Name: ______________________________
Course/Year/Section: ______________________________
Date Started: ____________ *Date Submitted:* ____________
Assessed by: ____________________ *Rating:* ________

INTRODUCTION TO MICROPROCESSORS AND MICROCONTROLLERS

Module 1

I. OBJECTIVES

At the end of the lesson, the students are expected to:

1. Know the basics of Microprocessor and Microcontroller systems – definition, types, brief history, and hardware and software requirements.
2. Appreciate the value of microprocessors and microcontrollers through analysis of their technical characteristics, features, development, circuit applications and designs.
3. Analyze the key parts and specify the application of a microcomputer system, then research on key trends with supporting data.

II. GENERAL INFORMATION

1. **MICROPROCESSORS AND MICROCONTROLLERS** – a major subject that scopes the theories and methods of interfacing of hardware and software components used in prototyping and project development. It integrates important major subjects such as Electronic Circuits Applications and Designs, Digital Electronics, and Computer Programming.
2. **MICROCOMPUTER** – a system that includes at minimum a microprocessor, program memory, data memory, and an input-output (I/O) device. Some microcomputer systems include additional components such as timers, counters, and analog-to-digital converters. Thus, a microcomputer system can be anything from a large computer having hard disks, memory devices, and printers to a single-chip embedded controller.

Figure 1
Microcomputer System and its Block Diagram

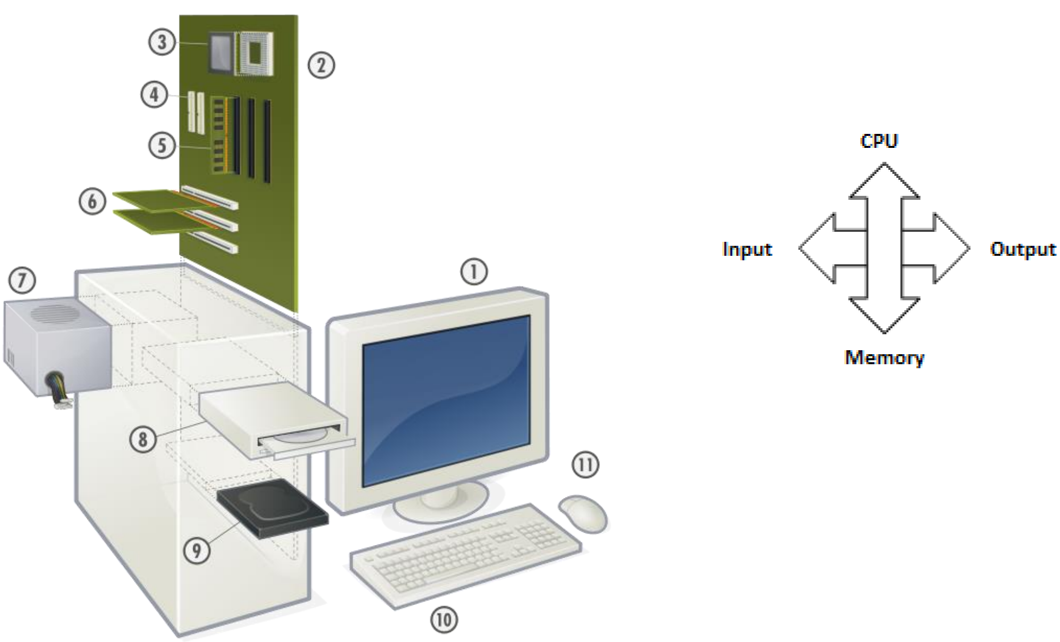
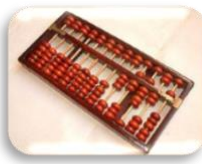
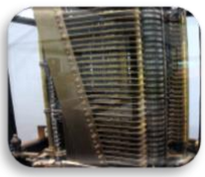
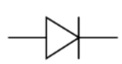


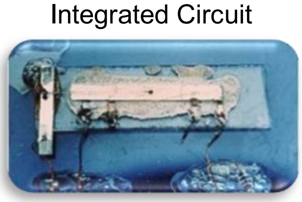
Fig. 1 shows the important parts of a microcomputer system such as (1) monitor, (2) motherboard, (3) microprocessor, (4) video card, (5) sound card, (6) program memory cards, (7) power supply, (8) DVD/CD Drive, (9) hard disk memory, (10) keyboard, and (11) mouse. Its 4 basic components include CPU, memory, input and output.

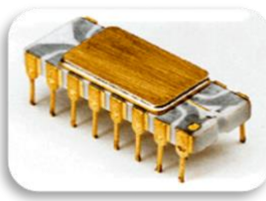
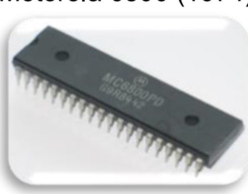
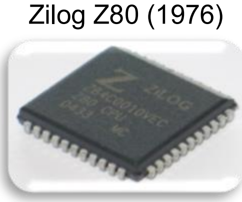
3. BRIEF HISTORY OF THE MICROCOMPUTER SYSTEM:

Table 1
Brief History of Microcomputer System

Year	***Technology***	***Description/Function***	***Proponent/s***
2nd BC	Abacus 	The first ancient mechanical computing device.	Chinese 中國人民
1st century BC	Antikythera Mechanism 	It is used for registering and predicting the motion of the stars and planets.	Hipparchus 
8th-9th century AD	Arabic Numerals 	A number system first introduced in Europe.	Arabs الشعب العربي
1500	Da Vinci Code 	The first mechanical calculator. The paper documents were discovered only in 1967.	Leorardo Da Vinci 
1642		A mechanical calculator with an 8-digit capacity.	Blaise Pascal 
1837	Telegraph	Electrical signals conveyed through radio communications.	Samuel Morse

					
	1910	Analytical Engine 	A mechanical computer that can solve any mathematical problem using punch-cards.	Charles Babbage 	
	1840s	Boolean Algebra AND $Y = AB$ OR $Y = A + B$ NOT $Y = \overline{A}$ NOR $Y = \overline{A + B}$ NAND $Y = \overline{AB}$ XOR $Y = A \oplus B$	Algebra of truth values 0 and 1 also known as binary or logic numbers.	George Boole 	
	1870s	Typewriter 	a mechanical or electromechanical device with keys that, when pressed, cause characters to be printed on a medium, usually paper; the first commercially successful typewriter with QWERTY keys	Sholes, Glidden, and Soule 	
	1874	Semiconductor Diode  	Also known as Whisker Diode; the first semiconductor electronic device, which is made of N (cathode) and P (anode) type materials used as switch, rectifier and regulator.	Karl Ferdinand Braun 	
	1941	Z3	The world's first functional program-controlled computer.	Konrad Zuse	

			
1945	ENIAC 	Electronic Numerical Integrator Analyzer and Computer; first general purpose, digital and programmable electronic computer.	University of Pennsylvania; Mauchly and Eckert.
1947	Transistor 	A three-layer semiconductor device used as switch and amplifier; it was first patented by the Bell laboratories.	Bardeen, Shockley, and Brattain 
1949	EDVAC 	Electronic Discrete Variable Automatic Computer; a programmable electronic computer, which uses binary numbers	University of Pennsylvania; Mauchly, Eckert, and Von Neumann
1951	UNIVAC 	UNIVAC I (UNIVersal Automatic Computer I) was the first commercial computer produced in the United States	Preseper Eckert and John Mauchly 
1959	Integrated Circuit 	Array of transistors used for complex switching in analog to digital instrumentation and controls.	Jack Kilby 

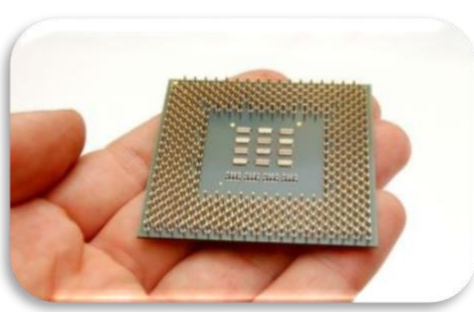
	1964	IBM 360 	The first standard institutional mainframe computer.	International Business Machines	
	1972	4 bits Microprocessor Intel 4004 	It can read/write 1 nibble at a time and can directly access 16 memory addresses. It is BCD-based 4 bit CPU.	Intel	
	1970s	8 Bits Microprocessor Intel 8008 (1972)  Motorola 6800 (1974)  Zilog Z80 (1976) 	It can read/write 1 byte at a time and can directly access 256 memory addresses.	Intel Motorola Zilog	

	1980S	16 Bits Microprocessor TI TMS9900 	It can read/write 2 bytes at a time, and can access 65,536 (64 KB) memory addresses.	Texas Instruments	
	1970s to the present	32 Bits Microprocessor Intel Pentium (2000s to present) 	It can read/write 4 bytes at a time, and can access 4,294,967,295 (4 GB) memory addresses	Intel and AMD	
	1970s to the present	64 Bits Microprocessor AMD64-Optron (2003),  Intel-Pentium 4 and later (2003 to the present) 	It can read/write 8 bytes at a time, and can address 18,446,744,073,709,551,616 (16 ExaB).	Intel and AMD	
	2005 to the present	Multicore Microprocessor Intel Core i 	A single microcomputer system package with 2 or more central processing units known as cores.	Intel and AMD	

2010 to the present	Tablet Computers iPad Galaxy Tab 	Ipad by Apple Inc. is the the first mobile tablet computer to achieve worldwide commercial success. The Samsung Galaxy Tab is an Android-based tablet computer produced by Samsung.	Apple Inc. Samsung
2017 to the present	 Core i9 desktop processor (2017) Core i9 mobile processor (2018)	The first desktop core i9 processor (e.g., i9-7900x) and mobile processes (e.g., i9-8950HK) was introduced in 2017 and 2018, respectively.	Intel

4. **MICROPROCESSOR** – a multipurpose, programmable, clock-driven, register-based electronic device that accepts binary data as input, processes it according to instructions stored in its memory, and provides results as output. It is also known as the Central Processing Unit (CPU).

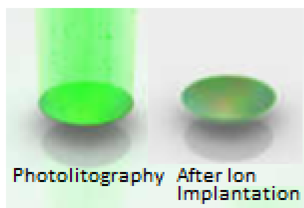
Figure 2
Example of a Microprocessor



5. **MICROPROCESSOR DEVELOPMENT:** Case in point: Core i5 2nd generation by Intel (2011)
   a. SiO_2 – sand - especially Quartz -has high percentages of Silicon and is the base ingredient for semiconductor manufacturing. (Fig. 3)

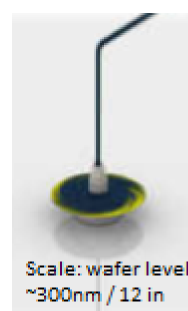
b. INGOT – a high-grade purified and melted Silicon mono crystal; the wafer scale level is ~300mm/12 in and weighs about 100 kg or 220 lb and has Si purity of 99.99%. Individual silicon disc is called wafer and is about 1mm thin. (Fig. 4)

c. PHOTOLITHOGRAPHY – the process of embedding beams of ions beneath the surface of the wafer to alter the conductive properties of Si. (Fig. 5)



d. HIGH K DIELECTRIC – layers of insulator applied between transistors' gate and its channel. It reduces electrical leakage and enables more energy efficiency. (Fig. 6)

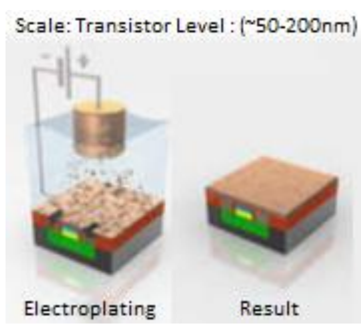
e. FILM PHOTOGRAPHY – process of filling dark liquid photo resist layer to enhance the high-k dielectric. (Fig. 7)



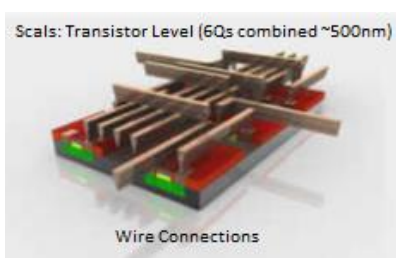
f. ULTRA VIOLET LIGHT EXPOSURE – process of diluting the photo resist finish with a mask that serves as stencil pattern on each layer. A lens (middle) reduces the mask's image. So what gets printed on the wafer is typically four times smaller linearly than the mask's pattern. (Fig. 8)

g. GOOEY PHOTO RESIST – a completely dissolved piece of wafer resulted from the mask, which is comparable to have 30 millions of transistors fit in headpin. (Fig. 9)

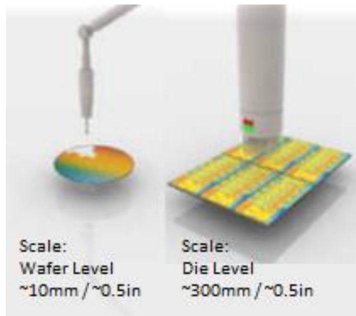
h. ELECTROPLATING – process of depositing copper ions onto the transistor, where copper ions travelled from positive terminal (anode) to the negative terminal (cathode). (Fig. 10)



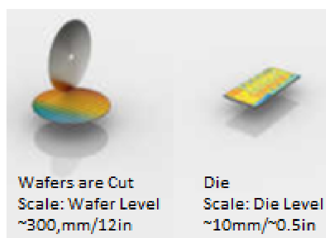
i. MULTIPLE INTERCONNECT LAYERS – the arrangement or creation of wires determined by the architecture type; microprocessors usually have 30 layers to form complex circuitry. (Fig. 11)



j. FUNCTIONALITY TEST – process of testing a fraction of a ready wafer. In this stage test patterns are fed into every single chip and the response from the chip monitored and compared to "the right answer". (Fig. 12)



k. DIE – a single cut of the wafer made of microprocessors (Fig. 13)



l. BINNING – process of classifying microprocessors according to the results of quality tests. (Fig. 14)

6. MICROPROCESSOR CLASSIFICATIONS:

a. ACCORDING TO DESIGN
- Microprocessor Unit/Central Processing Unit
- Microcontroller Unit
- Power PC

b. ACCORDING TO STANDARD SIZE
- 8 Bits
- 16 Bits
- 32 Bits

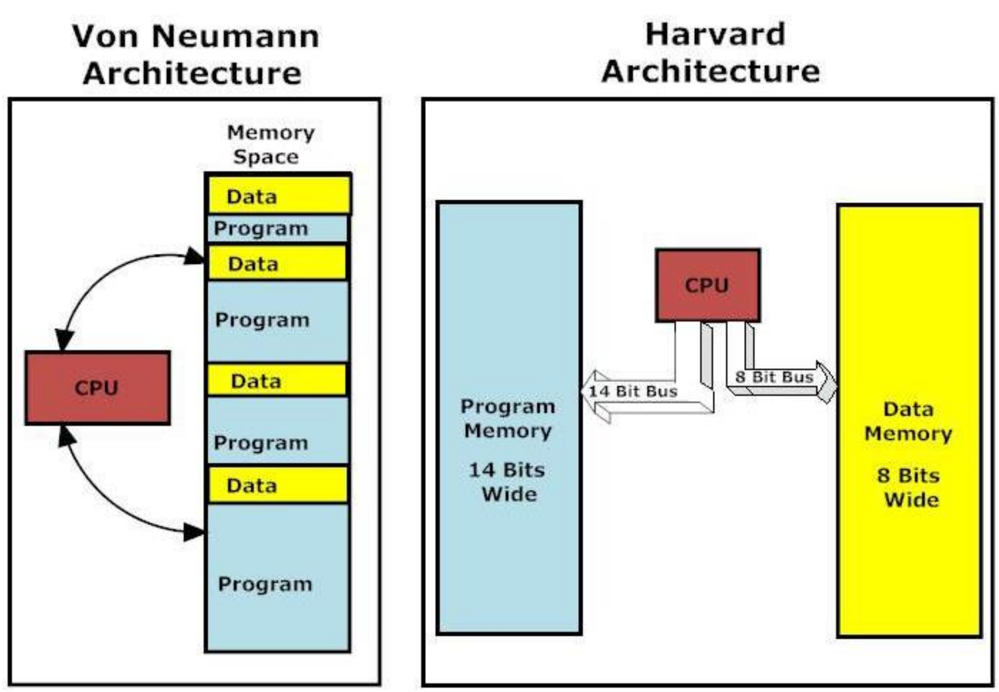
- 64 Bits

c. ACCORDING TO INSTRUCTION
- RISC (Reduced Instruction Set Computers) – used mostly in microcontroller systems; in an 8-bit RISC microcontroller, data is 8 bits wide but the instruction words are more than 8 bits wide (usually 12, 14, or 16 bits) and the instructions occupy one word in the program memory. Thus the instructions are fetched and executed in one cycle, which improves performance.
- CISC (Complex Instruction Set Computers) – used mostly in microprocessor and power PC systems where in both data and instructions are 8 bits wide. CISC microcontrollers usually have over two hundred instructions. Data and code are on the same bus and cannot be fetched simultaneously.

d. ACCORDING TO PURPOSE
- General Purpose
- Special Purpose

7. **MICROPROCESSOR ARCHITECTURE** – designs of various important components of a microprocessor system.
   - VON NUEMANN ARCHITECTURE – the memory space incorporates both the program (ROM) and the data (RAM)
   - HARVARD ARCHITECTURE – the data and program memories are separate.

Figure 15
Microprocessor Architectures



8. **MICROPROCESSOR OPERATION (Example scenario 1+3 = 4 process)**

Table 2
Sample Microprocessor Operation Matrix

REGISTERS			**CONTROL UNIT**			**PRE-FETCH UNIT**
4 Reg 1	Reg 2	Reg 3	1011010	1011010		
Reg 4	Reg 5	Reg 6	1011010			
Reg 7	Reg 8	Reg 9	1011010			1=X
ARITHMETIC LOGIC UNIT (ALU)				**DECODE UNIT**		3=Y
LOGIC		MATH		1=X	PRINTZ	X+Y=Z
AND	OR	***ADD***	SUB	3=Y		PRINTZ
NOT	XOR	DIV	MUL	X+Y=Z		
DATA CACHE				**INSTRUCTION CACHE**		
V	A			1=X		1
W	B			3=Y		2
1 X	C			X+Y=Z		3
3 Y	D			PRINTZ		4
Z	E	**BUS UNIT**				5
			1		**3**	
4			**+**		**=**	
OUTPUT			**INPUT**			

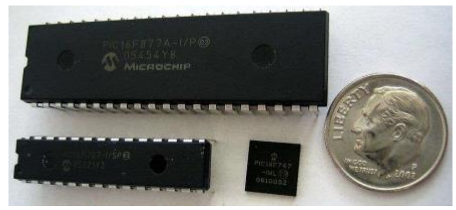
PRESS 1 > Bus Unit > Pre-fetch Unit confirms the code > Instruction Cache stores the code 1=X > Pre-fetch Unit fetches the code and sends to Decode Unit > Decode Unit decodes the code and sends 1=X=1011010 (binary code) to the Control Unit > once decoded, the Control unit sends the 1=X code to the Data Cache and wait more commands for further processing.

PRESS 3 > Bus Unit > Pre-fetch Unit confirms the code > Instruction Cache stores the code 3=Y> Pre-fetch Unit fetches the code and sends to Decode Unit > Decode Unit decodes the code and sends 3=Y=1011010 (binary code) to the Control Unit > once decoded, the Control unit sends the 3=Y code to the Data Cache and wait more commands for further processing

PRESS + > Bus Unit > Pre-fetch Unit confirms the code from the main memory's known as Z=X+Y> Instruction Cache stores the code Z=X+Y > Pre-fetch Unit fetches the code and sends to Decode Unit > the Decode Unit decodes Z=X+Y=1011010 (binary code) and sends to the Control Unit > the Control Unit sends the code Z=X+Y and stored to Data Cache while the ALU performs the ADD command the stores the correct answer to one of the Register Addresses.

PRESS = > Bus Unit > Pre-fetch Unit confirms the code from the main memory known as PRINT Z > Instruction Cache stores the code PRINT Z > Pre-fetch Unit fetches the code and sends to Decode Unit > Decode Unit decodes the code PRINT Z=1011010 (binary code) and sends to Control Unit > the Control Unit checks for the computed code from the Register Address, passes to the Bus Unit and then prints/displays the correct answer at the Output, which shows 4.

9. **MICROCONTROLLER** – a single-chip computer. Micro suggests that the device is small, and controller suggests that it is used in control applications. Another term for microcontroller is embedded controller, since most of the microcontrollers are built into (or embedded in) the devices they control. (Fig. 16)



10. **FUNDAMENTAL COMPONENTS OF MICROCONTROLLER:**
    - Central Processing Unit
    - Memory
    - System Clock (Oscillator)
    - Peripherals

11. **MICROPROCESSOR VS. MICROCONTROLLER**

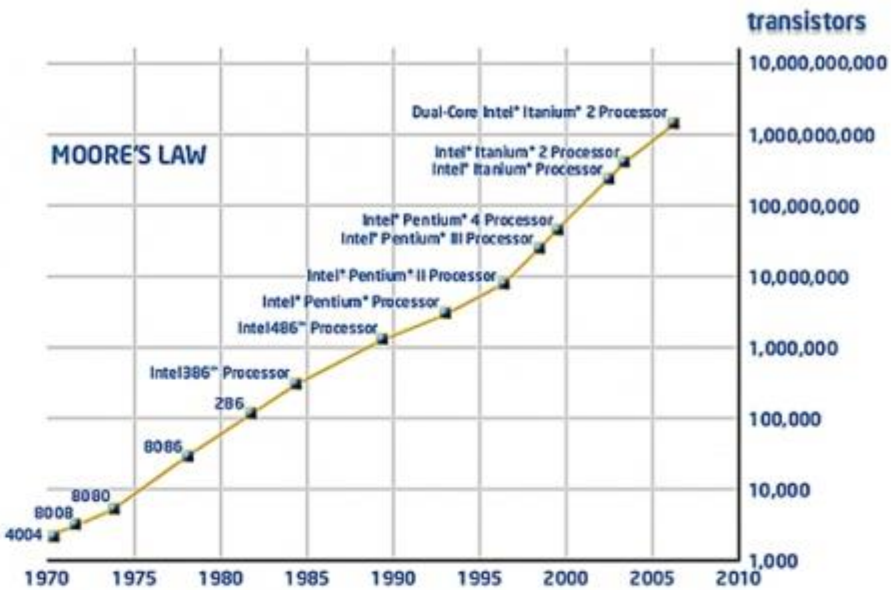
Table 3
Differences of a Microprocessor and Microcontroller

MICROPROCESSOR	MICROCONTROLLER
General-purpose	Special-purpose
No timers, parallel and serial I/O and internal RAM and ROM	It has timers, parallel and serial I/O and internal RAM and ROM
Many Op Codes	One or two Op Codes
Rapid movement of code and data from external address to chip	Rapid of bits within the chip
One or two types of bit handling instructions	Many types of bit handling instructions
Needs additional parts to be operational	Functions as computer with no addition of external digital parts

12. **TECHNOLOGICAL TRENDS:**

    a. MOORE'S LAW – postulated by Gordon Moore (1965), which states that the number of transistors on a single chip at the same price will double every 18 to 24 months. There is a direct relationship between the year and number of transistors used in fabrication of microprocessors.

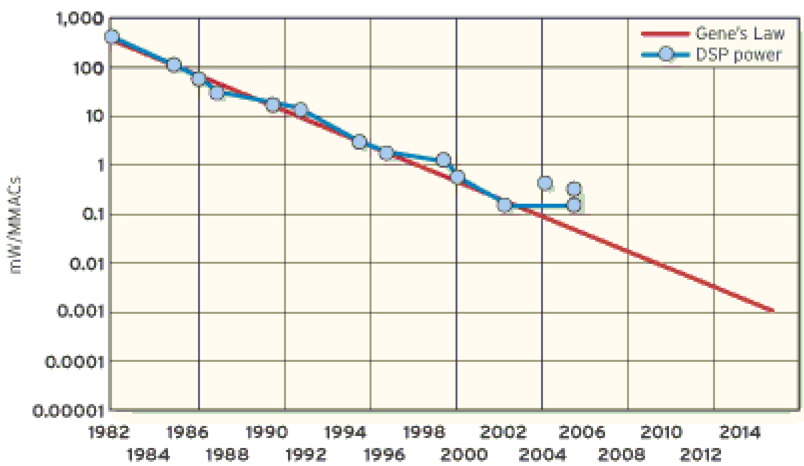
Figure 11
Moore's Law Trend



Credit: NJTechReviews (2011)

b. **GENE'S LAW** – proposed by Gene Frantz (2009), which states that the power dissipation of digital signal processor is reduced at a rate of one half every eighteen months. There is an inverse relationship between the years and power dissipation caused by the increasing number of transistors used in microprocessor designs. The decreasing power dissipation connotes an efficient heat management technology used in microprocessor development.

Figure 12
The Gene's Law



Credit: Johnson (2004)

c. **MULTICORE DESIGNS** – microprocessors made of more than 2 cores. A dual-core processor has two cores (e.g. AMD Phenom II X2, Intel Core Duo), a quad-core processor contains four cores (e.g. AMD Phenom II X4, Intel's quad-core processors, see i3, i5, and i7 at Intel Core), a hexa-core processor contains six cores (e.g. AMD Phenom II X6, Intel Core i7 Extreme Edition 980X), an octa-core processor contains eight cores (e.g. Intel Xeon E7-2820, AMD FX-8150). More cores are now being incorporated in a single microprocessor as years pass by.

d. **SPEED** – also known as clock rate is the measure of cycles (of execution of program) per second expressed in Hertz (Hz). The current rate is measured at Giga Hertz (GHz) speed. There is a direct relationship between the year of development and clock speed of computers.

Table 4
Latest Microprocessors in the Market (2012)

Date	***Name***	***Developer***	***Clock***	***Process***	***Transistors (M)***	***Cores / Die***
2010	POWER7	IBM	3-4.14 GHz	45 nm	1200	4, 6, 8 / 1, 4
2010	Itanium "Tukwila"	Intel	2 GHz	65 nm	2000	2, 4 / 1
2010	Opteron "Magny-cours"	AMD	1.7-2.4 GHz	45 nm	1810	4, 6 / 2
2010	Xeon "Nehalem-EX"	Intel	1.73-2.66 GHz	45 nm	2300	4, 6, 8 / 1
2010	z196	IBM	5.2 GHz	45 nm	1400	4 / 6
2010	SPARC T3	Sun	1.6 GHz	45 nm	2000	16 / 1
2010	SPARC64 VII+	Fujitsu	2.66-3.0 GHz	45 nm	?	4 / 1
2010	Intel "Westmere"	Intel	1.86-3.33 GHz	32 nm	1170	4-6 / 1
2011	Intel "Sandy Bridge"	Intel	1.6-3.4 GHz	32 nm	995	2, 4 / 1
2011	AMD Fusion	AMD	1.0-1.6 GHz	40 nm	380	1, 2 / 1
2011	Xeon E7	Intel	1.73-2.67 GHz	32 nm	2600	4, 6, 8, 10 / 1
2011	SPARC64 VIIIfx	Fujitsu	2.0 GHz	45 nm	760	8 / 1
2012	AMD Fx	AMD	8.429GHx	32nm	~1600	8 / 1
2023	Core i9 13980HX (mobile)	Intel	5.6 GHz	10 nm	~40M	24

e. **MEMORY CACHE** – a smaller, faster memory which stores copies of the data from the most frequently used memory locations. The effect of larger cache memory is that the miss rate of program execution by the microprocessor is decreased (inverse relationship). Memory is expressed in standard Gigabyte scale (GB). As more improved microprocessors are developed over the years, the more memory cache size is integrated.

Figure 19
Sample Cache Memory Mapping

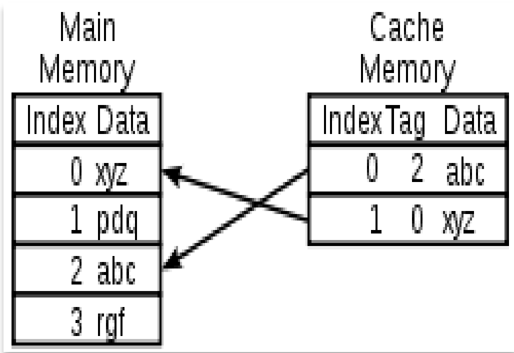
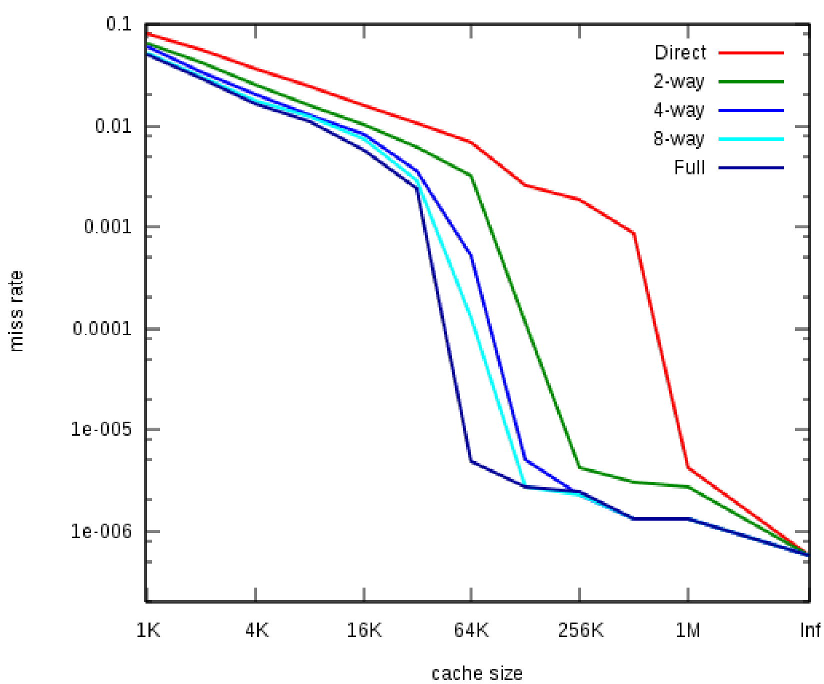


Figure 20
Miss Rate vs. Memory Cache Size



- **THE COMPUTING EXPERIENCE EVOLUTION**
  - **The beginning – ENIAC I (1946)** – thousands Ops/sec; tons of data
  - **Mainframes and Supercomputers – CDC 7600 (1969)** – million Ops/sec; millions of data
  - **Megascale Computing – IBM PC (1980)** – millions of Ops/sec; millions of data
  - **Gigascale Computing – Mobile (2000s)** – billions of Ops/sec; billions of data

f. **PROCESS TECHNOLOGY** – a semiconductor size fabrication process used to create integrated circuits, microcontrollers and microprocessors; it is expressed in (-) meter units. As years progress, the process technology is shrinking, which means that the chip/core size is decreasing each year.

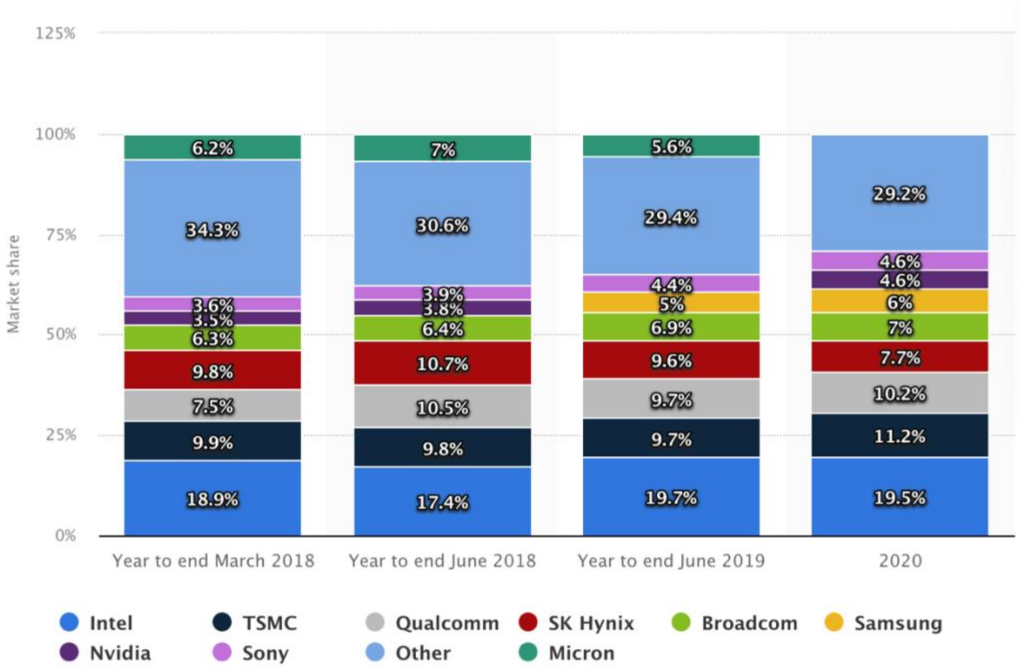
Table 5
Process Technology by Year

Process Technology	***Year***
10 µm	1971
3 µm	1975
1.5 µm	1982
1 µm	1985
800 nm (0.80 µm)	1989
600 nm (0.60 µm)	1994
350 nm (0.35 µm)	1995
250 nm (0.25 µm)	1998
180 nm (0.18 µm)	1999
130 nm (0.13 µm)	2000
90 nm	2002
65 nm	2006
45 nm	2008
32 nm	2010
28 nm	2011
22 nm	2011
16 nm	approx. 2013
11 nm	approx. 2015
3 nm	approx. 2022

13. POPULAR MICROPROCESSOR AND MICROCONTROLLER BRANDS

14. MARKET STATISTICS

Figure 22
Market Share Based on Vendor (Statista, 2018-2020)



15. MICROPROCESSOR AND MICROCONTROLLER APPLICATIONS

a. MICROPROCESSORS – the circuit designs are sophisticated, general-purpose and have complex programming or instruction sets.
   Examples are personal computers – desktops, laptops; power PCs; tablet computers; smartphones; general computing; graphic and gaming; data centers; content creation, etc.
b. MICROCONTROLLERS – the circuit designs are embedded, simple, usually mobile, and specialized.
   Examples are microwave ovens, calculators, alarm systems, elevator systems, surveillance systems, automotive, IOT, medical devices, robotics, etc.

III. CHECKPOINT

As a group, work on the following requirements:

1. Explain in layman's terms (1 paragraph or 5 sentences max) the microprocessor operation as shown in Table 2. (25 points)
2. If you were to design a microcomputer system, which architecture (i.e., Von Neumann or Harvard) will you use and why? Enumerate at least 5 advantages and disadvantages of each. (25 points)
3. Design a sample IPO system using a microprocessor or microcontroller. Identify the parts and specify the main function of the system. (25 points)
4. Research on at least 5 trends in microprocessors or microcontrollers. Specify the key proponent/s, timeline, and applications. Provide data in terms of figures and tables. Cite at least 5 references using APA v7. (25 points)