Advance Computer Architecture and x86 ISA

University of Science and Technology of Hanoi

MS. LE Nhu Chu Hiep

Personal Introduction

Personal Introduction: Basic Information

Contact:

- Name: LE Nhu Chu Hiep
- Email: <le-nhu-chu.hiep@usth.edu.vn>

Education:

- Master for ICT at USTH (2023)
    - Speciality: Data Mining for IoT
- Bachelor for ICT at USTH (2020)

Personal Introduction: Teaching Career

Teaching:

- Lecturer of ICTLab USTH from 2024 (I’m young !!!)
- Major: Cyber Security
- Teaching courses:
  - Distributed System (ICT3)
  - Advance Computer Architecture and x86 ISA (CS2)

Personal Introduction: Research Career

Research:

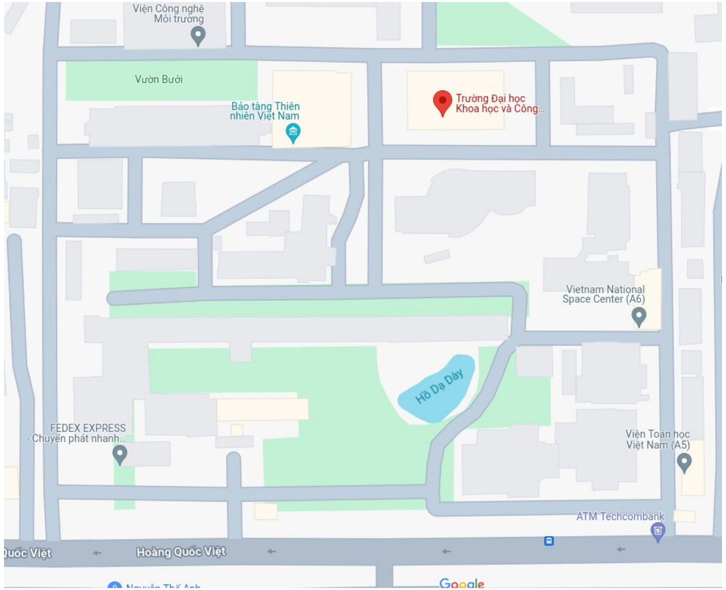
- Interested Domain:
  - Operating System
  - Networking
  - And Distributed System
- Research Topics:
  - Ulake: Microservice based data lake framework retrieving, storing, and querying scientific data
  - Pswap: Migration framework to move stateful container from VM to Host and vice versa

Personal Introduction: Working at ICTLab USTH

ICT Department:

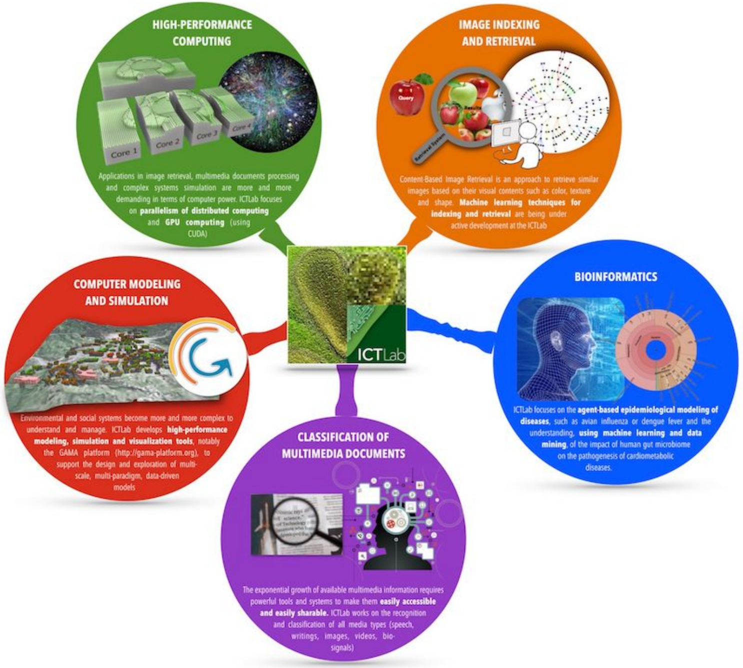
- Role: Researcher and Lecturer
- Website: https://ictlab.usth.edu.vn (**OLD** !!!)
- Location: 408, A21, 18 Hoang Quoc Viet,

  Nghia Do, Cau Giay, Hanoi



Personal Introduction: Working at ICTLab USTH (cont.)

- **Machine Learning, Deep Learning and Data Mining**
- Image and Speech Processing
- Modeling and Simulation
- **Sensor Networks and Embedded Systems**
- **High Performance Computing**
- Health Informatics and BioInformatics

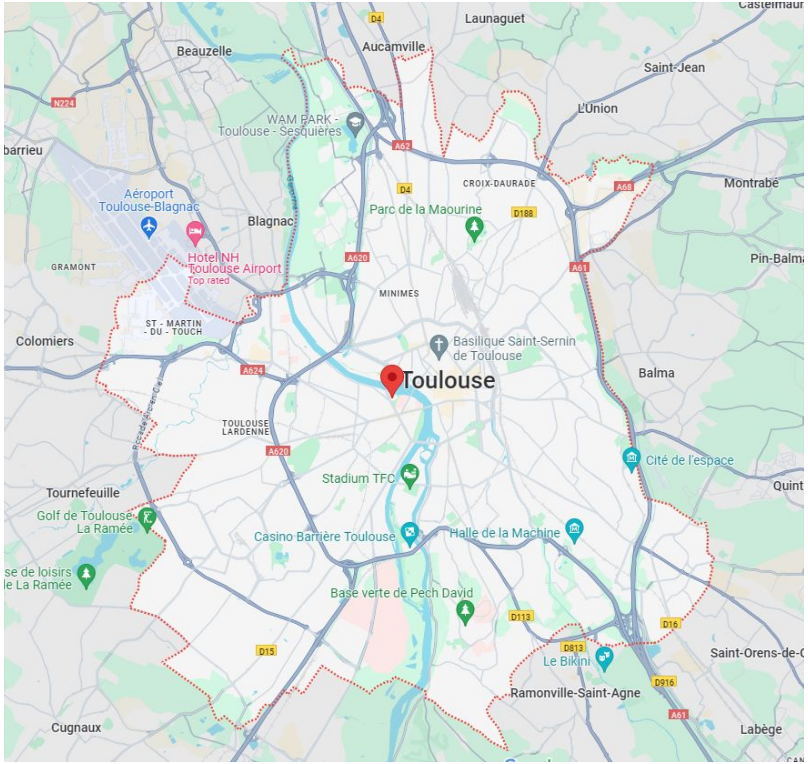


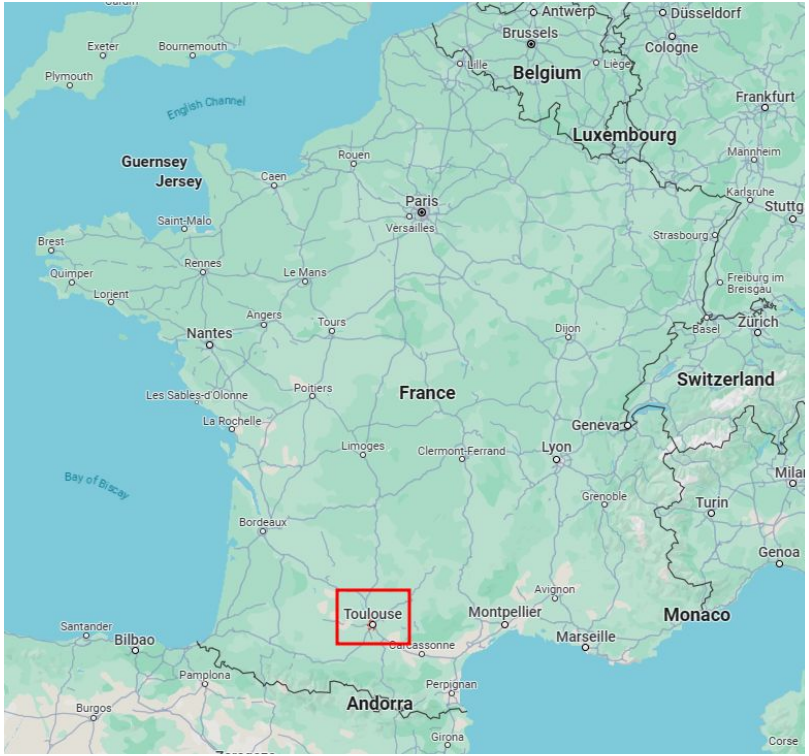
Personal Introduction: Working at INP ENSEEIHT

- National Polytechnic Institute of Toulouse [1]
- Role: M2 Internship ~ 6 months
- Ranking: **#943** in Best GLobal Universities [2]
- Website: https://www.enseeiht.fr/fr/index.html (Not **OLD**, but **FRENCH**)
- Location: 2 Rue Charles Camichel, 31000 Toulouse, France

1. C. (n.d.). *Ingénieur N7, Créateur du monde de demain*. Ametys V3. https://www.enseeiht.fr/fr/index.html
2. See where Institut National Polytechnique de Toulouse ranks among the world’s Best Universities. (n.d.-a). https://www.usnews.com/education/best-global-universities/institut-national-polytechnique-de-toulouse-505784

Personal Introduction: Working at INP ENSEEIHT (cont.)



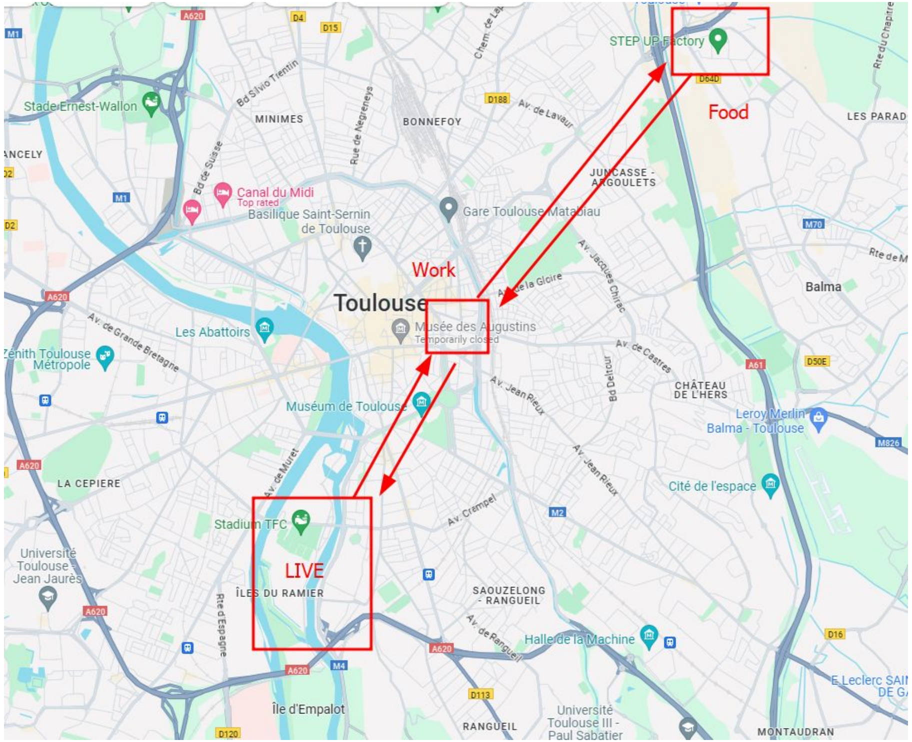


Personal Introduction: Working at INP ENSEEIHT (cont.)

- Top ranking universities (**INP**)
- Air France headquarter
- Old city with beautiful buildings
- Cheap cost of living
- Peaceful (**Not like Paris !!!**)
- Connect to USTH

TOULOUSE INP

Personal Introduction: Working at INP ENSEEIHT (cont.)



Course Introduction

Course Introduction

- 4 ETCS (40 hours)
  - 24h Lecturers - 16h Practical
  - Lecturers: 8 classes, 3 hours / class
  - Practicals: 4 classes, 4 hours / class
- Prerequisites:
  - Basic Programming
  - Computer Architecture
- Assessment:
  - Attendance: 10%
  - Assignment: 10%
  - Midterm: 30% (Project)
  - Final: 50% (Moodle Exam / Writing Exam)

Course Introduction: Objectives

- Understand basic concept of computer architecture (CA)
- Understand CA advance techniques to improve instruction execution
- Learn basic concept of x86 ISA
- Apply learned knowledge to improve instruction execution

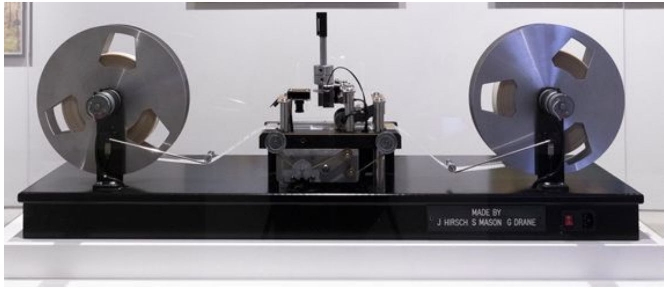
Course Introduction: Textbooks

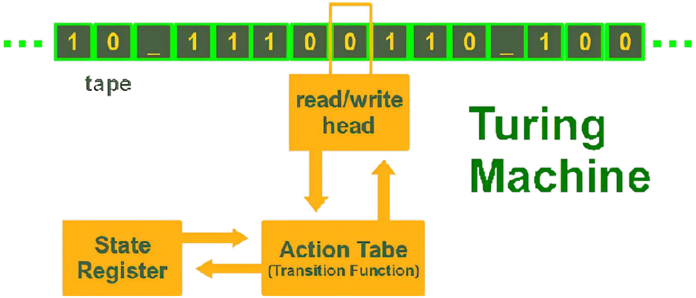
- **John L. Hennessy & David A. Patterson, Computer architecture : a quantitative approach, 5th Edition, Morgan Kaufmann, 2011**
- Andrew Tanenbaum & Todd Austin, Structured Computer Organization, 6th Edition, Pearson, 2012
- William Stallings, Computer organization and architecture, 10th Edition, 2015
- Barry Wilkinson & Michael Allen, Parallel programming, techniques and applications using networked workstations and parallel computers,Pearson, 2004

Computer Architecture

Computer

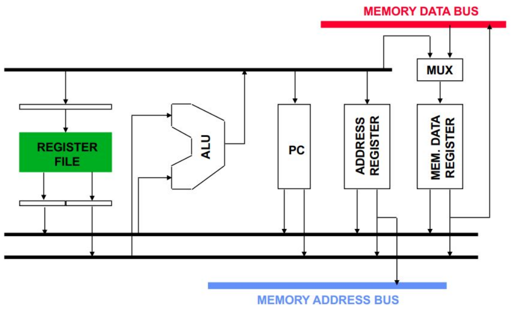
- A **digital system**
  - The finite state machine
  - The combination and sequential logic
  - The register and memory
- Purpose
  - Do whatever the **software** tell it to do
  - **Software** is a series of instructions

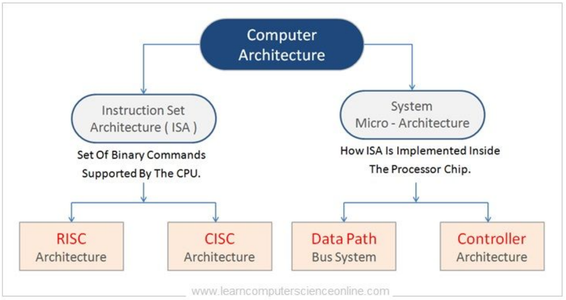


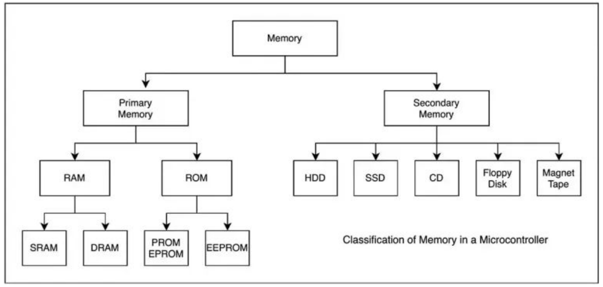


Computer Architecture

- Conceptual structure and functional behavior of computer
- Defines
  - Hardware **components** and their **organization**
  - Interaction among components to execute the program instructions
- Includes
  - **Instruction set architecture (ISA)**
  - **Memory organization**
  - Data paths and control mechanism
  - IO systems



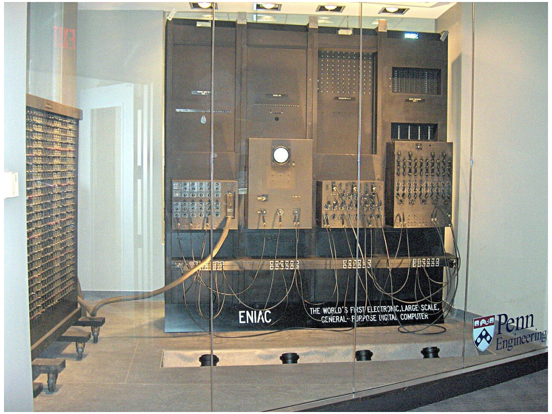




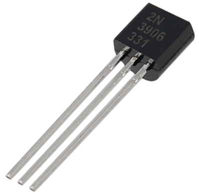
Computer History

Computer History: Early Computer

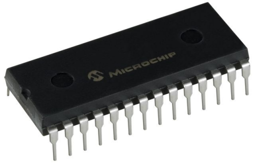
- **1940s - 1950s**: First general purpose computers using vacuum tubes and punched cards
- **ENIAC**: chiefly served the military like calculating artillery firing table
- **UNIVAC**: meant for scientific and business purpose
- **Authors**: **Dr. Presper Eckert** and **Dr. John Mauchly**
- **Interface**: IBM card reader and card punch



Computer History: Commercial Computer



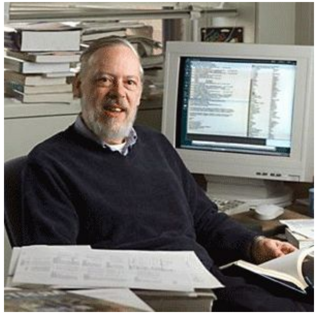
- **1950s - 1960s**: Introduction of transistors, leading to smaller, faster, and more reliable computers

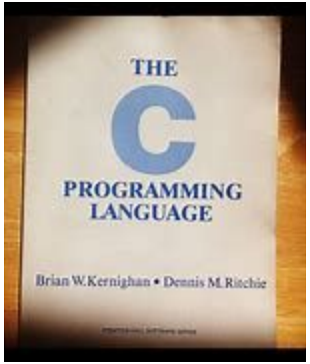


- **1960s - 1970s**: Emergence of integrated circuits (ICs) and microprocessors
- **1970s - 1980s**: Rise of personal computers (PCs)

Computer History: Commercial Computer (cont.)

- **In 1969, the creation of UNIX**
  - Operating System developed at AT&T Bell Labs
  - Invented by Dennis Ritchie and Ken Thompson
  - Lower the cost and risk of bringing out a new architecture
- **In 1972, the creation of C programming language**
  - First general purpose programming language
  - Invented by Dennis Ritchie
  - Reduce the need for object-code compatibility





Computer History: RISC vs CISC

- **1980s-1990s:** RISC and CISC
- **RISC:** Reduced Instruction Set Computing is a small, highly optimized set of instruction that are executed in a single clock cycle
- **CISC:** Complex Instruction Set Computing is a larger set of more complex instructions that can performance multiple operations
- **Performance:** RISC is highly suitable to **parallelize instructions**

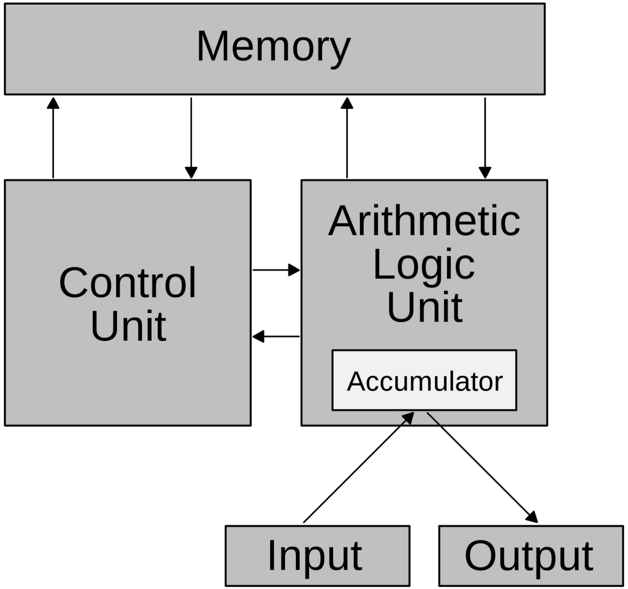
Computer History: Modern computer

- **1990s - Present: Shift toward parallel computing and multicore processors to improve performance**
- **21st Century:** Power-efficient design and specialized architectures for tasks like graphics processing and AI
- **Future Trends:** Exploration of quantum computing for exponential processing

Computer Components

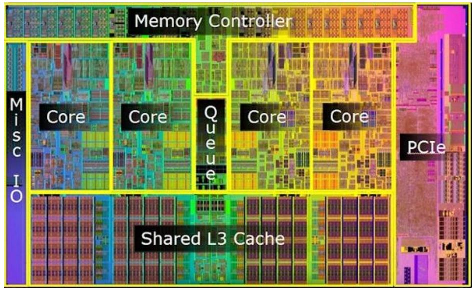
Computer Components: John von Neumann

- **CPU:** Central Processing Unit
    - **Control Unit:** coordinating and controlling the operation flow of computer
    - **Arithmetic Logic Unit (ALU):** performing a wide range of arithmetic, logical, and data manipulation operations
- **Memory:** primary storage for both instructions and data
- **IO Unit:** Input vs Output play essential roles in data exchange between the computer and the external world

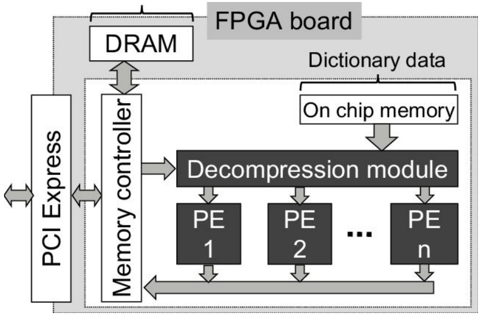


Computer Components (cont.)

- CPU: General-Purpose Processors
  - Designed for wide range of computing tasks
  - Examples: Intel Core series, AMD Ryzen series



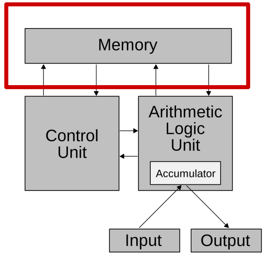
- FPGA: Field-Programmable Gate Arrays
  - Programmable logic devices that can be configured to perform specific tasks
  - Examples: Xilinx UltraScale series, Intel (formerly Altera) Stratix series



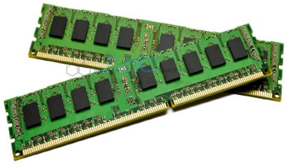
Computer Components (cont.)

- GPU: graphics Processing Units
  - Specialized for rendering graphics and accelerating parallel computations
  - Examples: NVIDIA GeForce, AMD Radeon

Computer Components: Memory



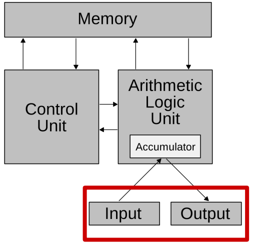
- RAM: Random Access Memory
  - Primary storage medium for data and instructions feeding to CPU during program execution
  - High transfer rate, volatile memory, small, expensive
  - Example: SRAM, DRAM, and DDR



- ROM: Read-Only Memory
  - Storing firmware and essential system instructions that is not frequently changed such as BIOS or embedded system firmware
  - Fast access specifically, difficult to write, non-volatile memory
  - Example: PROM, EPROM, and EEPROM

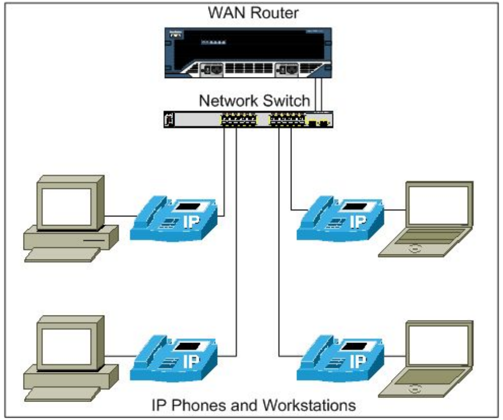
- Secondary Storage
  - Persisting data and program instruction in long time even after turning off power supply
  - Slow transfer rate, non-volatile memory, large, cheaper
  - Example: HDDs, SSDs, CD-ROM, and DVD

Computer Components: IO Devices



- Input Devices: Capture data and commands from user or other devices
  - **Examples:** Keyboards, mice, scanners, sensors, etc.

- Output Devices: Present information, results, or feedback to users or other devices
  - **Examples:** Monitors, printers, speakers, etc.



- Communication Devices: Communication between the computer and other devices or networks
  - **Examples:** Ethernet, Wi-fi, Bluetooth adapters, etc.

Binary number system & Digital logic

Binary number system

- Base-2 numeral system
- Represents using only 2 digitals: 0 and 1
- Each digit in a binary number is called a bit
- A bit have one of 2 possible values: 0 or 1

Binary Numbering System

Decimal number	Binary number code 8 4 2 1	Binary to decimal conversion
0	0 0 0 0	= 0 + 0 + 0 + 0 = 0
1	0 0 0 1	= 0 + 0 + 0 + 1 = 1
2	0 0 1 0	= 0 + 0 + 2 + 0 = 2
3	0 0 1 1	= 0 + 0 + 2 + 1 = 3
4	0 1 0 0	= 0 + 4 + 0 + 0 = 4
5	0 1 0 1	= 0 + 4 + 0 + 1 = 5
6	0 1 1 0	= 0 + 4 + 2 + 0 = 6
7	0 1 1 1	= 0 + 4 + 2 + 1 = 7
8	1 0 0 0	= 8 + 0 + 0 + 0 = 8

Binary numbers can be converted into decimal (base ten) numbers

Digital Logic

- Boolean algebra:
  - Mathematical system for expressing and manipulating logic expressions that take into account 2 values of false (0) and true (1)
  - Defines logical operations on binary values: AND, OR, NOT, XOR, NAND, etc.
- Logic Gates:
  - Electronic circuits performing logical operations on input signals to produce output signals
  - Building blocks of digital circuits, enabling more complex logic functions
- Combinational Logic:
  - Outputs depend only on the current inputs, with no memory or feedback
- Sequential Logic:
  - Outputs depend on both current inputs and the state of memory elements

Digital Logic (cont.)

A, B → OR → Q		A	
		0	1
B	0	0	1
	1	1	1

A, B → AND → Q		A	
		0	1
B	0	0	0
	1	0	1

A, B → XOR → Q		A	
		0	1
B	0	0	1
	1	1	0

A, B → NOR → Q		A	
		0	1
B	0	1	0
	1	0	0

A, B → NAND → Q		A	
		0	1
B	0	1	1
	1	1	0

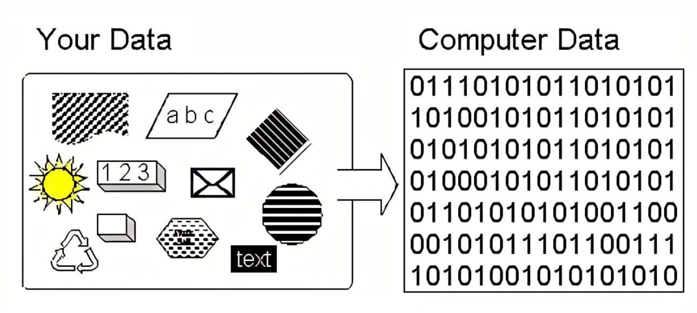
A → NOT → $\bar{A}$

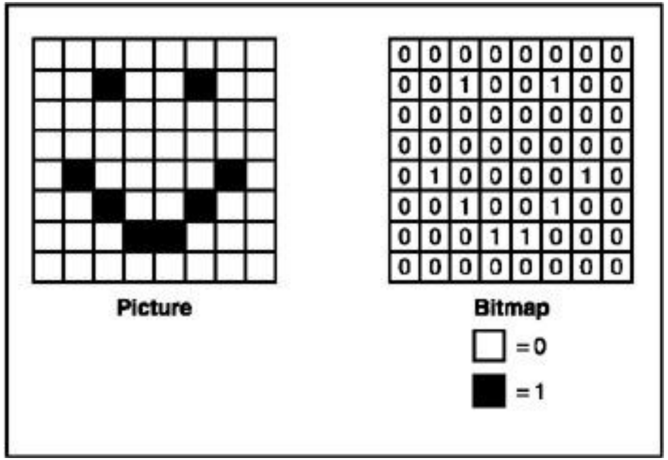
A	
0	1
1	0

Data Representation

Data Representation

- Computer understands only binary data
- Human works with different data types: text, number, image, etc.
- So, data representation: the process of encoding data in a format suitable for computer
- Binary representation: encode data using only 2 symbols 0 and 1





Data Representation: Primary Data

- **Integer:** converting directly to binary bases format (holded by 4 bytes in C)
- **Floating:** using a sign bit, mantissa, and exponent with wide range of values with varying precision (holded by 8 bytes in C)
- **Character:** applying ASCII to map characters to 7-bit binary codes, providing a standard encoding for text characters (holded by 1 byte in C)

Hex	Dec	Char		Hex	Dec	Char	Hex	Dec	Char	Hex	Dec	Char
0x00	0	NULL	null	0x20	32	Space	0x40	64	@	0x60	96	`
0x01	1	SOH	Start of heading	0x21	33	!	0x41	65	A	0x61	97	a
0x02	2	STX	Start of text	0x22	34	"	0x42	66	B	0x62	98	b
0x03	3	ETX	End of text	0x23	35	#	0x43	67	C	0x63	99	c
0x04	4	EOT	End of transmission	0x24	36	$	0x44	68	D	0x64	100	d
0x05	5	ENQ	Enquiry	0x25	37	%	0x45	69	E	0x65	101	e
0x06	6	ACK	Acknowledge	0x26	38	&	0x46	70	F	0x66	102	f
0x07	7	BELL	Bell	0x27	39	'	0x47	71	G	0x67	103	g
0x08	8	BS	Backspace	0x28	40	(	0x48	72	H	0x68	104	h
0x09	9	TAB	Horizontal tab	0x29	41	)	0x49	73	I	0x69	105	i
0x0A	10	LF	New line	0x2A	42	*	0x4A	74	J	0x6A	106	j
0x0B	11	VT	Vertical tab	0x2B	43	+	0x4B	75	K	0x6B	107	k
0x0C	12	FF	Form Feed	0x2C	44	,	0x4C	76	L	0x6C	108	l
0x0D	13	CR	Carriage return	0x2D	45	-	0x4D	77	M	0x6D	109	m
0x0E	14	SO	Shift out	0x2E	46	.	0x4E	78	N	0x6E	110	n
0x0F	15	SI	Shift in	0x2F	47	/	0x4F	79	O	0x6F	111	o
0x10	16	DLE	Data link escape	0x30	48	0	0x50	80	P	0x70	112	p
0x11	17	DC1	Device control 1	0x31	49	1	0x51	81	Q	0x71	113	q
0x12	18	DC2	Device control 2	0x32	50	2	0x52	82	R	0x72	114	r
0x13	19	DC3	Device control 3	0x33	51	3	0x53	83	S	0x73	115	s
0x14	20	DC4	Device control 4	0x34	52	4	0x54	84	T	0x74	116	t
0x15	21	NAK	Negative ack	0x35	53	5	0x55	85	U	0x75	117	u
0x16	22	SYN	Synchronous idle	0x36	54	6	0x56	86	V	0x76	118	v
0x17	23	ETB	End transmission block	0x37	55	7	0x57	87	W	0x77	119	w
0x18	24	CAN	Cancel	0x38	56	8	0x58	88	X	0x78	120	x
0x19	25	EM	End of medium	0x39	57	9	0x59	89	Y	0x79	121	y
0x1A	26	SUB	Substitute	0x3A	58	:	0x5A	90	Z	0x7A	122	z
0x1B	27	FSC	Escape	0x3B	59	;	0x5B	91	[	0x7B	123	{
0x1C	28	FS	File separator	0x3C	60	<	0x5C	92	\	0x7C	124	|
0x1D	29	GS	Group separator	0x3D	61	=	0x5D	93	]	0x7D	125	}
0x1E	30	RS	Record separator	0x3E	62	>	0x5E	94	^	0x7E	126	~
0x1F	31	US	Unit separator	0x3F	63	?	0x5F	95	_	0x7F	127	DEL

Data Representation: Complex Data

- **Image:** represented as grids of pixels, with each pixel encoded to represent color or grayscale using binary values
- **Audio:** a sequence of discrete samples using binary values encoded by pulse-code modulation (PCM)
- **Video:** Encodes moving images using binary data employing compression techniques (MPEG)

Data Representation: Stored format

- **File Formats**:
  - The structure and organization of data within files, facilitating interoperability and data exchange between different systems and applications
  - Examples: text format (plain text, CSV, etc.), binary formats (JPEG, MP3, etc.)
- **Endianness**:
  - Order in which bytes are stored in memory
  - **Little-Endian**: Least significant byte stored first
  - **Big-Endian**: Most significant byte stored first

Binary (Decimal: 149)	1	0	0	1	0	1	0	**1**
Bit weight for given bit position n (2^n)	2^7	2^6	2^5	2^4	2^3	2^2	2^1	$\mathbf{2^0}$
Bit position label	MSb							**LSb**

Thank you for you listening