**Anatomy of a CPU**

COMP2660: Microprocessor Programming

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***Abstract* -** **The main context of this technical article is to give a brief introduction related to the anatomy of the CPU. We will get to know that why the CPU is also called Processor? We will see the working of every part of the CPU like Main Memory, Control Unit (CU), and Arithmetic-Logic Unit (ALU) in Computer Systems. The article also includes the components like Bus, Clock, Registers, and Cache. We are going to see how these components of the CPU perform their task in the Instruction Execution Cycle and Multitasking in the Operating System (OS). Moreover, the article also gives a brief introduction related to CISC and RISC processor and their difference. At last, we will see the details of the latest Intel and AMD processors**.

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# INTRODUCTION

The Central Processing Unit (CPU) consists of the main memory, the Control Unit (CU), and the Arithmetic-Logic Unit (ALU)/Computing Unit. It is the most important part of any computer/laptop/mobile or related system, also it is called the brain of the entire computer system (both hardware and software) because various peripherals are connected to it, including I/O devices and additional memory units. In current computers, the CPU is contained in an integrated circuit chip called a microprocessor. The control unit of the CPU synchronizes and integrates computer operations. It takes and fetches the instructions from the main memory in the correct order and interprets them to activate other functional parts of the system at the right time to perform their given tasks [1]. All input data is transferred through the main memory to the arithmetic-logic unit for processing, which involves the four basic arithmetic operations (Addition, Subtraction, Multiplication, and Division) and some logical operations like data comparison and selection of the desired problem-solving procedure or valid alternative based on criteria determined decision. A register is a small amount of fast memory in the processor where the arithmetic-logic unit or control unit can store and change values ​​needed to execute instructions. Registers for 8086 and 80286 are 16 bits wide while IA32 family registers are 32 bits wide. Registers function under the direction of the control unit to receive, store and transfer instructions/data and to perform arithmetic or logic comparisons at high speed. Computers generally assign specific roles to certain registers, including these registers:

* An accumulator: Collects the result of calculations
* An address register: It keeps the track of where a particular instruction or data is stored in the memory
* A storage register: Temporarily holds data that has been retrieved or is about to be sent to memory
* A general-purpose register: Used for various operations

Memory in Computer Science (CS) is also known as primary storage, primary memory, internal storage, main memory, and Random Access Memory (RAM). Memory is the part of the computer that contains data and processing instructions. Although closely associated with the central unit, the memory stands out from it. Memory stores program instructions or data as long as the program to which they belong is executed. Keeping these items in memory when the program is not running is impossible for three reasons: [1]

* All most all types of memory only store an object when the computer is on, the data will be destroyed when the computer is turned off.
* If more than one program is running at the same time (often on mainframes and sometimes on small computers), a single program cannot claim exclusive memory.
* There may not be space in the memory to save the processed data.

The Cache is a small amount of fast RAM built directly into the processor. Cache temporarily stores data and instructions that the processor can reuse. These speeds up processing because the processor does not have to wait for data and instructions to be fetched from RAM [2]. The CPU contains a clock that, along with the control unit CU, is used to coordinate all of the computer's parts. The clock sends out a regular electrical signal that synchronizes (in times) all the parts. The frequency of the signals is called the clock rate, which is calculated in hertz (Hz). The higher the rate, the greater the number of instructions that can be executed at a given time. Like, In the 1980s, the processors normally operated at speeds between 3 megahertz (MHz) and 5 MHz, or 3 to 5 million signals or cycles per second. Now, the current/modern processors usually operate at speeds between 3 gigahertz (GHz) and 5 GHz, or 3 to 5 billion signals or cycles per second [2]. A Bus is an internal fast connection. They are used to transmit control signals and data between the processor and other elements of the computer systems. Generally, we use three types of buses, [2]

* Address bus: The address bus (uni-directional) transfers memory addresses from the processor to other units like primary storage and I/O device.
* Data Bus: The data bus (bi-directional) fetches data between the processor and other parts.
* Control Bus: The control bus (uni-directional) fetches control signals from the processor to other sections. It also carries the clock signals.

Diagram

Description automatically generatedFigure 1 (Source: https://www.it4nextgen.com/what-is-a-cpu-central-processing-unit/)

# IMPORTANCE

# *A. Instruction Execution Cycle*

An instruction cycle is a time, that takes the CPU for a single instruction. The instruction loop is the basic operation of the CPU, which consists of three phases,

Step-1: Fetches the instructions from memory

Step-2: Decode the instruction

Step-3: Executes the instruction

This cycle continues until the Halt condition is met. The main function of a computer system is to run programs. A computer program consists of a series of instructions. The CPU is responsible for executing these program instructions. The address instruction to be implemented is stored in the Program Counter (PC) [3]. The processor fetches instructions from the memory designated by the PC. Then a PC is added to display the address of the next instruction. These instructions are loaded into the instruction register. The processor reads instructions and performs important procedures. Data transfer for its implementation takes place in two ways [4],

1. Processor memory: data sent from processor to memory or from memory to processor.
2. Processor Input/Output: data can be transferred to or from a peripheral device by transferring between the processor and an I/O device.

In a run cycle, the processor performs critical operations on information, and consistently controls require changes in the order in which the data is implemented. These two methods link and complete the process cycle.

* Count Instruction Address: The address of the next instruction is calculated. The permanent number is entered at the address of the previous instruction [4].
* Instruction Fetch: An instruction is read from its specific memory location to the processor.

Some additional terminology related to Instruction Execution Cycle which are important for deeply understanding this cycle.

1. Decode Operation Instructions: Instructions are interpreted and the type of operation to be executed and the operand or operands to be used is decided.
2. Compute Operand Address: The operand address is evaluated if it has a reference to the operand in memory or can be applied through I/O [4].
3. Operand Fetch: Operand read from memory or I/O [4].
4. Data Operations: The actual operations contained in the instructions are performed [4].
5. Store Operand: Store the acquired results in memory or transfer them to I/O [4].

Diagram

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Figure 2 [4]

## *B. Multitasking*

When the CPU runs multiple tasks at the same time by switching between them the process is called Multitasking. The changes are so frequent that users can interact with any program while it is functioning [4]. The user gives instructions directly to the OS or a program and receives a quick response. The OS controlled multitasking so that it can process multiple operations/run multiple programs at the very same time. Multitasking OS is also known as a timesharing system. The development of Multitasking OS leads to enable the interactive use of computer systems at appropriate costs. The time-sharing OS uses the concepts of CPU scheduling and multiprogramming to provide a fraction of part of the time-sharing CPU to each user. Every computer system has at least one separate program in memory. The program that is loaded into memory and normally executed is called process. When a process is running, it usually only runs for a fraction of the time before exiting or having to perform I/O. Because interactive I/O normally runs at a slower speed, it can take a long time to complete. During this time, other processes may be using the CPU. The OS lets users share computers at the same time. Since each action or command on a time-sharing system tends to be brief, it consumes a bit of CPU time per user. Since the system quickly changes the CPU from one user/program to the next, every user feels that they have their CPU, but the fact is many users share a CPU.

By quickly switching tasks, the processor creates the illusion that they are running at the same time. One type of scheduling that the OS uses is called round-robin scheduling. For example, suppose the scheduler randomly assigns 100 milliseconds to each task and takes 8 ms to switch between tasks. A complete change of the task list would require 972 ms (9 × 100) + (9 × 8) [5].

Below are some diagrams related to multitasking,

Diagram

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Figure 3 [5]

Table

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Figure 4 (Source: My PC)

Graphical user interface, application

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Figure 5 (Source: My PC)

# TECHNOLOGICAL DETAILS

## *A. CISC (Complex Instruction Set Computer) Processor*

The CISC was developed by Intel. It has a large collection of complex instructions, ranging from simple to very complex, and specializes in the level of assembly language that takes a long time to complete the instructions. Therefore, CISC tries to reduce the number of instructions in each program and ignore the number of cycles per instruction. It is important to create complex instructions directly on the hardware, as the hardware is always faster than the software.A picture containing text, electronics, circuit

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Figure 6 (Source: https://www.elprocus.com/difference-between-risc-and-cisc-architecture/)

## *B. RISC (Reduced Instruction Set Computer) Processor*

This type of microprocessor architecture uses a small set of instructions of the same length. These are normal instructions that usually run on one clock cycle. We can design RISC chip easily and it is inexpensive. The drawback of this construction is that the computer must frequently perform simple operations to run a larger program with a large number of processing operations.

Table illustrating the difference between CISC and RISC processor [6]:

|  |  |
| --- | --- |
| CISC Processor | RISC Processor |
| Variable-length encodings of instructions. Example: The size of the IA32 command can vary from 1 to 15 bytes. | Encodings with a fixed length of the instructions are used. Example: In IA32, all commands are generally encoded as 4 bytes. |
| Various formats are supported for specifying operands. A memory operand specifier can have many different combinations of index, base, and offset registers. | Support the simple addressing format. Only basic and offset addresses are allowed. |
| Deployment programs are hidden from machine-level programs. ISA provides a clean abstraction between programs and their execution. | Deployment programs exposed to machine-level programs. Few RISC systems do not allow specific instruction orders. |
| The stack is used to process arguments and return addresses. | Registers are used to process arguments and return addresses. References to memory can be avoided by some processes. |
| On memory and register operands we can apply both arithmetic and logical operations. | Only on register operand, we can apply arithmetic and logical operations. Only memory referencing is allowed by load and store instructions. |
| Condition codes are used in CISC | No condition codes are used in RISC |
| Example: Intel, AMD | Example: POWER PC, SPARC, etc |

## *C. EPIC (Explicitly Parallel Instruction Computing) Processor*

EPIC is a set of 64-bit microprocessor instructions jointly defined and developed by Hewlett Packard and Intel that provides up to 128 floating-point and general unit registers and uses speculative loading, predication, and explicit parallelism to solve their arithmetic problems. In comparison, current 32-bit CISC and RISC microprocessor architectures rely on 32-bit registers, branch prediction, memory latency, and implicit parallelism, which are considered a less efficient approach to microarchitecture design. The IA64 (Intel Architecture 64), Intel's first 64-bit CPU microarchitecture, is based on EPIC. Intel's first long-awaited implementation known as Merced (its code name) was christened Itanium in October 1999. Itanium-based systems are expected to work with existing and future versions of operating systems, including HPUX. , 64-bit Windows, IA64-Linux, Project Monterey, and Novell Modesto [7].

# DISCUSSION:

## *A. 11th Generation Intel® Core ™ processors*

The 11th Generation Intel® Core ™ processors are redefining the performance of the Intel® CPU for laptops and desktops. The 11th Generation Intel® Core ™ USeries 25-Watt Notebook Processors with Intel® Iris® Xe Graphics deliver integrated Intel® WiFi 6 graphics at a discrete level. The 11th Generation Intel® Core ™ S-Series desktop processors deliver increased performance for everyday desktop users, avid gamers, and serious developers [8]. Unlocked 11th generation Intel® Core ™ desktop processor models offer powerful overclocking for the best games and challenging creative service. For business needs, the 11th Generation Intel® Core ™ vPro® processors are developed, which provides all the performance enhancements of the 11th Generation along with modern remote management for the IT companies. Exactly what it takes to work from anywhere around the globe.

Diagram

Description automatically generated with medium confidence

Figure 7 (Source: https://www.xda-developers.com/intel-11th-gen-vpro-h-series-mobile-processors-launched/)

## *B. AMD Processor*

The Ryzen 9 5950X is a beast that achieves the highest maximum boost frequency of 4.9 GHz of all Ryzen CPUs. However, the all-core boost for multi-threaded workloads dropped to just 3.85 GHz. This is to keep the monster within the 105W TDP limit [9]. Which means manual overclocking can result in significant performance gains when using multiple threads, however, it can also provide lower performance in situations where fewer high-frequency cores are useful. But this is the Zen 3 architecture, so anything is possible, and a lot depends on its cooling, and CPUs respond well to high-performance coolers and liquid cooling. We get the full 64MB L3 cache as both eight-core CCXs are active and 512KB per core L2 cache for a total of 8MB.

Graphical user interface

Description automatically generated with medium confidence

Figure 8 (Source: https://www.amd.com/system/files/2020-09/616656-amd-ryzen-9-5000-series-PIB-1260x709\_0.png)

## *C) Intel vs AMD processors*

The Ryzen 9 3950X has 16 cores and 32 threads, which gives users power and more need to handle daily multitasking and general workloads in an office environment. Not only this it has enough ability to give excellent frame rates on Full HD and 4K gaming settings, so we don't have to deal with terrible lags or screen tears. The entire Ryzen 3000 series is equally balanced in terms of frame rates and multitasking capabilities so that it depends on how many cores and threads are needed. The Ryzen 9 3950X offers dual-channel memory support and 64MB cache, which guarantees the faster recovery of frequently used files and programs. With a base clock frequency of 3.5 GHz and a maximum boost clock of 4.7 GHz, you can get a nice experience at an impressive speed. While the Intel i9-9900K has half the cores and threads compared to the Ryzen 9 3950X, it has a slightly stronger single-core performance. The i9-9900K has a base clock of 3.6 GHz and a heavy 5 GHz turbo clock. The Intel i9-9900K consumes just 95 watts compared to the Ryzen 9's 105 watts, although you get about half the total power. With Intel integrated graphics, one can get 4K and Full HD video and graphics support immensely, so you get great frame rates that prevent lag and screen tearing.

# CONCLUSION

The Central Processing Unit (CPU) consists of the main memory, the Control Unit (CU), and the Arithmetic-Logic Unit (ALU)/Computing Unit. A register is a small amount of fast memory in the processor where the arithmetic-logic unit or control unit can store and change values needed to execute instructions. Registers function under the direction of the control unit to receive, store and transfer instructions/data and to perform arithmetic or logic comparisons at high speed. Memory (RAM) is the part of the computer that contains data and processing instructions. Memory stores program instructions or data as long as the program to which they belong is executed. Cache temporarily stores data and instructions that the processor can reuse. The CPU contains a clock that, along with the control unit CU, is used to coordinate all of the computer`s parts. The instruction loop is the basic operation of the CPU, which consists of three phases, Fetches the instructions from memory, Decodes the instruction, and Executes the instruction. The CPU is responsible for executing these program instructions. The address instruction to be implemented is stored in the Program Counter (PC). The OS controlled multitasking so that it can process multiple operations/run multiple programs at the very same time. By quickly switching tasks, the processor creates the illusion that they are running at the same time.

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