COMP 204: Computer Programming for Life Sciences

What is a computer: CPU, RAM, storage, communication. Binary numbers, instructions

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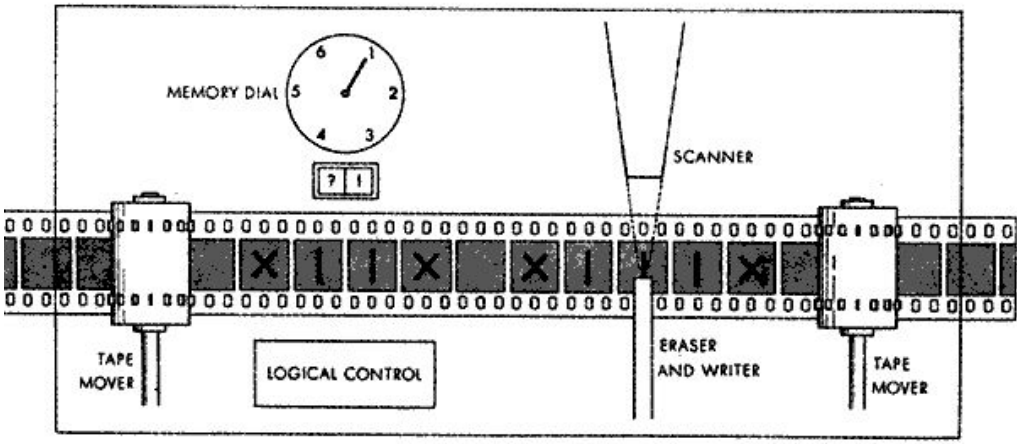
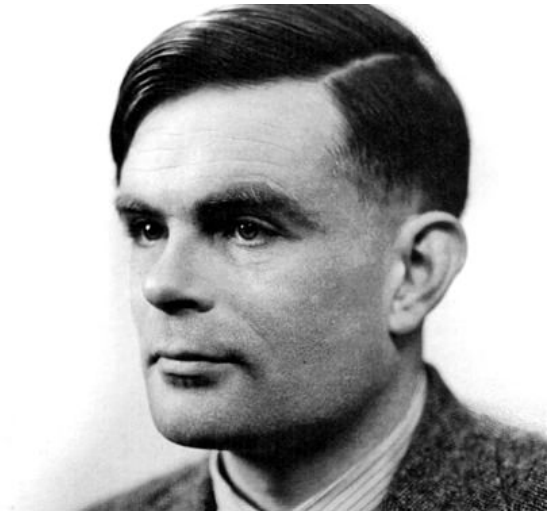
based on slides by Mathieu Blanchette, Christopher Cameron, and Carlos Oliver

Midterm time and location update

- Tentative Time: Tuesday, February 19th from 17:35-18:55 pm
- Location: ENGMC 304

Turing Machine: inception of modern computer in 1936

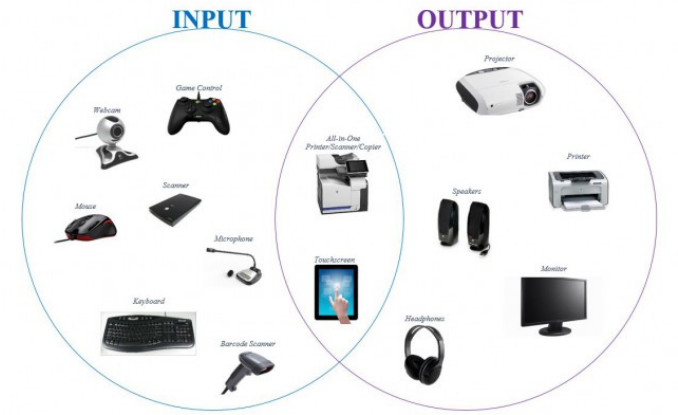




(Informally) Turing machine operates on an infinite memory tape. On this tape are symbols, which the machine can read and write, one at a time, using a tape head. Operation is fully determined by a finite set of elementary instructions such as "in state 42, if the symbol seen is 0, write a 1; if the symbol seen is 1, change into state 17; in state 17, if the symbol seen is 0, write a 1 and change to state 6". Despite the model's simplicity, Alan Turing mathematically proved that a Turing Machine can simulate any computer algorithm's logic therefore is a *Universal Machine*.

Modern computers appear in variety of form factors

Key physical components of modern computer devices



Modern computers consist of two classes of components:

1. **Hardware:** physical machinery
2. **Software:** instructions and data executed by the hardware (focus of the course)

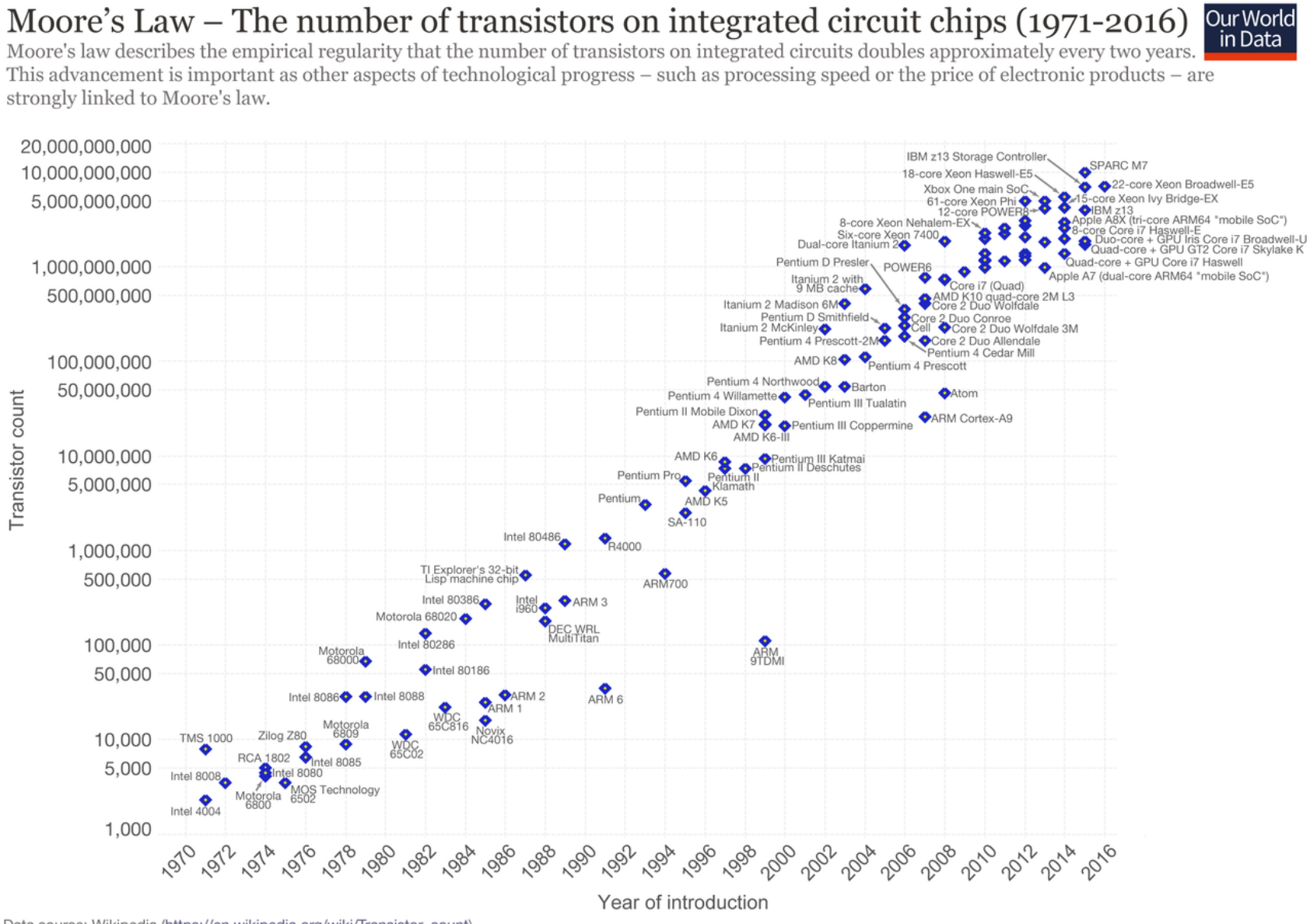
Typical hardware components are:

- Random Access Memory (RAM)
- Mass storage device
- Input device(s)
- Output device(s)
- **Central Processing Unit (CPU)**

Central Processing Unit (CPU)

- Commonly referred to as the 'brains' of a computer
- Responsible for executing sets of software instructions (called 'programs')
- Programs take input from input devices, process data, and provide output to an output device
- CPUs aren't limited to desk/laptop computers
  - Can be found in mobile phones, watch, media players, gaming consoles, loundry machines, etc.

Moore's Law: transistors doubles every two years



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Computer memory (or 'primary storage')

- Refers to hardware devices that allow for the storage of, at least temporary, data and programs
- These devices operate at high-speeds, which is a distinction from mass storage devices

Volatile memory

Electrical power must be maintained for stored information not to be lost by memory (e.g., **Random Access Memory (RAM)**).
Typical laptop computer: 8 Gb = 8 Billion bytes = 8,000,000,000.

Non-volatile memory

Hardware retains stored information even when not powered.
Examples include:

- Flash memory
- Read Only Memory (ROM)

Mass storage (or 'secondary storage')

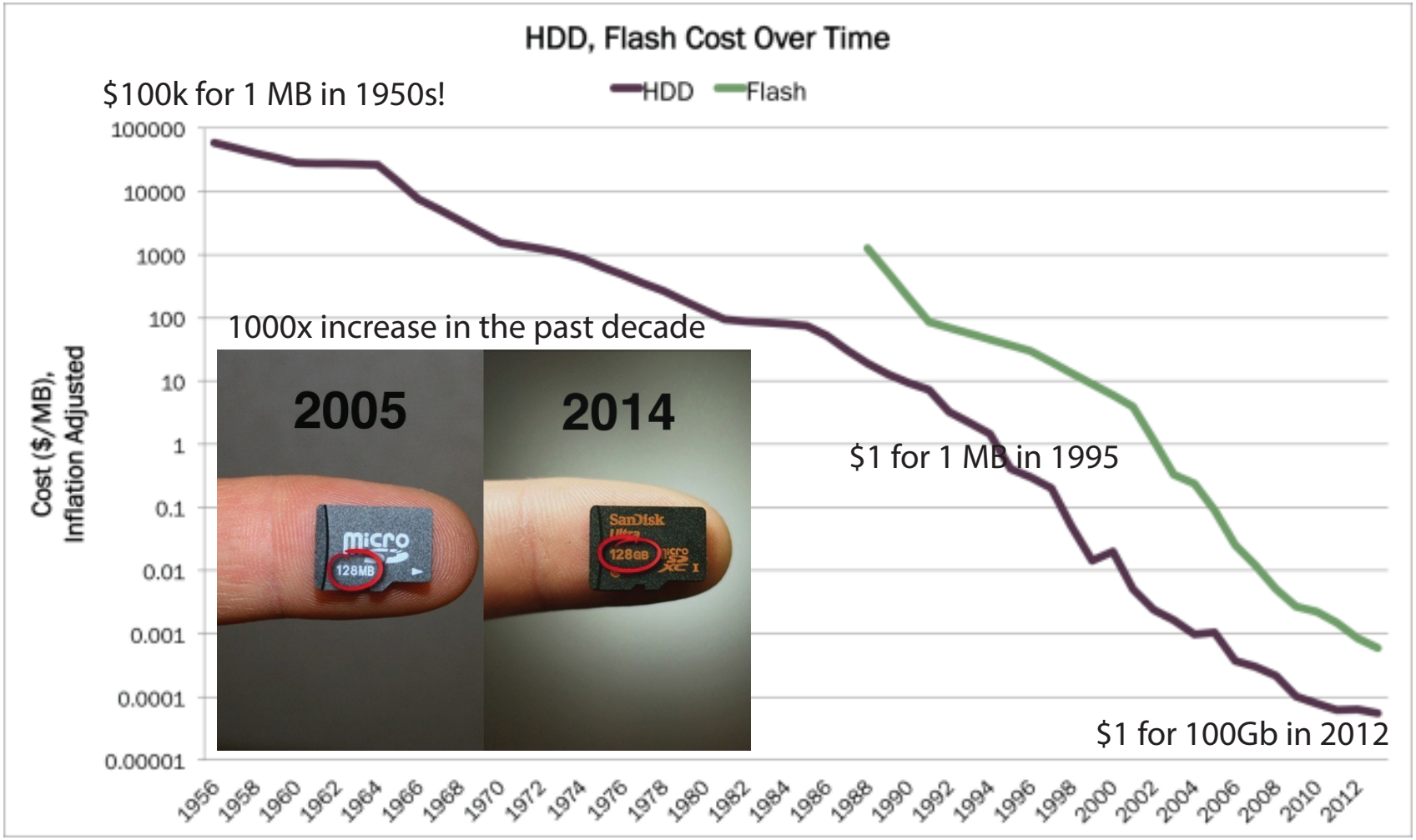
Differs from primary storage in the following ways:

- Typically, not directly accessible by the CPU
- Much slower to access
- Non-volatile
- Typically costs much less (per Giga-byte) than computer memory
- Much larger in capacity than computer memory. Typical laptop: 250 Gb = 250 Billion bytes.

Examples of storage devices:

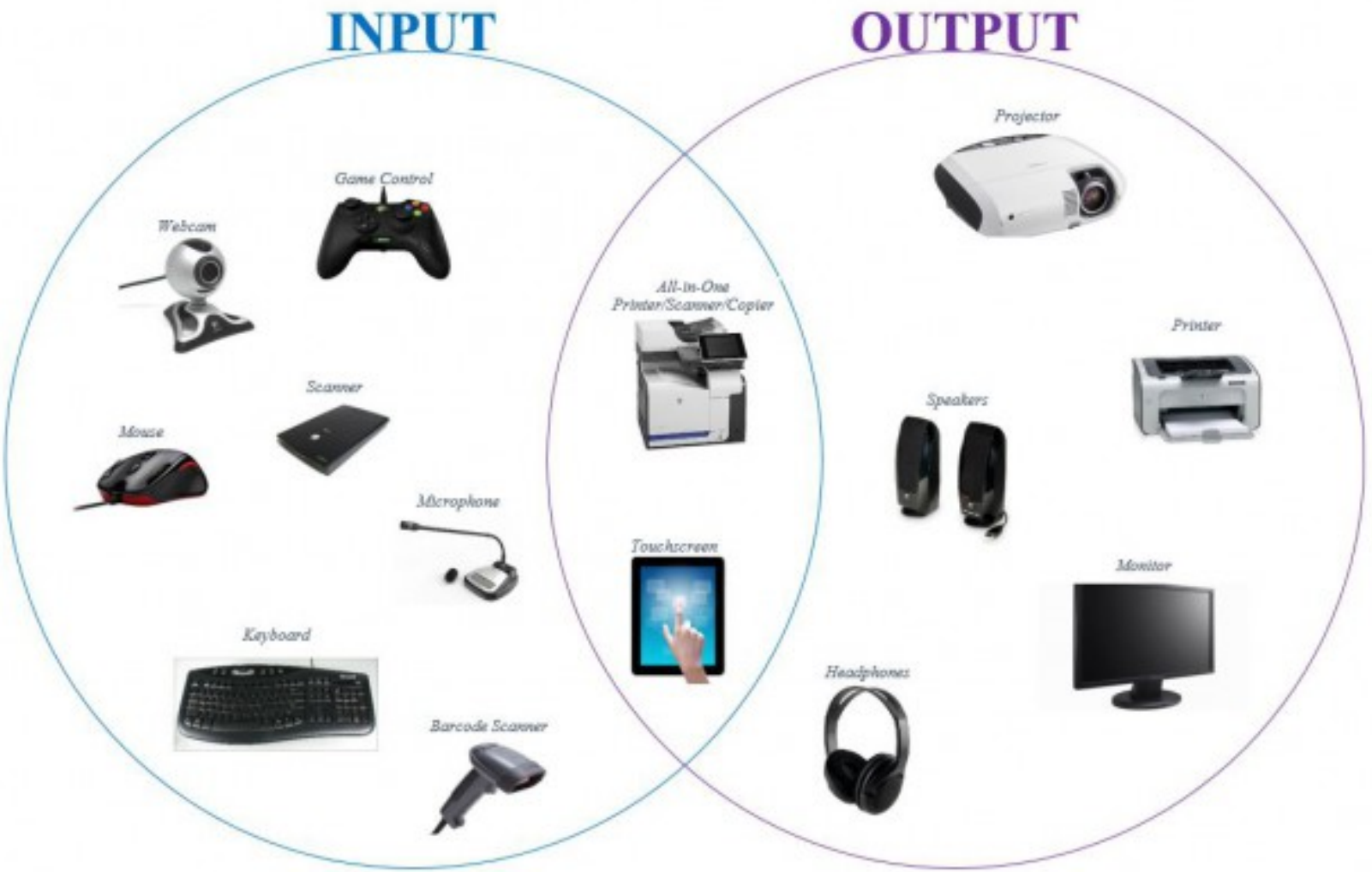
- hard disk drives
- optical (CD/DVD/Blu-ray)
- punch cards

Drastically Decreasing cost of mass storage (1956 - 2012)

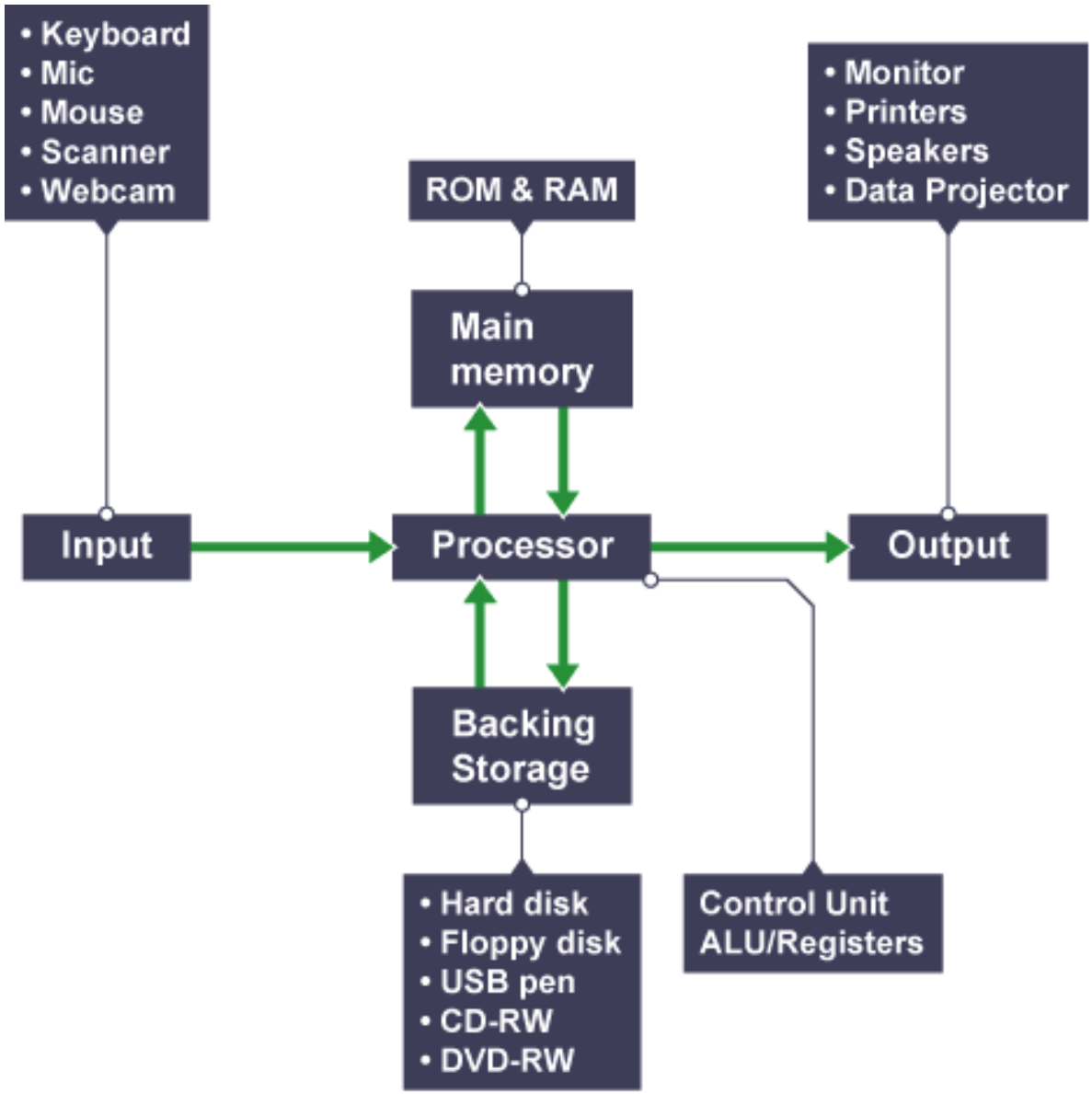


source:
https://www.schoolsofkingedwardvi.co.uk/ks2-computing-computing-theory-5-computer-networks/

Input/output devices allow communicate with computers

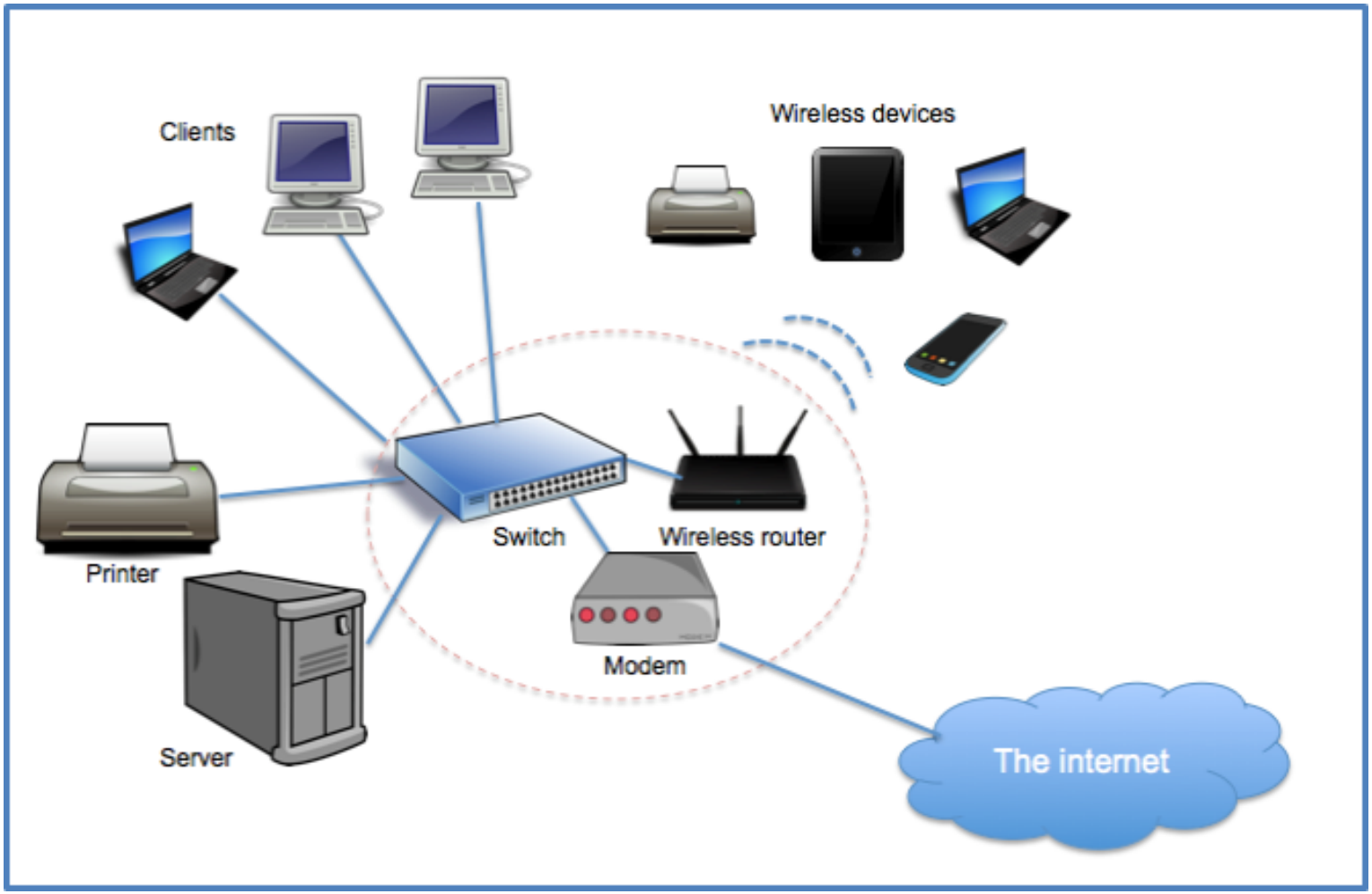


Summary of computer components



Computer network

A computer network is a number of computers linked together to allow them to "talk" to each other and share resources. Networked computers can share hardware, software and data.



source:
https://www.schoolsofkingedwardvi.co.uk/ks2-computing-computing-theory-5-computer-networks/

Binary numbers

All data stored in primary and secondary storage is stored as bits: 0 and 1. Sequence of bits can be used to represent:

1. Numbers (next slides)
2. Text (ASCII characters): 'A' = 10000001, 'B' = 10000010, ...
3. Images: one pixel at a time, RGB encoding (e.g., Red is rgb(255,0,0), Yellow is rgb(255,255,0), etc), the hexadecimal triplets are then converted into bits (next slides).
4. Digital audio: encoder and decoder for rate, bit depth and bit rate
5. Everything is stored as bits!!

But... dealing directly with bits is cumbersome for humans. That's why the computer's operating system allows you to interact with the computer with text.

Decimal number system

- The number system that you use every day
- Contains ten digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9
- How do we count to numbers greater than 9?
  - Start counting: 0... 1... 2... 3... 4... 5... 6... 7... 8... 9... ?
  - We're out of digits
  - Add a second column worth ten times the value of the first
  - Continue counting: 10... 11... 12... 13... and so on

Expanded notation:

$365_{10} = (3 \times 10^2) + (6 \times 10^1) + (5 \times 10^0)$

$2032_{10} = (2 \times 10^3) + (0 \times 10^2) + (3 \times 10^1) + (2 \times 10^0)$

Binary number system

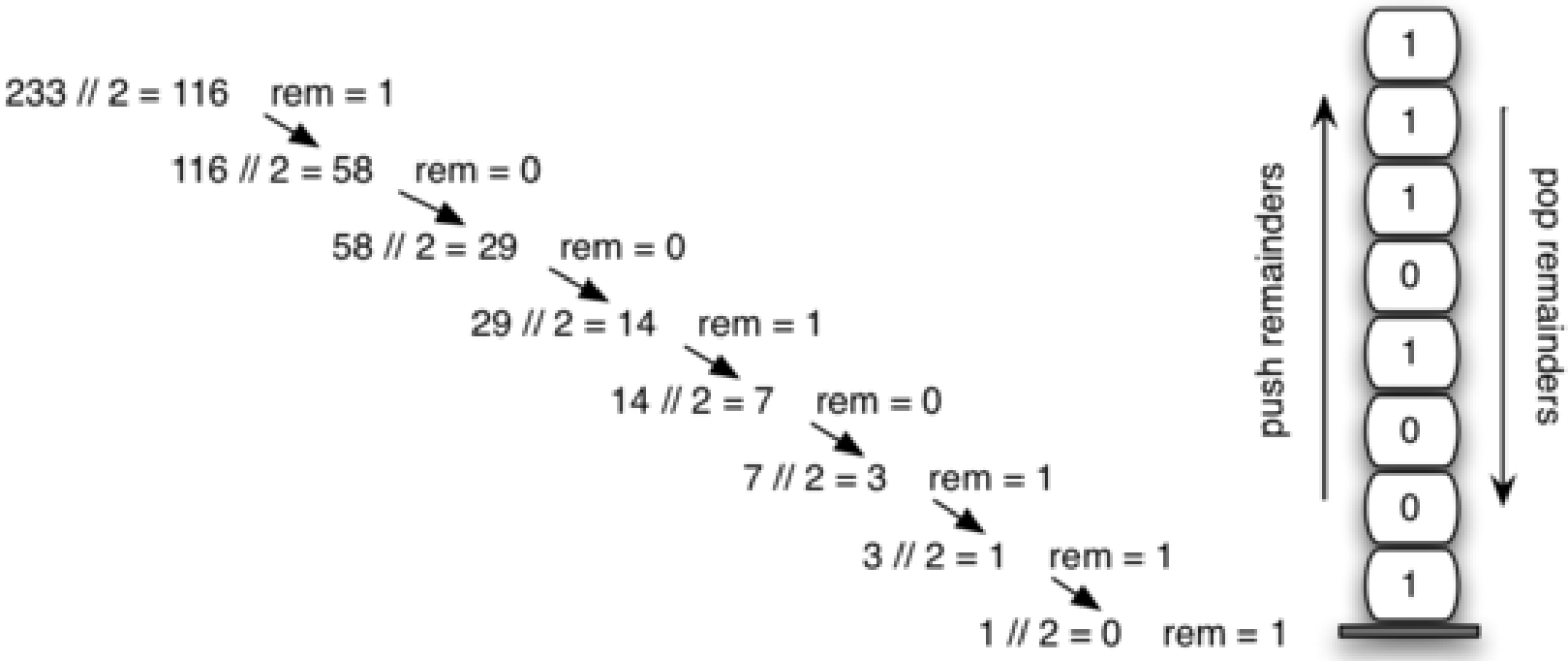
- The binary number system is the exact same except
- Contains **only two** digits: 0 and 1
  - *'It was just a dream, Bender.*
    There's no such thing as two' - Philip J. Fry I
- How do we count to numbers greater than 1?
  - Start counting: 0... 1... ?
  - We're out of digits...again
  - Let's try adding a second column again
  - Continue counting: 10 (2)... 11 (3)...

Expanded notation:

$101101_2 = (1\times2^5)+(0\times2^4)+(1\times2^3)+(1\times2^2)+(0\times2^1)+(1\times2^0) = 45$

Converting from decimal to binary

How to go from decimal to binary? $233_{10} = ?_2$
The algorithm to convert decimal to binary is called "Divide by 2" that uses a *stack* to keep track of the digits for the binary result.



So: $233_{10} = 11101001_2$
Check: $233_{10} = (1 \times 2^7) + (1 \times 2^6) + (1 \times 2^5) + (0 \times 2^4) + (1 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (1 \times 2^0)$

Let's do another example

How to go from decimal to binary? $89_{10} = ?_2$

- Continually divide-by-two until result is equal to zero

	result	remainder
divide 89 by two	44	1
divide 44 by two	22	0
divide 22 by two	11	0
divide 11 by two	5	1
divide 5 by two	2	1
divide 2 by two	1	0
divide 1 by two	0	1

So: $89_{10} = 1011001_2$.
Check (pop bits from the "stack"): $89_{10} =$
$(1 \times 2^6)+(0 \times 2^5)+(1 \times 2^4)+(1 \times 2^3)+(0 \times 2^2)+(0 \times 2^1)+(1 \times 2^0)$.

In-class Quiz: go to myCourse (password revealed in class)

Computers operate on Bytes

- Computers almost always operate on at least 8 bits at a time. 1 byte = 8 bits. So...
  $0_{10} = 00000000_2$
  $1_{10} = 00000001_2$
  $89_{10} = 01011001_2$
- To store larger numbers, we need more bits, e.g. 16 or 32. Programmers can choose how many bits they want to use: 8 bits = byte. 16 bits = word, 32 bits = double word, etc.
- For example, our computers often operate on a 64-bit operating system, that means it uses 64 bits to represent numbers and instructions. The largest positive integer a 64-bit system can represent by binary is:
  $0111111111111111111111111111111111111111111111111111111111111111$
  which is $2^{63} - 1 = 9,223,372,036,854,775,807$ or over 9,223 trillion)

Beyond positive integers

Signed integers: How to represent -13 on a byte?

- The Most Significant Bit (MSB) = leftmost bit is used to represent the sign: 0 = positive, 1 = negative
  $+13_{10} = 00001101$ as a signed byte
  $-13_{10} = 10001101$ as a signed byte
- So to know the value represented by a byte, we must know if it is a signed byte or an unsigned byte:
  unsigned byte value of $10001101 = 141_{10}$
  signed byte value of $10001101 = -13_{10}$
- How does computer know whether it is an unsigned or signed byte?
  Answer: The type unsigned and signed are stored in other memory location and specified by the programmers.

Computer instructions

- How to tell a computer what to it is supposed to do?
  Give it *instructions*.
- Instructions inform a computer's processor to perform specific basic operations
  - Add/subtract/multiply/divide two numbers,
  - Retrieve or store value at specific address in memory
  - Jump to another instruction
  - etc.
- Instructions are represented in binary (usually 32 or 64 bits)
- Computers can be programmed by writing the sequence of instructions to be performed (using assembly language). This very tedious, error prone.
- Instead, programmers use *high-level languages* (i.e., Python, Java, C) that are easier for humans to write and understand. Programs written in text get translated to instructions by an interpreter (for Python) or a compiler (for Java, C++).

Python code for converting decimal to binary

```
from pythonds.basic.stack import Stack

def divideBy2(decNumber):
    remstack = Stack()

    while decNumber > 0:
        rem = decNumber % 2
        remstack.push(rem)
        decNumber = decNumber // 2

    binString = ""
    while not remstack.isEmpty():
        binString = binString + str(remstack.pop())

    return binString

print(divideBy2(42))
```

Compilers vs. Interpreters

Compilers

Languages: C and Java (taught in COMP 202)

Instructions are generated from a compiler that produces a compiled file from source code

Compiled code execute faster

Compilation can take a significant amount of time

Lots of type checking and book keeping are needed in the source code

Interpreters

Languages: Ruby and Python

The interpreter is called at runtime to translate source code into instructions within memory

Interpreted code executes slower

No compilation needed

Automatic type convertion and requires fewer lines of code than compiled language

In-class Quiz: go to myCourse (password revealed in class)