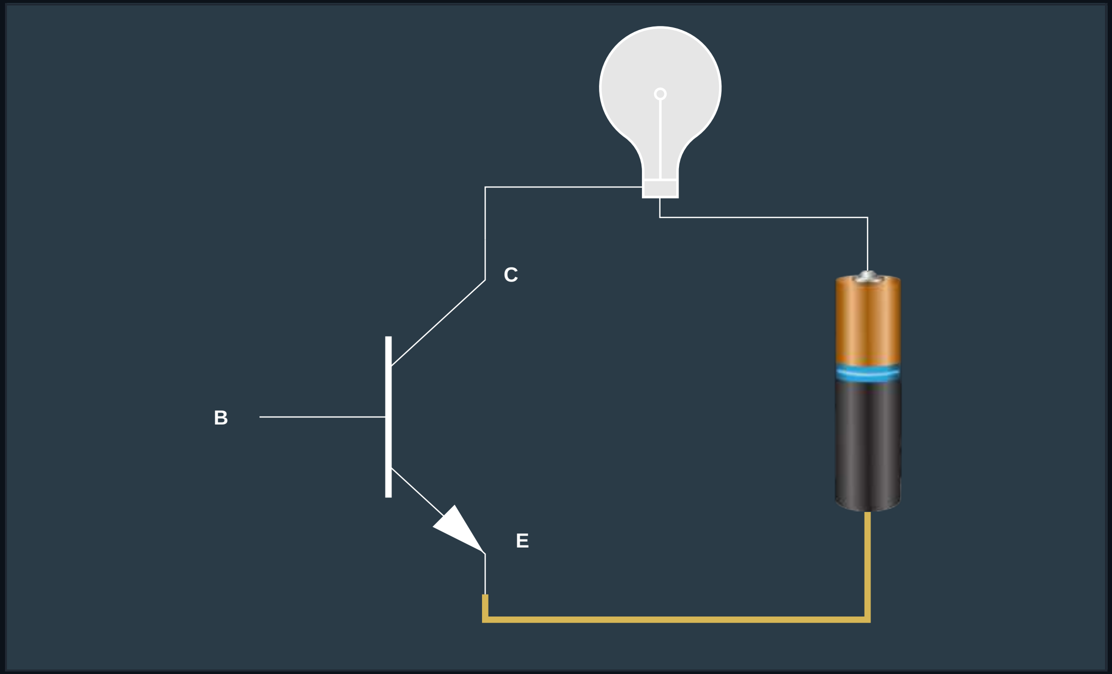
A transistor is an electronic device made of semiconductor materials that can amplify or switch electronic signals and electrical power

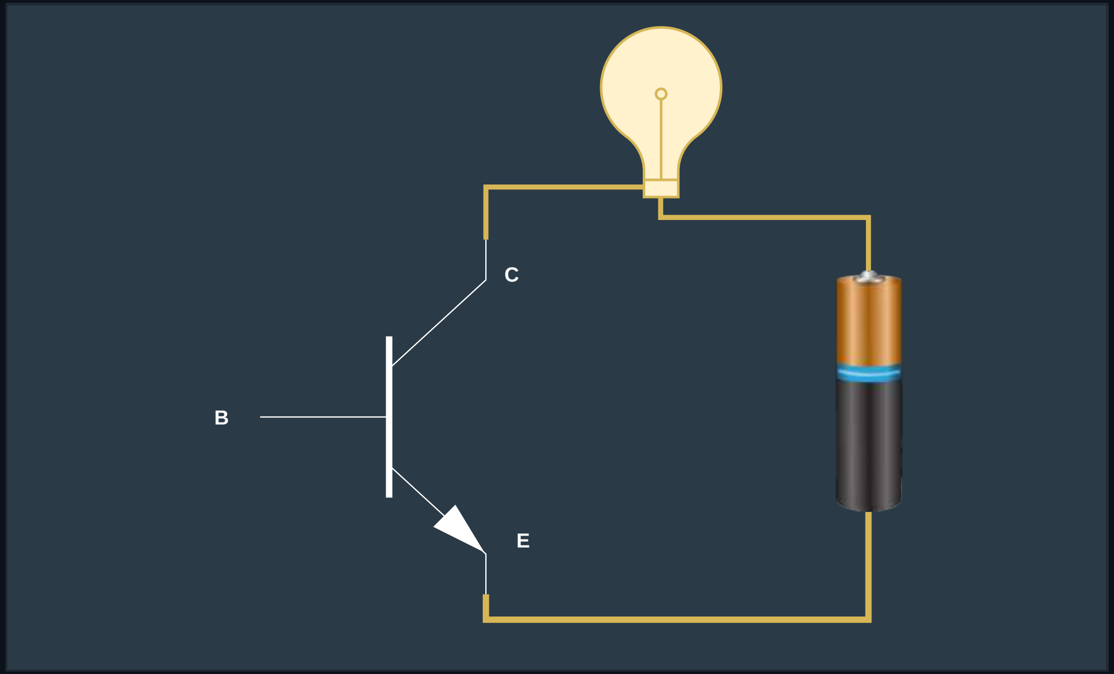
- Semiconductors are materials that have properties in between **conductors** (which allow the flow of electricity easily such as metals) and **insulators** (which block the flow of electricity such as ceramics)

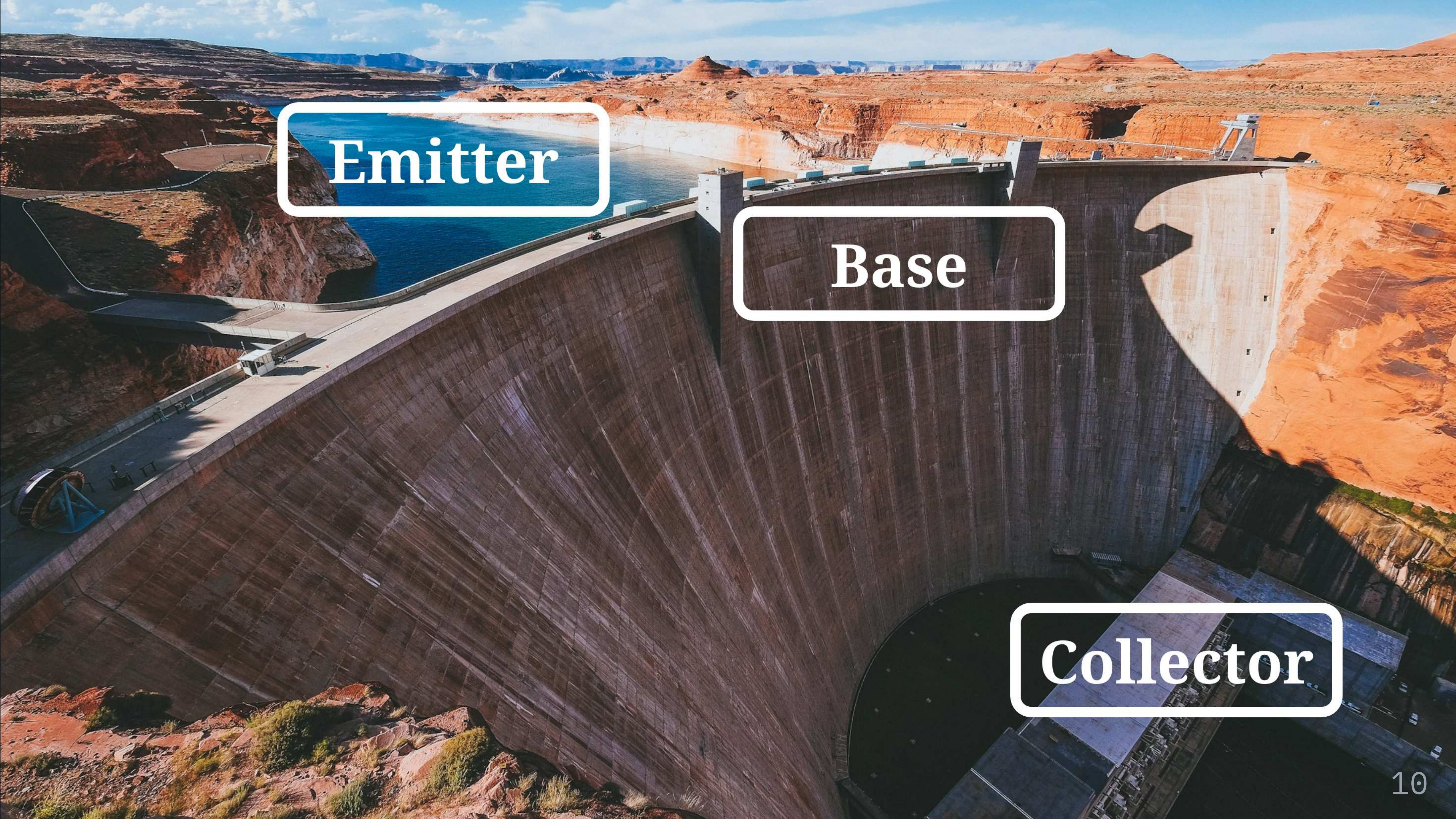


- It consists of three layers (**emitter, base, and collector**) and can control the flow of current by applying a small input signal
  - **Emitter** → Pump that pushes carriers into the transistor
  - **Base** → Narrow valve that regulates the flow
  - **Collector** → Reservoir that receives and uses the flow

If enough voltage is applied to the base electrode, current can flow between emitter and collector and the transistor can like a switch ⏯️



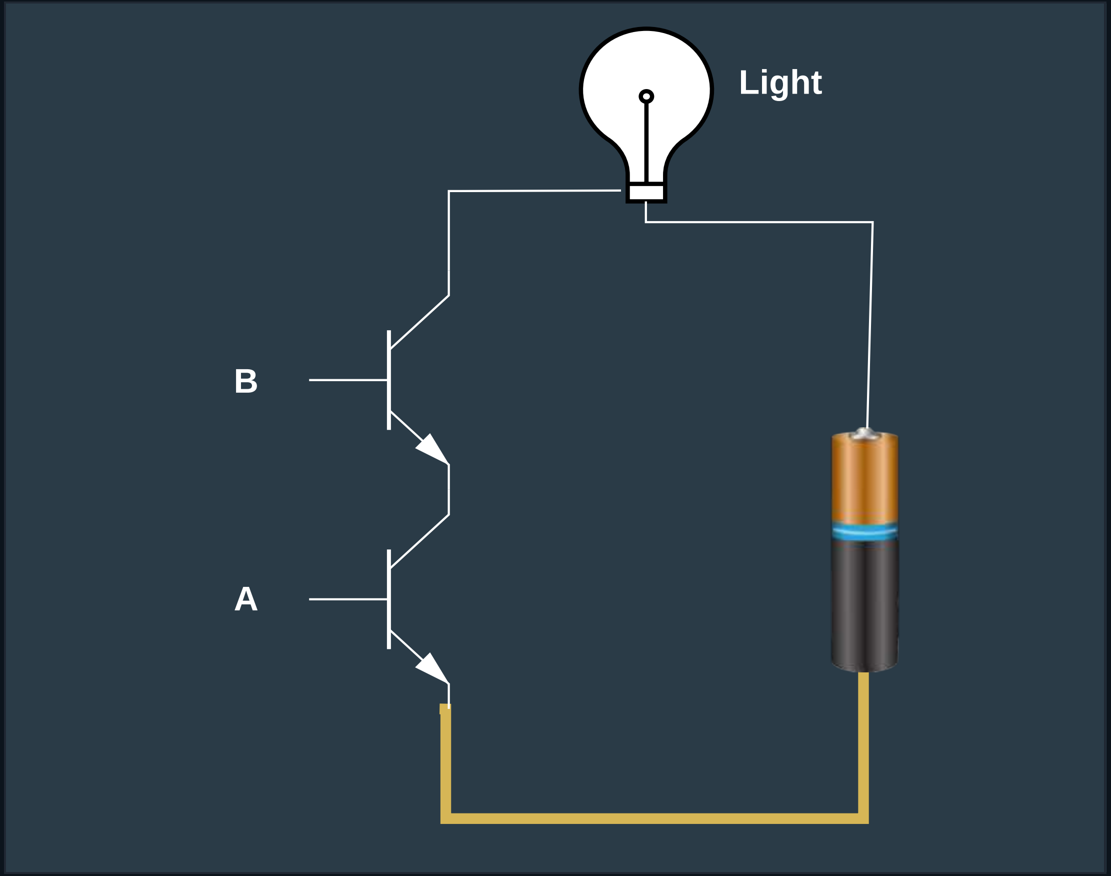



Emitter
Base
Collector

iPhone 16

- Has over **20,000,000,000** transistors (switches)
- to count from 1 to 16B would take you about *one thousand and seventeen years*!

Combining Transistors



Truth Table

> You can do quite a lot when you combine these transistors

A	B	Light
True	True	True
True	False	False
False	True	False
False	False	False

Current and Bits

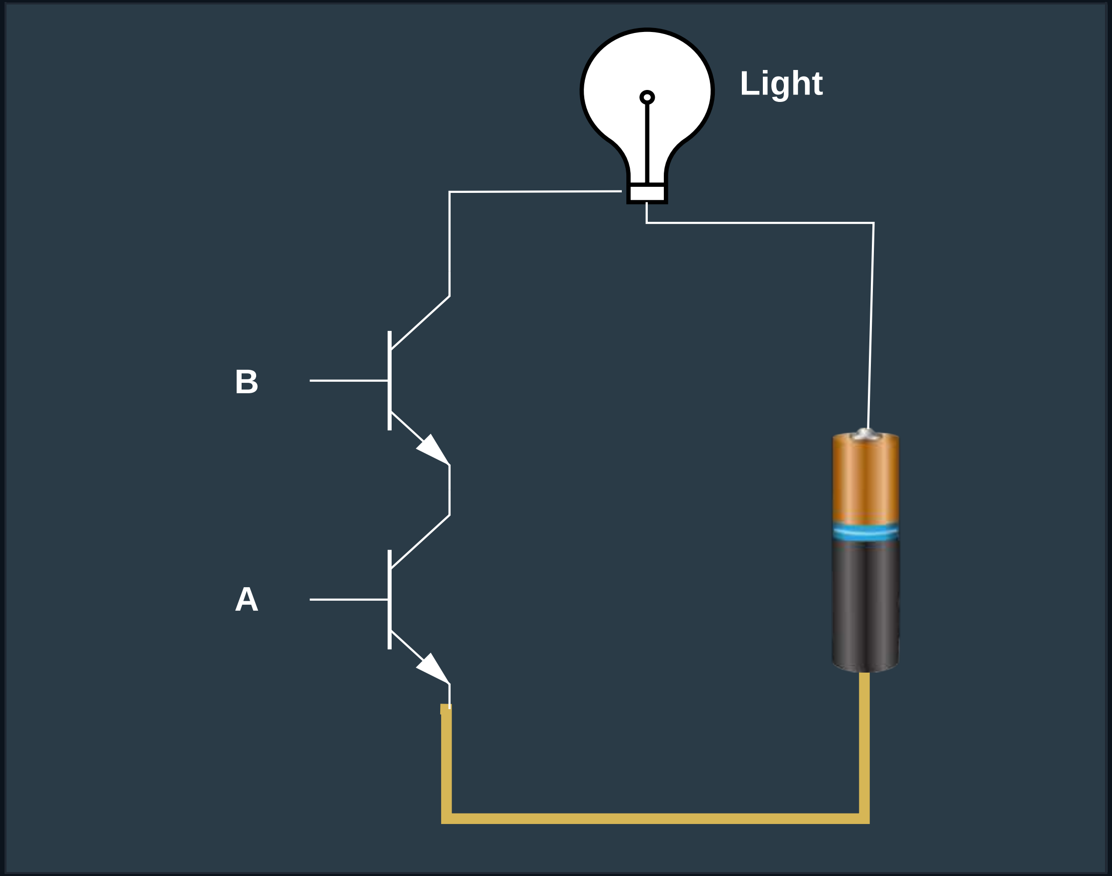
Current is the flow of electric charge through a conductor, like a wire, measured in units of amperes (A)

- When current flows: 1 ✅
- When current is not flowing: 0 ⛔

AND Gate

Truth Table

A	B	Light
True	True	True
True	False	False
False	True	False
False	False	False

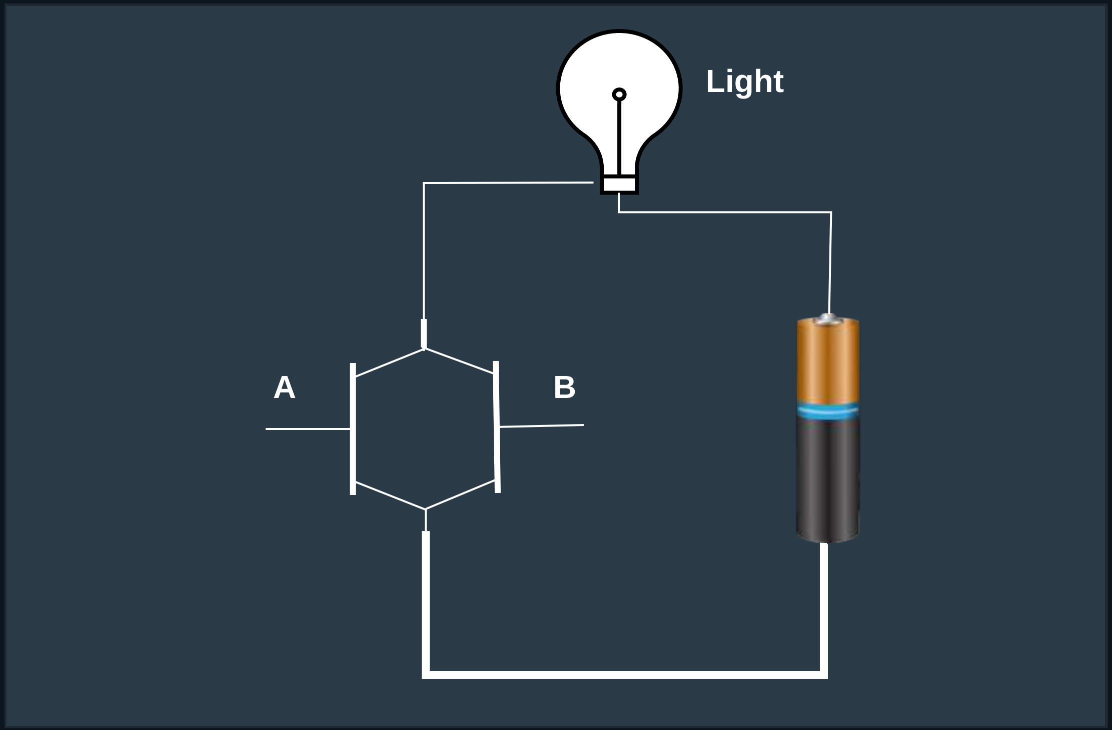


Combining Transistors

You can do quite a lot when you combine these transistors

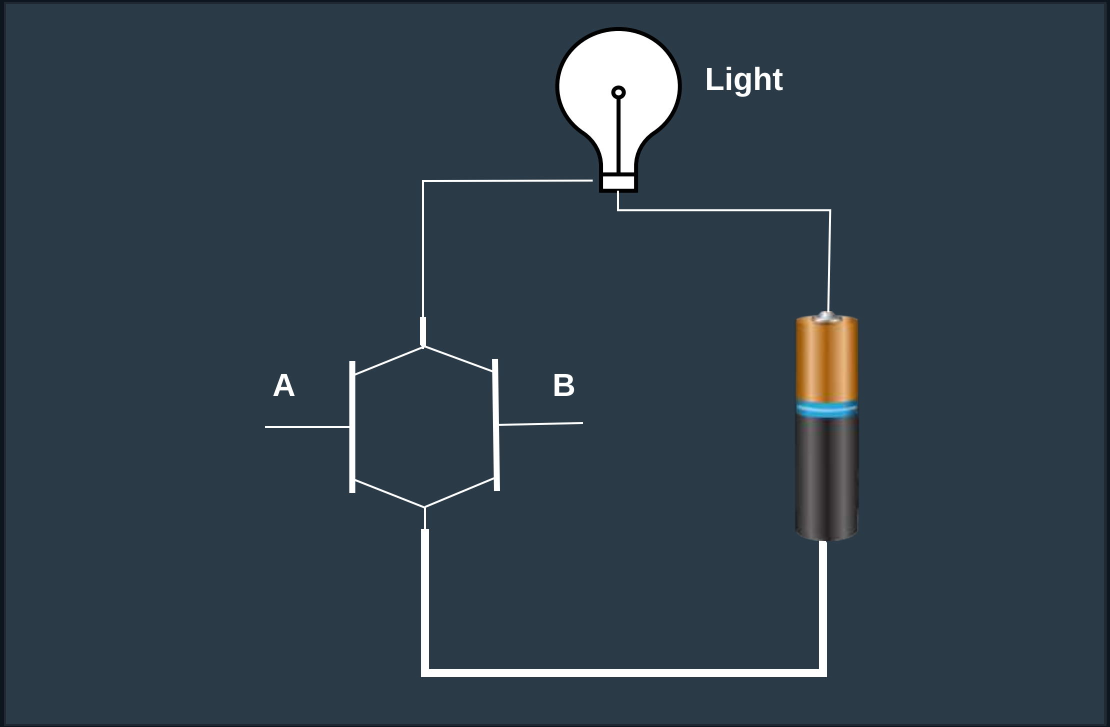
What else can we do with these transistors?

- *Put them next to each other!*



- This is an **OR gate**

OR Gate



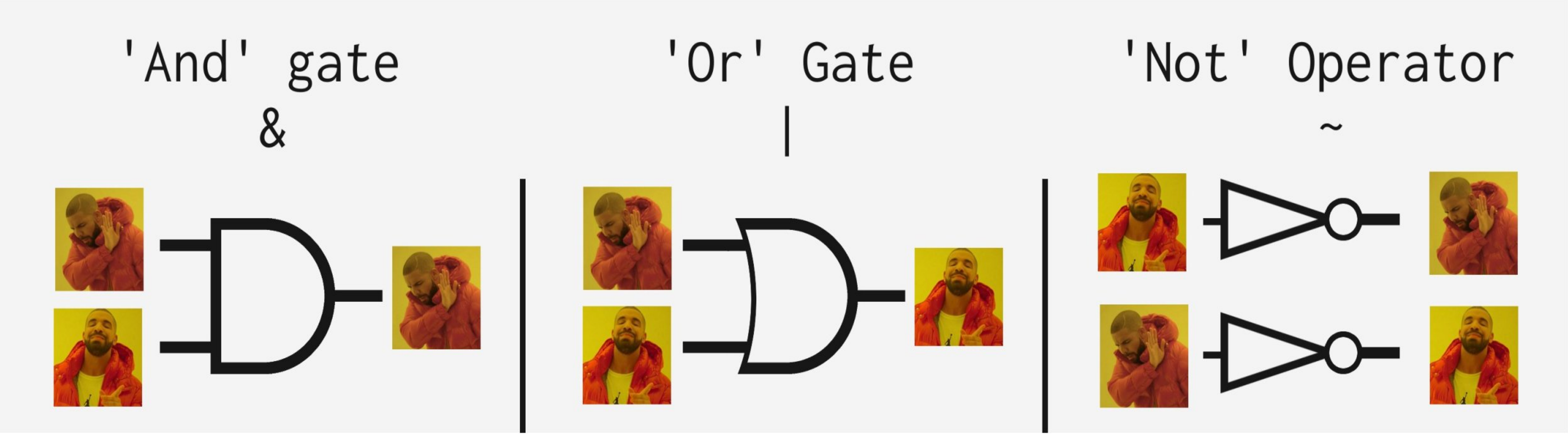
There are many ways of drawing this

Truth Table

A	B	Light
True (1)	True (1)	True (1)
True (1)	False (0)	True (1)
False (0)	True (1)	True (1)
False (0)	False (0)	False (0)

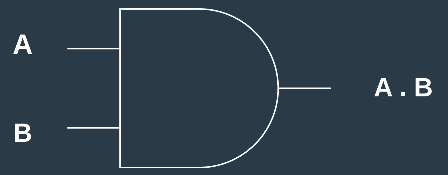
There is a lot that goes on with a transistor and gates, we only scratch the surface in this course

Drake's Logic Gates



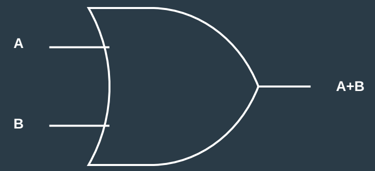
The Four Basic Gates and Their Symbols

AND Gate



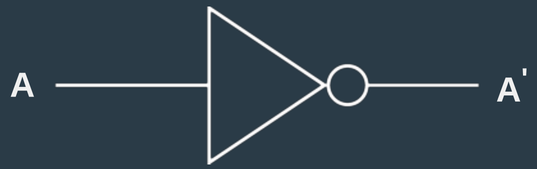
A	B	Output
1	1	1
1	0	0
0	1	0
0	0	0

OR Gate



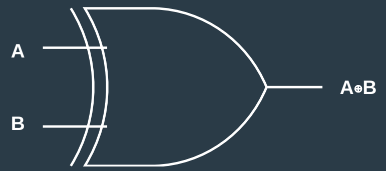
A	B	Output
1	1	1
1	0	1
0	1	1
0	0	0

NOT Gate



A	Output
1	0
0	1

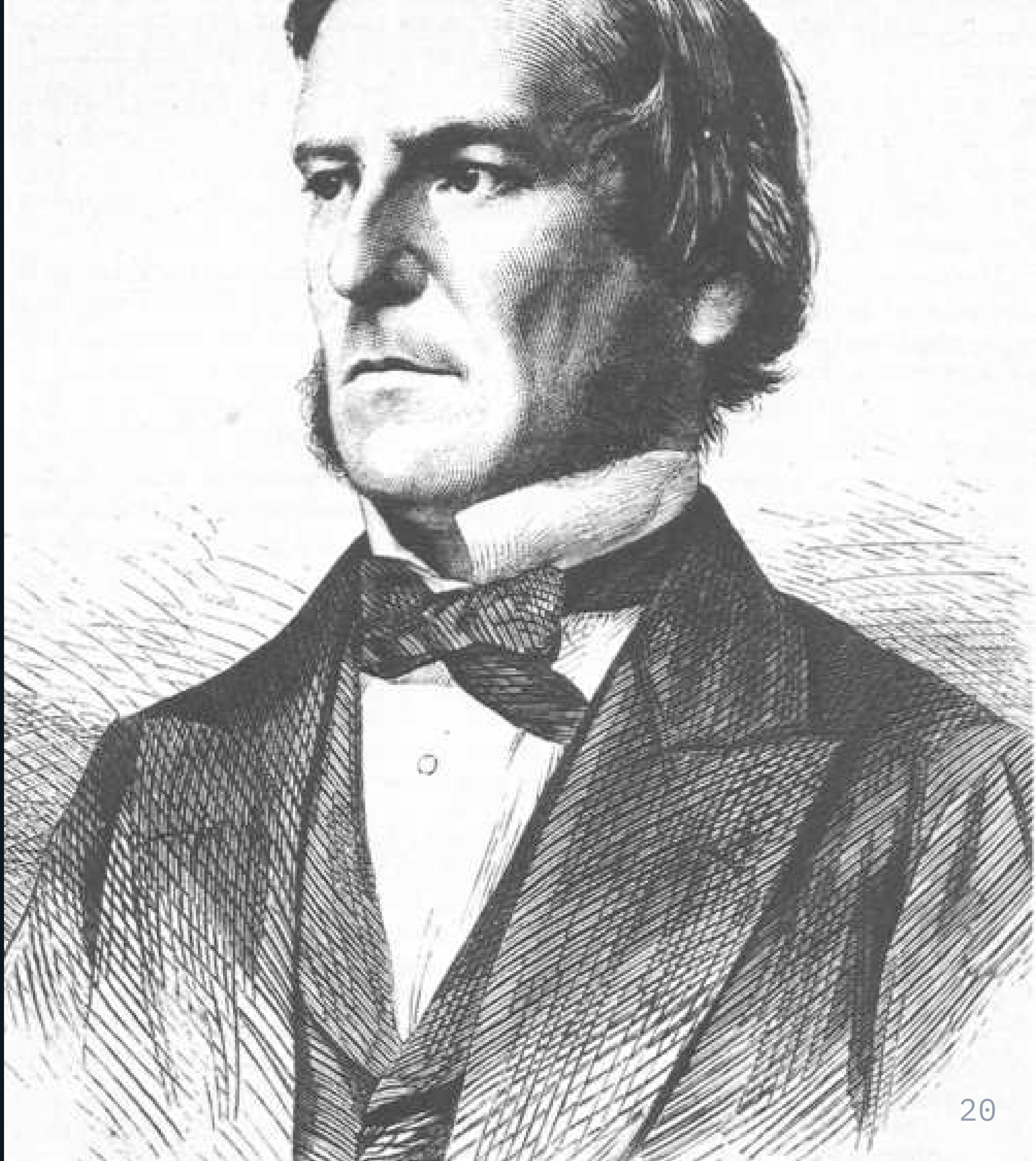
XOR Gate



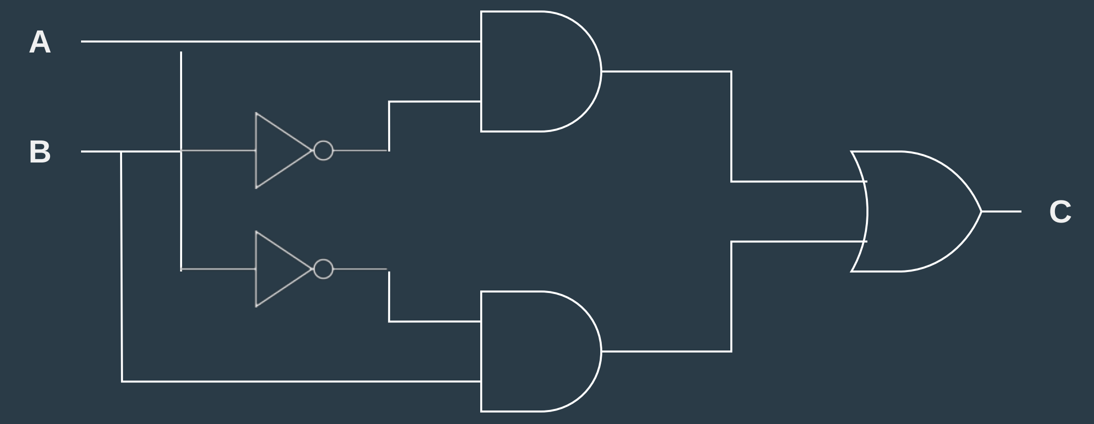
A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

Boolean Algebra

- Boolean algebra is a mathematical system that deals with true and false values, represented as **1** and **0**
- It provides a framework for manipulating logical expressions using operators like **AND**, **OR**, and **NOT**
- **Boolean Expression for XOR Gate**: $A.B' + A'.B$



Combinational Circuits



> $XOR : A.B' + A'.B$

Abstraction in Hardware

Part 2/4

Abstraction in hardware design

- Map hardware devices^ to Boolean logic
- Design more complex devices in terms of logic, not electronics
- Conversion from logic to hardware design may be automated

^: *Such as the combinational gates you just looked at*

Some Background: Binary Number System

- Humans use Decimal number system
  - $7809 = 7 \times 10^3 + 8 \times 10^2 + 0 \times 10^1 + 9 \times 10^0$
  - Each digit is from $0, 1, 2, 3, 4, 5, 6, 7, 8, 9$ - Base 10
  - (We happen to have ten fingers 🤲)
- Computers use Binary number system
  - $(1101) = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 13$
  - Each binary digit (bit) is $0, 1$ - Base 2
  - (IT people have 2 fingers [not really!])

Convert Decimal Number 🔟 to Binary 2️⃣

Conversion steps:

- Divide the number by 2
- Get the integer quotient for the next iteration
- Get the remainder for the binary digit
- Repeat the steps until the quotient is equal to 0

Example:

Division by 2	Quotient	Remainder	Bit #
$13/2$	6	1	0
$6/2$	3	0	1
$3/2$	1	1	2
$1/2$	0	1	3

So $13_{10} = 1101_2$

Convert Binary 2️⃣ to Decimal Number 🔟

- For binary number with n digits: $d_{n-1} \ldots d_3 d_2 d_1 d_0$
- The decimal number is equal to the sum of binary digits $(d\, n)$ times their power of 2 (2^n): $decimal = d_0 \times 2^0 + d_1 \times 2^1 + d_2 \times 2^2 + ..$

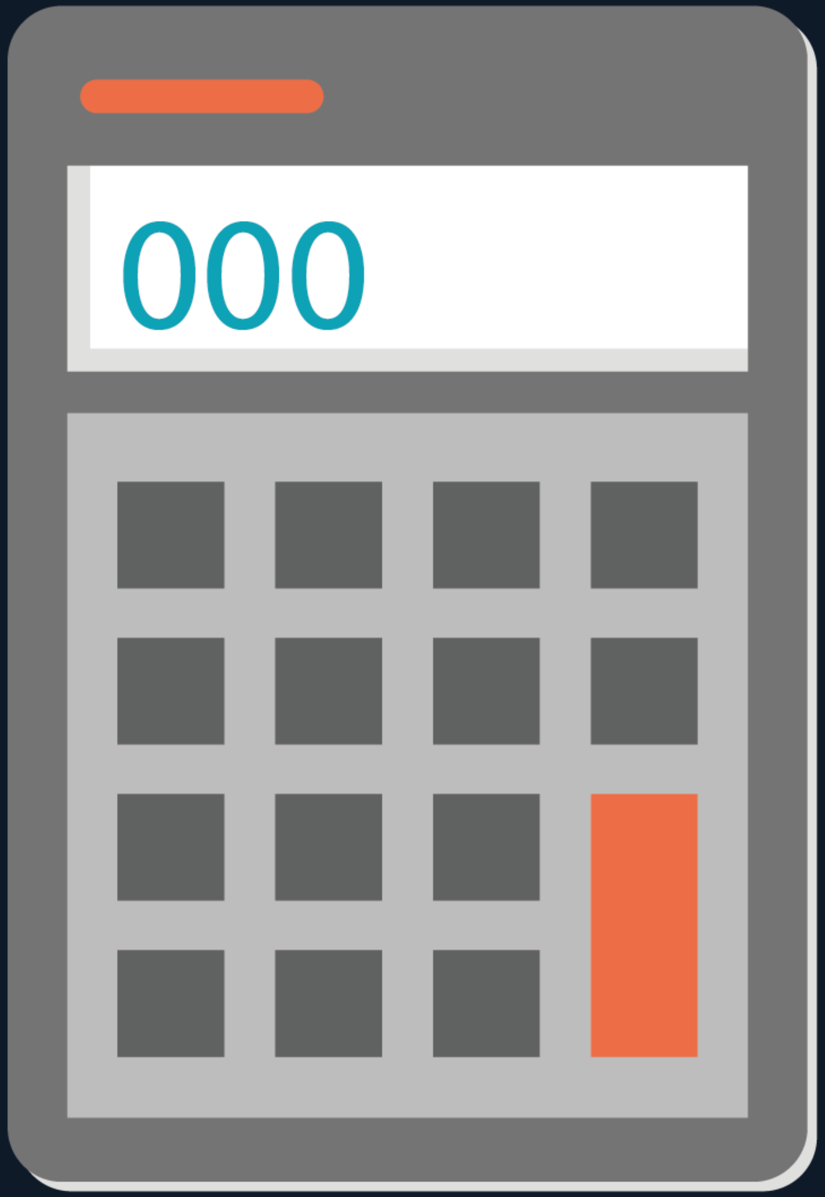
Example:
Find the decimal value of 111001_2:

binary number:	**1**	**1**	**1**	**0**	**0**	**1**
power of 2:	2^5	2^4	2^3	2^2	2^1	2^0

> $1110012 = 1 \cdot 2^5 + 1 \cdot 2^4 + 1 \cdot 2^3 + 0 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0 = 57_{10}$

Creating a calculator capable of adding two numbers using a combinational circuit

Part 3/4



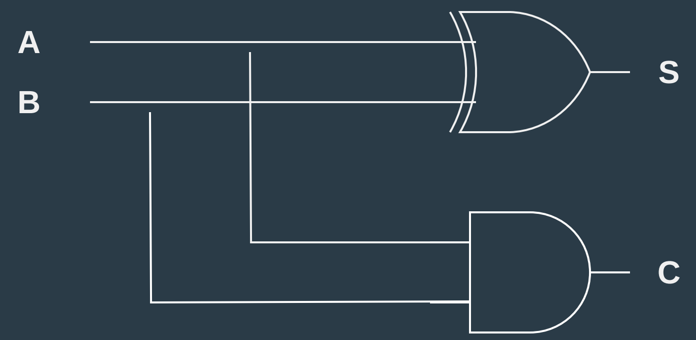
Easy Case: 2 Digit Addition

A	B	Output (A+B)	C S
0	0	0	0 0
0	1	1	0 1
1	0	1	0 1
1	1	2	1 0

> For now, we only add two digits without a carry forward number

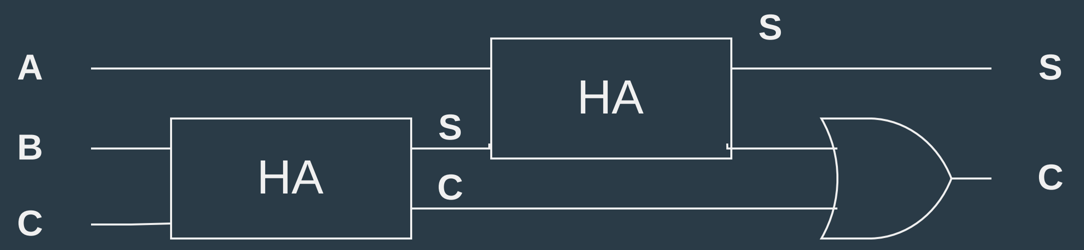
You need one **AND** gate and **XOR** gate to get this output

Half Adder (HA)



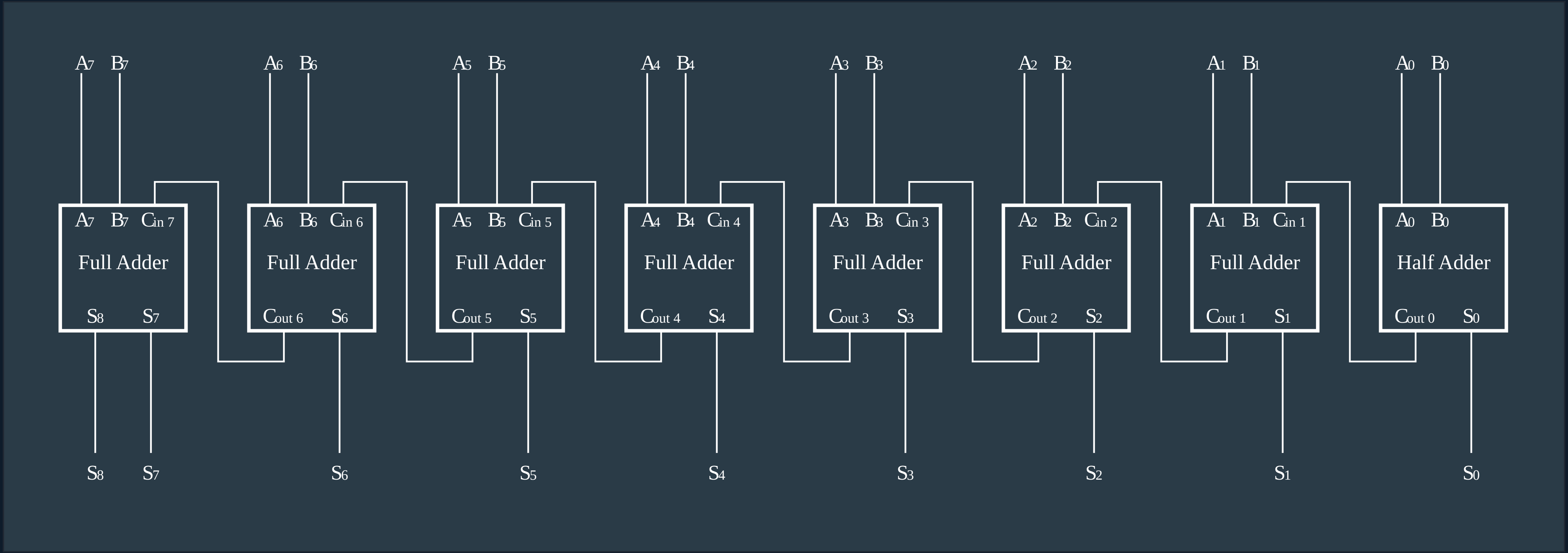
A	B	C S
0	0	0 0
0	1	0 1
1	0	0 1
1	1	1 0

More abstraction (Handling the carry bit)

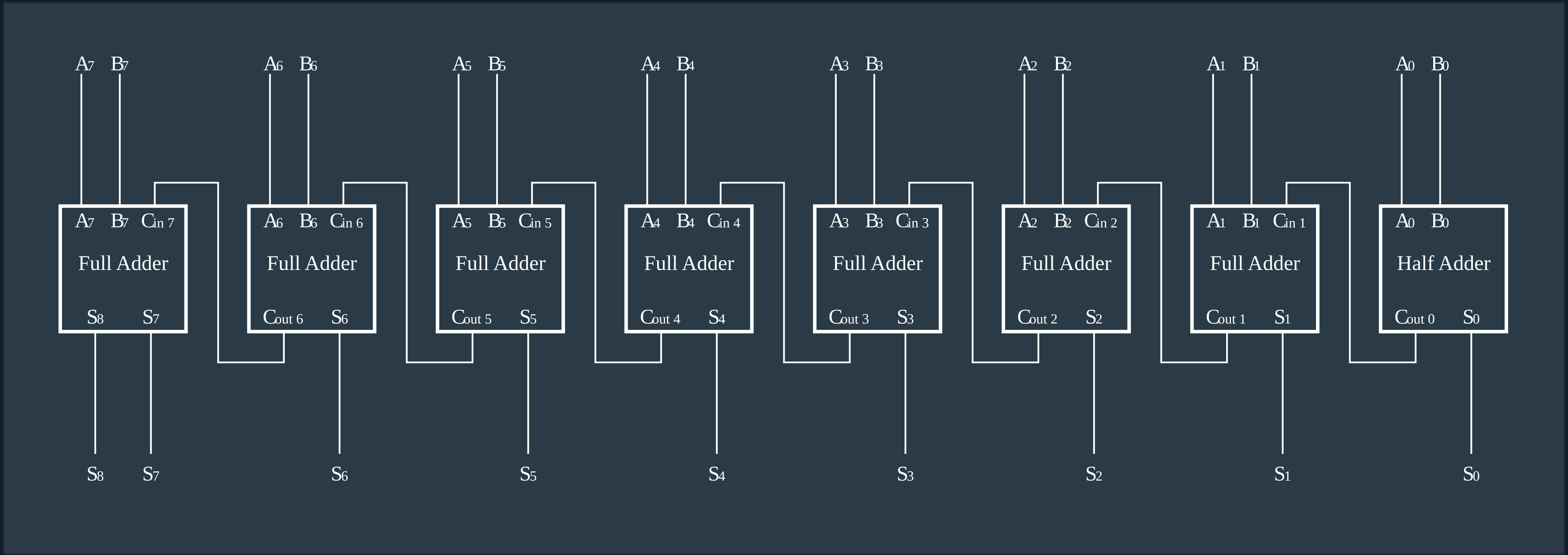


A	B	C	C (Carry)	S (Sum)
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

8 Bit Full Adder



^This is the most complex circuit we will look at



Calculate: $153 + 75$

Binary: $10011001 + 01001011$

+−×÷

- You already know how to add
- You can also build subtractor^
- You can substitute multiplication with addition ($5 * 4$ is $5 + 5 + 5 + 5$)
- You can substitute division with subtraction

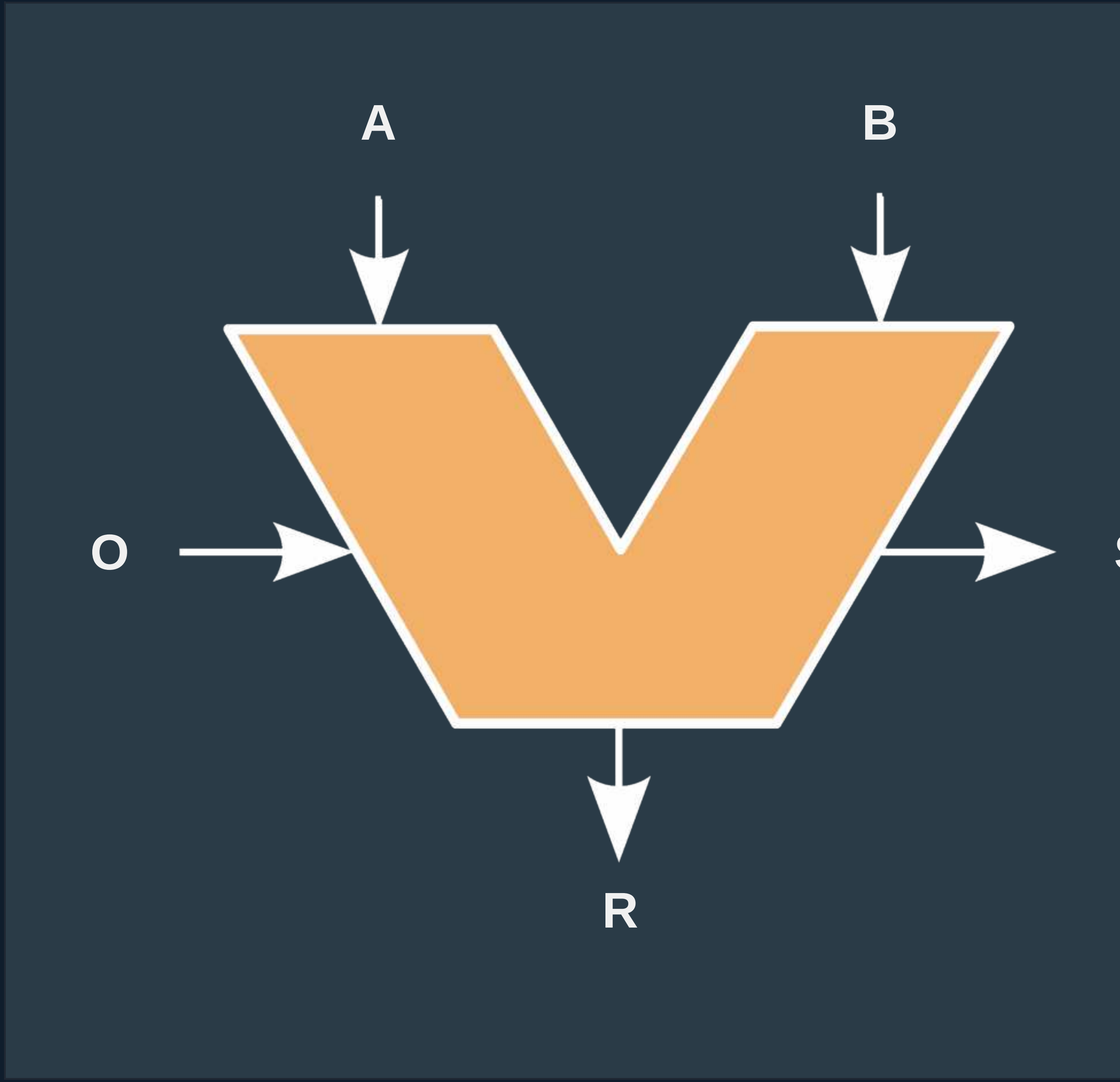
^*We do not cover subtractors in this course*

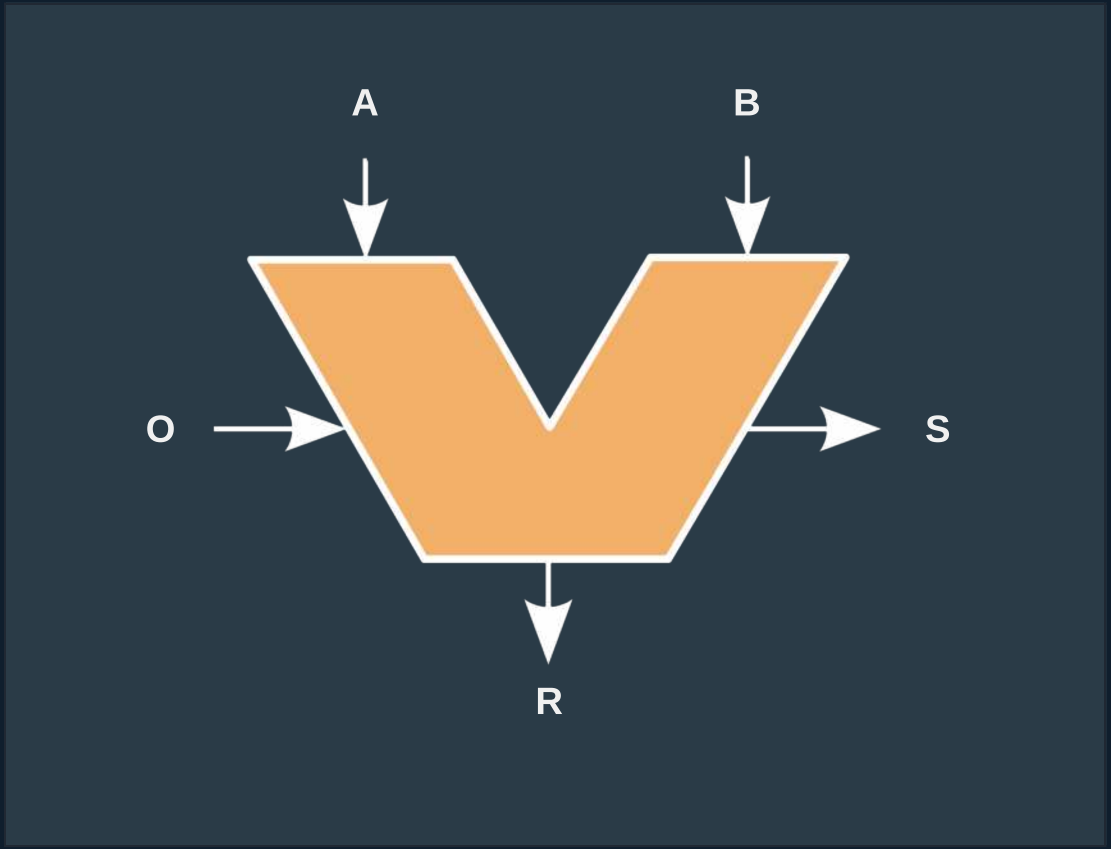
Arithmetic Logic Unit

Part 3/4

Arithmetic Logic Units

The ALU combines multiple full adders and additional logic circuits to perform arithmetic and logical operations (**AND**, **OR**, **XOR** and even more) 🪄



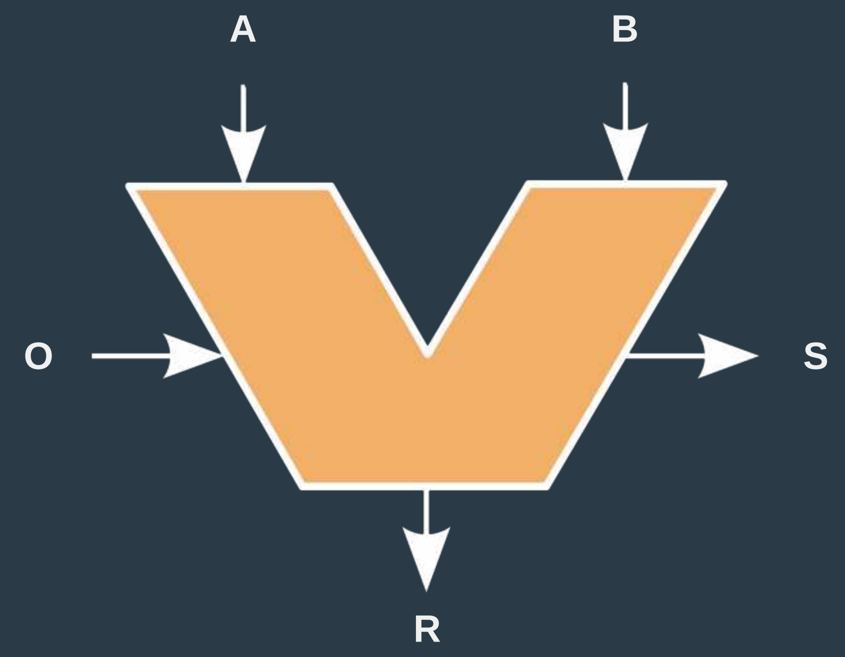


- What happens when you add 10000000 to 10000000?
- Both the **zero** and **overflow** flags are on here as adding these numbers result in a number greater than 8 bits.

Opcode

Opcode	Instruction
0000	A AND B
0001	A OR B
0010	A XOR B
0010	NOT A
0100	ADD A+B
0101	SUB A-B

- O = 0100
- A = 00001010 & B = 01011101
- R = **?**



- The answer is **0110111**

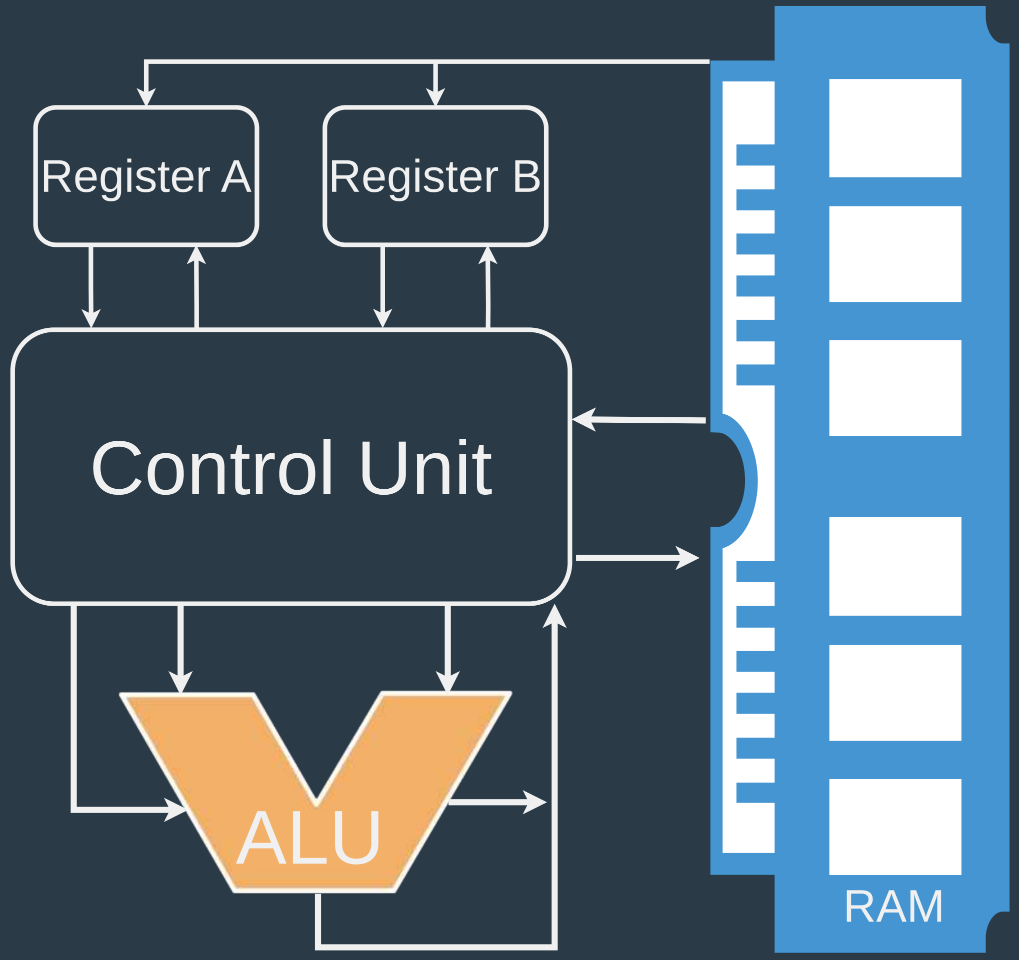
What do you do when you have to perform multiplication?

(Or anything that requires more than one instruction)

More Abstraction CPU

Central Processing Unit

Part 3/4


Register A
Register B
Control Unit
ALU
RAM

Control Unit

- The control unit receives instructions from memory and controls the flow of data within the CPU
- It interprets opcode (operation code) to determine the operation to be performed by the ALU or memory

Memory and Random Access Memory (RAM)

- Registers are temporary storage units within the CPU that hold data during processing
- **RAM** (Random Access Memory) stores data and instructions that the CPU accesses during execution
- Data and instructions are loaded from RAM into the CPU registers for processing

Instruction Set

- Instruction sets are collections of binary-coded instructions that a computer's CPU can execute
- These instructions represent specific operations like arithmetic, memory access, and control flow
- There are two main types: RISC with simple instructions for faster execution and CISC with more complex instructions to reduce program size

> Different processors use specific instruction sets optimized for various applications and performance requirements

Instruction Set Example

Intruction	Opcode	Memory Location	Description
ADD	0 0 0 1	2* 2-bit register ID	Add two numbers^
AND	0 0 1 0	2* 2-bit register ID	Add operation
LOAD_A	0 1 1 0	4-bit memory address	Load memory address in register A
LOAD_B	0 1 1 1	4-bit memory address	Load memory address in register B
STORE_B	1 0 1 1	4-bit memory address	Write register A into memory address
HALT	0 1 0 0	N/A	Halt the program

[^Result is stored in the second register]

Let’s write your first program

Program to add two numbers

1. Load numbers into registers from RAM
    - 1.1 Locate the number in RAM (use LOAD_A & LOAD_B Opcode)
        - LOAD_A + address 1 -> 0110 1110
        - LOAD_B + address 2 -> 0111 1111
2. Add the values at register A and B
   - Add opcode + 2 register IDs -> 0001 01 10
3. Save our result into the RAM
   - STORE_B + memory address -> 1011 1101
4. Stop the program
   - HALT -> 0100

Congratulations! You just wrote your first program in machine language (code)

```
0110 1110
0111 1111
0001 01 10
1011 1101
0100
```

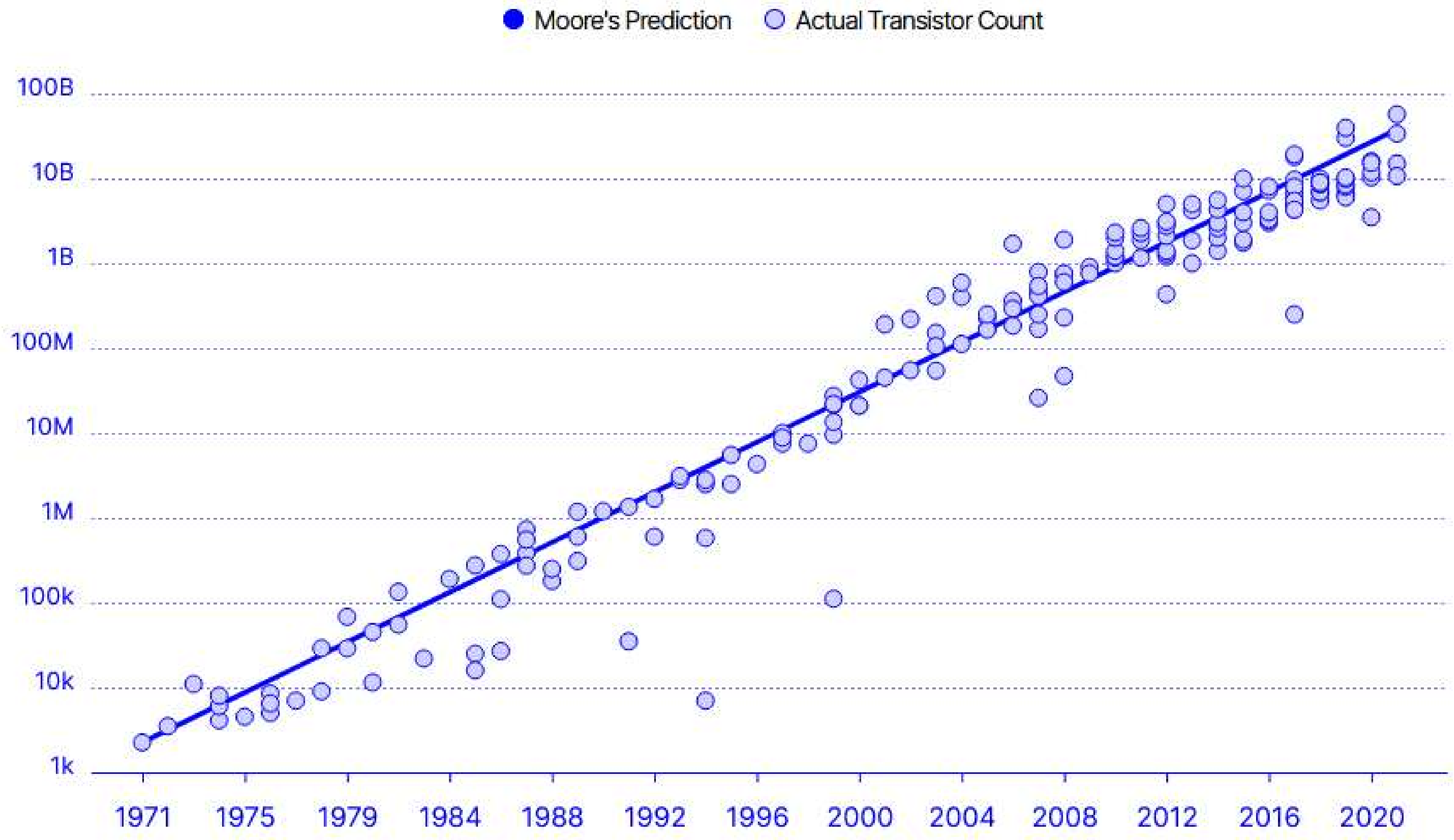
Machine Language

- Machine language consists of binary instructions (1s and 0s) that the CPU can directly execute
- Each instruction is represented by an opcode, specifying the operation, and memory addresses for data access

> Very difficult for humans to work with machine code! **->** Use abstraction - high level programming languages such as C, C++ and Java

Moore's Law

"The number of transistors in a dense integrated circuit (IC) doubles about every two years."



:(

Your PC can't even

Computer Dissection

🖥️ 🪛

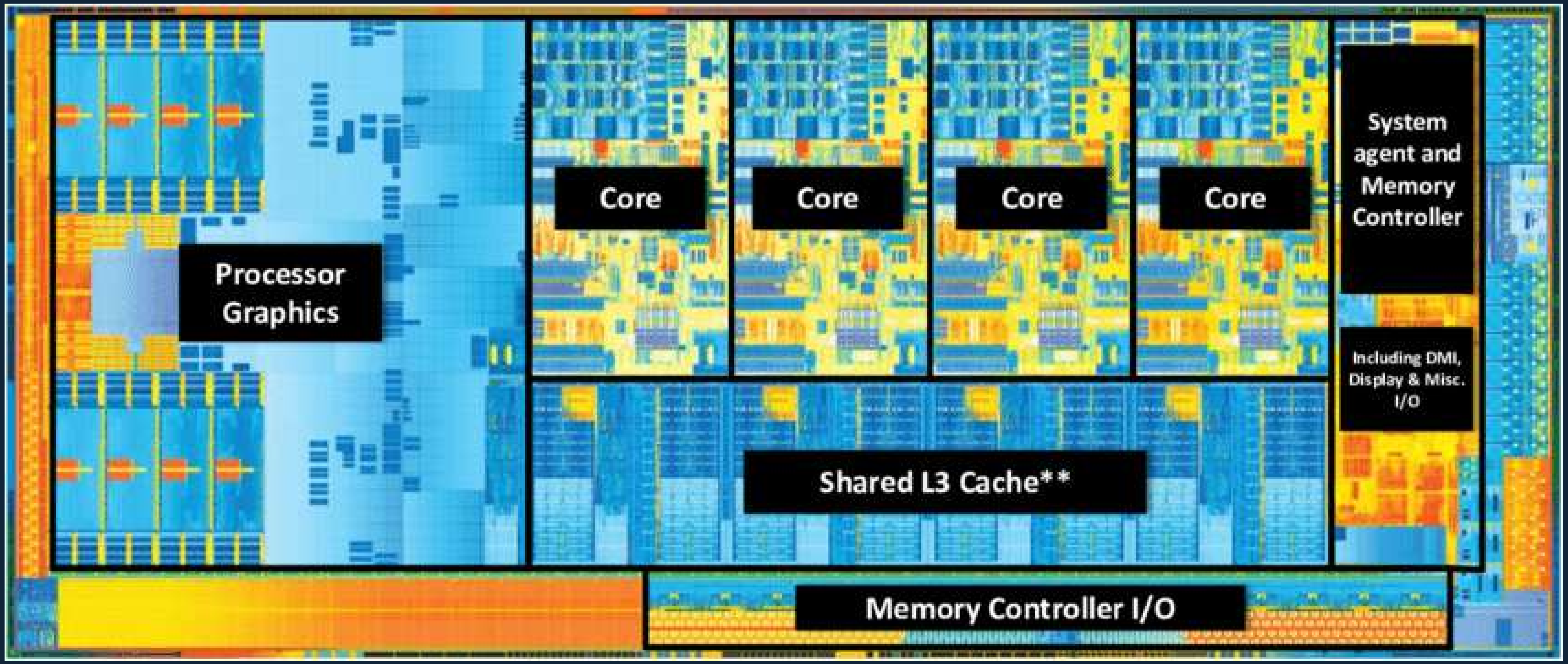
Part 4/4

Central Processing Unit

- The CPU is the computer's brain 🧠
- It consists of an integrated ♨️ heat spreader cover, a metal package holding the integrated circuit (die), and a printed circuit board for connection to the motherboard
- The die contains various sections, including cores for executing programs and instructions

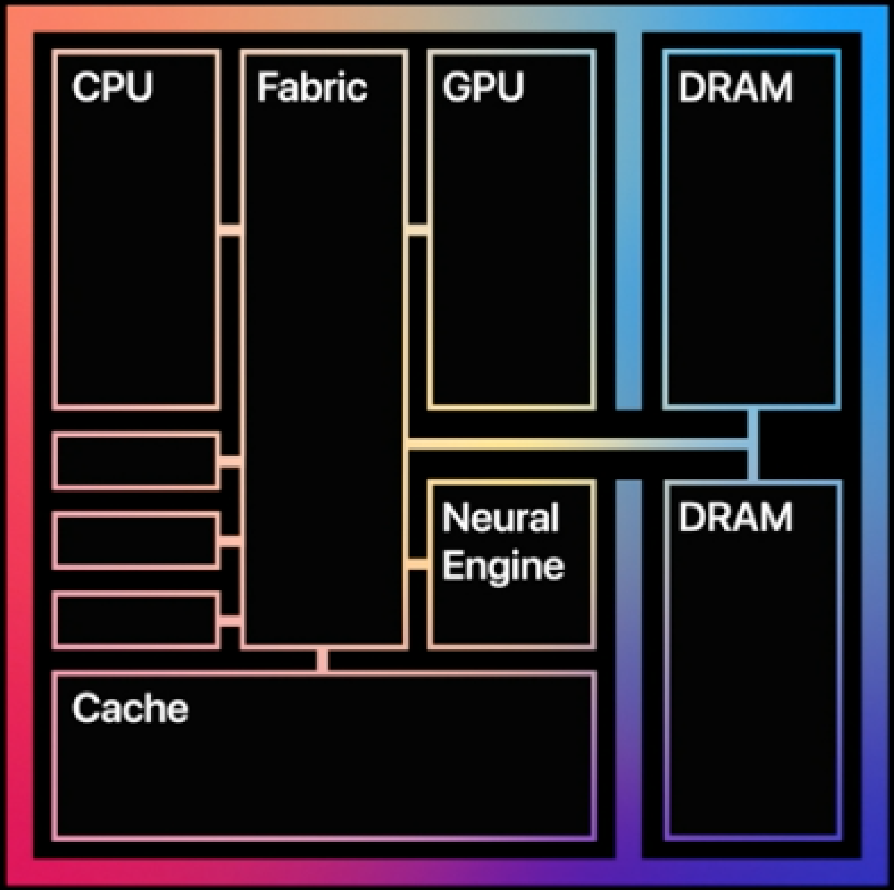
CPU Functional Sections

- The CPU has additional sections, such as shared L3 memory cache, integrated graphics processor, memory controller, and system agent/platform I/O
- The memory controller manages data transfer to and from DRAM, while the system agent facilitates communication with the motherboard chipset



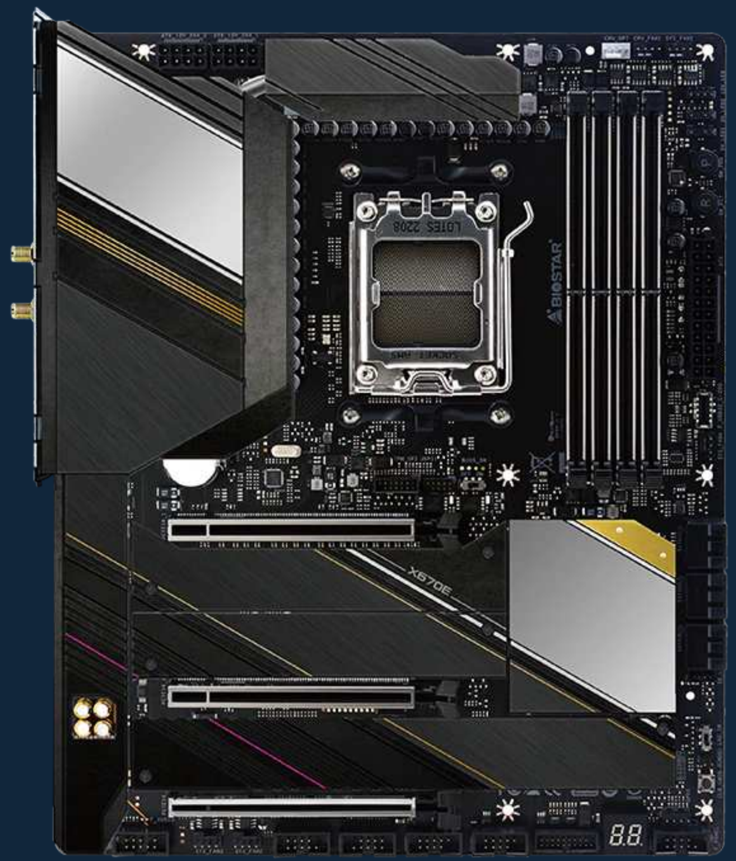
Intel Ivy Bridge 💻

🧑‍💻 Apple M1

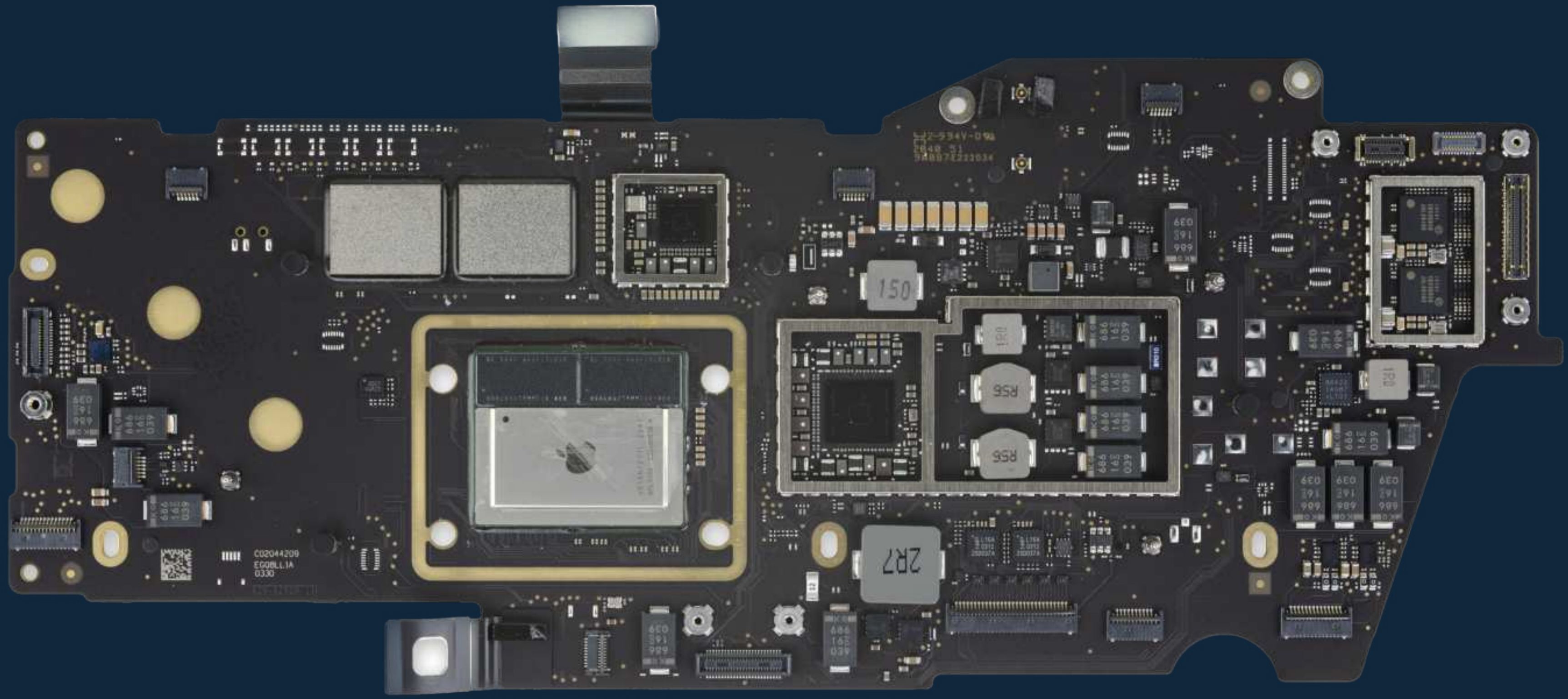


Motherboard

A large printed circuit board with numerous wires and various microchips, components, sockets, ports, slots, headers, and connectors.



Motherboard for a laptop 💻



Power Supply ⚡

- The power supply unit (**PSU**) distributes power throughout the computer

- It contains a main transformer, control PCB, switching power transistor, and various components for voltage regulation and output stability

CPU Cooler 🧊

CPU cooler includes a pump, tubes, radiator, and fans to dissipate heat generated by the CPU. The liquid circulates through the system, transferring heat to the radiator, and then the fans cool the liquid.

GPU 🎨

- The GPU is the brain of the computer's graphics capabilities

- It consists of a PCB, integrated circuit (IC), VRAM chips, voltage regulator module, and cooling system
- The GPU IC contains billions of transistors and performs parallel processing using multiple cores

Storage

Part 4/4

Dynamic Random Access Memory

- The CPU communicates directly with the DRAM through memory channels on the motherboard
- DRAM chips store data temporarily and use capacitors and transistors organized into 2D arrays

Solid-State Drives (SSDs) 💾

- SSDs store data permanently using 3D arrays of memory cells called **3D NAND**
- These arrays are stacked within a single SSD chip, enabling the storage of **terabytes of data**

Hard Disk Drives (HDDs) 📀

- HDDs use spinning disks and read/write heads to access data stored on magnetic surfaces.
- The read/write head moves across data tracks to read or write information


delete
fn
home
page up
clear
delete
end
page down
return
shift
command
option
control
enter
esc
delete
tab
caps lock
return
shift
shift
fn
control
option
command
command
option

Conclusion

- Building blocks of a computer
- Construction of an Arithmetic Logic Unit (ALU)
- Central Processing Unit (CPU)
- Computing Hardware Overview

See you in the lab! 👋