Anatomy of a Central Processing Unit

COMP 2660: COMPUTER ARCHITECTURE II: MICROPROCESSOR PROGRAMMING

Submitted by

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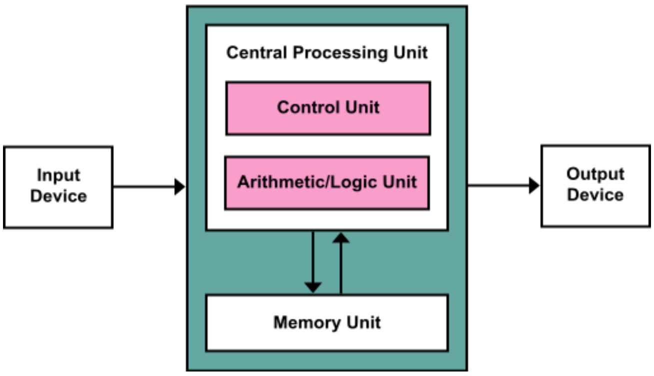
I. INTRODUCTION

The **central processing unit**, well known as the CPU or the brain of the computer is originated way back in the mists of computer times when a single massive cabinet contained the circuitry required to interpret machine level program instructions and perform operations on the data supplied. The CPU was first introduced by Intel with the help of Ted Hoff on 15th November 1971. They named it Intel 4004. It had two thousand three hundred transistors, performing sixty thousand operations per second, and addressed six hundred forty bytes in the memory (Computer Processor History , 2020). A CPU is made of three components. (i) **Arithmetic Logic Unit** (ALU), (ii) **Memory Unit** and (iii) **Control Unit.**



(CPU diagram , 2016)

The **Arithmetic Logic Unit (ALU)** is the part of the CPU that performs the arithmetic operations and logical operations on the data supplied. Other parts of the CPU only transfer data from one place to another (Control Unit, ALU and Memory). The **Memory Unit**, also known as primary/internal memory is a component of a computer system. Its job is to store data, information, and instructions. It is mostly like a work area of a computer. Memory unit has two types of memories. (i) **Read Only Memory (ROM)** – it is used in the situation where data must be held permanently. (ii**) Random Access Memory (RAM)** – it is used for temporary store program's data and data is lost when power is turned off (Jatain, n.d.). The **Control Unit** is an integrated circuit in a processor. It controls input and output. The Control Unit receives instructions from the running program and then passes them to ALU which performs the specific calculations and sends back the result to control unit which finally sends the result values to the running program as output (Control Unit, 2020). We will talk about each of the aspect in details later in this article.

II. IMPORTANCE OF CPU

A. What is a CPU

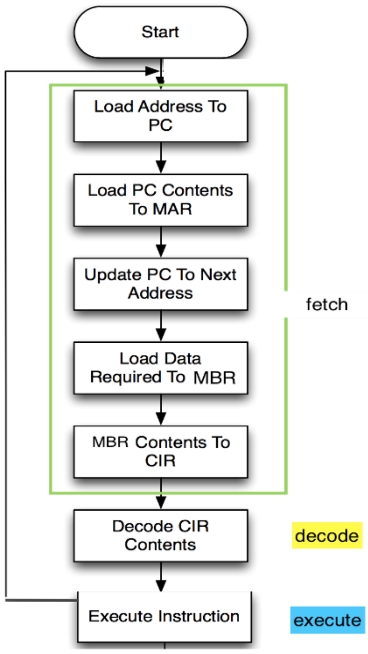
Before knowing the importance of the CPU, we should know how it works. The CPU is not the only processing unit in the computer. There are many. However, it is the central processing unit and is, therefor, the most important. A good analogy of a CPU – and one you might have likely heard a lot – is the brain. The brain is not only the hub of nerves in your body as it does not carry out all the decisions in your body. The spinal cord is also a hub of nerves, and so are your eyes and many other parts of your body. Think about all of these as processing units of your body. However, since the brain is the central processing center in your body, directing the greatest number of organs and processes – it is also the most important. Your brain is the CPU in your body and the CPU is the brain in the computer.

The uses of the CPU are many and include performing the calculations, running programs, and so on. The CPU works as part of a broader, more diverse ecosystem that includes Random Access Memory (RAM) and other parts of the computer. The RAM sends many instructions to the CPU – which decides the instructions and then processes these instructions and delivers the output based.

On the motherboard, the CPU has the capabilities to interact and control other pieces of hardware to bring the computer to life (LaMacro, 2019).

B. How does it work ?

From decades, CPU has constantly developing. All the CPUs since they manufactured the first CPU have the same basic functions. CPU has 4 main functions. (i) **Fetch** next instruction then increment IP. (ii) **Decode** the instruction. (iii) **Execute** the instruction. (iv) **Store** output to memory.



A computer program consists of a series of steps called instructions. Instructions tells the computer what to do. Each instruction can be a basic arithmetic calculation or a logic operation that ALU must perform. Before the program can be executed, all the data and instructions are loaded into CPU's memory.

(Fundamental of Computer organization and architecture)

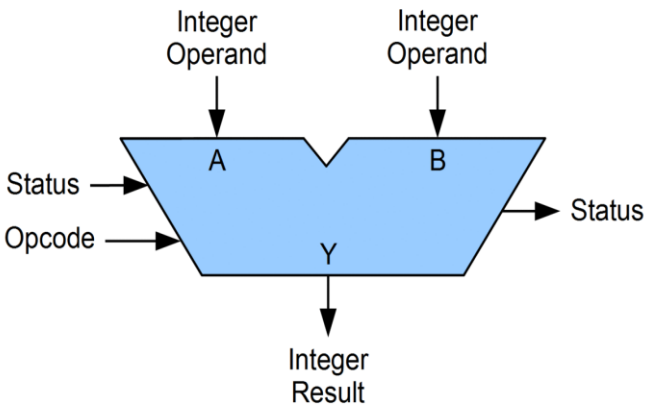
Microprocessor's job is to control the computer to fetch a running program's instruction from the memory, decode the instruction and then carry out some action that might be needed to get the required output. This process is called execution process. It is the responsibility of the processor inside the computer operating from the instructions it obtain from the main memory (LaMacro, 2019).

III. Technological Details

So, let us go into details. Every digital system needs some form of CPU. A programmer writes a code to execute some data to complete their task. This code is steps of instructions for the CPU to execute the task and output required results. The CPU is connected to the system input/output and memory which helps it to collect required data to process (Gayde, 2020).

A. *The Arithmetic Logic Unit*

Arithmetic instructions are fed into arithmetic logic unit for processing data which is inputted by two inputs with control signal and output the result.



(Arithmetic and logic unit)

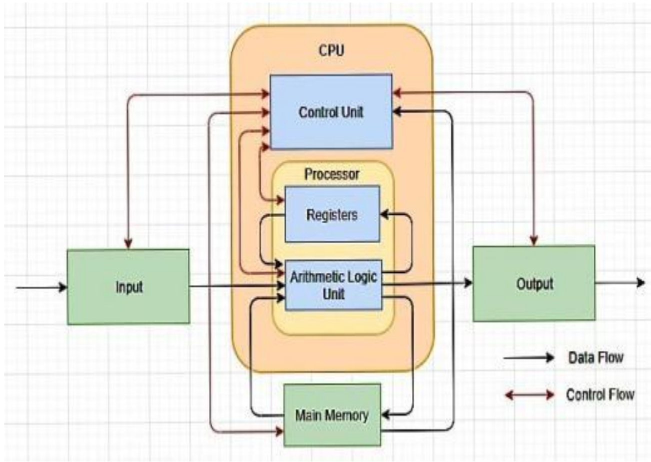
Take calculator as an example, we input two numbers in the calculator including what type of operation we need to perform. The calculator then executes the instruction and perform the task and output the result. In the CPU, the control unit tells the ALU to perform on the given data. While executing the addition operator, the ALU uses bitwise operators like AND, OR, NOT and XOR. After completing the operation, ALU sends signals to the control unit giving information about whether the result is positive, negative, zero or overflow.

The ALU is also used for Jump instruction or Branch Instructions. When program uses if-else statement, for loop or switch loop, the CPU jumps over some steps of instruction. E.g., 'if the result is zero, end the remaining program.' will jump to the end of the program if the result is zero.

B. *Conrtol Unit and it's Datapath*

Central Processing Unit has two parts. (i) Control Unit, and (ii) Datapath. When we drive a car, the engine is the one which is moving the car forwards, but we as a driver stepping on the accelerator and control the movement of the car. Same method applies to the CPU (Gayde, 2020).

The Datapath works the same as an engine as seen above, where the data moves from one part to another. The Datapath receive some data as an input, processes the input data and move the data to the required place when processed successfully. The control unit's job is to tell the Datapath how to process data and get the output needed. Based on the instructions given to the CPU, the Datapath will direct signals to different components of the CPU, switch route and monitor the state of the CPU (Gayde, 2020).



(Gayde, 2020)

C. *Data Bus*

After reading this word, we immediately think about a bus carrying data from one place to another. The CPUs different part may work as perfectly, but it needs some way to transfer data from one part to another to get the output (ourPCB, n.d.).

Buses in real life uses road to tranfer, same for the CPU, data bus uses various wires to tranfer data. Each lines of bus conveys one bit of information. Thus, using more lines meaning transferring more data together (ourPCB, n.d.).

Data bus has many different types. (i) External Data Bus, (ii) Address Bus and (iii) Control Bus (ourPCB, n.d.).

D. *Instruction register and Pointer*

We can get the location of the following instruction by the instruction pointer. After getting the location, the CPU can execute the instruction and the next instruction is loaded in the register for the CPU to execute after the current instruction is executed successfully (Both, 2020).

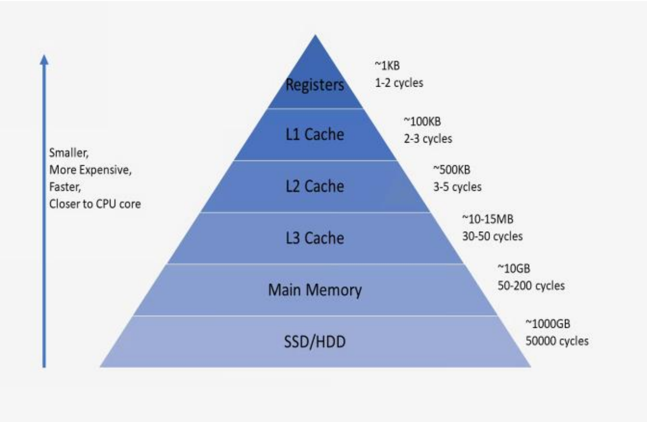
When the instruction is loaded successfully into the instruction register, register pointer is set to current instruction pointer incremented by one instruction address. This process helps pointer to locate the next instruction in the register (Both, 2020).

IV. Discussion

In this computer/modern era, we now rely on computers, and computer are replied on the Central Processing Unit which helps the computer complete their required task. After receiving the very first instruction, what CPU does is it send the instruction from memory into the CPU to execute that instruction. Each CPU has Industry Standard Architecture (**ISA**), that shares instructions like addition, subtraction, load and store. The control unit then takes care of what signals to send according to the instruction received (Gayde, 2020).

A. *Memory Instruction and Hierarchy*

The Memory Instruction concept is dependent on Hierarchy. Cache, primary storage and Random Access Memory (RAM)'s relation is based on Memory Hierarchy. After receiving the instruction in the CPU, it goes through the memory hierarchy and then locate the instruction register. Normally CPU cache has three levels. (i) L1, (ii) L2 and (iii) L3. L1 is the smallest and fastest and is the first level amongst all three levels (Gayde, 2020).



(Gayde, 2020)

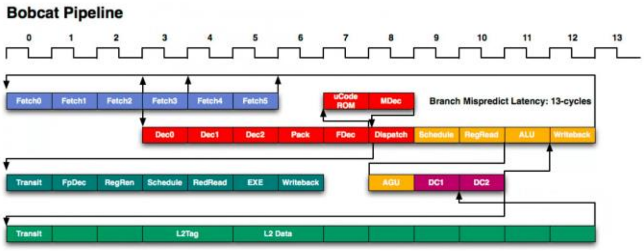
If the CPU is looking for something, first it looks in the L1 cache, which might be few hundred KB. If not found in the l1 cache, it will go to L2 cache and do the same process again, but as the level increases, the space of the levels increases by order of magnitude. L2 cache maybe few MB and L3 cache is roughly few tens of MB. And finally, if still CPU cannot find what it is looking for, then it goes to RAM and then main storage (Gayde, 2020).

After finding the data the CPU is looking for, it will automatically bring the data to the higher levels of hierarchy in case needed in the future. The CPU has millions of data, but it ensures that the next time, when the CPU is looking for the same data, it will find it faster. E.g., when the CPU goes to the registers, it will take one/two cycle(s). L1 takes about 5/6 cycles, ten or more cycles to reach L2 and 25/50 for L3 (Gayde, 2020).

B. *Branch and Jump Instructions*

While using statements like if-else statement, for/while loops and return statements, the CPU, while executing these instructions, often jumps and switches to a different part of the program. This is called jump instructions and Branch instructions comes from the instructions above.

First, we need to understand pipelining to understand the concept of branch instruction. While executing the instruction, the instruction cycle takes couple of cycles to complete and in that time, the ALU is just sitting idle and does nothing. IN order to get more work done from the CPU and maximize its efficiency, that is why we divide each stage in a process called pipelining. To understand this concept, think that you have two loads of laundry to do and each washing the clothes and drying the clothes takes about 1 hour each and you have only one washing machine and one drying machine. At first, you wash and dry one of you load of clothes that will take about two hours. When the first load is done completely, you start the second load and it also takes the same time. So total time will be four hours. Instead, when drying the first load, you start the second load to wash and then both are done at the same time, you put the second load to the drying machine and wait one more hour. That will take total of three hours. So that will save an hour. The CPUs uses the same method to organize the instructions and work faster to increase the efficiency (Gayde, 2020).



(Gayde, 2020)

But the issue in this method is that if we do not know that the instruction on cycle 7 is a branch and we will have started executing 6 new instruction that may be invalid if the branch is taken. To solve this issue, CPUs have complex structure called branch predictors. We will not talk about this concept in details in this article, but how it works is that it uses machine learning and predicts the next branch according to the previous branch predictors. The accuracy of branch predictor is 95% or higher.

After getting the result of a branch, CPU will execute the next instruction. If not found or mispredicted, the CPU will remove all the instruction and then start over again from the correct place.

When running a specific program in the computer, first, the program is stored into memory and then from memory, the CPU take instructions one-by-one and execute them. The CPU always stores the next instruction's memory address in its internal registers. This is called the Program Counter (Gayde, 2020).

V. Conclusion

Finally, we can say that the CPU contains lots of different parts that works differently to get the output needed. Every part works together and works ideally. The CPU will take steps of instructions from the program and store it to memory. The CPU will also store the next instruction memory address into its internal register. After getting the instruction, the CPU's control unit will decide how to execute the instruction. The it sends the data to the ALU which performs arithmetic operations and logical operations to the data and send it back to the CPU to store it in the memory and/or output the result based on the instruction given. The CPU also uses memory instruction to find the data or the memory needed.

The CPU is now a part of the human being. CPU is mostly in every portion of the world, whether it is from online shopping to online meeting people, watching movies, playing games and much more. With every new technology or every invention, the CPUs are getting more complex and faster which can work on millions of data at a time and capable of monitoring every situation. In the future, we might see different kinds of new features and technologies that will take us to a whole new world.

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