

INTRODUCTION TO COMPUTER ARCHITECTURE

COURSE CODE: CSCD211

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UNIVERSITY OF GHANA
DEPARTMENT OF COMPUTER SCIENCE



COURSE GOAL

The goal of this course is to introduce students to the principles and precedents of design and organization of various components of the computer system.

LEARNING OUTCOMES

At the end of the course, students are expected to;

- Know the various Hardware components of the computer system and their functionalities.
- Understand the principles and precedents of designs of various components of the computer system
- Evaluate tradeoffs of different designs
- Describe the Architectures of the main components of the computer system including CPU, I/O, memory etc.
- Understand CPU performance issues
- Describe the design of logical components of the computer system
- Understand the different numbering systems used by the computer system

OVERVIEW OF COURSE OUTLINE

- Introduction to computers
- Historical development of computers
 - evolution of computers, generations of computers*
- Types of computers
- Introduction to computer hardware
 - Functional units of the computer system*
- Introduction to number systems
 - binary, octal, hexadecimal number systems, compliment arithmetic*

OVERVIEW OF COURSE OUTLINE

- ❑ Introduction to digital Logic design
 - Boolean algebra and expressions, logic gates*
- ❑ Introduction to computer architecture and organization
 - von Neumann architecture, Harvard architecture, instruction set architecture*
- ❑ Evaluating CPU performance
- ❑ Processor design
 - instruction processing cycle, data paths*
- ❑ Memory organization and hierarchy
- ❑ I/O architecture and performance
- ❑ CPU clock cycles and pipelining

COURSE EVALUATION

The assessment of students on this course will be made up of the following components:

Coursework/continuous assessment

-assignments, quizzes, class tests

Class participation

Class attendance

Mid-semester exams

End-of-semester exams

Role of architect

- ❑ Look backwards(to the past)

Understand tradeoffs and designs, upsides/downsides, past workloads, analyze and evaluate the past designs

- ❑ Look forward (to the future)

 - ❑ Be the dreamer and create new designs

 - ❑ Push the state of the arts

 - ❑ Evaluate new design choices

- ❑ Look up (towards problems in the computing stack)

 - ❑ Understand relevant problems and their nature

 - ❑ Develop solutions to these problems

- ❑ Look down (towards devices and circuitry technologies)

 - ❑ Understand the capabilities of the underlying technologies

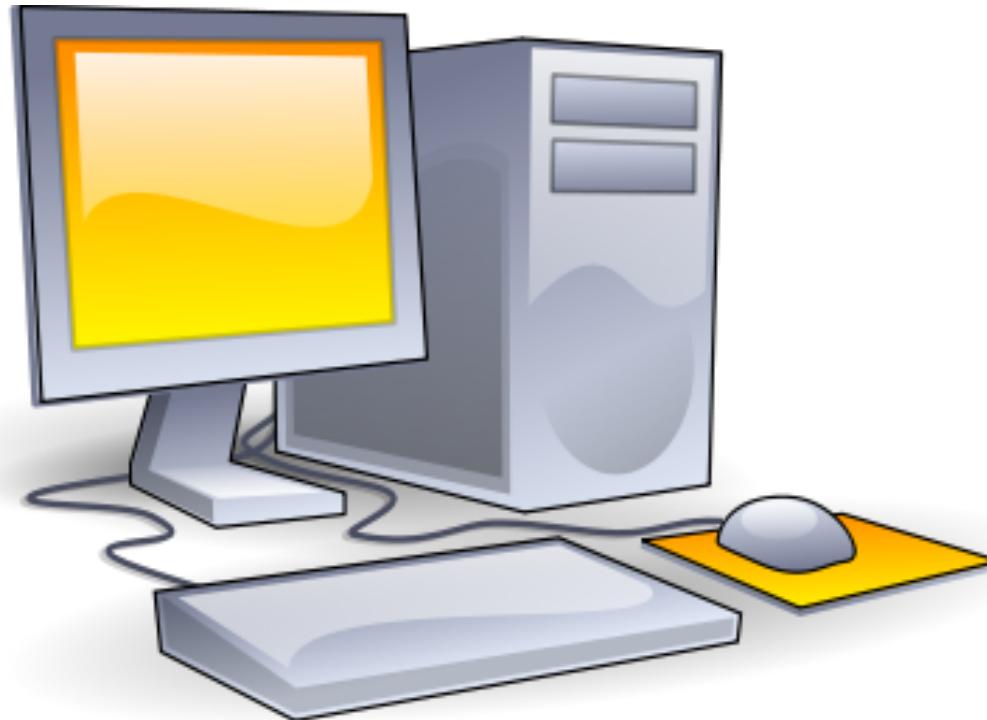
RECOMMENDED TEXT

Hayes, J. P. (2002). Computer Architecture and Organization. New York: McGraw-Hill Science. ISBN-10: 0072861983, ISBN-13: 978-0072861983

J. Hennessy & A. Patterson(2007). Computer architecture: a quantitative approach, 4th edition

Stallings, William (2010). Computer Organization and Architecture: Designing for Performance, seventh edition. Prentice Hall

INTRODUCTION TO COMPUTERS



What is a computer system?

- A computer can be defined as an electronic device that follows commands to accept input, process it and produce an output, which can be stored and used later.
- The computer system has one or more *inputs* to provide data. This data is then *processed* in some way. The outcome of the processing is sent to an *output* or it may be *stored* until some event happens to cause it to be output.
- Computer can capture, store, retrieve, process data.
- This data could be numeric, textual, audio, video and images

→Continue from here

CHARACTERISTICS OF A COMPUTER

Computer is a powerful device.

It can be designed to do any kind of activity provided all data and instructions are made available to it in digital form.

The basic characteristics of a modern computer include:

- *Speed:* Computer have incredible speed of processing data, which is measured in Hertz.
- *Accuracy:* Computer can ensure consistently very high degree of accuracy in computations.
- *Huge storage:* Computer has large storage capability, which is measured in Byte

Versatility:

computers are capable of performing almost any task that has a series of finite logical steps. These include communication, process control, research, weather forecasting, healthcare, online trading, education, training and so on.

Programmable:

Computer can be programmed to function automatically and this differentiates it from any other calculation device.

It functions as programmed for any stretch of time until the condition to terminate is satisfied.

Tirelessness:

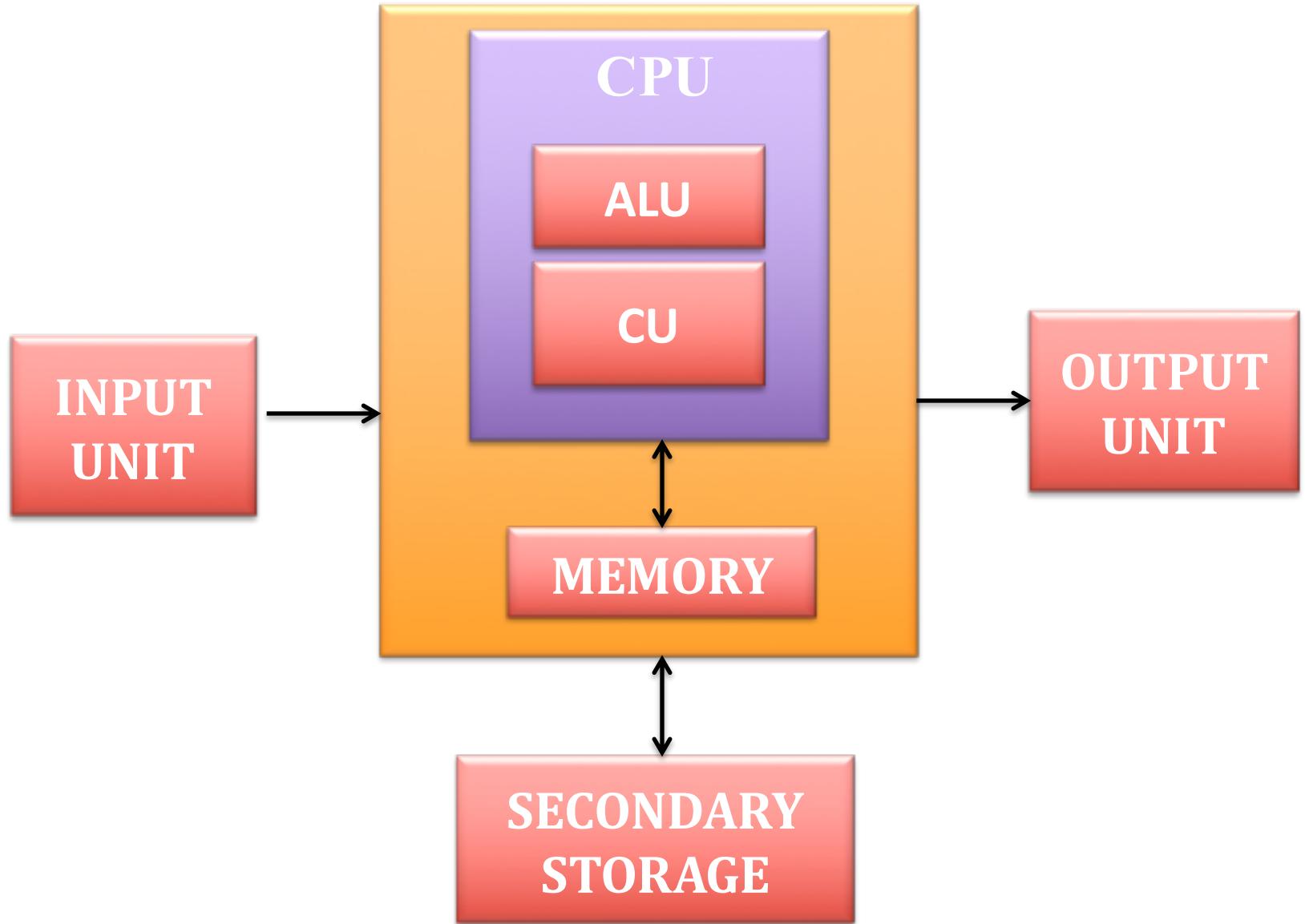
Computer is free from fatigue. It does not get tired of work and never loses concentration.

It can perform basic arithmetic operations with the same degree of speed and accuracy for any extent of time continuously, with the same amount of efficiency

LIMITATIONS OF COMPUTER SYSTEM

Computer is, no doubt, a very powerful machine. Yet it has some limitations, which include:

- Computers cannot think on their own, hence relies on instructions to do anything
- Computers do not have conscience, hence unable to differentiate between right and wrong
- Cannot learn from experience, hence can commit the same error repeatedly
- It can do a task only if it can be expressed in a series of finite steps leading to the completion of the task.

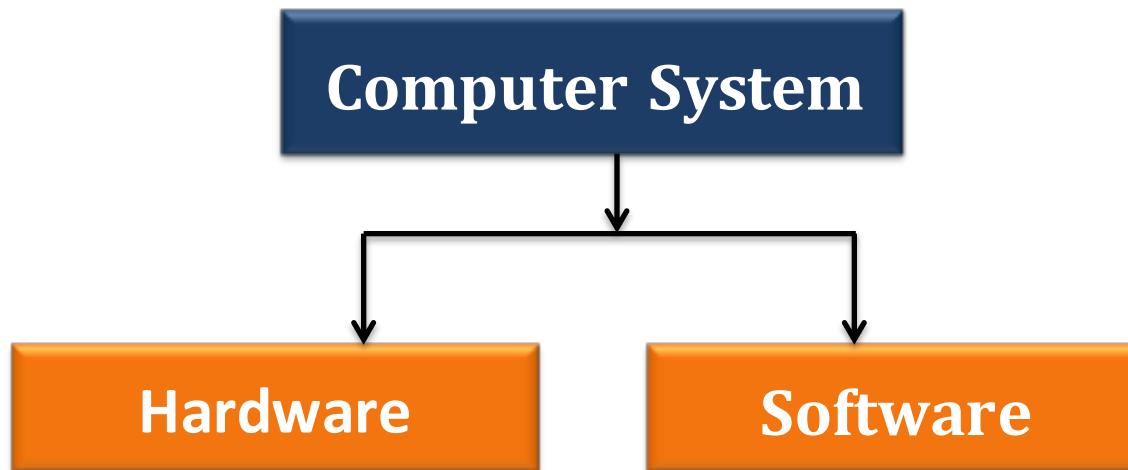


THE STRUCTURE OF THE COMPUTER SYSTEM

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COMPOSITION OF COMPUTER SYSTEM

- The computer system is made up of hardware and software. These two components of the computer system work together to accomplish the functionality of the entire computer system.
- The hardware refers to the physical components of the computer system
- software refers to the set of instruction called program, which directs the computer to perform its task.



Historical development of computers



EARLIEST COMPUTER

- Originally calculations were computed by humans, whose job title was computers.
- These human computers were typically engaged in the calculation of a mathematical expression.
- The calculations of this period were specialized and expensive, requiring years of training in mathematics.
- The first use of the word "computer" was recorded in 1613, referring to a person who carried out calculations, or computations
- The word continued to be used in that sense until the middle of the 20th century.

THE BIGGEST QUESTION

WHO INVENTED COMPUTER SYSTEM ???



THE BIGGEST QUESTION

- The development of a computer is evolutionary.
- Computer system evolved over the years through continuous advancement in hardware and software technologies.
- It is therefore difficult to attribute the development of computers to a single individual.
- The development of computers started as a mechanical devices and eventually became an electronic device due to development in electronic technologies.

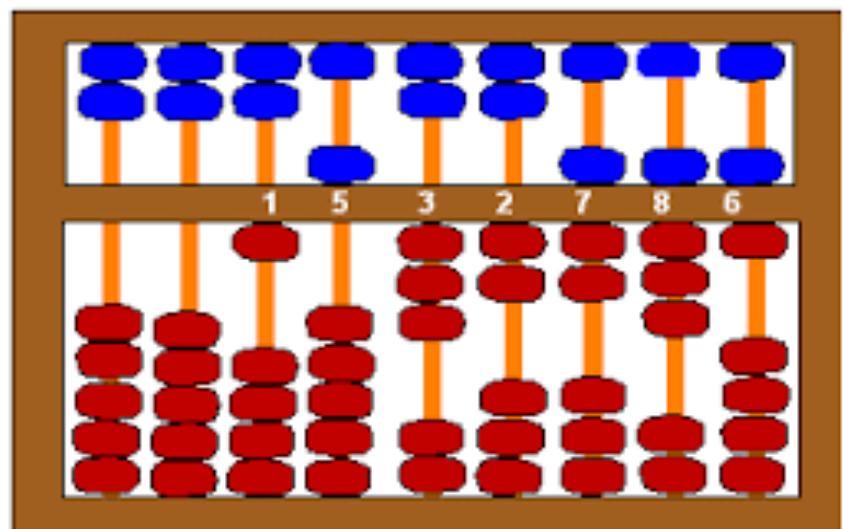
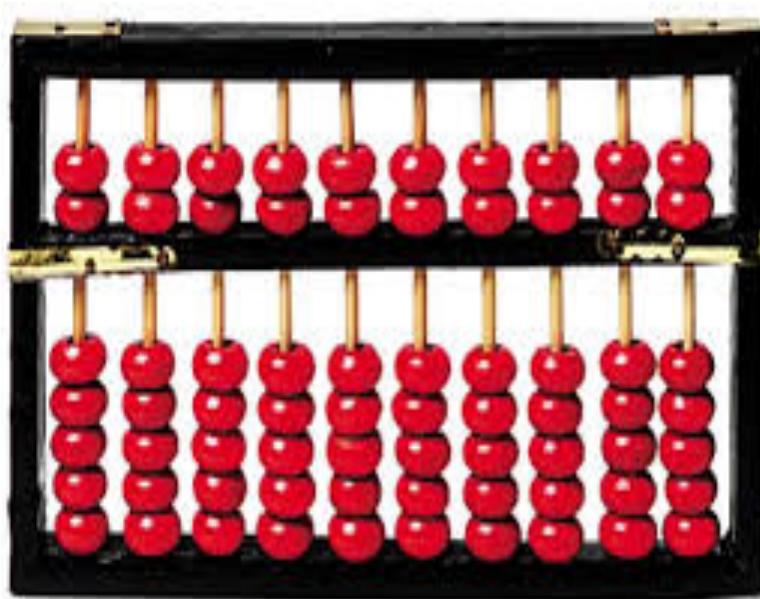
THE BIGGEST QUESTION

- The answer to the question “Who invented the computer?” is not a simple one.
- Computer system is not a single machine but a collection of different complicated parts,
- The development of each part can be considered as a separate invention.
- Many Scientists have contributed to the history of computers.
- Let us go through various computing devices which were developed prior to the existing computer.

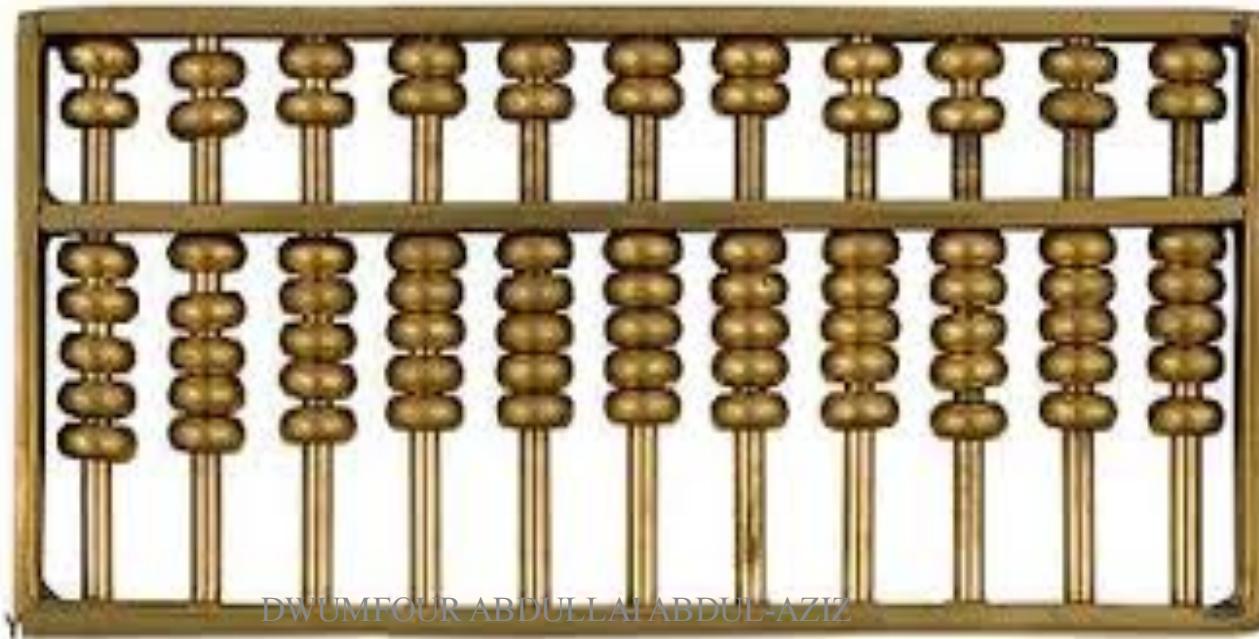
EVOLUTION OF EARLY COMPUTING

THE ABACUS

- Abacus is known to be the first mechanical calculating device.
- it was used to perform addition and subtraction easily and speedily.
- This device was first developed by the Egyptians in the 10th century B.C
- it was given its final shape in the 12th century A.D. by the Chinese educationists.
- Abacus is made up of wooden frame in which rods are fitted across with round beads sliding on the rod.



ABACUS



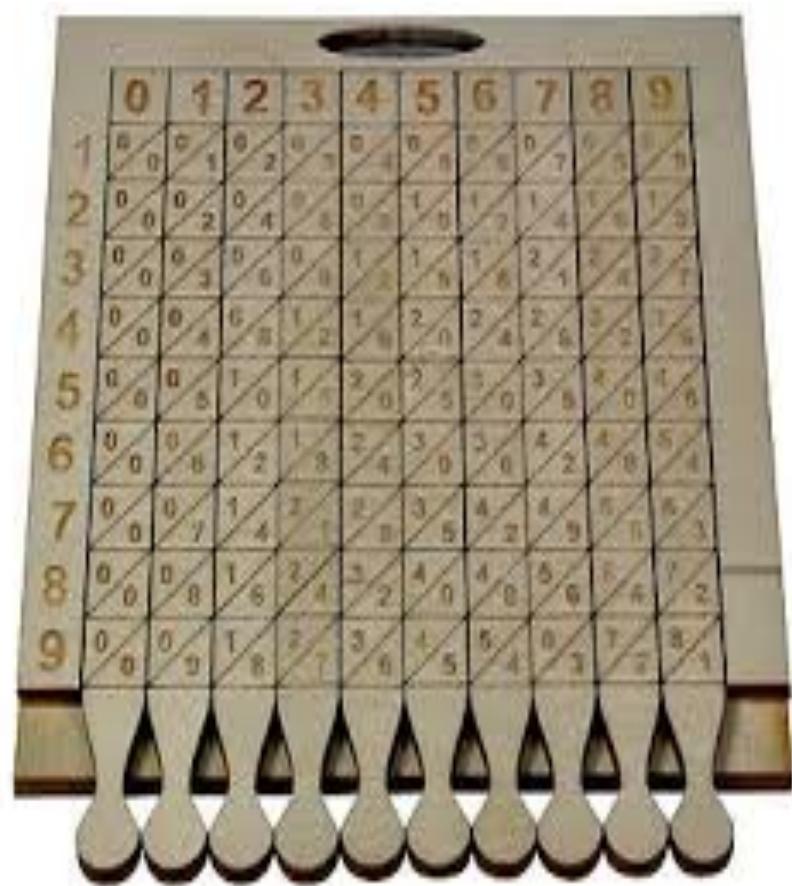
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EVOLUTION OF EARLY COMPUTING

John Napier(1550-1617):Napier's Bone

- In 1617, shortly before his death, John Napier of Scotland invented a mechanical calculating device called the Napier Bones.
- Napier's Bone could perform addition, subtraction multiplication and division.
- It was later modified to perform compute logarithms
- "Napier's bones," was based upon manipulation of rods with printed digits.
- The rods were made of bone, ivory, wood, or metal.
- Napier's bones became a very popular device for calculating in England and western Europe, because most people lacked these mathematical skills

1	0	1	2	3	4	5	6	7	8	9
2	0	2	4	6	8	0	2	4	6	8
3	0	3	6	9	1	5	8	2	4	7
4	0	4	8	2	6	0	4	8	2	3
5	0	5	1	0	5	2	5	3	5	0
6	0	6	2	8	4	0	6	2	8	5
7	0	7	1	4	2	3	5	4	9	6
8	0	8	6	2	4	3	0	8	5	7
9	0	9	1	2	7	3	6	5	4	3



Napier's Bones

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John Napier



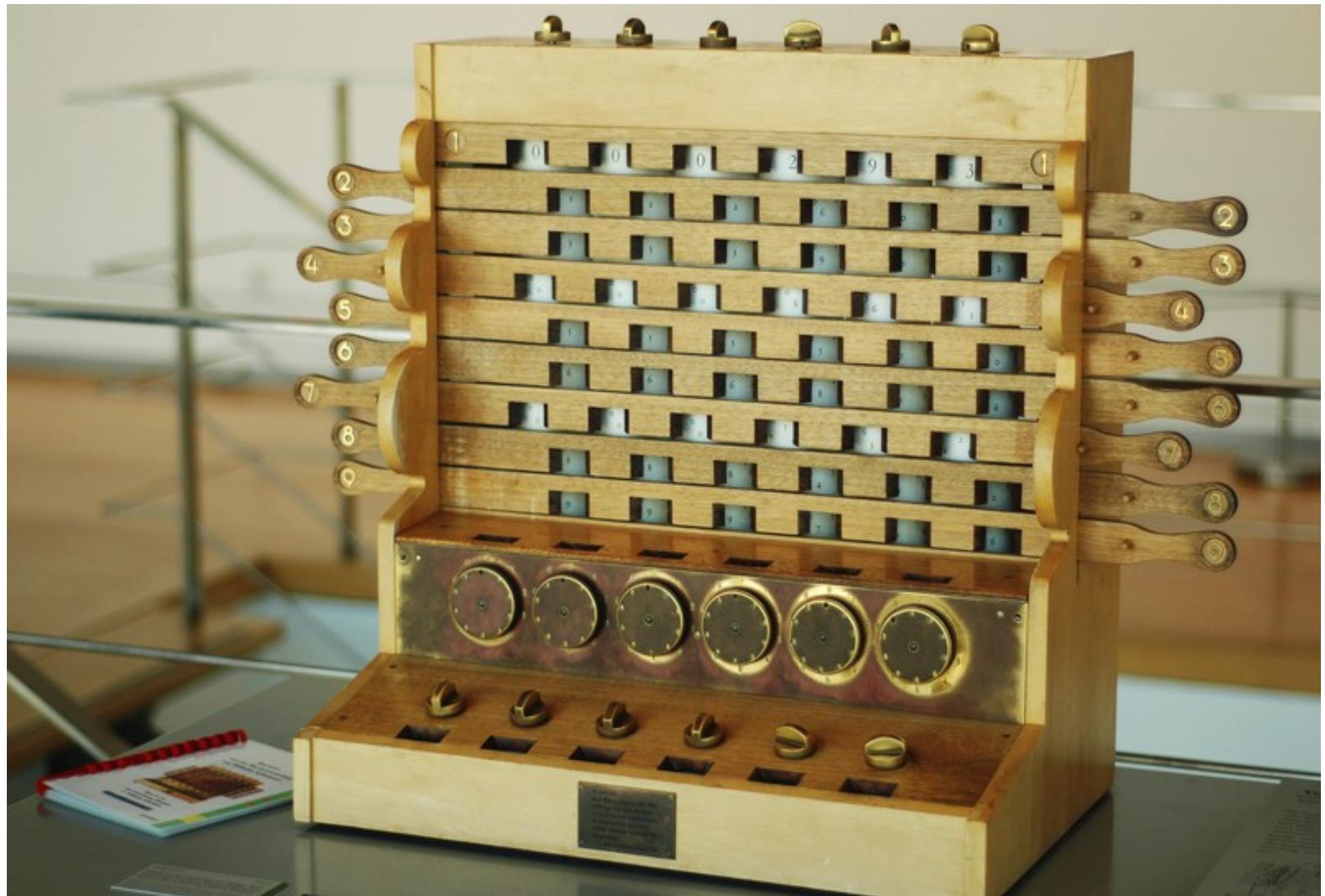
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EVOLUTION OF EARLY COMPUTING

Wilhelm Schickard (1592-1635): Calculating Clock

- In 1623, the German astronomer and mathematician, invented a calculating machine popularly known as the “speeding clock or calculating clock”.
- Schickard machine could add and subtract
- The machine was very influential in the calculation of astronomical tables
- Unfortunately a fire destroyed the machine as it was built in 1624.
- Schickard abandoned the project as a result of the fire incident
- His machine was never popularly known to the world for several centuries till around 1950s

EVOLUTION OF EARLY COMPUTING



Wilhelm Schickard



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EVOLUTION OF EARLY COMPUTING

Blaise Pascal (1623-1662): The Pascaline

- In 1642 invented what he called a numerical wheel calculator popularly known as the Pascaline .
- The machine was made of clock gears and levers
- It was considered as the first Mechanical Automatic Calculator
- His calculator performs addition and subtraction
- Pascaline never became popular due to the following;
 - The machine broke often and its inventor was the only person who could fix it.
 - it was slow.
 - Third, clerks would not use it: They were afraid it might replace them at their jobs



Pascaline



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Blaise Pascal



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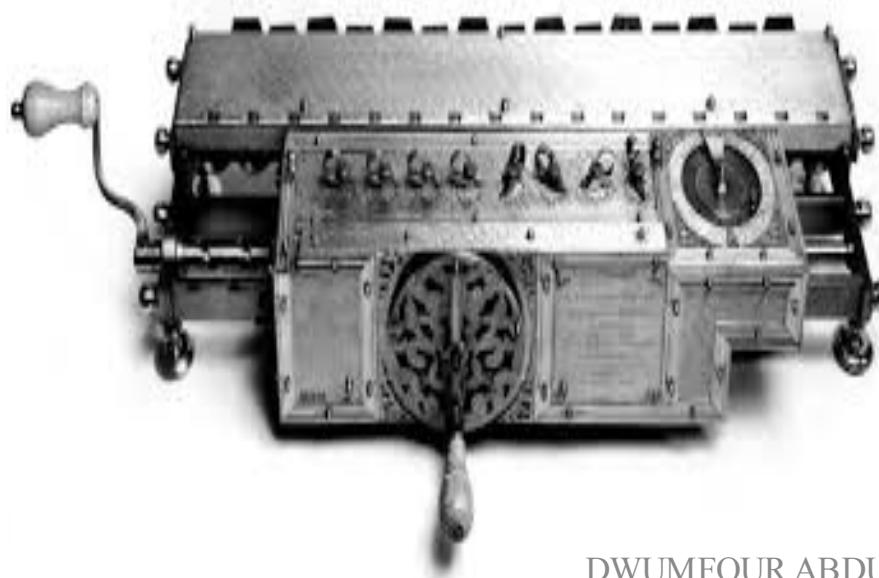
EVOLUTION OF COMPUTERS

Gottfried Wilhem Leibniz (1646-1716): The Stepped Reckoner

- In 1694, a German mathematician improved the Pascaline by creating a machine called Leibniz calculator, popularly known as the Stepped Reckoner
- The Leibniz calculator was also a calculating machine, but much superior to that of the Pascaline.
- It could do more than just add and subtract.
- The Leibniz Calculator could also multiply, divide, and find square roots of numbers.



Leibniz Calculator



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Gottfried Leibniz



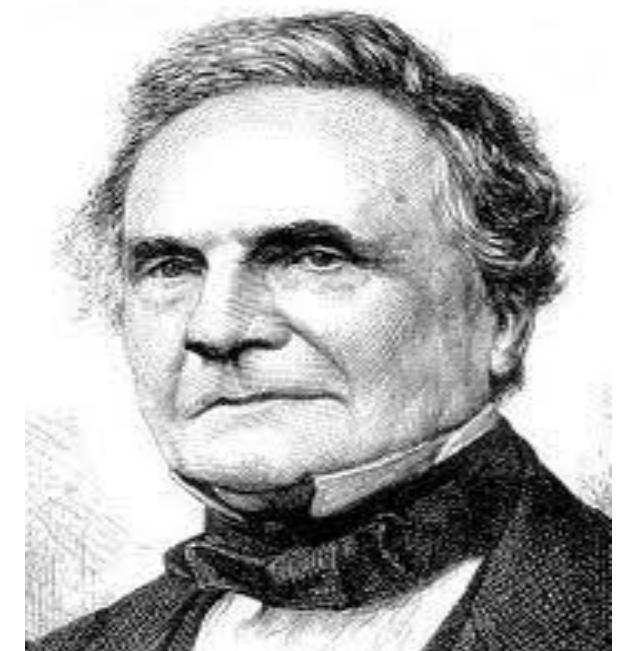
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EVOLUTION OF COMPUTERS

Charles Xavier Thomas (1785-1870): Arithmometer

- French entrepreneur in the insurance industry, invented the Arithmometer, in 1820.
- It was the first commercially successful digital mechanical calculator
- The machine could perform addition, subtraction, multiplication and division
- Arithmometer was extremely popular and sold for several decades till the WWI

EVOLUTION OF COMPUTERS



Arithmometer

EVOLUTION OF COMPUTERS

Joseph-Marie Jacquard(1752-1834): Jacquard Loom

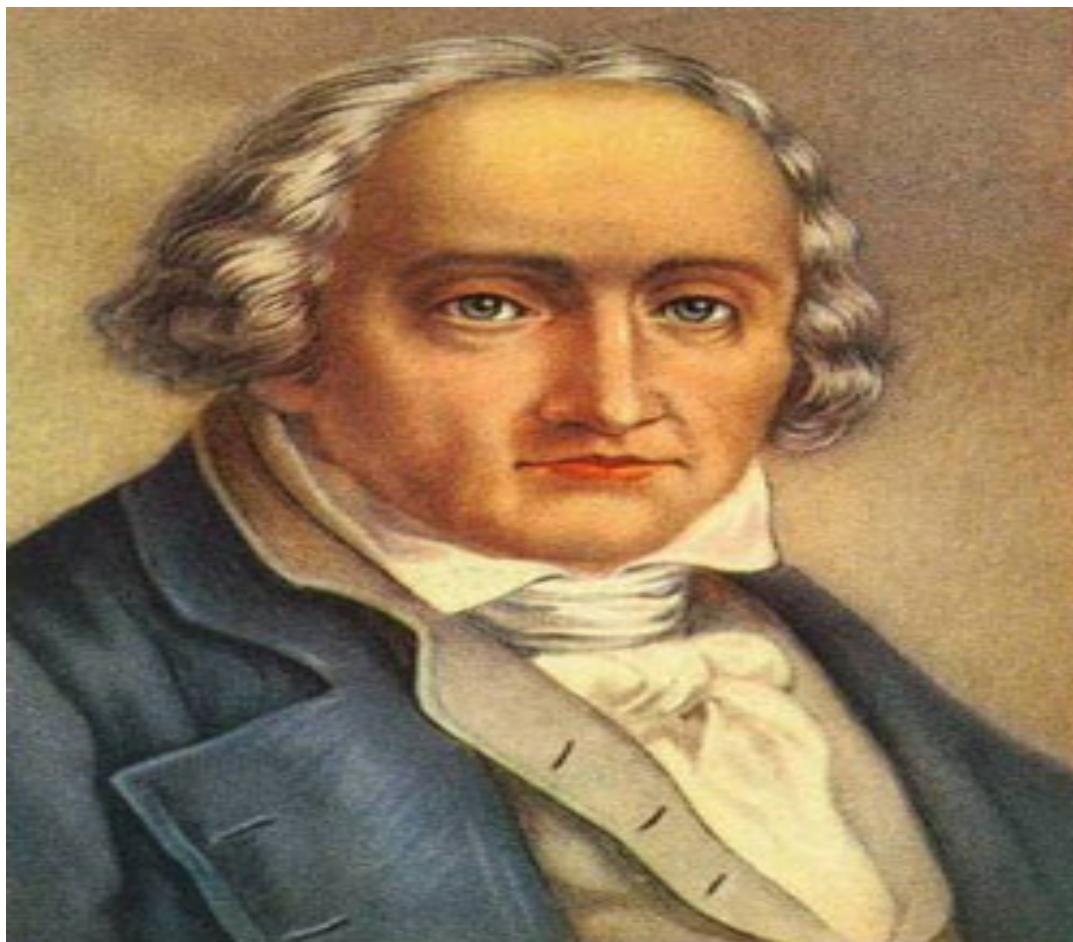
- In 1804, the French weaver Jacquard invented the Jacquard loom.
- It was a weaving machine that was automatically controlled by punched cards.
- It was the first machine to use punch card
- These cards would feed the right pieces of thread into the loom to make a beautiful cloth.
- His Loom played important role in the development of other programmable machines



Jacquard Loom

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Joseph Marie -Jacquard



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EVOLUTION OF COMPUTERS

Charles Babbage(1791-1871):Difference and Analytical Engines

- In 1822 the English mathematician proposed the Difference Engine, used for tabulating algorithm, trigonometry and polynomials functions
- The machine has a stored program and perform calculations and print the results automatically.
- After working on the Difference Engine for 10 years(1833), Babbage was suddenly inspired to begin work on the first general-purpose computer, which he called the Analytical Engine
- The analytical engine had a number of features starting up those which are in today's computer. He included the concept of central processor, Memory and Input/output devices in his design.

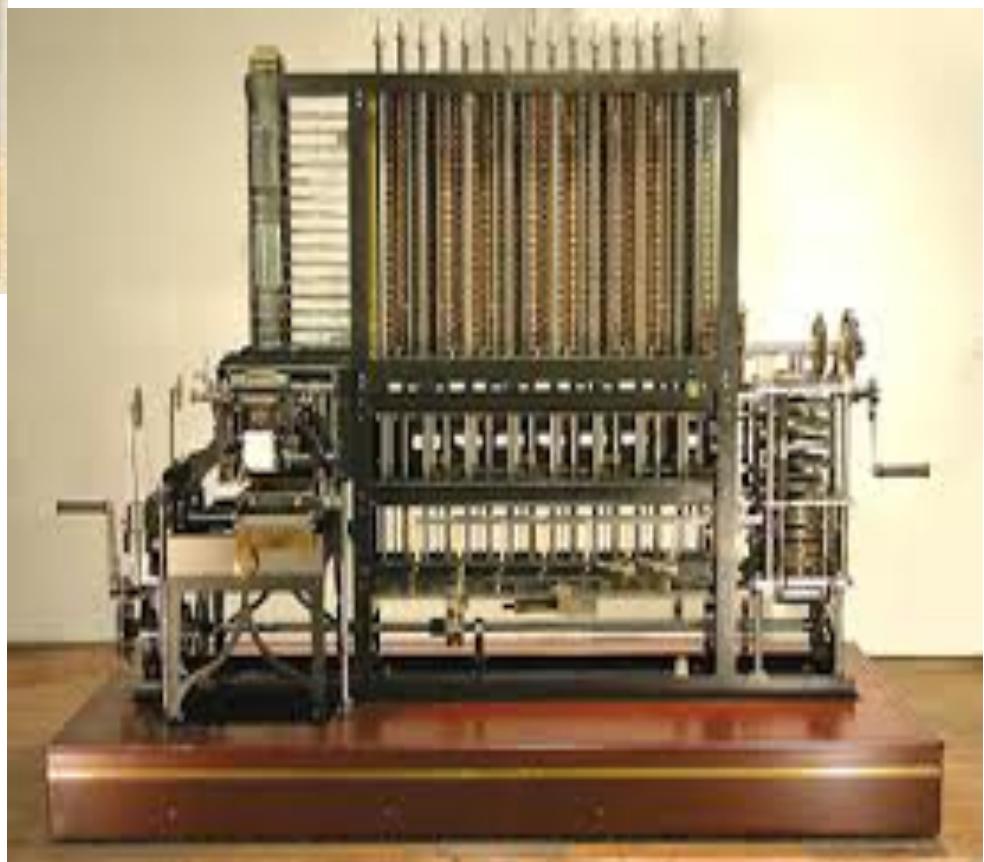
EVOLUTION OF COMPUTERS

Charles Babbage(1791-1871):Difference and Analytical Engines

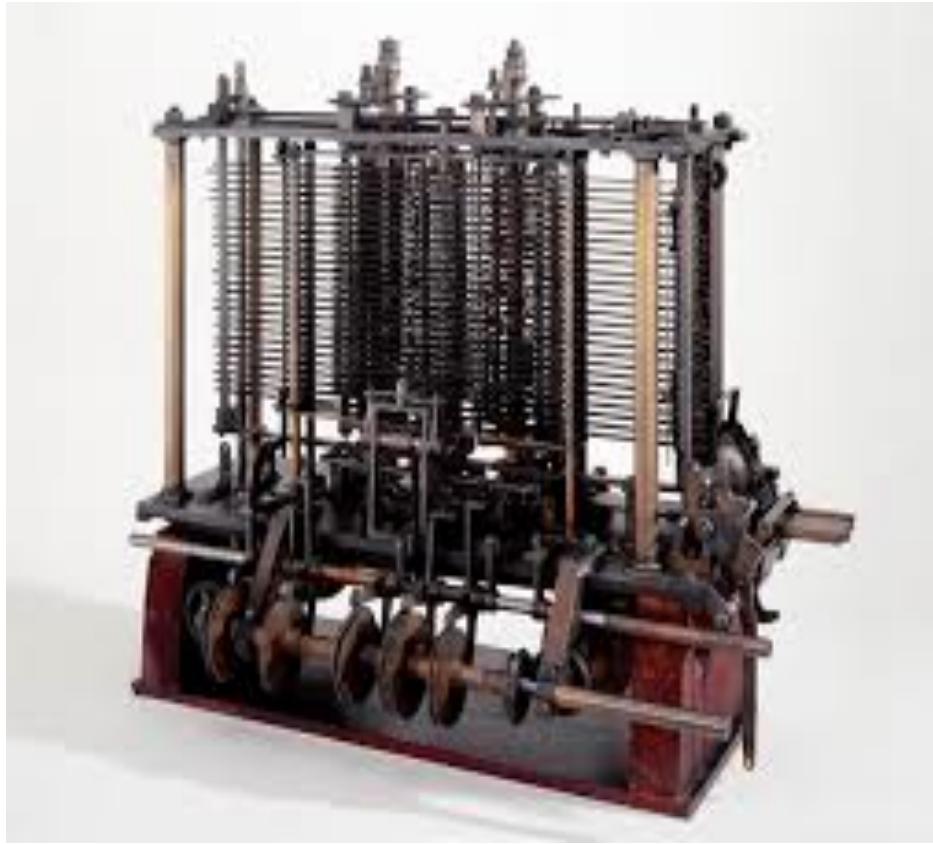
- The Analytical Engine was to be a general-purpose, fully program-controlled, automatic mechanical digital computer.
- The machine was designed to consist of four components: the mill, the store, the reader, and the printer.
- Charles Babbage is regarded as the “Father of computers”



Difference Engine



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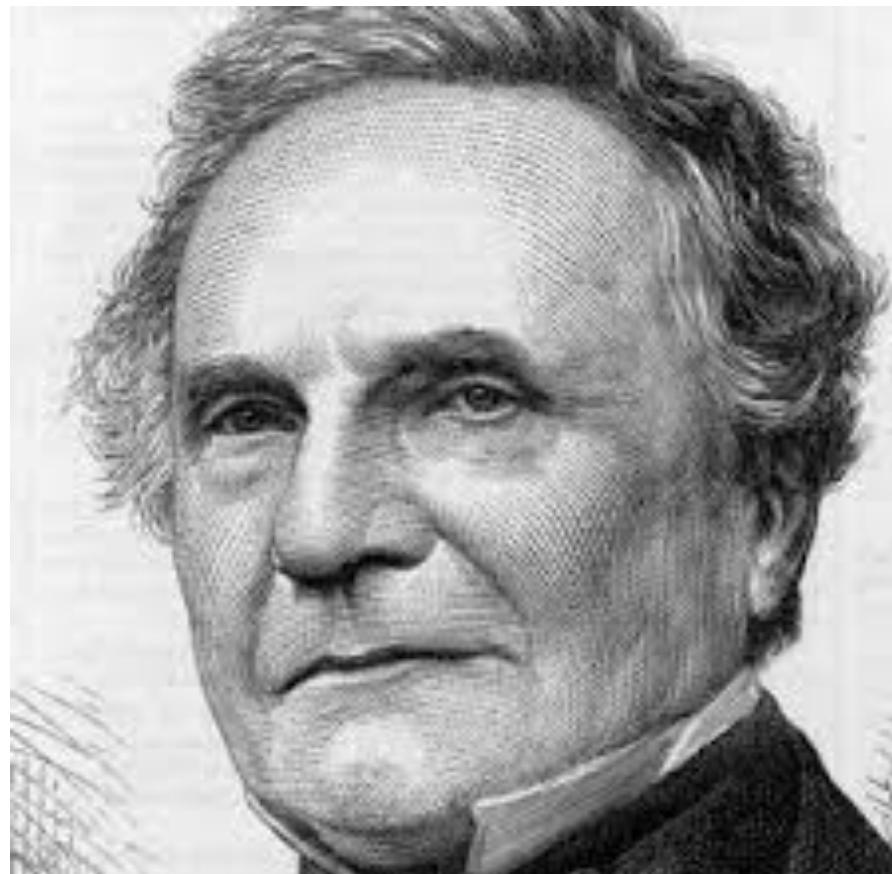


Analytical Engine



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Charles Babbage



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EVOLUTION OF COMPUTERS

Augusta Ada Lovelace(1816-1852)

- Ada is regarded as the first programmer
- Ada Lovelace, a friend of Babbage wrote the first sequence of instructions for various tasks for the analytical engine.
- She is regarded as the first programmer
- Used programming concept of looping for repetitive actions.
- Example: repeat block in Scratch. She used subroutines in her programs.

EVOLUTION OF COMPUTERS



Augusta Ada Lovelace

THE ELECTRO-MECHANICAL COMPUTING ERA



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EVOLUTION OF COMPUTERS

Herman Hollerith (1860-1929):The Tabulator

- In 1890, the American fabricated what was dreamt of by Charles Babbage.
- He fabricated the first electro-mechanical Punched-card tabulator that used punched-cards for input, output and instructions.
- This machine was used by American department of census to compile their 1890 census data and were able to complete compilation in 3 years which earlier used to take around 10 years.
- He formed a Tabulating Machine Company which later become IBM



HOLLERITH TABULATOR

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HERMAN HOLLERITH

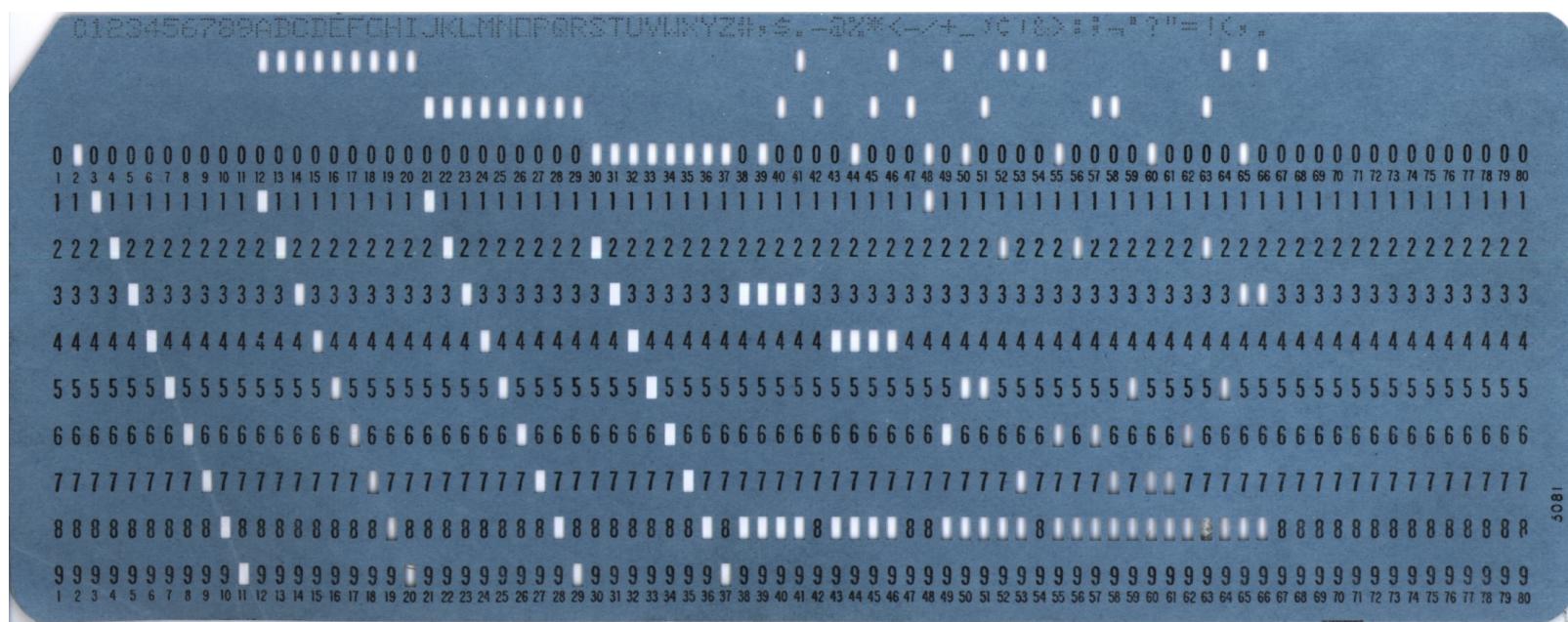
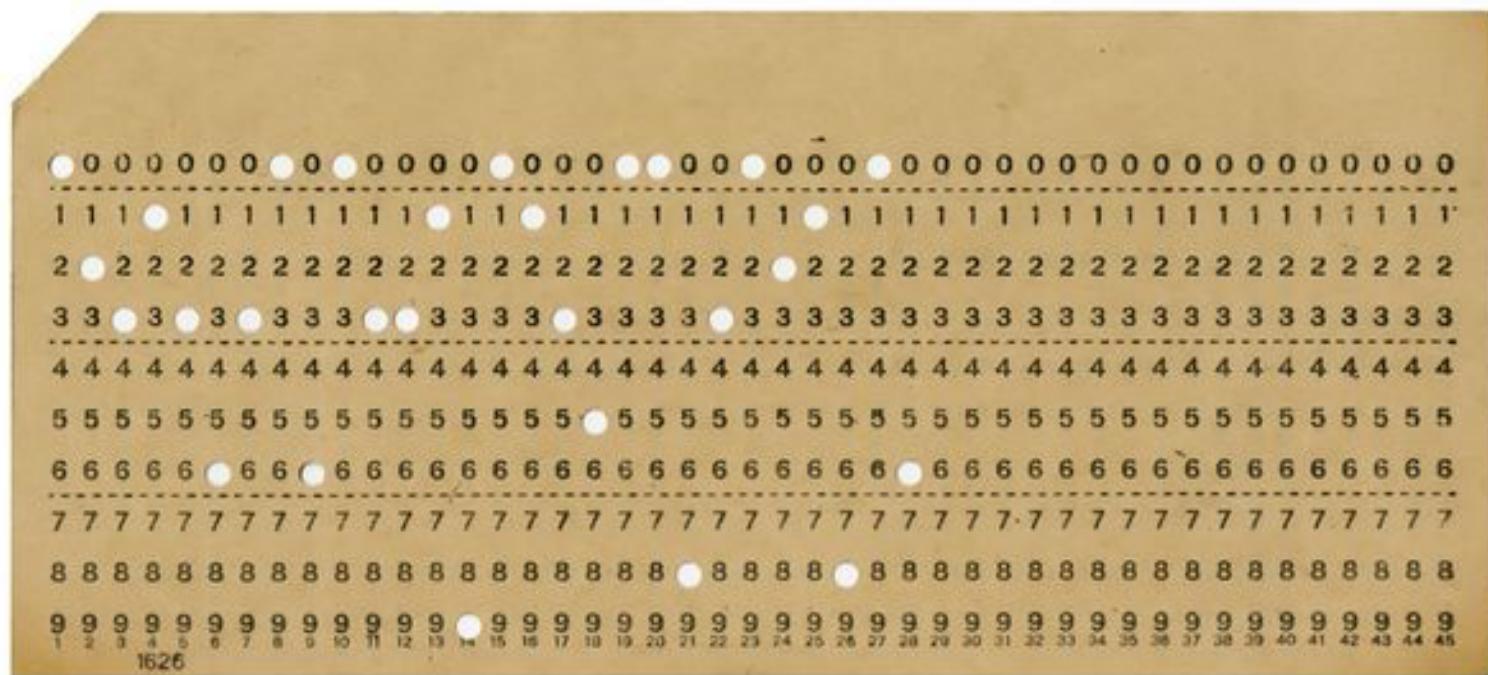
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EVOLUTION OF COMPUTERS

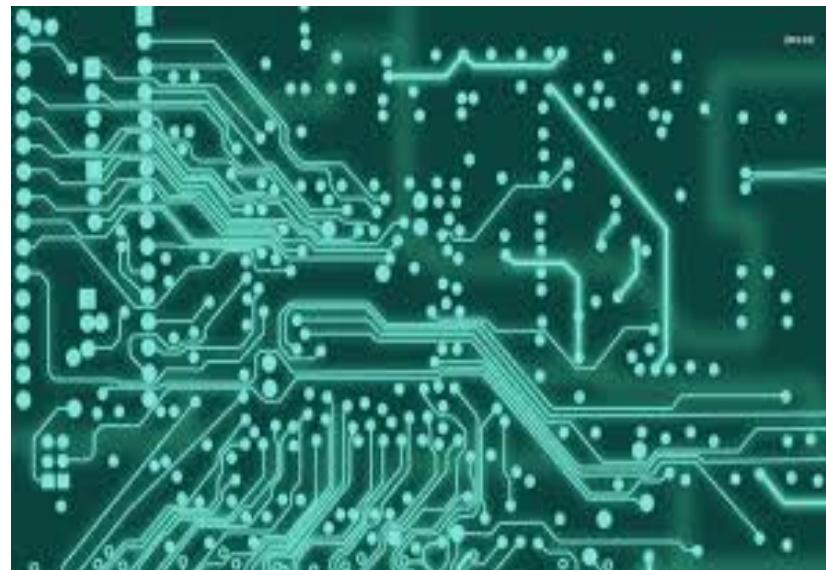
Punch Card

- Punch cards also known as Hollerith cards and IBM cards are paper cards containing several punched or perforated holes to represent data.
- This was invented by Herman Hollerith, an American Statistician in US Census Bureau.
- Punched Card System is used for storing and retrieving data.
- These cards allowed companies to store and access information by entering the card into the computer.

Punch card



THE TRANSITION FROM THE MECHANICAL/ ELECTROMECHANICAL ERA TO ELECTRONIC/ DIGITAL ERA



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EVOLUTION OF COMPUTERS

The Enigma machine

In 1915, it was used to by the German to send secrete messages among the military

The Colossus

In 1943, the British completed a secret code-breaking computer called Colossus to decode German messages.

THE ABC

Being completed by 1942, the Atanasoff-Berry Computer (ABC) was the first electronic computer.

It was designed and built by John Vincent Atanasoff and his assistant, Clifford E. Berry.

First generation (1940-1956): Vacuum Tube

- Use vacuum tubes for electronic components and CPU
- Very large in size and produce a lot of heat
- Consume high amount of electricity
- Very slow in operation
- Use machine language for programming
- Very costly and difficult to maintain
- Use magnetic drum as primary storage
- Use punch cards for input and printout for outputs

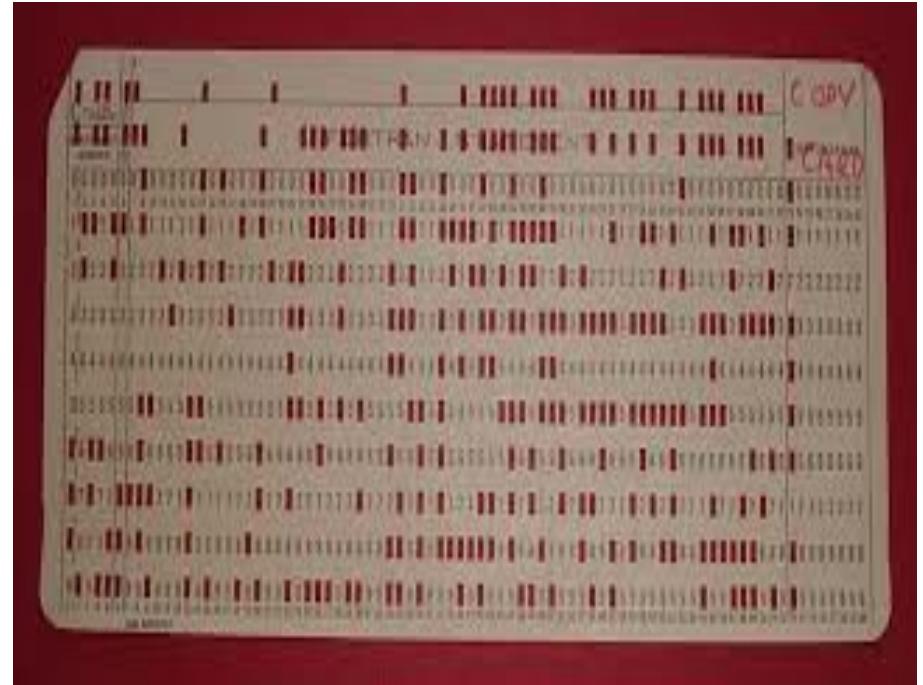
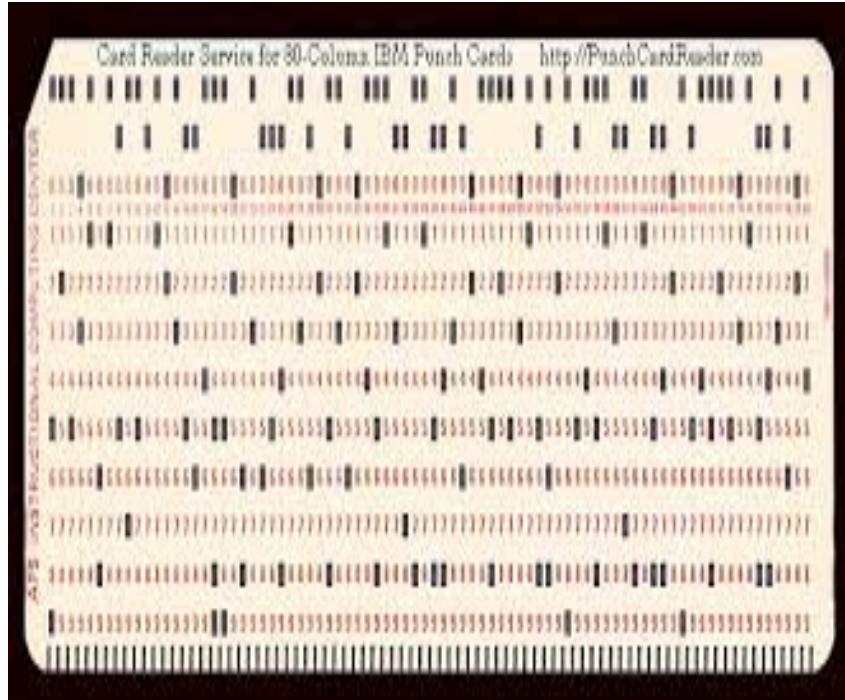
First generation (1940-1956): Vacuum Tube

- Batch processing operating system was used
- They could solve only one problem at a time and could take days or weeks to setup a new problem.
- Example are
 - ENIAC: Electronic Numerical Integrator & Computer; Octal based
 - EDVAC: Electronic Discrete Variable Automatic Computer: binary based
 - UNIVAC: Universal Automatic Computer
 - IBM701



Vacuum tube Technology

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PUNCH CARDS

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SECOND GENERATION (1956-1963): TRANSISTOR TECHNOLOGY

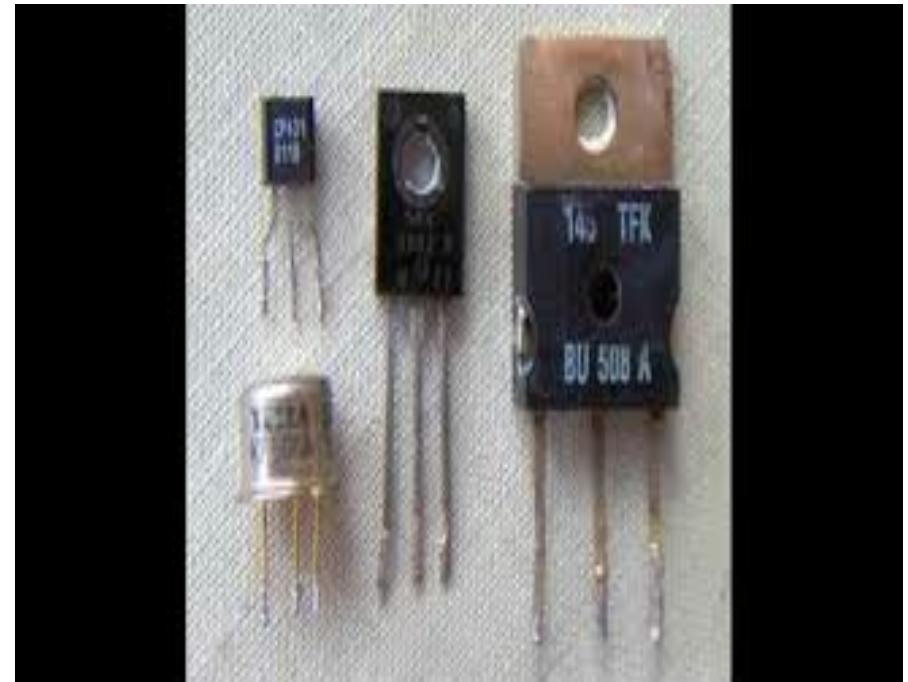
- Use Transistors as circuitry Technology
- Computers were smaller, faster, cheaper and more energy-efficient.
- Relied on low-level Assembly Language.
- Used magnetic core technology for primary storage instead of magnetic drum

SECOND GENERATION (1956-1963): TRANSISTOR TECHNOLOGY

- Input was based on punched cards and paper tape, and output was displayed on printouts
- Uses batch processing operating system
- Example of include: IBM 7000, NCR 304, IBM 1620, IBM 1401



wiseGEEK



Transistor Technology

*Thanks be to John Bardeen, Walter Brattain,
and William Shockley*

HISTORICAL DEVELOPMENT OF COMPUTERS

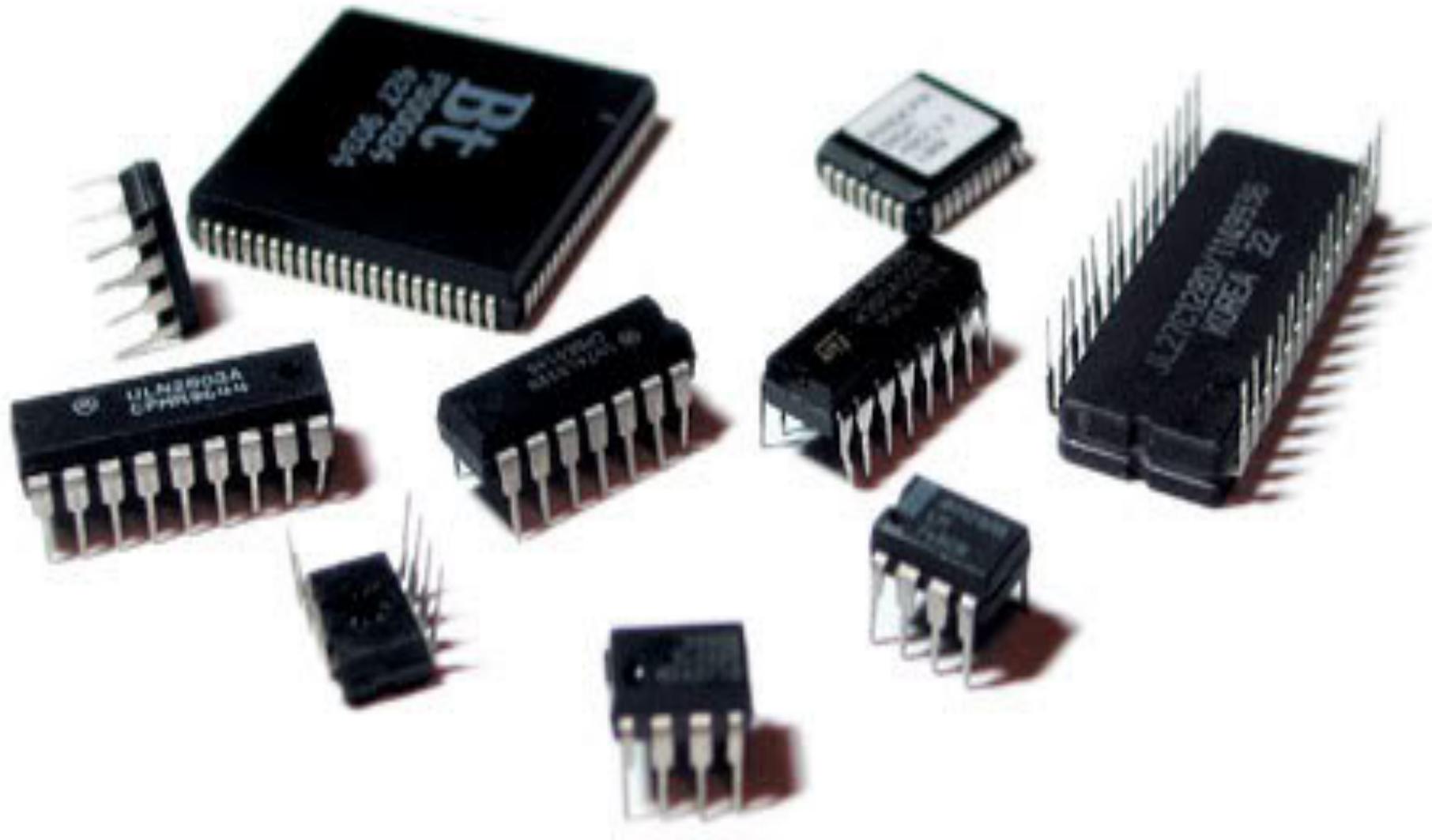
Third Generation (1964-1971): Integrated Circuit

- Integrated circuit was the hallmark of the third generation computers.
- Computers were much smaller, faster, cheaper and more energy-efficient.
- They use keyboard for inputs and monitors for output.
- Uses time-sharing and multi-programming operating system

HISTORICAL DEVELOPMENT OF COMPUTERS

Third Generation (1964-1971): Integrated Circuit

- It is able to solve several problems at the same time.
- They relied on High level programming language(COBOL, FORTRAN, BASIC, ALGOL)
- Example IBM-360 series, Honeywell-6000 series



Integrated Circuit Technology

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HISTORICAL DEVELOPMENT OF COMPUTERS

Fourth Generation (1971-present): Microprocessor

- Microprocessor technology; thousands of integrated circuits built on a single silicon chip.
- It uses Very Large Scale Integrated (VLSI) circuit
- Very fast, much smaller, cheaper, less energy consumption
- The speed, accuracy and reliability of the computers were improved
- Improved Input and output devices
- Parallel processing and multi-tasking capabilities
- Network capabilities

HISTORICAL DEVELOPMENT OF COMPUTERS

Fourth Generation (1971-present): Microprocessor

- Support for GUI applications were developed
- Support primary and secondary storage devices
- It uses time-sharing, real time, distributed operating system
- High Level Language such as C, C++ ,Java etc.
- 1981 IBM introduced its computer for the home user
- In 1984 Apple introduced the Macintosh Microprocessor.



Microprocessor Technology

HISTORICAL DEVELOPMENT OF COMPUTERS

Fifth Generation (present and future): *Artificial intelligence*

- Fifth generation computers are computing devices created based on artificial intelligence.
- The goal is to develop computing devices that are able to exhibit autonomous intelligence
- The computers should be able to respond to natural language input and possess machine learning capabilities.



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TYPES OF COMPUTERS

Computers can be classified into three (3) kinds, namely;

- Digital computers
- Analog computers
- Hybrid computers

Digital computers

- ❖ A Digital Computer, works with digits to represent numerals, letters or other special symbols.
- ❖ Digital computers process information in binary mode
- ❖ A digital computer can be used to process numeric as well as non-numeric data.
- ❖ It can perform arithmetic operations like addition, subtraction, multiplication and division and also logical operations.

Type of Digital computers

Digital computers are classified into four kinds:

- ✓ Supercomputers
- ✓ Mainframes
- ✓ Minicomputers
- ✓ Microcomputers

Super computers

- ✓ These are the most powerful type of digital computer.
- ✓ It is large, extremely fast, expensive and high capacity computer used for complex or sophisticated calculations.
- ✓ Supercomputers are used for weather forecasting, large-scale scientific modeling, and oil exploration.
- ✓ NASA uses supercomputers to track and control space explorations.



SUPERCOMPUTERS

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Mainframe

- ✓ These large computers occupy specially wired, air-conditioned rooms.
- ✓ Although not nearly as powerful as supercomputers, *mainframe computers are* capable of great processing speeds and data storage.
- ✓ A mainframe computer often allows hundreds of users simultaneous access.
- ✓ Insurance companies, banks, universities and government agencies use mainframes to process information about millions of transactions.



MAINFRAME COMPUTERS

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Minicomputer

- ✓ *Minicomputers are desk-sized machines.*
- ✓ They are referred to as mid-range computers since they fall between the capabilities and size of mainframes and microcomputers.
- ✓ Minicomputers process data a little slower than mainframes.
- ✓ A small minicomputer might be able to support between ten and twenty users.
- ✓ Medium-sized companies or departments of large companies typically use them for specific purposes



MINI COMPUTERS

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Microcomputers

- ❖ Although the least powerful, *microcomputers* are the most widely used and fast-growing type of computer.
- ❖ Microcomputers are usually accompanied by a single keyboard and printer, have one or two hard-disk drives, smaller in size and may be connected to a network.
- ❖ They are less expensive and can be found in homes and offices
- ❖ Microcomputers can be subdivided into two categories:
 - ✓ Desktop computers
 - ✓ Portable computers

Desktop computers

- ✧ Desktop computers are small enough to fit on top of or alongside a desk yet are too big to carry around.
- ✧ Desktop computers often come in two orientations. One sits flat (horizontal) on the desk. This is referred to as desktop computer.
- ✧ The other desktop computer stands straight (vertically) on the desk. This is referred to as a tower



Tower



Desktop

DESKTOP COMPUTERS

Portable computers

These are small enough and light enough to carry around. They are all built into one unit and do not need to be assembled whenever they are moved.

There are four categories of portable computers.

- ✓ Laptop
- ✓ Notebooks
- ✓ Palmtops
- ✓ Personal digital assistants (PDAs)



LAPTOP COMPUTER

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NOTE BOOK COMPUTER

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PALMTOP COMPUTER

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PDA

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INTRODUCTION TO COMPUTER HARDWARE

- Computer Hardware refers to the physical components of the computer.
- This is the tangible part of the computer you can see and touch.
- Microcomputer hardware can be classified into the several functional units.
- Each Functional unit is composed of several hardware devices that perform specific function