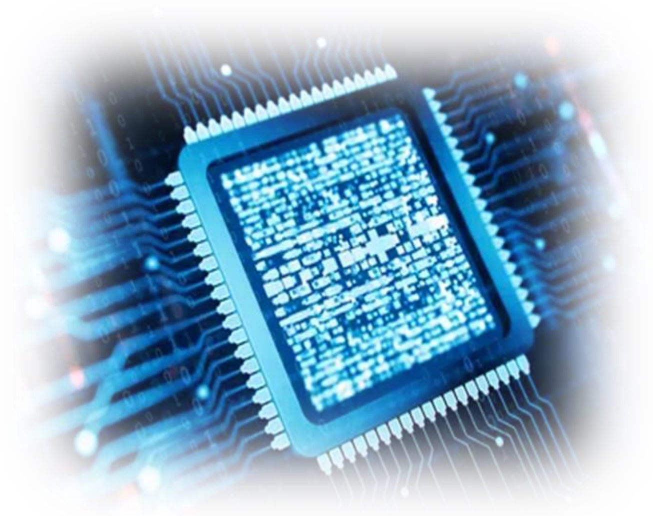


MICROPROCESSOR SYSTEMS

BLG212E

Burak Berk Üstündağ   CRN: 11450

Gökhan İnce / Ayşe Yılmazer   CRN: 11446

İTÜ Bilgisayar ve Bilişim Fakültesi

Week 2: Introduction to Microprocessors

Topics

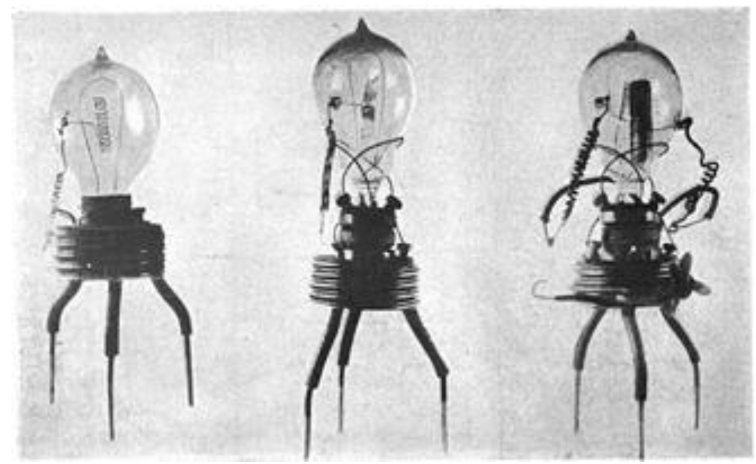
- Introduction: Computer History
- Microprocessor based Systems
- Number Systems

Computer History

Advances in computer technology

- Pre-electronics era
  - Gears and mechanical systems
- Electronics era

  Vacuum tubes, transistors



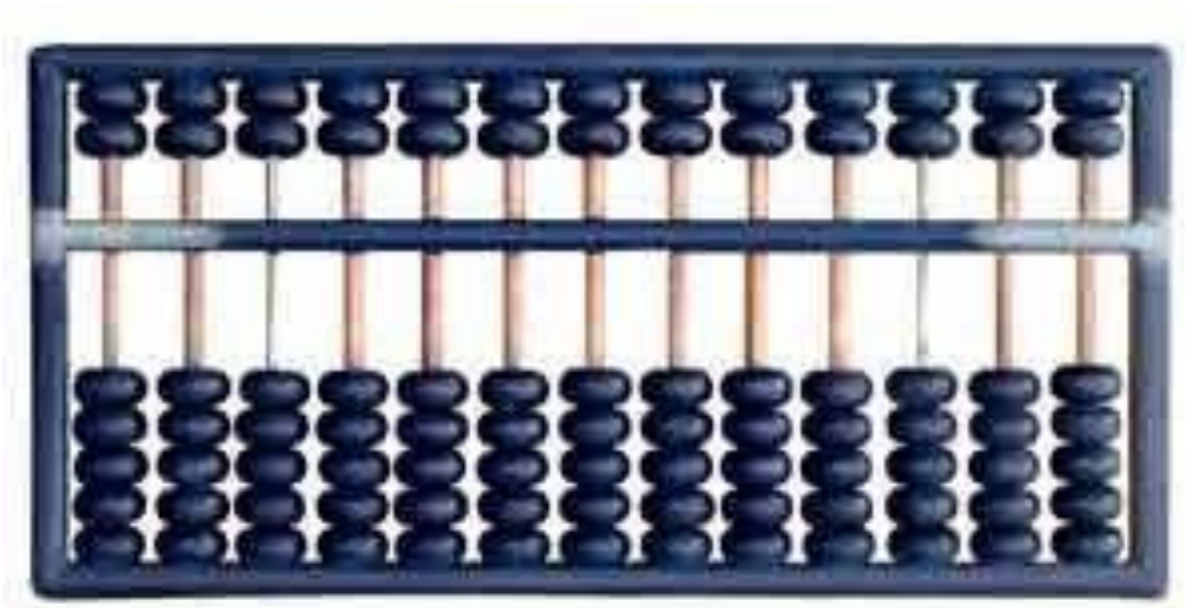
(Thermoionic valve, 1904 – Fleming)

- Microprocessor age (1971-)
  - Integrated circuits and single-chip microprocessors

Computer History

- The first computers were people (predominantly women). "Computer" was originally a job title to perform the repetitive calculations required to compute such things as **navigational tables, tide charts, and planetary positions** for astronomical almanacs.
- The abacus, also called a counting frame, is a calculating tool used primarily in parts of Asia as an aid for mathematical computations

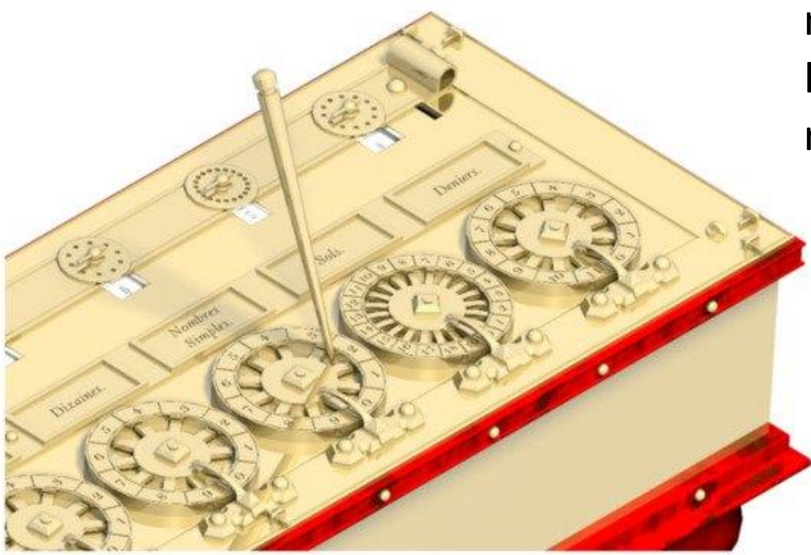
Ref: http://www.computersciencelab.com/ComputerHistory/History.htm



In 1642, first Calculator: Blaise Pascal invented the mechanical calculator.

Pascal received a Royal Privilege in 1649 from king of France.
This granted him exclusive rights to make and sell calculating machines in France

This calculator was designed to add and subtract two numbers directly.
It can also perform multiplication and division through repeated addition or subtractions.



Rojas-Sola, José del Río-Cidoncha, Gloria, Fernández de la Puente Sarriá, Arturo, Galiano-Delgado, Verónica, - Blaise Pascal's **"Mechanical Calculator: Geometric Modelling and Virtual Reconstruction"** , Machines, MDPI , 2021, volume 91

Carry mechanism with two accumulators

9's complement usage in Pascals Calculator :

The 9's complement of any one digit decimal number d is 9-d. So the 9's complement of 4 is 5 and the 9's complement of 9 is 0. Similarly the 11's complement of 3 is 8.

In a decimal machine with n dials the 9's complement of a number A is:

$CP(A)=10^n-1-A \rightarrow$ 9's complement of (A-B) is:

$CP(A-B)=10^n-1-(A-B)=10^n-1-A+B = CP(A)+B$

Example: 123-105= ? CP(123)=1000-1-123=876

$CP(A-B)= CP(A)+B=876+105=981 \rightarrow A-B=CP(CP(A-B))=1000-1-981=18$

Subtraction of Binary Numbers :

$$A - B = A + (-B) = A + not(B) + 1$$

85-66=?

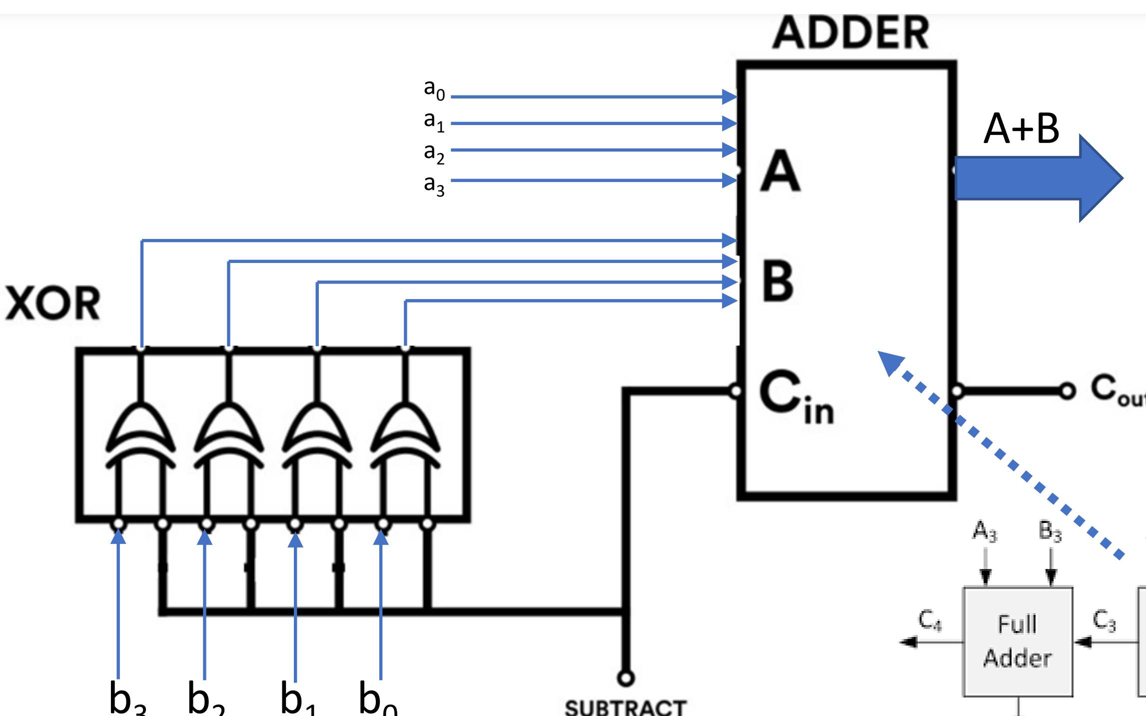
$85\text{-}66=(1010101)_2\text{-}(1000010)_2$

$85\text{-}66=(1010101)_2+(0111101)_2+1$

$$\begin{array}{r} (1010101)_2 \\ (0111101)_2 \\ +\ (0000001)_2 \\ \hline 1(0010011)_2 \end{array} \quad =19$$

Decimal	Two's Complement
-1	1111
-2	1110
-3	1101
-4	1100
-5	1011
-6	1010
-7	1001
-8	1000

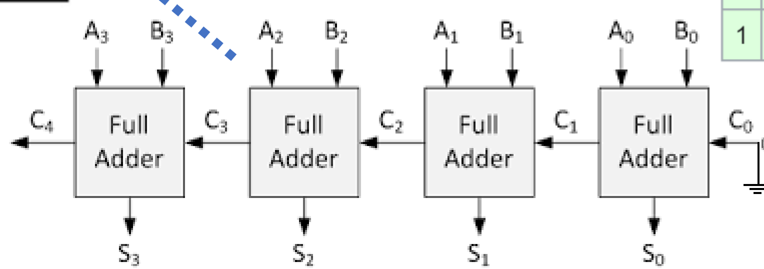
4-bits Adder & Subtractor:



One-bit full adder:

Inputs			Outputs	
A	B	C_{in}	C_{out}	S
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

4-bits full adder:



Step Reckoner by Gottfried Leibniz (1671) :

Gottfried Leibniz developed a machine to perform multiplication, division and square roots.

Step Reckoner expanded on Pascal's ideas and did multiplication by repeated addition and shifting

a) adds and subtracts an 8-digit number to/from a 16-digit number,
b) multiplies two 8-digit numbers to get a 16-digit result,
c) divides a 16-digit number by an 8-digit divisor.

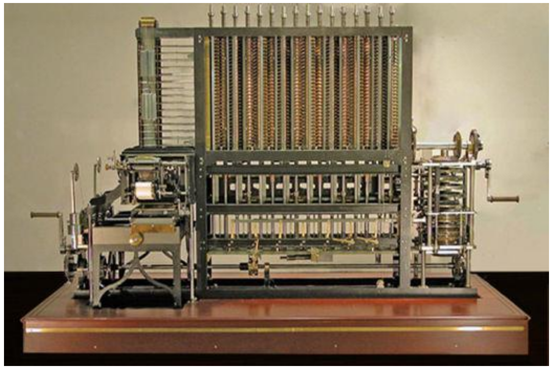
Computer History – Pre Electronics

- In 1804, Joseph-Marie Jacquard designed a loom capable of following instructions on a punched paper tape.

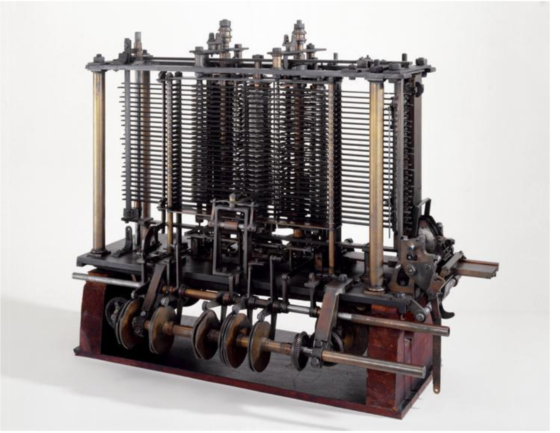
Computer History – Pre Electronics

Charles Babbage – Difference Engine

- 1822 the English mathematician ***Charles Babbage*** proposed a steam driven calculating machine the ***Difference Engine***.
- This machine would be able to compute tables of numbers (polynomials), such as logarithm tables.
- He obtained government funding for this project due to the importance of numeric tables in ocean navigation.
- In that time frame the British government was publishing a seven volume set of navigation tables which came with a companion volume of corrections.
- It was hoped that Babbage's machine could eliminate errors in these types of tables.
- Construction of Babbage's Difference Engine proved exceedingly difficult and the project soon became the most expensive government funded project up to that point in English history.



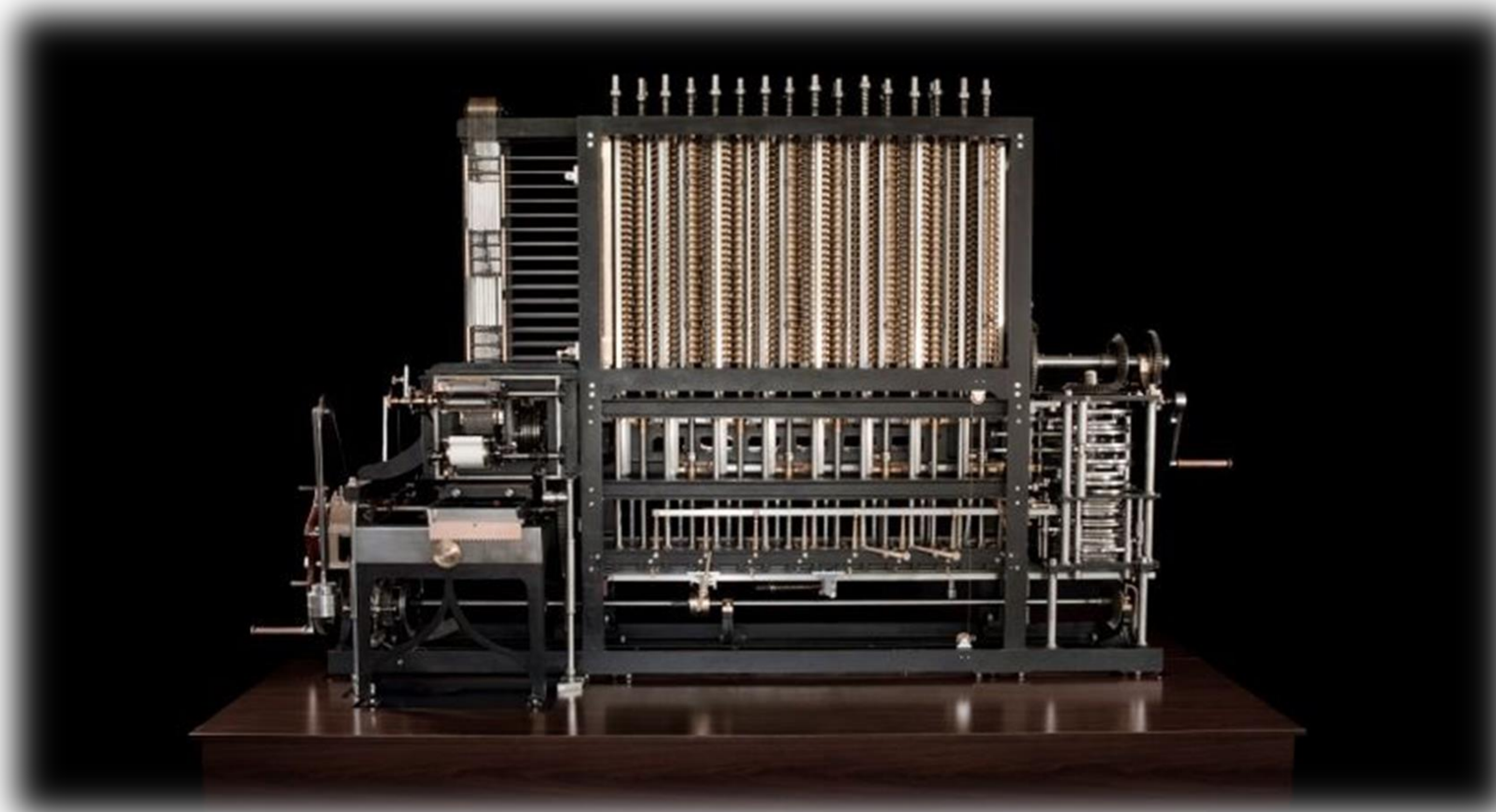
Computer History – Pre Electronics



Charles Babbage – Analytic Engine

- This large device, powered by 6 steam engines, would be more general purpose in nature because it would be **programmable**, thanks to the punched card technology of Jacquard.
- Babbage saw that the pattern of holes on a punch card could be used to represent an abstract idea such as a problem statement or the raw data required for that problem's solution. Babbage realized that **punched paper** could be employed as a **storage mechanism**, holding computed numbers for future reference.
- Because of the connection to the Jacquard loom, Babbage called the two main parts of his Analytic Engine the "Store" and the "Mill", as both terms are used in the weaving industry. The Store was where numbers were held and the Mill was where they were "woven" into new results. In a modern computer these same parts are called the ***memory unit*** and the ***central processing unit*** (CPU).
- The Analytic Engine also had a key function that distinguishes computers from calculators: **the conditional statement**. Based on the conditional statement, the path of the program (that is, what statements are executed next) can be determined based upon a condition or situation that is detected at the very moment the program is running.
- Ref: http://www.computersciencelab.com/ComputerHistory/History.htm

Charles Babbage – Difference Engine

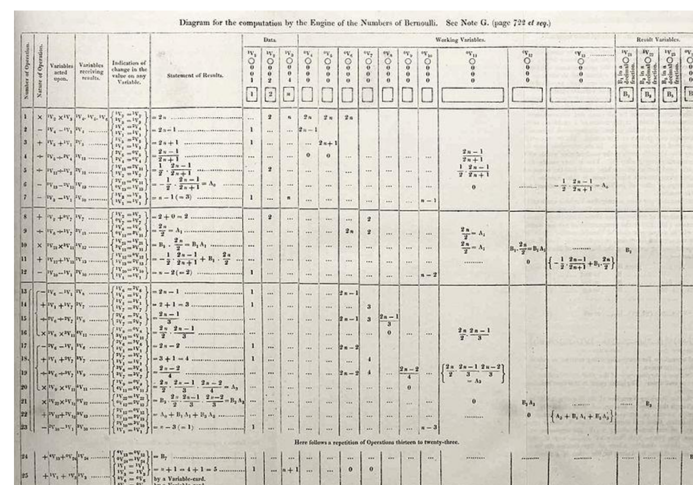


Engine calculates with numbers thirty-one digits long and can tabulate any polynomial up to the seventh order (1847).
8000pieces, 5tons (2002)

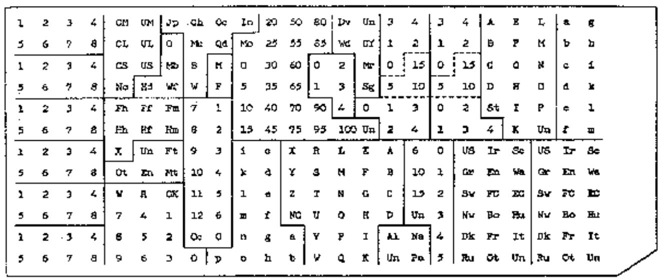
Computer History – Pre Electronics

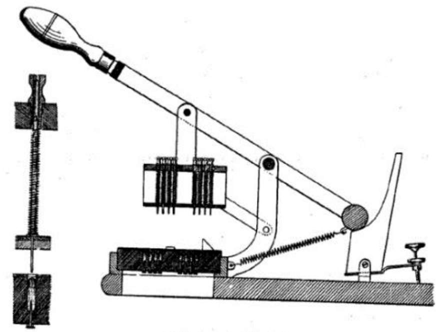
Ada Byron, the first programmer

- Babbage befriended ***Ada Byron***, the daughter of the famous poet Lord Byron
- She was only 19, she was fascinated by Babbage's ideas and thru letters and meetings with Babbage she learned enough about the design of the Analytic Engine to begin fashioning programs for the still unbuilt machine.
- While Babbage refused to publish his knowledge for another 30 years, Ada wrote a series of "Notes" wherein she detailed sequences of instructions she had prepared for the Analytic Engine.
- The Analytic Engine remained unbuilt (the British government refused to get involved with this one) but Ada earned her spot in history as the first computer programmer.
- **Ada invented the subroutine and was the first to recognize the importance of looping.**



Computer History – Pre Electronics

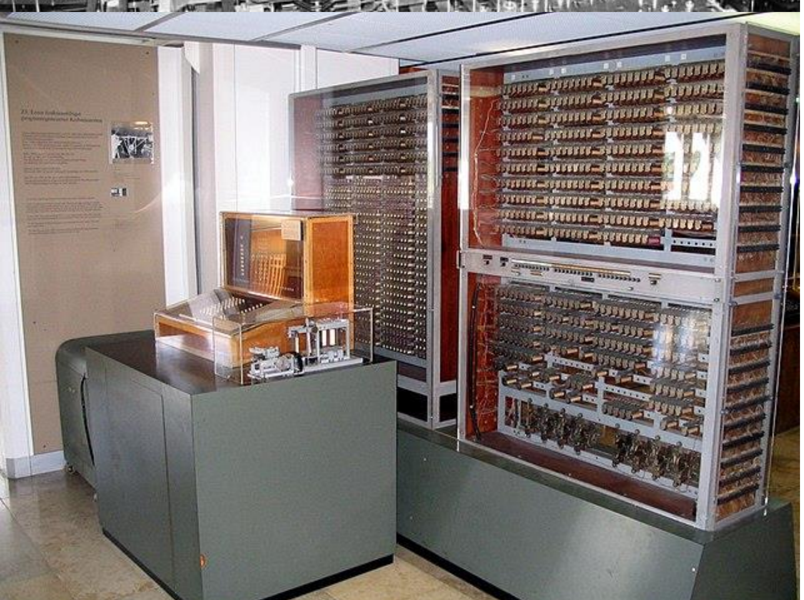




- In 1890 Herman Hollerith built machines under contract for the Census Office, which used them to tabulate the 1890 **census** in only one year.
- ->1924:IBM
- In 1935, at Cambridge University, **Turing** conceived the principle of the modern computer. He described an abstract digital computing machine consisting of a **limitless memory** and a **scanner** that moves back and forth through the memory. The actions of the scanner are dictated by a program of instructions that is stored in the memory in the form of symbols.

Conrad Zuse

Z1: 1938, binary electrically driven mechanical calculator with limited programmability, reading instructions from punched celluloid film.
The “Z1” was the first freely programmable computer in the world.
It uses Boolean logic and binary floating-point numbers.



Z3: 1941 world's first working programmable, fully automatic digital computer.
The Z3 was built with 2,600 relays, implementing a 22-bit word length that operated at a clock frequency of about 5–10 Hz
Hans Georg Küssner, used Z3 for "Program to Compute a Complex Matrix" that was written and used to solve wing flutter problems.
Z3 was Turing-complete
Zuse had also offered SolidState version of Z3.

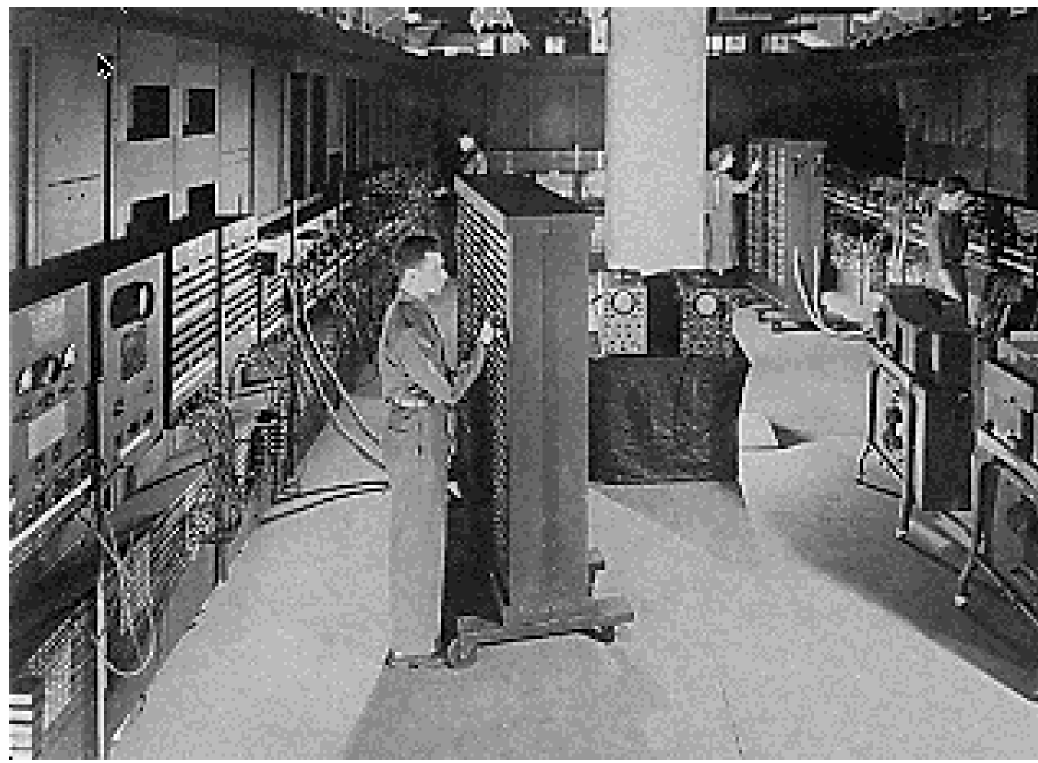
Electronics Age

- The Electronic Numerical Integrator and Computer (ENIAC), was the first general-purpose electronic computer (1945).
- 100kW power consumption
- 30x10x3m dimensions, 18.000 tubes, 30 tonnes
- Used decimal system,
- no internal memory
- One operation in 200 µs.

-> 5000 cycles per second

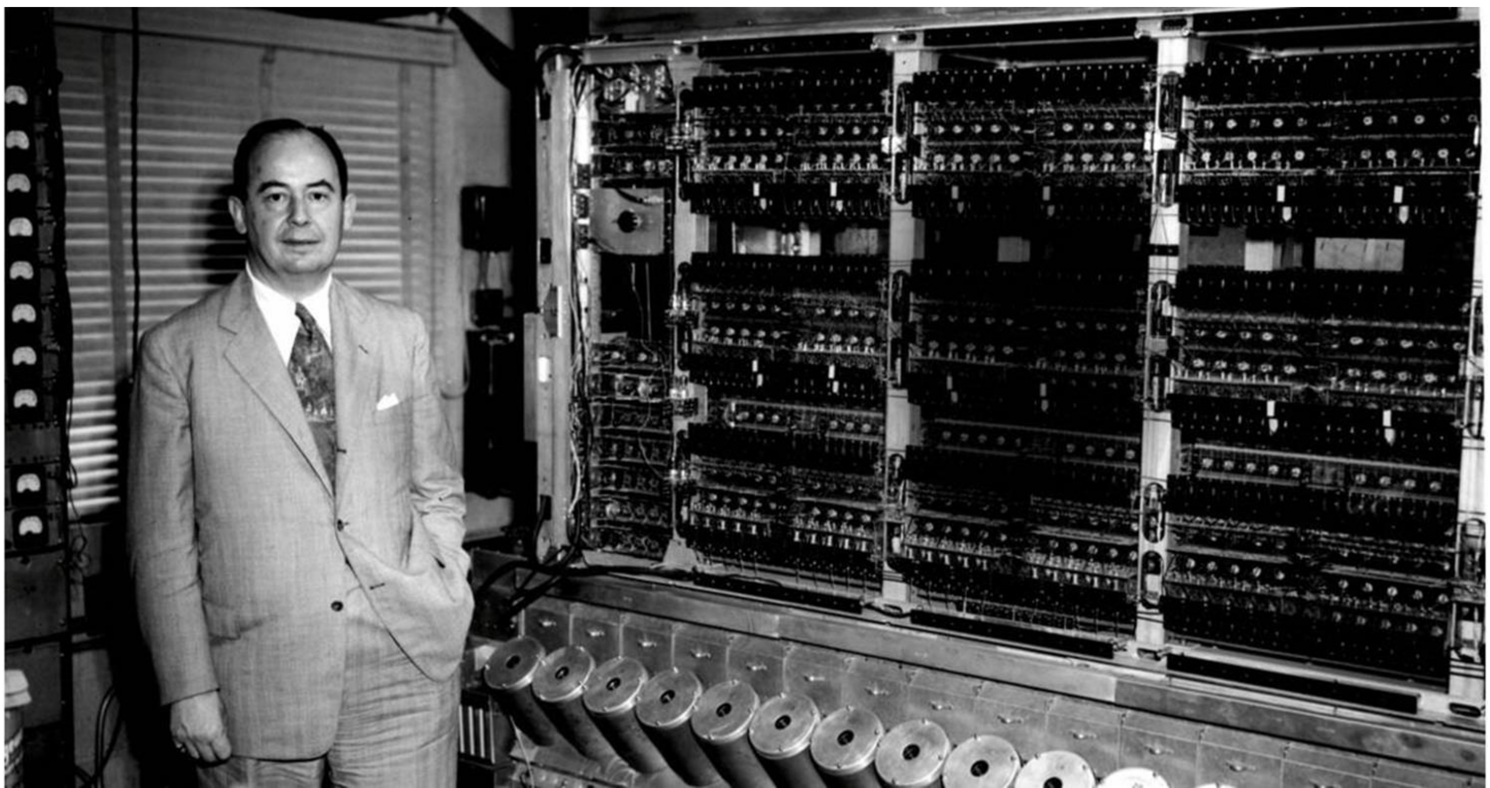
-> 5kHz

- $ 500,000
- University of Pennsylvania
- 1.500 relays
- 70.000 resistances



Electronics Age

- In 1945, in his first draft of a report on the EDVAC, von Neumann proposed the stored program concept.
  - instructions and data are both stored in the same medium.
  - should be able to hold any programme in memory
  - same hardware can be loaded with different software to make a computer perform different types of jobs
    - a multipurpose computer



EDVAC was built in 1952.

(John Von Neumann)

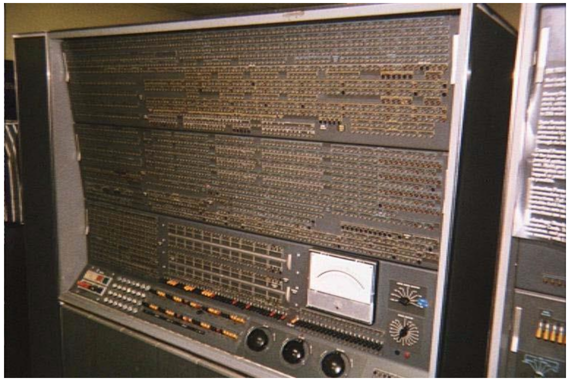
Computer History

- First generation computers (1945-1955): **vacuum tubes for circuitry and magnetic drums for memory**, and were often enormous, taking up entire rooms

- These computers would be miniaturized in the future!
* I hope they shrink the ELEPHANTS, too.

Electronics Age

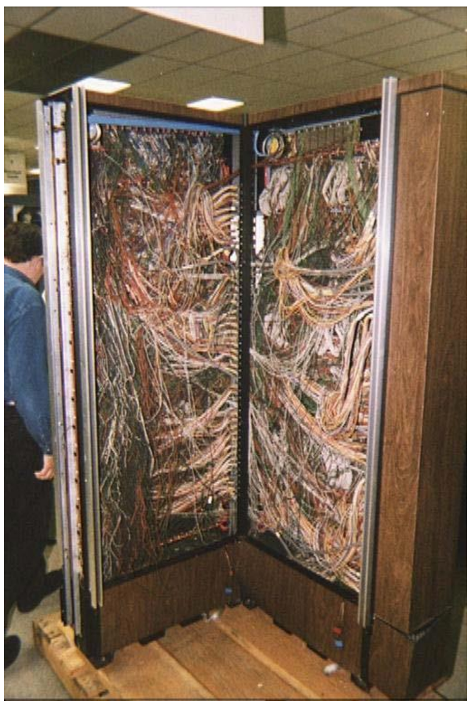
- Second generation computers (1956-1965): **Transistors**, invented in 1948, replaced vacuum tubes; **assembly language**

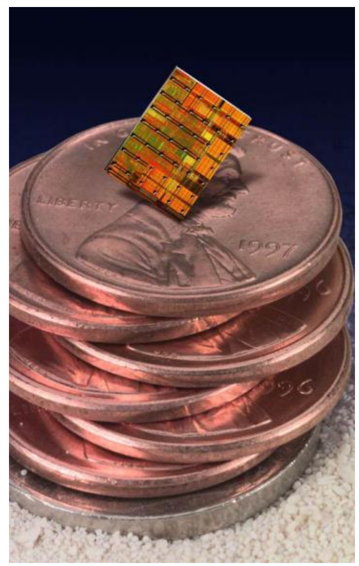


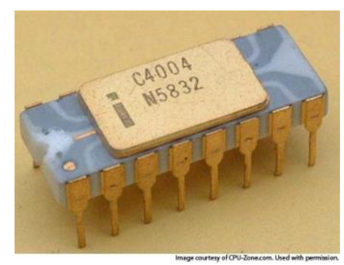
- Third generation computers (1966-1975): Transistors were miniaturized and placed on **silicon chips**, called semiconductors.

The Age of Microprocessors

- Fourth generation computers (1971-): Thousands of integrated circuits were built onto a single silicon chip. (Intel 4004)







Intel 4004 :**2300 transistors and 108 kHz**
Intel i7 quad-core :**731 million transistors** and **3.5 GHz**

Topics

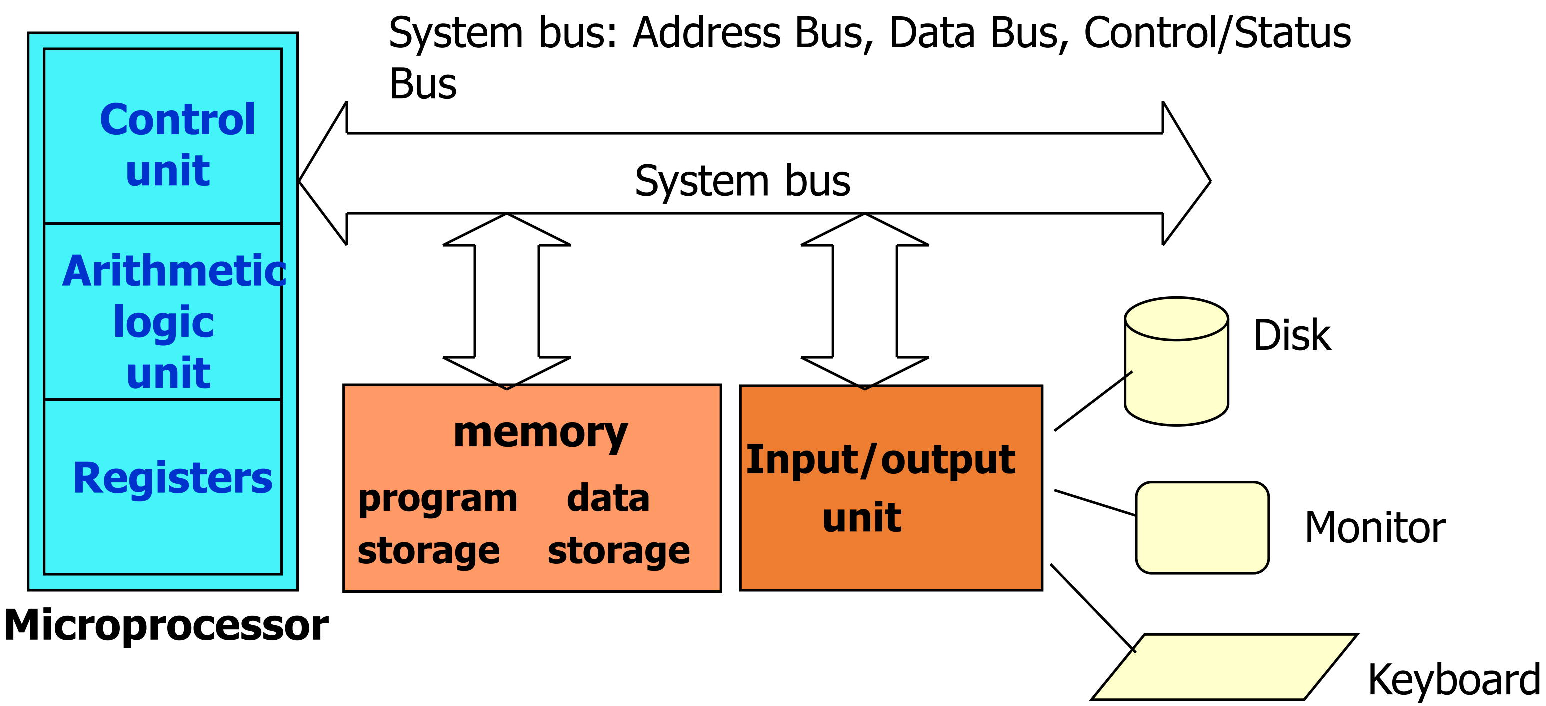
- Introduction: Computer History
- Microprocessor based Systems
- Number Systems

Microprocessor based Systems

- A computer is a programmable machine designed to automatically carry out a sequence of arithmetic or logical operations.
  - **Embedded System** is a special-purpose computer system designed to perform one or a few dedicated functions
  - **General purpose computer systems** provide programmability to users to carry out a finite set of arithmetic or logical operations.

Computer Organization

- The block diagram of a micro-computer system is shown below. In this course we will discuss about such systems.



What is a microprocessor?

- The microprocessor is a programmable device that takes in numbers, performs on them arithmetic or logical operations according to the program stored in memory and then produces other numbers as a result

What is a microprocessor?

- Programmable device: The microprocessor can perform different sets of operations on the received data depending on the sequence of instructions supplied in the given program.
  By changing the program, the microprocessor manipulates the data in different ways.

- Instructions: Each microprocessor is designed to work with its own instruction set. This instruction set defines what the microprocessor can and cannot do.

What is a microprocessor?

- Takes in: Input devices (such as keyboard, mouse...) feed data into computer

- Numbers: Microprocessors operate on numbers in the form of binary. The number of bits it can run simultaneously defines its word length. Microprocessor input and output are digital numbers

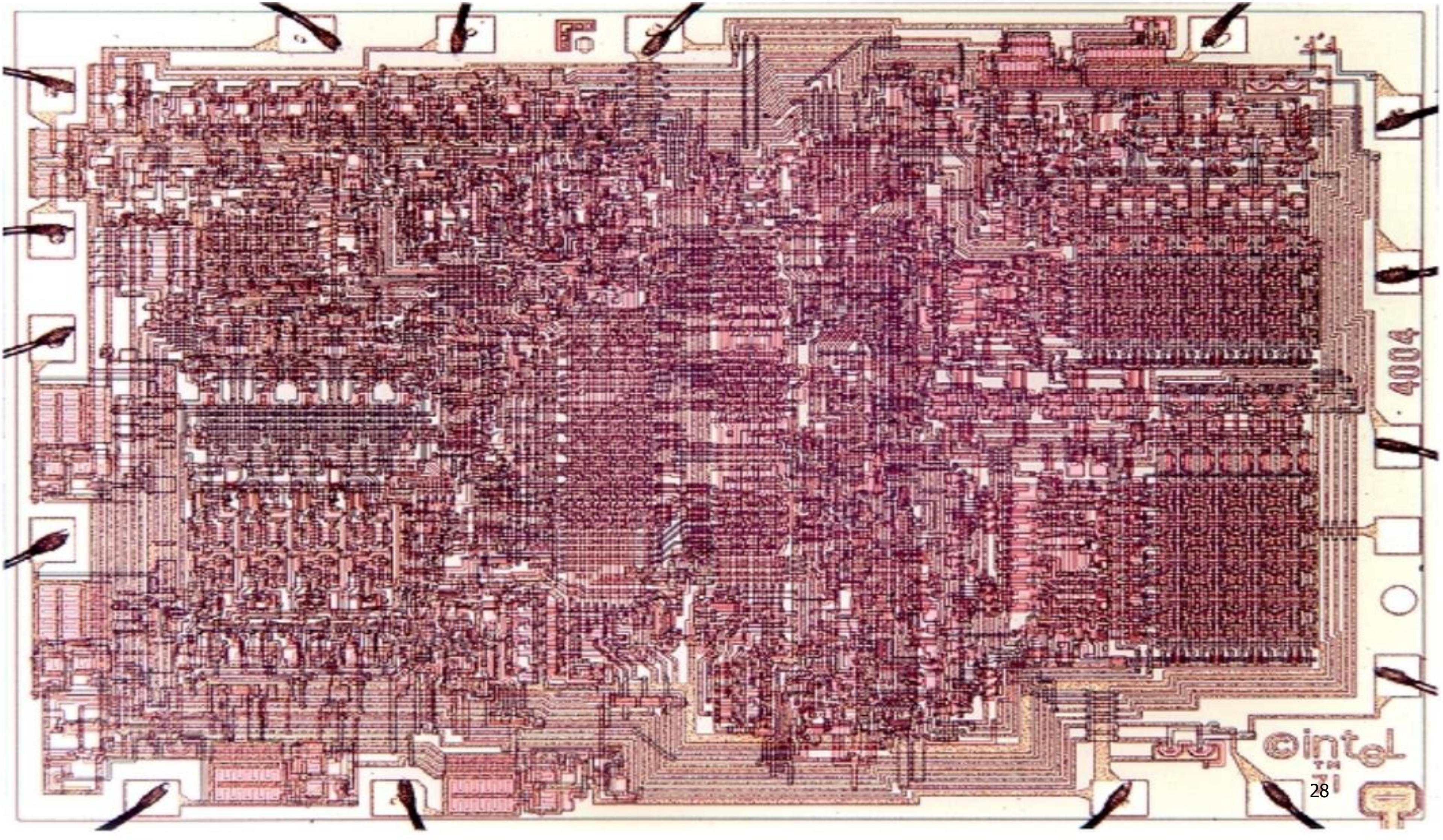
- Arithmetic and Logic Operations: Every microprocessor has arithmetic operations such as add and subtract and logic operations such as AND, OR, XOR, shift left, shift right, etc.

What is a microprocessor?

- Program: A program is a sequence of instructions to operate the computer
  - Machine language: Low level instructions in binary form specific for the microprocessor. In this language, every instruction is described by binary patterns.
    - ex. 11001101   may mean   1 + 2
  - Assembly Language: Symbolic language to represent low level machine code
  - Languages such as C, Fortran, Pascal etc… are high level languages, which are compiled (translated into the machine language)

Intel 4004, 1971

first monolithic processor, 2250 transistors, 750kHz Clock frequency



Machine Language

- The number of bits that form the **word** of a microprocessor is fixed for that particular processor.
  - These bits define a maximum number of combinations.
  - For example an 8-bit microprocessor can have at most $2^8 = 256$ different combinations.

- However, in most microprocessors, not all of these combinations are used.
  - Certain patterns are chosen and assigned specific meanings.
  - Each of these patterns forms an instruction for the microprocessor.
  - The complete set of patterns makes up the microprocessor’s machine language.

Assembly Language

- Entering the instructions using **hexadecimal** is quite easier than entering the binary combinations.
  - However, it still is **difficult** to understand what a program written in hexadecimal does.
  - So, each company defines a symbolic code for the instructions.
  - These codes are called **mnemonics**.
  - The mnemonic for each instruction is usually a group of letters that suggest the operation performed.

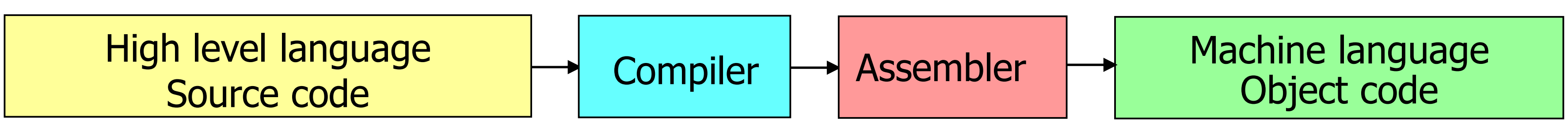
Assembly Language

- It is important to remember that a **machine language** and its associated **assembly language** are completely **machine dependent**.
  - In other words, they are not transferable from one microprocessor to a different one.

- For example, Motorola has an 8-bit microprocessor called the 6800.
  - The Intel 8085 machine language is very different from that of the 6800. So is its assembly language.
  - A program written for the 8085 cannot be executed on the 6800 and vice versa.

High Level Languages

- We said earlier that assembly and machine language are completely dependent on the microprocessor. They can not be easily moved from one to the other.
- To allow **programs** to be developed **for multiple machines** high level languages were developed.
  - These languages describe the operation of the program in general terms.
  - These programs are translated into microprocessor specific assembly language using a **compiler** or **interpreter** program.
  - These programs take as an input **high level statements** such as “ i= j + k;” and translate them to **machine language** compatible with the microprocessor being used.



Microprocessor vs. Microcontroller

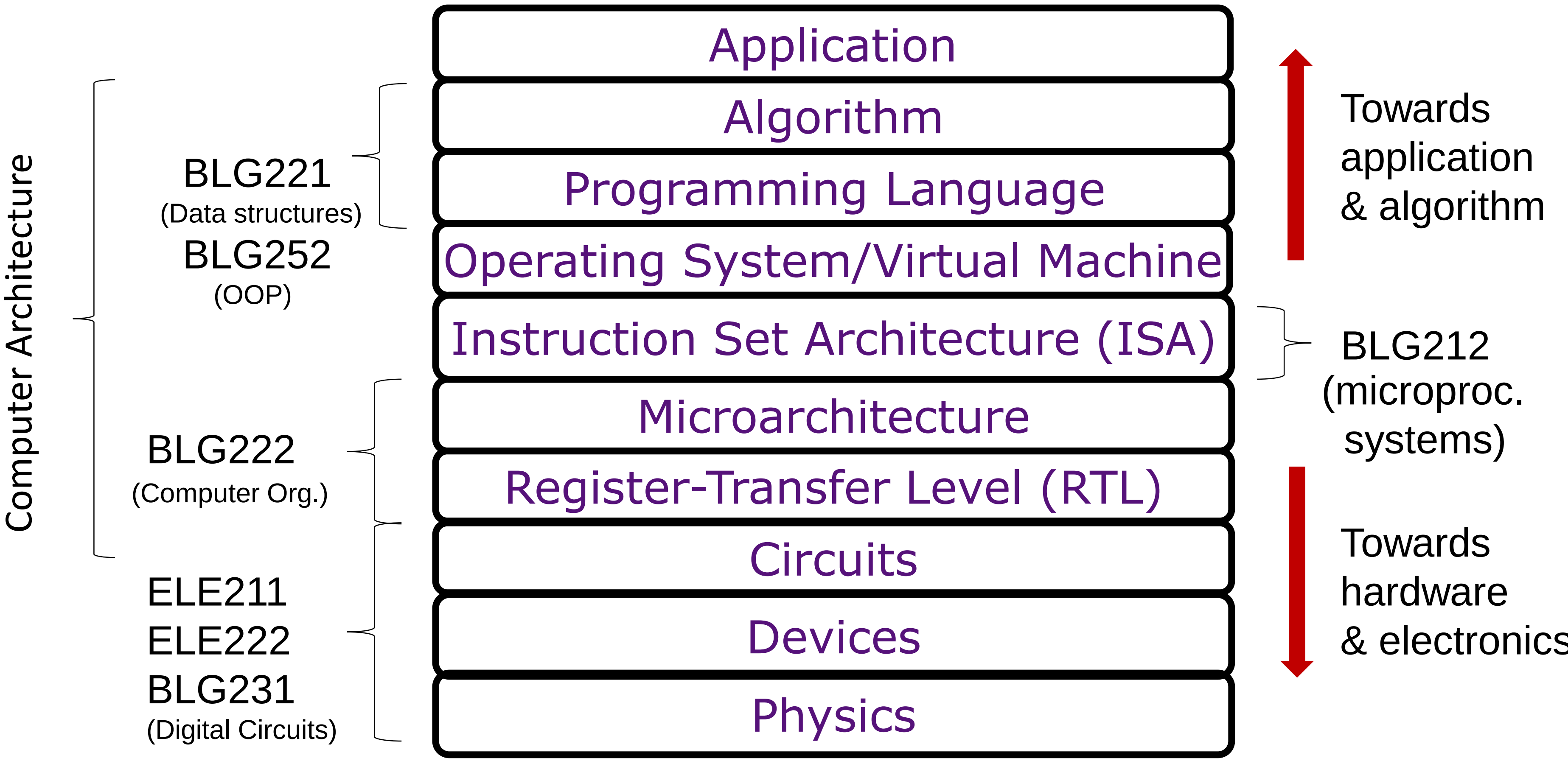
- The processor (Central Processing Unit - CPU)
  - Registers -- storage locations in the processor
  - Arithmetic logic unit
  - Control unit
- The microprocessor
  - A processor implemented on a Very Large Scale Integration (VLSI) chip
  - Peripheral chips are needed to construct a product
- The microcontroller
  - The processor and peripheral functions implemented on one VLSI chip

Microcomputer vs. Microcontroller

- The differences between MicroController (MCtrl) and MicroComputer (MCmp) are
  - MCtrl has timers and counters inbuilt but MCmp does not have inbuilt timers and counters.
  - MCtrl is used for specific task purpose. MCmp is used for general purpose.
  - MCtrl is having less flexibility in design. MCmp is having flexibility in design.

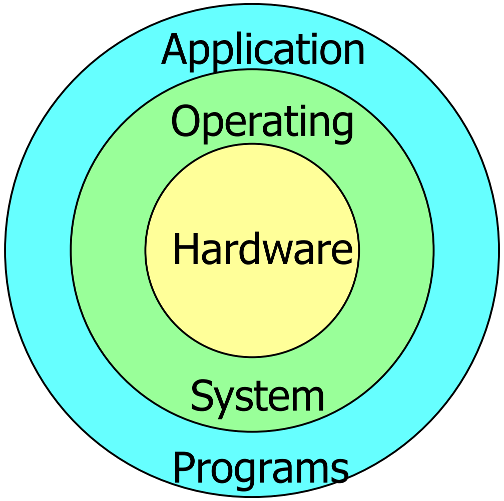
Operation of a microcomputer

LAYERS OF ABSTRACTION



The Hardware/Software interaction

- The **hardware** of a computer system is **the collection of chips** that make up its different pieces, including the microprocessor.
- **Software** refers to any **program** that is executed on the hardware.
- The interaction between the two systems (hardware and software) is managed by a group of programs known collectively as Operating system.



Topics

- Introduction: Computer History
- Microprocessor based Systems
- Number Systems

Number Systems

- Decimal (DEC)

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

Human has 10 fingers, Base 10 (Decimal seems intuitive)

- Digital systems have two states 0 and 1 (ON / OFF)

Binary system 0, 1 (electronic computers use binary system)

Word length in computers can be 8, 16, 32, 64 bits etc…

It is hard to define such long strings in binary format like:

0010101101101100 b = 11116

$ 2 B 6 C

Group them into four bits and define the Hexadecimal (HEX) system

Number Systems

Group them into three bits and define the Octal (OCT) system

$$\text{octal}\quad \underbrace{000}_{0}\ \underbrace{010}_{2}\ \underbrace{101}_{5}\ \underbrace{101}_{5}\ \underbrace{101}_{5}\ \underbrace{100}_{4}\ \text{b} = 11116 = \$2B6C$$

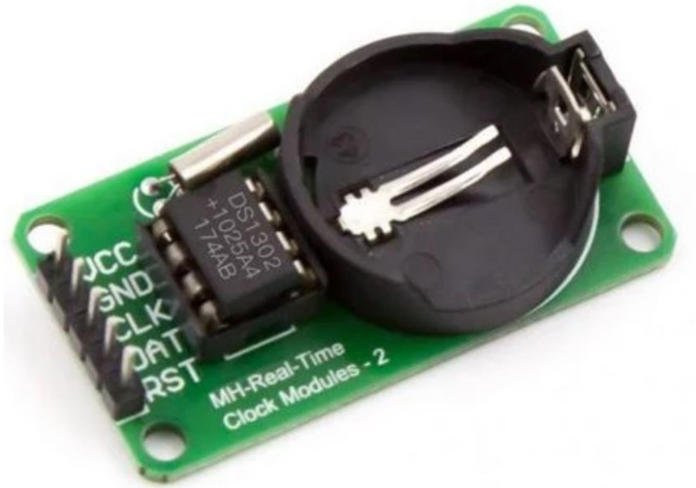
Binary Coded Decimal (BCD) system

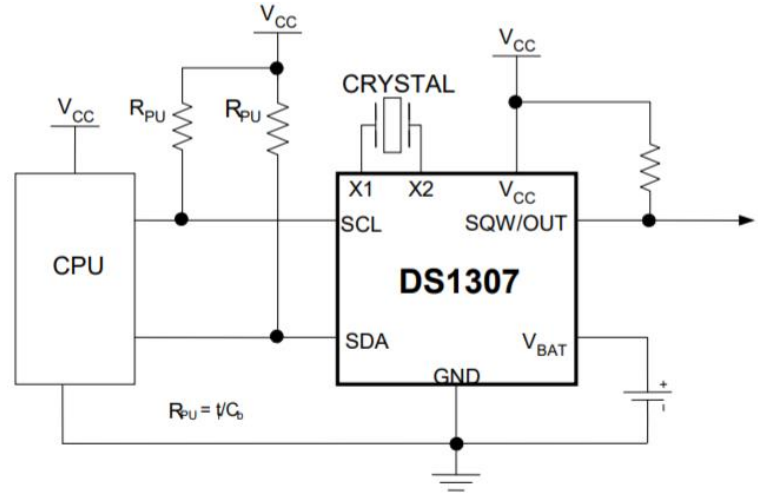
Example: $13_{10} = 1101_2 = 0001\ \ 0011$ BCD

Number Systems

Decimal	Binary (% or b)	Octal	Hexadecimal ($ or h)	Binary Coded Decimal (BCD)
0	0000 0000	000	00	0000
1	0000 0001	001	01	0001
2	0000 0010	002	02	0010
3	0000 0011	003	03	0011
4	0000 0100	004	04	0100
5	0000 0101	005	05	0101
6	0000 0110	006	06	0110
7	0000 0111	007	07	0111
8	0000 1000	010	08	1000
9	0000 1001	011	09	1001
10	0000 1010	012	0A	0001 0000
11	0000 1011	013	0B	0001 0001
12	0000 1100	014	0C	0001 0010
13	0000 1101	015	0D	0001 0011
14	0000 1110	016	0E	0001 0100
15	0000 1111	017	0F	0001 0101
16	0001 0000	020	10	0001 0110
20	0001 0100	024	14	0010 0000
160	1010 0000	240	A0	0001 0110 0000
248	1111 1000	370	F8	0010 0100 1000

BCD Data Content Example:





Real-Time Clock IC with I²C serial communication interface

<table>
<tr><th>ADDRESS</th><th>BIT 7</th><th>BIT 6</th><th>BIT 5</th><th>BIT 4</th><th>BIT 3</th><th>BIT 2</th><th>BIT 1</th><th>BIT 0</th><th>FUNCTION</th><th>RANGE</th></tr>
<tr><td>00h</td><td>CH</td><td colspan="3">10 Seconds</td><td colspan="4">Seconds</td><td>Seconds</td><td>00–59</td></tr>
<tr><td>01h</td><td>0</td><td colspan="3">10 Minutes</td><td colspan="4">Minutes</td><td>Minutes</td><td>00–59</td></tr>
<tr><td rowspan="2">02h</td><td rowspan="2">0</td><td>12</td><td>10 Hour</td><td rowspan="2">10 Hour</td><td rowspan="2" colspan="4">Hours</td><td rowspan="2">Hours</td><td rowspan="2">1–12 +AM/PM 00–23</td></tr>
<tr><td>24</td><td>PM/ AM</td></tr>
<tr><td>03h</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="3">DAY</td><td>Day</td><td>01–07</td></tr>
<tr><td>04h</td><td>0</td><td>0</td><td colspan="2">10 Date</td><td colspan="4">Date</td><td>Date</td><td>01–31</td></tr>
<tr><td>05h</td><td>0</td><td>0</td><td>0</td><td>10 Month</td><td colspan="4">Month</td><td>Month</td><td>01–12</td></tr>
<tr><td>06h</td><td colspan="4">10 Year</td><td colspan="4">Year</td><td>Year</td><td>00–99</td></tr>
<tr><td>07h</td><td>OUT</td><td>0</td><td>0</td><td>SQWE</td><td>0</td><td>0</td><td>RS1</td><td>RS0</td><td>Control</td><td>—</td></tr>
<tr><td>08h–3Fh</td><td colspan="8"></td><td>RAM 56 x 8</td><td>00h–FFh</td></tr>
</table>

Number Conversions

Decimal	$953{,}78=9*10^2+5*10^1+3*10^0+7*10^{-1}+8*10^{-2}$ $=900+50+3+0{,}7+0{,}08=953{,}78$
BIN to DEC	$\%1011=1*2^3+0*2^2+1*2^1+1*2^0$ $=8+0+2+1=11$
Hex to DEC	$\$A2F=10*16^2+2*16^1+15*16^0$ $=2560+32+15=2607$
BIN to OCT	$10101001_2 = (010\ \ 101\ \ 001)_2 = 251_8$
BIN to HEX	$10101001_2 = (1010\ \ 1001)_2 = A9h$
DEC to BCD	$13_{10} = 1101_2 = 0001\ \ 0011$

Number Conversions

DEC to BIN

Method 1: Divide to 2’s until reaching 1

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
1	0	1	0	1	0	0	1

DECIMAL		Remainder
169	169/2=84	1
84	84/2=42	0
42	42/2=21	0
21	21/2=10	1
10	10/2= 5	0
5	5/2=2	1
2	2/2=1	0
1	1/2=0	1

Number Conversions

DEC to BIN

Method 2: Look for the highest 2^n

		2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
DECIMAL	Largest 2^n	1	0	1	0	1	0	0	1
169	169-128=41								
41	41- 32=9								
9	9- 8=1								
1	1- 1=0								

References

- Lecture Slides: Dr. Şule Gündüz Öğüdücü
- Lecture Slides: Dr. Erdem Matoğlu
- Lecture Slides: Dr. Feza Buzluca
- Lecture Slides: Dr. Bassel Soudan
- Lecture Slides: Dr. Gökhan İnce
- Lecture Slides: Dr. B.Berk Üstündağ