

Summer 2023

Abstract

The project report "CPU Trends in the Last decade" explores the development and advancement of central processing units (CPUs) from 2013 to 2023. It covers key trends like multi-core processors, nanometer-scale manufacturing, and specialized accelerators. The report examines the impact on CPU industries how the improvement process going on by the two major CPU manufacturers. This analysis provides valuable insights for researchers, tech enthusiasts, and industry professionals, showcasing the informative journey of CPUs and inspiring future innovation with its performances and power.

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1. Introduction

In the world of computing, the Central Processing Unit (CPU) stands as a testament to the extraordinary capabilities of human ingenuity. Serving as the brain of every computing device, the CPU is responsible for processing vast amounts of data and executing complex instructions at lightning speed. Without this technological marvel, the digital landscape as we know it would not exist.

This report delves into the inner workings of the CPU, uncovering its architecture, key components, and the vital role it plays in powering modern computing systems. By understanding the fundamental principles behind the CPU's design and operation, we gain valuable insights into the underlying mechanics of all computing devices.

1.1 Background

The development of the Central Processing Unit (CPU) has been a remarkable journey in the history of computing. From the early electronic computers that used vacuum tubes to the modern-day multi-core processors, CPUs have evolved exponentially, driving the advancement of technology and revolutionizing the way we live, work, and interact. Understanding the CPU's architecture and functionalities is crucial to grasp the core principles of computing and the fundamental mechanisms that power our digital world. This report aims to provide a comprehensive overview of the CPU, shedding light on its historical evolution, components, operation. By exploring the CPU's intricacies, we gain insights into the essence of modern computing and its potential to reshape our future.

1.2 Objectives

The objectives of this report are as follows:

- **To Provide an Insightful Overview:** The report aims to offer readers a comprehensive understanding of the Central Processing Unit, including its historical development, key components, and its central role in computing devices.
- **To Examine the CPU's Components and Operation:** A detailed examination of the CPU's components, such as the Control Unit, Arithmetic Logic Unit, and Register File, will be presented, along with an exploration of the instruction cycle and its various stages.
- **To Compare RISC and CISC Architectures:** The report will compare the Reduced Instruction Set Computer (RISC) and Complex Instruction Set Computer (CISC) architectures, discussing their design philosophies and how they impact CPU performance.
- **To Discuss Multi-Core Processors:** The report will explore multi-core CPU designs and their significance in enhancing performance through parallel processing while managing power consumption.
- **To Address Future Directions and Innovations:** The report will examine the challenges faced by CPU designers in terms of power efficiency and clock speeds, and explore

potential solutions and innovations. Additionally, it will introduce the concept of quantum computing and its potential impact on the future of CPU technology.

By achieving these objectives, this report aims to equip readers with a comprehensive understanding of the CPU's significance and the driving force behind the continuous advancement of computing technology. It seeks to illuminate the intricacies of the CPU, enabling readers to appreciate the profound role it plays in shaping our digital landscape and paving the way for an exciting future of computing.

1.3. What is computer?

A computer is an electronic device that can follow instructions to accept input, process that input, and produce information.

A computer system is one that is able to take a set of inputs, process them and create a set of outputs and this is done by a combination of hardware and software.

Basically, computer systems are composed of –

1. Hardware: The term hardware refers to the physical components of a computer system.

Example: Monitor, Keyboard, Mouse, Hard drive

2. Software: The term software refers to the programs that execute on the computer. It is a program is the step-by-step instructions that tell the computer how to do its work.

Example: Word processing program, Web browser

3. Firmware: Firmware combines hardware and software into important chips inside the microcomputer that can be touched and felt like hardware, but have software written into them.

Example: ROM (Read Only Memory)

1.3.1 Desktop Computer and Laptop Computer

Desktops and laptops are two different types of PCs. They are used for the same basic functions but have significant differences in design. Laptops are designed to be portable computers. They are smaller and lighter than desktops. The name connotes the user's ability to put the computer in their lap while they use it.

Laptops have a built-in monitor, a built-in keyboard and a trackpad to replace the mouse, and they can vary in size from 10 inches to 21 inch curved-screen gaming behemoths. The biggest difference between a desktop and laptop is that laptops are limited by the size of the battery inside them.

1.4 Main Components of a Computer

Three Main Components of a Computer-

1.4.1. Central Processing Unit (CPU):

The computer CPU is responsible for handling all instructions it receives from hardware and software running on the computer. It does all computation/work for the computer-

Primary component of CPU

- ALU (Arithmetic Logic Unit)
- CU (Control Unit)

Examples: Intel i7, Intel Core 2 Duo, AMD Sempron, AMD Athlon, and so on

1.4.2. Memory: Memory is the part of the computer that stores data and programs.

Two Types of Memory

1. Main Memory (or Primary Memory)

- Data is stored as electric signals in circuitry, used to store active data
- Memory is volatile – data is lost when the computer is turned off
- Examples: Random Access Memory (RAM), Cache
- More main memory to allow for quick access to more data and programs
- Fast and expensive

2. Secondary Memory

- Use different technologies (magnetic signals on hard disk, reflective spots on CD)
- Memory is permanent – useful for storing long-term data
- Examples: hard disk drive (HDD), flash drive, compact disk (CD)
- More secondary memory to allow for storing more long-term data
- Slower but cheaper

1.4.3. I/O Devices:

Input devices allow us to enter data into the computer like-

- Keyboard (most common)
- Mouse
- Voice recognition devices
- Scanner
- Digital camera
- Touch screen

Output devices are the devices which have the ability to read/see/use what the computer is doing like the components-

- Monitor
- Printer
- Speakers
- Headphones

- Projector

1.4.4. Importance of CPU in computer

The Central Processing Unit (CPU) is a critical component of a computer and holds significant importance for its overall functioning. Here are the key reasons why the CPU is essential in a computer:

1. **Processing Power:** The CPU is often referred to as the "brain" of the computer because it performs most of the calculations and data processing tasks. It is responsible for executing instructions, performing arithmetic and logic operations, and managing data flow within the computer.
2. **Control Unit:** The CPU contains a control unit that fetches and interprets instructions from computer memory. It coordinates the execution of instructions and ensures that tasks are carried out in the correct order, enabling the computer to execute complex programs and tasks.
3. **System Performance:** The CPU's processing power directly impacts the overall performance of the computer. A faster and more powerful CPU can handle more tasks and process data more quickly, resulting in better overall system performance.
4. **Multitasking:** The CPU enables multitasking, allowing the computer to run multiple applications and processes simultaneously. It switches between tasks quickly, giving the appearance of concurrent execution.
5. **Compatibility:** The CPU architecture defines the instruction set that the computer can understand and execute. It ensures compatibility with software applications and operating systems designed for that specific architecture.
6. **Graphics and Media Processing:** Modern CPUs often include integrated graphics processing units (GPUs) that handle graphics and media-related tasks. This integration improves multimedia performance and simplifies the design of computers without dedicated graphics cards.
7. **Virtualization:** The CPU's support for virtualization technology allows the computer to run multiple virtual machines or operating systems concurrently, enabling better resource utilization and efficient server management.
8. **Real-Time Processing:** In embedded systems and critical applications, CPUs with real-time capabilities ensure that tasks are executed within precise time constraints, essential for control systems and other time-sensitive applications.

9. Upgradability: CPUs are often replaceable, allowing users to upgrade their computer's performance by installing a more powerful processor without replacing the entire system.
10. Future-Proofing: Investing in a powerful CPU ensures that the computer will remain relevant and capable of handling more demanding applications and tasks in the future.

Overall, the CPU is a crucial component that determines the computer's speed, performance, and ability to handle complex tasks. It plays a central role in enabling the computer to function effectively and efficiently for a wide range of applications, from everyday computing to high-performance tasks like gaming and data-intensive workloads.

1.4.5. Operations of a CPU

The Central Processing Unit (CPU) performs various operations to execute instructions and process data in a computer. These operations can be summarized as follows:

1. Fetch: The CPU fetches the next instruction from the computer's memory, which is typically stored in the instruction register.
2. Decode: The fetched instruction is decoded by the CPU to determine the specific operation it needs to perform and the memory addresses or data involved.
3. Read: If the instruction requires data from memory or registers, the CPU reads the data from the specified memory location or registers.
4. Execute: The CPU performs the operation specified by the instruction. This can include arithmetic operations (e.g., addition, subtraction), logic operations (e.g., AND, OR), data movement (e.g., load, store), or control flow operations (e.g., jump, branch).
5. Write: After the execution, the result of the operation may need to be stored back in memory or registers. The CPU writes the result to the appropriate memory location or register.
6. Fetch Next: After completing the current instruction, the CPU fetches the next instruction to continue the process, and the cycle repeats.

These operations are part of the CPU's instruction cycle, also known as the fetch-decode-execute cycle. The CPU performs these operations repeatedly to execute a series of instructions, which form programs and tasks. The speed at which the CPU can complete these operations, known as clock speed or clock rate, determines its processing power and overall performance. Additionally, modern CPUs often have multiple cores, allowing them to execute multiple instructions concurrently, further improving performance and multitasking capabilities.

2. History and Development of CPU

The history and development of CPUs (Central Processing Units) is a fascinating journey that has spanned over several decades. Here is a brief overview of the key milestones in the history of CPUs:

1. Early Computers and Vacuum Tubes (1940s-1950s):

- The first electronic digital computers, like ENIAC and UNIVAC, used vacuum tubes for computation.
- Vacuum tubes were large, power-hungry, and prone to failure, limiting the capabilities of early computers.

2. Transistors (1950s-1960s):

- The invention of transistors in the late 1940s revolutionized electronics and computing.
- Transistors were smaller, more reliable, and consumed less power than vacuum tubes, enabling more powerful and compact computers.

3. Integrated Circuits (ICs) and Microprocessors (1960s-1970s):

- The development of Integrated Circuits (ICs) in the early 1960s allowed multiple transistors to be fabricated on a single silicon wafer.
- The first microprocessor, the Intel 4004, was introduced in 1971. It contained 2,300 transistors and marked the beginning of the era of microprocessors.

4. Moore's Law and Advancements (1970s-1980s):

- Moore's Law, proposed by Gordon Moore in 1965, observed that the number of transistors on a chip doubled approximately every two years, leading to exponential growth in computing power.
- The 8-bit and 16-bit microprocessors became popular in the 1970s and 1980s, powering early personal computers like the Apple II and IBM PC.

5. 32-bit and 64-bit Processors (1990s-2000s):

- The 32-bit microprocessors gained dominance in the 1990s, offering enhanced performance and capabilities.

- In the early 2000s, 64-bit processors emerged, providing greater memory addressability and enabling more extensive software applications.

6. Multi-Core Processors (2000s-2010s):

- As transistor densities increased, it became feasible to integrate multiple CPU cores on a single chip, leading to the development of multi-core processors.
- Multi-core processors allowed parallel processing, improving overall system performance and enabling better multitasking.

7. Advancements in Efficiency and Specialization (2010s-present):

- In recent years, there has been a focus on energy efficiency and specialization in CPUs.
- Low-power processors, like ARM-based CPUs, gained popularity in mobile devices and IoT applications.
- Specialized processors, such as GPUs for graphics and AI accelerators for machine learning, have become prevalent in high-performance computing.

The history of CPUs reflects a continuous drive for miniaturization, increased performance, and energy efficiency. CPUs have become an integral part of nearly every electronic device, from smartphones and laptops to servers and supercomputers, playing a central role in advancing technology and computing capabilities.

2.1. Processor Architecture Evolution

Processor architecture evolution has been a continuous journey of innovation and advancement in the design and organization of CPUs. Over the years, several key architectural changes and improvements have driven the evolution of processor technology. Here's an overview of the major stages of processor architecture evolution:

1. Single-Core Processors:

- Early processors were single-core, meaning they had a single processing unit capable of executing one instruction at a time.
- These processors were sequential and had limited parallelism, which constrained their overall performance.

2. Pipelined Processors:

- Pipelining, introduced in the 1960s, improved processor performance by dividing the instruction execution into multiple stages or pipeline segments.

- Each pipeline stage handled a specific part of the instruction, allowing multiple instructions to be in various stages of execution simultaneously.

3.Superscalar Processors:

- Superscalar architecture, developed in the 1980s, enabled processors to execute multiple instructions in parallel.
- These processors featured multiple execution units and could issue and execute multiple instructions per clock cycle.

4.Out-of-Order Execution:

- Out-of-order execution, introduced in the 1990s, further improved performance by allowing the processor to execute instructions in a more efficient order.
- It involved reordering instructions to avoid data dependencies and maximize the use of execution units.

5.Multi-Core Processors:

- As transistor densities increased, multi-core processors emerged in the early 2000s, featuring multiple independent CPU cores on a single chip.
- Multi-core processors offered better parallelism and higher performance for multi-threaded and multitasking workloads.

6.Simultaneous Multi-Threading (SMT):

- SMT, also known as Hyper-Threading, was introduced by Intel in the late 1990s and later by AMD as SMT in the early 2000s.
- SMT allows a single CPU core to execute multiple threads concurrently, improving utilization and performance in multi-threaded workloads.

7.Heterogeneous Computing:

- Heterogeneous computing involves combining different types of processors, such as CPUs and GPUs, to perform specialized tasks efficiently.
- GPUs are particularly suited for parallel processing, making them useful for tasks like graphics rendering and machine learning.

8.Vector Processing and SIMD:

- Vector processing and Single Instruction, Multiple Data (SIMD) architectures enhance performance by processing multiple data elements simultaneously.
- SIMD instructions allow processors to perform the same operation on multiple data elements in parallel.

9.Power Efficiency and Low-Power Designs:

- Recent processor architectures have focused on power efficiency and low-power designs to meet the demands of mobile devices and energy-conscious applications.

The evolution of processor architecture continues to be driven by the need for higher performance, improved power efficiency, and the growing demand for specialized tasks, such as AI and machine learning. Processors have become more complex and sophisticated, enabling a wide range of computing applications and contributing to advancements in various fields, from personal computing to scientific research.

2.2. Number System

In a computer's central processing unit (CPU), data is represented and manipulated using binary, which is a base-2 number system. This means that all data in the CPU, including instructions, addresses, and numerical values, are represented using only two symbols: 0 and 1.

The binary system is used because electronic circuits can easily distinguish between two voltage levels, which correspond to the binary digits 0 and 1. These binary digits are also called "bits." A bit is the smallest unit of data in a computer and can represent either an "on" or "off" state.

However, CPUs work with data in groups of bits. Common groupings of bits are:

1. Nibble: 4 bits (half a byte).
2. Byte: 8 bits. A byte can represent a single character or a small integer value.
3. Word: The size of a word can vary depending on the CPU architecture. It typically represents the amount of data that the CPU can process in a single operation. Common word sizes include 16-bit, 32-bit, 64-bit, and even larger sizes.

The choice of word size affects the CPU's performance, memory addressing capabilities, and the maximum amount of data it can process efficiently. Modern CPUs commonly use 64-bit architectures, which allow them to work with data in chunks of 64 bits at a time.

To perform operations with numbers larger than the word size, CPUs use a combination of multiple words, a technique known as "word chaining" or "multiple precision arithmetic."

In addition to binary, CPUs also support other number systems like:

1. Decimal: Decimal numbers are often used for displaying data to users, but they are internally converted to binary for processing in the CPU.
2. Hexadecimal: Hexadecimal (base-16) is commonly used to represent binary numbers in a more compact and readable form, especially in programming and debugging. Each hexadecimal digit represents 4 binary digits (bits).

CPU architectures have specific instruction sets and operations designed to work with binary data efficiently. These instructions enable arithmetic operations, logical operations, memory access, and control flow, allowing the CPU to execute complex tasks and run various software applications.

2.3 Machine Language

In a CPU (Central Processing Unit), machine language, also known as machine code or binary code, is the lowest level of programming language understood by the CPU. It consists of a series of binary instructions that the CPU can directly execute. Each instruction corresponds to a specific operation that the CPU can perform, such as arithmetic calculations, data movement, logical operations, and control flow.

Machine language instructions are represented using binary digits (0s and 1s) and are specific to the architecture of the CPU. Different CPU architectures have their own unique instruction sets, which are collections of machine language instructions that the CPU can understand and execute.

Each instruction in machine language is composed of two main parts:

1. **Opcode:** The opcode (operation code) specifies the type of operation or instruction to be executed, such as addition, subtraction, loading data from memory, etc.
2. **Operand(s):** The operand(s) specify the data on which the instruction operates. It could be the memory location where the data is stored, the registers (small, fast storage locations within the CPU), or immediate values (constants directly embedded in the instruction).

For example, a simple machine language instruction for adding two numbers might look like this:

Opcode: 0001 (representing addition operation)

Operand 1: Register A

Operand 2: Register B

Result: Store the sum in Register A

The CPU fetches these machine language instructions from memory one by one and executes them sequentially. It follows a fetch-decode-execute cycle:

1. **Fetch:** The CPU fetches the next instruction from memory.
2. **Decode:** The CPU decodes the binary instruction to determine the operation and the operands.
3. **Execute:** The CPU performs the specified operation on the operands.

The process continues, with the CPU fetching, decoding, and executing instructions until the program's end is reached or until a branch or jump instruction alters the program flow.

Writing programs directly in machine language is extremely difficult and error-prone for humans due to its low-level nature. As a result, higher-level programming languages were

developed to make programming more accessible and less error-prone. These higher-level languages are then compiled or interpreted into machine language so that the CPU can understand and execute the instructions.

2.4 Register in the CPU

In a CPU (Central Processing Unit), registers are small, fast storage locations used to hold data temporarily during the execution of a program. They are an integral part of the CPU and play a crucial role in the computer's operation. Registers are much faster to access than other types of memory, such as RAM (Random Access Memory), which allows the CPU to perform operations more efficiently.

Here are some important characteristics and uses of registers in a CPU:

1. **Speed:** Registers are the fastest form of memory available in a computer. They are built directly into the CPU, enabling the processor to quickly access and manipulate data.
2. **Data Storage:** Registers store data, addresses, and instructions that the CPU needs to execute. This includes intermediate results of calculations, variables, and memory addresses.
3. **Operand Source:** Registers are often the source of operands for arithmetic and logical operations performed by the CPU. For example, when adding two numbers, the CPU may fetch the numbers from registers, perform the addition, and store the result back in another register.
4. **Control and Addressing:** Some registers have specific roles in controlling the CPU's behavior or managing memory addressing. For example, the program counter (PC) keeps track of the memory address of the next instruction to be executed.
5. **Size and Types:** CPU architectures have different types and sizes of registers. Common types include general-purpose registers (used for various purposes), floating-point registers (for floating-point arithmetic), and status registers (to store flags indicating the result of operations).
6. **Context Switching:** Registers play a critical role in context switching, which is the process of saving the state of a process or thread to switch to another. When the CPU switches to a different task, it saves the current task's registers, allowing it to resume the task later with its previous state intact.
7. **Cache:** Some modern CPUs have special high-speed memory called register files, which are used as cache memory for frequently accessed data. These register files provide even faster access times than regular CPU registers.

Registers are organized into a register file, which contains all the different types of registers used by the CPU. The number and types of registers can vary depending on the CPU architecture. Typically, modern CPUs have a combination of general-purpose registers, floating-point registers, and other specialized registers to support various operations efficiently. The size of registers, measured in bits, also varies between different CPU architectures. For example, common register sizes are 8-bit, 16-bit, 32-bit, and 64-bit, but some CPUs may have even larger register sizes.

2.5 Transistor in the CPU

Transistors are fundamental electronic components found in modern CPUs (Central Processing Units) and are the building blocks of digital circuits. They play a crucial role in the operation of a CPU, allowing it to perform complex computations and execute instructions.

A transistor is a semiconductor device that can act as an electronic switch or an amplifier. In the context of CPUs, transistors are primarily used as switches. They can be in one of two states: ON or OFF, representing the binary digits 1 and 0, respectively. This binary representation forms the basis of digital computation.

Transistors are used in CPUs for various purposes, including:

1. **Logic Gates:** Transistors are combined to create logic gates, such as AND gates, OR gates, NOT gates, and more complex gates like NAND and NOR gates. These logic gates are the fundamental building blocks of digital circuits and are used to perform logical operations.
2. **Memory Cells:** Transistors are used to create memory cells in various forms, such as SRAM (Static Random Access Memory) and DRAM (Dynamic Random Access Memory). These memory cells are used to store data temporarily (in registers and caches) or permanently (in RAM).
3. **Arithmetic and Logic Units:** Transistors are used in the Arithmetic and Logic Units (ALUs) of CPUs, where they perform mathematical operations (e.g., addition, subtraction) and logical operations (e.g., AND, OR) on binary data.
4. **Control Units:** Transistors play a vital role in the control unit of the CPU, which manages the flow of data and instructions within the processor. They help in decoding instructions and determining the next actions to be taken by the CPU.
5. **Clock Signals:** Transistors are used to generate clock signals, which synchronize the activities of different components within the CPU. The clock signal determines the rate at which instructions are fetched, decoded, and executed.

As technology has advanced, the number of transistors that can be integrated into a single CPU chip has increased dramatically. This phenomenon, known as Moore's Law, has led to the development of more powerful and efficient CPUs with higher processing capabilities.

Modern CPUs contain billions of transistors that work together to perform intricate computations and execute complex software applications. The miniaturization of transistors and the ability to pack more of them into a small space have been key factors in the continuous improvement of

CPU performance over the years

2.6 Early Processor Designs

Early processor designs refer to the early developments and architectures of central processing units (CPUs) in the history of computing. These early designs paved the way for modern CPUs and computing technologies. Here are some notable early processor designs:

1. **First Generation Computers:** The earliest electronic computers, developed during the 1940s and 1950s, used vacuum tubes as the main electronic component. Examples include the ENIAC (Electronic Numerical Integrator and Computer) and the UNIVAC I. These computers used a combination of vacuum tubes, mechanical switches, and punched cards for data input and output.
2. **Second Generation Computers:** In the late 1950s and early 1960s, the second generation of computers emerged, characterized by the use of transistors instead of vacuum tubes. Transistors were more reliable, smaller, and more energy-efficient than vacuum tubes. This allowed for more compact and faster computer designs. Examples of second-generation computers include the IBM 7090 and the CDC 1604.
3. **Third Generation Computers:** The third generation of computers, developed in the mid-1960s, featured integrated circuits (ICs), which combined multiple transistors on a single chip. This made computers even more compact, efficient, and reliable. Notable examples of third-generation computers include the IBM System/360 and the DEC PDP-8.
4. **CISC (Complex Instruction Set Computer) Architectures:** In the 1970s, processor designs with complex instruction sets became popular. These CPUs had a large number of instructions that could perform various operations, often taking multiple clock cycles to execute. Examples include the Intel 8086 and the Motorola 68000.
5. **RISC (Reduced Instruction Set Computer) Architectures:** In the 1980s, the RISC architecture emerged as an alternative to CISC. RISC processors had a reduced and simplified instruction set, which allowed for faster and more efficient execution of instructions. The IBM POWER architecture and the ARM processors are early examples of RISC designs.
6. **VLIW (Very Long Instruction Word) Architectures:** In the 1990s, some experimental processor designs explored VLIW concepts. These CPUs attempted to execute multiple instructions in parallel by packing long instruction words. However, VLIW architectures faced challenges in compiler optimization and did not gain widespread popularity.

7. **Superscalar Architectures:** Around the same time, superscalar architectures were developed, which allowed CPUs to execute multiple instructions in parallel through multiple execution units. Examples include the Intel Pentium and the DEC Alpha.

These early processor designs laid the foundation for the continuous evolution of CPU technology. As computing demands increased, processors became faster, more powerful, and capable of executing complex instructions efficiently. The principles developed during these early stages continue to influence modern CPU designs, enabling the advanced computing systems we use today.

2.7 Clock Generator

In a CPU (Central Processing Unit), the clock generator is a critical component responsible for producing the clock signal that synchronizes the operation of the CPU and other system components. The clock signal generated by the clock generator ensures that all operations within the CPU occur at a regular and coordinated pace, allowing the CPU to function correctly and efficiently.

Key functions and features of the clock generator in a CPU include:

1. **Clock Signal Generation:** The primary function of the clock generator is to produce a stable and precise clock signal. The clock signal is typically a square wave with a specific frequency and duty cycle.
2. **Frequency Determination:** The clock generator sets the frequency of the clock signal, which defines how fast the CPU can perform its operations. The clock frequency is measured in Hertz (Hz) and determines the number of clock cycles the CPU can execute per second.
3. **Duty Cycle Control:** The duty cycle of the clock signal represents the proportion of time the clock signal remains in the "high" state (logical 1) during one clock cycle. For most CPUs, the duty cycle is 50%, meaning the signal is "high" for half the time and "low" (logical 0) for the other half.
4. **Clock Speed:** The clock speed, which is determined by the clock frequency, directly affects the performance of the CPU. Higher clock speeds allow the CPU to execute more instructions per second, leading to faster processing.
5. **Synchronization:** The clock signal produced by the clock generator is distributed to all the relevant components of the CPU, including the arithmetic and logic units (ALUs), registers, cache, and other functional units. This synchronization ensures that all parts of the CPU operate in harmony and follow the same timing.
6. **Pipelining and Instruction Fetch:** The clock signal plays a vital role in pipelining and instruction fetch. Pipelining is a technique that allows multiple instructions to be executed

concurrently, and the clock signal controls the movement of instructions through the pipeline stages. The clock signal also determines the rate at which the CPU fetches instructions from memory.

7. **Power Management:** The clock generator can be involved in power management strategies, such as dynamically adjusting the clock frequency and voltage based on the CPU's workload. This technique, known as dynamic frequency scaling, helps optimize power consumption and reduce heat generation when the CPU is not fully utilized.
8. **Overclocking and Underclocking:** Some CPUs and systems allow users to modify the clock frequency to increase performance (overclocking) or decrease power consumption (underclocking). These practices should be done with caution, as extreme clock modifications can lead to instability and potential damage to the CPU.

Overall, the clock generator is a critical component that ensures the CPU operates in a controlled and coordinated manner. It provides the fundamental timing mechanism necessary for the CPU to execute instructions, access memory, and perform calculations efficiently.

2.8 Control Unit and Arithmetic Logic Unit

In a CPU (Central Processing Unit), the Control Unit (CU) and Arithmetic Logic Unit (ALU) are two essential components that work together to execute instructions and perform computations. They are responsible for the core processing tasks of the CPU.

1. **Control Unit (CU):** The Control Unit is responsible for controlling the flow of data and instructions within the CPU and coordinating the activities of other hardware components. Its main functions include:
 - **Instruction Fetch:** The CU fetches the next instruction from memory, typically based on the program counter (PC), which keeps track of the memory address of the next instruction to be executed.
 - **Instruction Decoding:** After fetching an instruction, the CU decodes it to determine the operation to be performed and the operands involved.
 - **Operand Fetch:** The CU coordinates the retrieval of operands (data) from memory or registers, which are needed to execute the instruction.
 - **Execution Control:** The CU directs the ALU and other functional units to execute the instruction and perform the necessary operations.
 - **Timing and Synchronization:** The CU generates and manages the clock signal that synchronizes the various components in the CPU, ensuring that they perform operations in harmony.

- **Control Flow:** The CU handles control flow instructions, such as jumps, branches, and subroutine calls, which determine the order in which instructions are executed.
2. **Arithmetic Logic Unit (ALU):** The Arithmetic Logic Unit is responsible for performing arithmetic operations (e.g., addition, subtraction, multiplication) and logical operations (e.g., AND, OR, NOT) on binary data. Its key functions include:
- **Arithmetic Operations:** The ALU can perform basic arithmetic calculations, such as addition and subtraction, on binary numbers. More complex operations, like multiplication and division, are often built using a series of simpler ALU operations.
 - **Logical Operations:** The ALU performs logical operations, such as AND, OR, and NOT, which are essential for handling data comparisons and decision-making in the CPU.
 - **Data Manipulation:** The ALU can shift or rotate binary data to the left or right, enabling bitwise operations on binary values.
 - **Conditional Execution:** In some CPUs, the ALU is equipped with conditional execution capabilities. This means that certain operations are executed only if specific conditions are met, based on the results of previous operations.

Both the Control Unit and Arithmetic Logic Unit are crucial components in a CPU. The Control Unit manages the overall operation of the CPU, while the ALU performs the actual computations and logical operations. Together, they enable the CPU to execute instructions, process data, and perform the complex tasks required to run software applications and perform various computing tasks.

2.9 Types of Processors

2.9.1. CISC – Complex Instruction Set Computer

- CISC is a processor architecture that focuses on providing a wide variety of complex and specialized instructions. The key features of CISC architecture include:
- **Complex Instructions:** CISC processors have a larger and more diverse set of complex instructions, capable of performing multiple tasks in a single instruction. This may include memory access, arithmetic operations, and addressing modes.
- **Memory-to-Memory Operations:** In CISC architectures, some instructions can directly operate on data stored in memory, reducing the need for register usage.
- **Variable-Length Instruction Format:** CISC instructions can have variable lengths, making instruction decoding more complex and potentially slower.

- **Implicit Addressing Modes:** CISC instructions may use implicit addressing modes, where operands are assumed to be in specific memory locations, reducing the need for explicit memory references.

Examples of CISC architectures include x86 (Intel and AMD processors), Motorola 68k, and VAX.

2.9.2 RISC – Reduce Instruction Set Computer

- **RISC** is a processor architecture that emphasizes simplicity and streamlined instruction execution. The key features of RISC architecture include:
- **Simple Instructions:** RISC processors use a small and fixed set of simple instructions, each designed to perform a single operation. This simplicity allows for faster instruction decoding and execution.
- **Load-Store Architecture:** RISC CPUs typically follow a load-store architecture, where all arithmetic and logical operations are performed on data loaded from memory into registers. The results are then stored back into memory.
- **Register-Rich Design:** RISC CPUs often have a large number of general-purpose registers that allow the processor to store and access data quickly. Register-to-register operations are common in RISC architectures.
- **Pipelining:** RISC processors are well-suited for pipelining, a technique that allows multiple instructions to be executed concurrently, enhancing overall performance.
- **Uniform Instruction Format:** Instructions in RISC architectures often have a uniform length, making decoding and fetching more straightforward.

Examples of RISC architectures include ARM, MIPS, RISC-V, and PowerPC.

2.10 CPU's packaging and socket types

CPU packaging and socket types refer to the physical design and connectivity interface used to connect a central processing unit (CPU) to a motherboard. Different CPUs have specific packaging and socket requirements that must be matched for compatibility.

CPU packaging refers to the protective covering that houses the CPU chip. There are various packaging types, including the pin grid array (PGA) and land grid array (LGA). PGA CPUs have pins on the underside that connect to corresponding holes in the socket, while LGA CPUs have lands (contacts) on the CPU that connect to pins in the socket.

Socket types, also known as CPU sockets or CPU interfaces, are the connectors on the motherboard that the CPU is inserted into. Different CPU manufacturers and architectures have unique socket designs. For example, Intel CPUs commonly use sockets such as LGA1151 or LGA1200, while AMD CPUs use sockets such as AM4 or sTRX4.

The socket type of a CPU determines its physical compatibility with a specific motherboard. It is crucial to ensure that the CPU and motherboard have a matching socket type to ensure proper connectivity and functionality. Socket types may also have different pin layouts, power delivery configurations, and feature sets, which can influence the supported CPUs, memory types, and expansion options on a motherboard.

When upgrading or building a computer system, it is essential to consider the CPU's packaging and socket type requirements to select a compatible motherboard that can accommodate the chosen CPU model.

3. List of early processors and modern processors of last decade Early Processors:

Early Processors (Before Last Decade):

1. Intel Core 2 Duo (2006)
2. AMD Phenom X4 (2007)
3. Intel Core i7-900 series (2008)
4. AMD Athlon II X4 (2009)
5. Intel Core i5-600 series (2010)

Modern Processors (Last Decade):

- Intel Haswell (4th Gen Core) series (2013)
- AMD Ryzen series (2017)
- Intel 8th and 9th Gen Core series (2017-2019)
- AMD Ryzen 3000 series (2019)
- Intel 10th Gen Core series (2020)
- AMD Ryzen 5000 series (2020)
- Intel 11th Gen Core series (2021)
- AMD Ryzen 6000 series (expected in 2022)

These are just a few examples of early processors and modern processors from the last decade. It's worth noting that both Intel and AMD have released numerous models and generations within this timeframe, each with their own improvements in performance, power efficiency, and features.

3.1 Manufactures

The primary manufacturers of CPUs (central processing units) for personal computers are:

1. **Intel Corporation:** Intel is one of the leading CPU manufacturers globally, known for its Intel Core series processors. They have a long history of producing CPUs for desktops, laptops, and servers.

2. **Advanced Micro Devices (AMD):** AMD is another major player in the CPU market. They offer a range of processors under the AMD Ryzen and AMD Threadripper brands. AMD CPUs are known for their competitive performance and value.

In addition to Intel and AMD, there are other manufacturers that produce CPUs for specific markets or specialized applications:

These two are the prominent CPU manufacturers, but the market is dynamic, and new players may emerge over time. It's worth noting that CPU design and manufacturing involve complex

processes, and often companies outsource manufacturing to foundries like TSMC, GlobalFoundries, or Samsung Semiconductor.

3.2 Differences

Here's a basic table outlining some key differences between an older CPU (Intel 8086, released in 1978) and a modern CPU (Intel Core i9-11900K, released in 2021):

Table 3.1: Key Differences between Earlier and Latest CPU

Feature	Intel 8086 (Oldest CPU)	Intel Core i9-11900K (Latest CPU)
Architecture	16-bit x86	64-bit x86
Clock Speed	5 MHz	Up to 5.3 GHz
Manufacturing Process	3 micronm	10 nm
Number of Cores	1	8
Number of Threads	1	16
Cache Size	16 KB	16 MB L3
Integrated Graphics	No	Intel UHD Graphics 750
TDP (Thermal Design Power)	N/A	125 W
Instruction Set	x86	x86-64 (with support for SIMD, AVX)
Memory Support	1 MB	Up to 128 GB DDR4-3200
Maximum Power Draw	N/A	251.2 W

It's important to note that this is a very simplified comparison, and there are many other factors that contribute to the overall performance and capabilities of a CPU.

3.3 Types of processors based on core

Processors can be categorized based on the number of cores they have. Here are the common types of processors based on the number of cores:

1. **Single-Core Processors:** These processors have a single processing core. They are the oldest type of processors and are limited in their multitasking capabilities. Single-core processors are typically found in older computers and low-end devices.
2. **Dual-Core Processors:** Dual-core processors have two processing cores on a single chip. They provide improved multitasking capabilities compared to single-core processors. Each core can handle separate tasks simultaneously, enhancing overall performance and responsiveness.
3. **Quad-Core Processors:** Quad-core processors contain four processing cores. They offer even greater multitasking capabilities and are widely used in modern computers. Quad-core processors are capable of handling more demanding applications and workloads efficiently.

4. **Hexa-Core Processors:** Hexa-core processors feature six processing cores. They provide increased processing power and are particularly useful for resource-intensive tasks such as video editing, 3D rendering, and gaming.

5. **Octa-Core Processors:** Octa-core processors consist of eight processing cores. They deliver high-performance capabilities and are commonly found in high-end desktops, workstations, and gaming systems. Octa-core processors excel in multitasking and handling demanding applications.

6. **Multi-Core Processors:** Multi-core processors refer to processors with more than eight cores. These processors are typically used in specialized applications such as data centers, scientific computing, and server environments. They offer immense processing power and can handle heavy workloads efficiently.

It's worth noting that the number of cores is not the sole determinant of a processor's performance. Other factors, such as clock speed, cache size, architecture, and efficiency, also influence a processor's overall capabilities.

3.4: Specialized processors (GPU, AL accelerators)

Specialized processors, such as GPUs (Graphics Processing Units) and AL (Accelerator) accelerators, are designed to perform specific tasks efficiently and offload processing from the central processing unit (CPU). Here are the details about these specialized processors:

3.4.1. Graphics Processing Units (GPUs):

GPUs are primarily designed for rendering and manipulating computer graphics. They excel at parallel processing, making them ideal for tasks that require high computational throughput, such as 3D graphics rendering, video encoding/decoding, and machine learning. GPUs consist of thousands of cores optimized for handling multiple calculations simultaneously, allowing them to process massive amounts of data in parallel. They have their memory, known as video RAM (VRAM), to store and manipulate graphical data efficiently.

GPUs are widely used in gaming, scientific simulations, data analysis, and artificial intelligence applications. They can be integrated into the CPU as integrated GPUs or exist as separate add-on cards for desktop computers.

3.4.2. Accelerator Processors (AL accelerators):

Accelerators are specialized processors designed to accelerate specific types of workloads. They are optimized for tasks like artificial intelligence (AI), machine learning (ML), deep learning, data analytics, and scientific simulations. These processors are highly parallel and leverage specialized architectures, such as field-programmable gate arrays (FPGAs) or application-specific integrated circuits (ASICs), to deliver exceptional performance.

AL accelerators are used to accelerate tasks that involve heavy matrix computations, such as training deep neural networks or processing large datasets. They offer higher performance and energy efficiency compared to general-purpose CPUs, as they are tailored specifically for these workloads. Companies like Nvidia (with their Tensor Cores) and Google (with their Tensor Processing Units) have developed popular AL accelerators for AI and ML applications.

The integration of GPUs and AL accelerators in modern computing systems has significantly improved the performance and capabilities of various applications, enabling faster and more efficient processing of complex workloads. They work in conjunction with CPUs, offloading specific tasks to specialized processors and enabling more efficient utilization of resources for specific types of computations.

3.5 Thermal design and cooling solutions

The thermal design and cooling solutions for CPUs are essential to maintain their temperature within safe operating limits and prevent overheating.

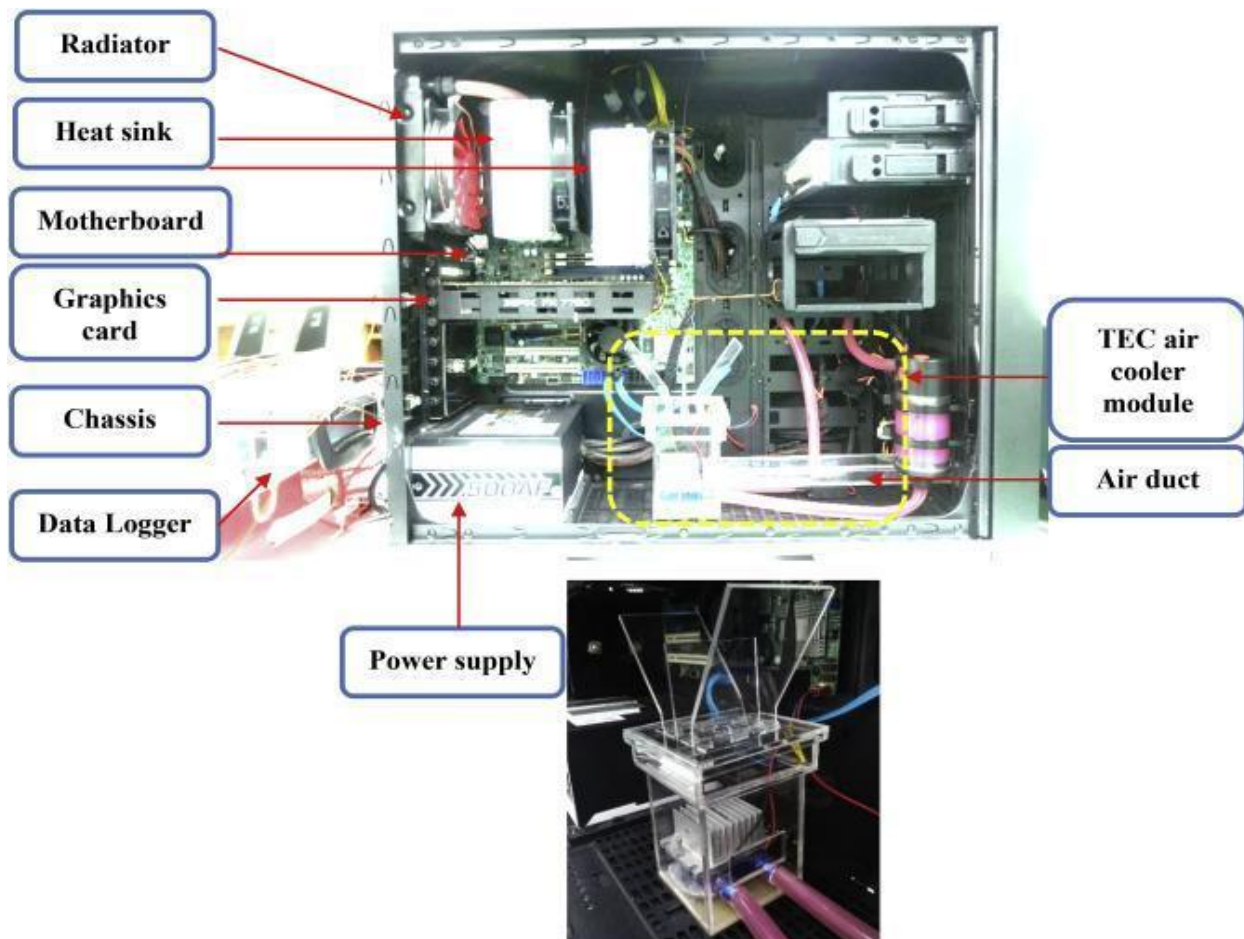


Figure 3. 1- Typical Thermal System

Here are some details about thermal design and cooling solutions for CPUs:

1. Heat Sink: A heat sink is a passive cooling solution commonly used in conjunction with a CPU. It consists of a metal block with numerous fins to increase the surface area for heat dissipation. The heat sink is attached to the CPU using a thermal interface material, such as thermal paste or thermal pads, to improve heat transfer.

2. Cooling Fans: Fans are active cooling components used alongside heat sinks. They facilitate airflow over the heat sink, expelling hot air and bringing in cooler air. CPU fans are typically attached to the heat sink and are controlled by the system or motherboard to adjust their speed based on the CPU temperature.

3. Liquid Cooling: Liquid cooling is an advanced cooling solution that involves circulating a liquid coolant through a closed-loop system. It typically includes a CPU block with a copper or aluminum plate that makes direct contact with the CPU, absorbing heat. The heated liquid then passes through tubes to a radiator where the heat is dissipated with the help of fans. Liquid cooling offers enhanced heat dissipation and can be more efficient in cooling high-performance CPUs.

4. All-in-One (AIO) Coolers: AIO coolers combine the advantages of liquid cooling with the simplicity of pre-assembled units. They consist of a radiator, pump, and CPU block connected by tubes. AIO coolers are often easier to install compared to custom liquid cooling setups and provide effective cooling for high-performance CPUs.

5. Thermal Design Power (TDP): TDP is a specification provided by CPU manufacturers that indicates the maximum amount of heat generated by the CPU under normal operation. It helps determine the appropriate cooling solution required to dissipate the heat generated by the CPU.

6. Overclocking Considerations: Overclocking, pushing the CPU beyond its stock clock speeds, can generate more heat. In such cases, more robust cooling solutions, such as high-performance air coolers or custom liquid cooling setups, may be required to maintain safe temperatures.

It's important to choose a cooling solution that matches the CPU's thermal requirements and supports the intended usage scenario. Proper installation and maintenance of cooling solutions, including regular cleaning to remove dust buildup, are crucial for maintaining optimal CPU temperatures and prolonging the CPU's lifespan.

4. What are the key changes during the last decade (2013 to 2023)?

4.1: CPU trends and developments during the last decade:

During the last decade, the CPU industry witnessed several notable trends and developments that further pushed the boundaries of performance, power efficiency, and architecture advancements. Here are some key trends and developments during that time:

1. Increasing Core Counts: CPU manufacturers continued their focus on increasing the number of cores in their processors. This trend was particularly evident in consumer-grade CPUs. It became common to see mainstream desktop processors with six, eight, or even more cores. Additionally, server-grade processors also saw a significant increase in core counts, with many offerings featuring 24 cores or more.

2. Enhanced Power Efficiency: Power efficiency remained a crucial aspect of CPU development. Manufacturers such as Intel and AMD improved their manufacturing processes to produce CPUs with lower power consumption and reduced heat output. This led to better battery life in laptops and mobile devices and contributed to the increasing popularity of energy-efficient computing.

3. 7nm and 10nm Process Nodes: Leading CPU manufacturers made strides in transitioning to smaller process nodes, such as 7nm and 10nm. Smaller nodes allowed for more transistors to be packed into the same area, leading to improved performance and energy efficiency. Both Intel and AMD released CPUs based on 7nm and 10nm processes, with AMD's Ryzen 3000 series (7nm) and Intel's 10th Gen Core processors being prominent examples.

4. AMD's Ryzen 3000 Series: AMD continued to challenge Intel's dominance in the consumer CPU market with its Ryzen 3000 series processors. These CPUs were built on the 7nm Zen 2 architecture, offering excellent multi-core performance and competitive single-core performance at more affordable price points than Intel's counterparts. This led to increased market share for AMD in the consumer desktop CPU segment.

5. Intel's Comet Lake and Tiger Lake: In response to AMD's competition, Intel launched its 10th Gen Core processors (Comet Lake) for desktops and the 11th Gen Core processors (Tiger Lake) for laptops. These CPUs featured higher core counts, improved IPC (Instructions Per Clock), and integrated Intel Xe graphics, offering better overall performance and power efficiency.

6. Rise of Mobile and Low-Power CPUs: The demand for low-power and efficient CPUs continued to grow due to the increasing popularity of mobile devices, IoT (Internet of Things) devices, and ultra-thin laptops. Manufacturers worked on developing CPUs specifically tailored for these applications, striking a balance between performance and energy efficiency.

7. AI Acceleration: CPUs with built-in AI acceleration capabilities became more common during this period. Features like Intel's DL Boost and AMD's support for AI frameworks enabled faster and more efficient, benefiting applications in machine learning and artificial intelligence.

5. Period 1: 2013-2015:

During the period of 2013 to 2015, CPU development was characterized by the increasing adoption of multicore architectures, with CPUs featuring multiple cores to enable parallel processing and enhanced multitasking capabilities. There was a strong emphasis on power efficiency, driving advancements in process node shrinking and the integration of specialized components like GPUs. Mobile CPUs saw significant improvements, catering to the demand for energy-efficient devices with improved performance. Additionally, the rise of ARM-based CPUs in data centers challenged the dominance of traditional x86 server CPUs in certain workloads.

The focus on performance per watt and the availability of unlocked CPUs for overclocking appealed to enthusiasts seeking higher performance. These trends laid the groundwork for subsequent CPU innovations and shaped the trajectory of computing technology.

Below the Intel and AMD's 2013 to 2015 processor's specification that you can understand what is the improvement in these 3 years.

Table 5.1 Intel's 2013 to 2015 processor's specification comparison:

Introduction date	2013	2014	2015
Model number _	i3-3210	i5-4460T	i7-5775C
Maximum base frequency	3.2 GHz / 3200 MHz	1.9 GHz / 1900 MHz	3.3 GHz / 3300 MHz
Maximum turbo frequency	N/A	2.7 GHz / 2700 MHz	3.7 GHz / 3700 MHz
Bus speed	5 GT/s Direct Media Interface	5 GT/s Direct Media Interface	
Package	1155-land Flip-Chip Land Grid Array	1150-land Flip-Chip Land Grid Array	1150-land Flip-Chip Land Grid Array
Socket	Socket 1155 / H2 / LGA1155	Socket 1150 / H3 / LGA1150	Socket 1150 / H3 / LGA1150
Size	1.48" x 1.48" / 3.75cm x 3.75cm	1.48" x 1.48" / 3.75cm x 3.75cm	1.48" x 1.48" / 3.75cm x 3.75cm
Total number of CPU cores	2	4	4
Total number of threads	4	4	8
Clock multiplier	32	19	33
Level 1 cache size	2 x 32 KB instruction caches 2 x 32 KB data caches	4 x 32 KB instruction caches 4 x 32 KB data caches	4 x 32 KB 8-way set associative instruction caches 4 x 32 KB 8-way set associative data caches
Level 2 cache size _	2 x 256 KB	4 x 256 KB	4 x 256 KB 8-way set associative caches
Level 3 cache size	3 MB	6MB	128 MB 16-way set associative shared cache
Level 4 cache size	N/A	N/A	N/A
GPU Type	HD 2500	HD 4600	Intel Iris Pro 6200

Instruction set	x86	x86	x86
Data width	64 bit	64 bit	64 bit
Supported memory:	32 GB	32 GB	32 GB
Thermal Design Power	55 Watt	35 Watt	65 Watt

5.1 The improvements in-between 2013-2015 for Intel Processors

From the **table 6.1** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The Intel Core i7-5775C has the highest base clock and comes with hyper-threading, allowing it to handle multi-threaded tasks more efficiently compared to the other two processors. The i5-4460T has a lower base and turbo clock speed, while the i3-3210 is the least powerful in terms of processing speed.

Cores and Threads: The i7-5775C offers 4 cores and 8 threads, enabling better multitasking and handling parallel workloads. The i5-4460T has 4 cores and 4 threads, while the i3-3210 has 2 cores and 4 threads.

Integrated Graphics: The i7-5775C features Intel Iris Pro Graphics 6200, which is more powerful than the graphics on the other two processors. The i5-4460T has Intel HD Graphics 4600, and the i3-3210 has Intel HD Graphics 2500.

TDP: The i5-4460T has the lowest TDP of 35W, making it the most energy-efficient option. The i3-3210 and i7-5775C have TDPs of 55W and 65W, respectively.

Generation: The i3-3210 is from the Ivy Bridge generation (3rd Gen), the i5-4460T is from the Haswell generation (4th Gen), and the i7-5775C is from the Broadwell generation (5th Gen). Generally, newer generations offer better performance and efficiency.

Price: Since processor prices can vary over time, it's essential to check the current market prices to determine which processor offers the best value for your budget.

5.2 Conclusion for Intel's 2013 to 2015 processor trends.

Based on this comparison, we can see as multi-core performance and better integrated graphics capabilities, the Intel Core i7-5775C was the most improved one. The Intel Core i5-4460T was a good balance between performance and energy efficiency, while the Intel Core i3-3210 was budget-friendly but less powerful compared to the other two options.

So, we can see that in-terms of time period, CPU is going much faster and powerful.

Table 5.2. AMD's 2013 to 2015 processor's specification comparison:

Introduction date	2013	2014	2015
Model number	AMD Athlon II X2 280	A10-7850K	A10-7870K
Maximum base frequency	3.6 GHz / 3600 MHz	3.7 GHz / 3700 MHz	3.9 GHz / 3900 MHz
Maximum turbo frequency	N/A	4 GHz / 4000 MHz	4.1 GHz / 4100 MHz
Package	938-pin organic micro Pin Grid Array (UOF938)	906-pin lidded micro-PGA package	906-pin lidded micro-PGA package
Socket	Socket AM2+ Socket AM3	Socket FM2+	Socket FM2+
Size	N/A	1.57" x 1.57" / 4cm x 4cm	1.57" x 1.57" / 4cm x 4cm
Total number of CPU cores	2	4	4
Total number of threads	1	4	4
Clock multiplier	18	N/A	N/A
Level 1 cache size	2 x 64 KB instruction caches 2 x 64 KB data caches	2 x 96 KB 3-way set associative shared instruction caches 4 x 16 KB 4-way set associative data caches	2 x 96 KB instruction caches 4 x 16 KB data caches
Level 2 cache size	2 x 1 MB	2 x 2 MB 16-way set associative shared caches	2 x 2 MB
Level 3 cache size	N/A	N/A	N/A
Level 4 cache size	N/A	N/A	N/A
GPU Type	N/A	Radeon R7 series	Radeon R7 series
Instruction set	x86	x86	x86
Data width	64bit	64bit	64bit
Supported memory:	8 GB	8 GB	16 GB
Thermal Design Power	65 Watt	95 Watt	95 Watt

5.3 The improvements in-between 2013-2015 for AMD Processors

From the **table 6.2** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The AMD A10-7870K and A10-7850K are both quad-core processors, offering better multi-core performance compared to the dual-core AMD Athlon II X2. This means they can handle multitasking and multi-threaded tasks more efficiently.

Clock Speed: The A10-7870K has a slightly higher base and turbo clock speed than the A10-7850K, which could lead to slightly better performance in certain applications.

Integrated Graphics: Both the A10-7870K and A10-7850K come with Radeon R7 Series integrated graphics with 512 GPU cores. This integrated GPU can handle light gaming and multimedia tasks, making it suitable for systems without a dedicated graphics card. The Athlon II X2, however, lacks integrated graphics and requires a dedicated GPU for any graphical tasks.

TDP: All three processors have a TDP of 95W, meaning they have similar power consumption and thermal characteristics.

Upgradability: The A10-7850K and A10-7870K are part of AMD's APU lineup, which means they combine both CPU and GPU capabilities. While this is beneficial for integrated graphics, it may limit future upgrade options since the CPU and GPU are integrated into one chip. The Athlon II X2, on the other hand, allows more flexibility for future GPU upgrades.

Price: Depending on the current market prices and availability, the AMD Athlon II X2 is likely to be more budget-friendly compared to the A10-7850K and A10-7870K, which are APUs with integrated graphics.

5.4 Conclusion for AMD's 2013 to 2015 processor trends.

In conclusion, we can say in the time frame AMD's processor also improve its processor power in-terms of high budget as well as budget friendly. They tried to improve the technology but trying to reduce the price. AMD Athlon II X2 could be a cost-effective choice. However, if we focus on decent integrated graphics performance and better multi-core processing capabilities, the AMD A10-7850K or A10-7870K were more suitable options, with the A10-7870K offered slightly higher clock speeds.

6. Period 2: 2016-2018:

During the years 2016 to 2018, CPU trends and developments focused on increasing core counts and introducing processors with more threads to enhance multitasking and performance in multi-threaded applications. CPU manufacturers transitioned to smaller process nodes, such as 10nm and 7nm, leading to more powerful and energy-efficient CPUs. Specialized AI accelerators were incorporated into CPUs to handle complex AI workloads, while security mitigations were implemented to address vulnerabilities related to speculative execution.

The introduction of AMD Ryzen CPUs brought significant competition to the market, prompting improved price-performance ratios. CPU designers also worked on enhancing thread synchronization techniques, and server CPUs saw increased core counts to meet the demands of cloud computing and data centers. Overall, these developments resulted in significant improvements in performance, energy efficiency, and computing capabilities.

Below the Intel and AMD's 2016 to 2018 processor's specification that you can understand what is the improvement in these 3 years.

Table 6.1 Intel's 2016 to 2018 processor's specification comparison:

Introduction date	2016	2017	2018
Model number _	i5-6585R	i7-7700K	i7-8086K
Maximum base frequency	2.8 GHz / 2800 MHz	4.2 GHz / 4200 MHz	4 GHz / 4000 MHz
Maximum turbo frequency	3.6 GHz / 3600 MHz	4.5 GHz / 4500 MHz	5 GHz / 5000 MHz
Bus speed	8 GT/s Direct Media Interface	8 GT/s Direct Media Interface	8 GT/s Direct Media Interface
Package	1440-ball micro-FCBGA	1151-land Flip-Chip Land Grid Array	1151-land Flip-Chip Land Grid Array
Socket	BGA1440	Socket 1151 / H4 / LGA1151	Socket 1151 / H4 / LGA1151
Size	1.65" x 1.1" / 4.2cm x 2.8cm	1.48" x 1.48" / 3.75cm x 3.75cm	1.48" x 1.48" / 3.75cm x 3.75cm
Total number of CPU cores	4	4	6
Total number of threads	4	8	12
Clock multiplier	28	42	40
Level 1 cache size	4 x 32 KB 8-way set associative instruction caches 4 x 32 KB 8-way set associative data caches	4 x 32 KB 8-way set associative instruction caches 4 x 32 KB 8-way set associative data caches	6 x 32 KB instruction caches 6 x 32 KB data caches
Level 2 cache size _	4 x 256 KB	4 x 256 KB 4-way set associative caches	6 x 256 KB
Level 3 cache size	6 MB shared cache	8 MB 16-way set associative shared cache	12 MB
Level 4 cache size	128 MB	N/A	N/A
GPU Type	Intel Iris Pro 580	Intel HD 630	
Instruction set	x86	x86	x86
Data width	64 bit	64 bit	64 bit
Supported memory:	64 GB	64 GB	64 GB
Thermal Design Power	65 Watt	91 Watt	95 Watt

6.1 The improvements in-between 2016-2018 for Intel Processors

From **table 6.1** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The Intel Core i7-8086K outperforms both the i7-7700K and i5-6585R due to its higher core count (6 cores) and more threads (12 threads). It is more suitable for heavy multitasking, content creation, and CPU-intensive tasks.

Clock Speed: The i7-8086K has a higher base clock (4.0 GHz) and significantly higher max turbo clock (5.0 GHz) compared to the i7-7700K (4.2 GHz base, 4.5 GHz turbo) and the i5-6585R (clock speeds not specified). This gives the i7-8086K a substantial advantage in single-core performance.

Integrated Graphics: All three processors come with integrated graphics, but specific details about the i5-6585R's integrated graphics were not provided. The i7-8086K has Intel UHD Graphics 630, while the i7-7700K has Intel HD Graphics 630. The i7-8086K may offer slightly better integrated GPU performance.

Generation: The i7-7700K is from the 7th Gen, while the i7-8086K is from the 8th Gen. The generation differences can lead to improvements in architecture, efficiency, and performance.

TDP: The i7-7700K has a TDP of 91W, while the i7-8086K has a slightly higher TDP of 95W. Details about the TDP of the i5-6585R were not provided.

Price: The prices of these processors may vary depending on availability and location. It's essential to consider the cost of each processor when making a decision.

6.2 Conclusion for Intel's 2016 to 2018 processor trends.

In summary, if we look the prioritize single-core performance and gaming capabilities, the Intel Core i7-8086K is the strongest choice. However, if we need a good balance of multi-core performance and price, the Intel Core i7-7700K could be a more budget-friendly option.

Table 6.2 AMD's 2016 to 2018 processor's specification comparison:

Introduction date	2016	2017	2018
Model number	AMD Athlon X4	AMD Ryzen 3	AMD Ryzen 5
Maximum base frequency	3.5 GHz / 3500 MHz	3.5 GHz / 3500 MHz	3.6 GHz / 3600 MHz
Maximum turbo frequency	3.8 GHz / 3800 MHz	3.7 GHz / 3700 MHz	3.9 GHz / 3900 MHz
Package	1331-pin lidded micro-PGA package	1331-pin lidded micro-PGA package	1331-pin lidded micro-PGA package
Socket	Socket AM4	Socket AM4	Socket AM4
Size	1.57" x 1.57" / 4cm x 4cm	1.57" x 1.57" / 4cm x 4cm	1.57" x 1.57" / 4cm x 4cm
Total number of CPU cores	4	4	4
Total number of threads	4	4	8
Level 1 cache size	2 x 96 KB instruction caches 4 x 32 KB data caches	4 x 64 KB 4-way set associative instruction caches 4 x 32 KB 8-way set associative data caches	4 x 64 KB 4-way set associative instruction caches 4 x 32 KB 8-way set associative write-back data caches
Level 2 cache size	2 x 1 MB	4 x 512 KB inclusive 8-way set associative unified caches	4 x 512 KB 8-way set associative caches
Level 3 cache size	N/A	8 MB exclusive 16-way set associative shared cache	4 MB 16-way set associative shared cache
Level 4 cache size	N/A	N/A	N/A
GPU Type	N/A	Radeon R7 series	Radeon RX Vega 11
Instruction set	x86	x86	x86
Data width	64bit	64bit	64bit
Supported memory:	64 GB	64 GB	64 GB
Thermal Design Power	65 Watt	65 Watt	65 Watt

6.3 The improvements in-between 2013-2015 for AMD Processors

From **table 6.2** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: AMD Ryzen 5 processors generally offer better multi-core performance due to their higher core and thread count compared to both AMD Athlon X4 and AMD Ryzen 3 processors. This makes Ryzen 5 processors more suitable for multitasking and CPU-intensive tasks.

Core and Thread Count: The AMD Ryzen 5 typically comes with 6 cores and 12 threads, which provides a significant advantage over the 4-core and 4-thread configuration of most AMD Athlon X4 and Ryzen 3 processors. Ryzen 3 models with SMT (Simultaneous Multithreading) do offer 4 cores and 8 threads, but Ryzen 5 still has a higher thread count.

Integrated Graphics: Some AMD Ryzen 3 and Ryzen 5 models come with integrated Radeon Vega Graphics, providing a reasonable level of graphics performance without the need for a dedicated GPU. The AMD Athlon X4, on the other hand, may require a dedicated GPU for graphical tasks, as not all models have integrated graphics.

Generation: All three processor families, the AMD Athlon X4, Ryzen 3, and Ryzen 5, have various models spanning different generations. Generally, newer generations offer improved performance and efficiency.

TDP: The TDP varies based on the specific model within each processor family. Ryzen processors tend to have higher TDPs due to the increased core count and performance capabilities.

Price: Prices for these processors will vary depending on the specific model and market conditions. Generally, AMD Athlon X4 processors tend to be more budget-friendly, while Ryzen 3 and Ryzen 5 processors offer a better balance between performance and cost.

6.4 Conclusion for AMD's 2016 to 2018 processor trends.

In summary, the AMD is tried a lot to cap the market with introduced more advance technology and adding the more transistor in the processor. In these three years period AMD rise the market with its better performance CPUs. If we looking for a budget-friendly option, the AMD Athlon X4 suitable on that period. If you need better multi-core performance and some integrated graphics capability, consider AMD Ryzen 3. For even higher multi-core performance and more advanced capabilities, AMD Ryzen 5 processors would be a better choice. We can notice, form the table that, AMD improved a lot in these three years compare to period 1(2013-2015).

7. Period 3: 2019-2020:

During the period from 2019 to 2020, CPU trends and developments were characterized by increased core counts, advancements in process technology with 7nm and 5nm nodes, and the dominance of AMD Ryzen and EPYC CPUs in the consumer and server markets. CPUs integrated specialized hardware for high-performance computing and artificial intelligence, resulting in improved performance for AI workloads.

Multi-chip modules (MCMs) were adopted to overcome physical limitations and enhance CPU configurations. Energy efficiency remained a priority, with CPUs implementing advanced power management techniques. Additionally, there was a focus on security mitigations, AI and machine learning acceleration, cloud-optimized designs, and advancements in mobile CPU technology. These developments led to more powerful, energy-efficient, and versatile CPUs, shaping the computing landscape during this time-frame.

Below the Intel and AMD's 2019 to 2020 processor's specification that you can understand what is the improvement in these 2 years.

Table 7.1 Intel's 2019 to 2020 processor's specification comparison:

Introduction date	2019	2020
Model number _	i3-9100F	i7-10700K
Maximum base frequency	3.6 GHz / 3600 MHz	3.8 GHz / 3800 MHz
Maximum turbo frequency	4.2 GHz / 4200 MHz	5.1 GHz / 5100 MHz
Bus speed	8 GT/s Direct Media Interface	8 GT/s Direct Media Interface
Package	1151-land Flip-Chip Land Grid Array	1200-land Flip-Chip Land Grid Array
Socket	Socket 1151 / H4 / LGA1151	Socket 1200
Size	1.48" x 1.48" / 3.75cm x 3.75cm	1.48" x 1.48" / 3.75cm x 3.75cm
Total number of CPU cores	4	8
Total number of threads	4	16
Clock multiplier	36	38
Level 1 cache size	4 x 32 KB instruction caches 4 x 32 KB data caches	8 x 32 KB instruction caches 8 x 32 KB data caches
Level 2 cache size _	4 x 256 KB	8 x 256 KB
Level 3 cache size	6 MB	16 MB
Level 4 cache size	N/A	N/A
GPU Type	N/A	Intel UHD 630
Instruction set	x86	x86
Data width	64 bit	64 bit
Supported memory:	64 GB	128 GB
hermal Design Power	65 watt	65 watt

7.1 The improvements in-between 2019-2020 for Intel Processors

From **table 7.1** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The Intel Core i7-10700K significantly outperforms the i3-9100F due to its higher core count (8 cores) and threads (16 threads) with Hyper-Threading enabled. The i7-10700K is more suitable for heavy multitasking, content creation, gaming, and CPU-intensive tasks compared to the i3-9100F.

Clock Speed: The i7-10700K has a higher base clock (3.8 GHz) and a much higher max turbo clock (5.1 GHz) compared to the i3-9100F (3.6 GHz base, 4.2 GHz turbo). This makes the i7-10700K much faster in both single-core and multi-core performance.

Hyper-Threading: The i7-10700K comes with Hyper-Threading, which allows each core to handle two threads simultaneously. This enables better multi-tasking and boosts overall performance, a feature not available in the i3-9100F.

Integrated Graphics: The i7-10700K includes Intel UHD Graphics 630, which is a decent integrated GPU suitable for light gaming and basic graphical tasks. The i3-9100F lacks integrated graphics and requires a dedicated GPU for any graphical tasks.

Generation: The i7-10700K is from the 10th Gen, which is a more recent generation compared to the i3-9100F, which is from the 9th Gen. Newer generations often bring improvements in architecture, efficiency, and performance.

TDP: The i3-9100F has a lower TDP of 65W, while the i7-10700K has a higher TDP of 125W. The higher TDP of the i7-10700K is due to its higher core count and clock speeds.

Price: As processor prices can vary over time and depending on your location, it's essential to consider the current market prices. Generally, the i7-10700K is more expensive due to its higher performance and features.

8.2 Conclusion for Intel's 2019 to 2020 processor trends.

In summary, in these two years time frame Intel mostly focused on new technology like Hyper-Threading enabled. And they are looking for also reduced the price for their earlier processor like i3. For general office tasks, light multitasking, and a budget-friendly option, the Intel Core i3-9100F could be sufficient. However, if we look at the a powerful processor for demanding tasks like gaming, content creation, and heavy multitasking, the Intel Core i7-10700K is the better choice due to its higher core count, Hyper-Threading, and significantly higher clock speeds.

Table 7.2 AMD's 2019 to 2020 processor's specification comparison:

Introduction date	2019	2020
Model number	AMD Ryzen 5 3400G	AMD Ryzen 7 5800X
Maximum base frequency	3.7 GHz / 3700 MHz	3.8 GHz / 3800 MHz
Maximum turbo frequency	4.2 GHz / 4200 MHz	4.7 GHz / 4700 MHz
Package	1331-pin lidded micro-PGA package	1331-pin lidded micro-PGA package
Socket	Socket AM4	Socket AM4
Size	1.57" x 1.57" / 4cm x 4cm	1.57" x 1.57" / 4cm x 4cm
Total number of CPU cores	4	8
Total number of threads	8	16
Level 1 cache size	4 x 64 KB instruction caches 4 x 32 KB data caches	8 x 32 KB instruction caches 8 x 32 KB data caches
Level 2 cache size	4 x 512 KB	8 x 512 KB
Level 3 cache size	4 MB	32 MB
Level 4 cache size	N/A	N/A
GPU Type	Radeon RX Vega 11	N/A
Instruction set	x86	x86
Data width	64bit	64bit
Supported memory:	64 GB	64 GB
Thermal Design Power	65 Watt	105 Watt

7.3 The improvements in-between 2019-2020 for AMD Processors

From **table 8.2** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The AMD Ryzen 7 5800X outperforms the Ryzen 5 3400G by a significant margin due to its higher core count (8 cores vs. 4 cores) and clock speeds. The Ryzen 7 5800X is designed for high-end gaming, content creation, and CPU-intensive tasks, making it a much more powerful processor overall.

Clock Speed: The Ryzen 7 5800X has a higher base clock (3.8 GHz) and a significantly higher max turbo clock (4.7 GHz) compared to the Ryzen 5 3400G (3.7 GHz base, 4.2 GHz turbo). This means the Ryzen 7 5800X offers better single-core and multi-core performance.

Cores and Threads: The Ryzen 7 5800X comes with 8 cores and 16 threads due to Simultaneous Multithreading (SMT), which allows each core to handle two threads simultaneously. In contrast, the Ryzen 5 3400G has 4 cores and 8 threads.

Integrated Graphics: The Ryzen 5 3400G features integrated Radeon RX Vega 11 Graphics with 11 GPU cores, which can handle light gaming and multimedia tasks without the need for a dedicated GPU. The Ryzen 7 5800X, however, does not have integrated graphics and requires a separate graphics card for any graphical tasks.

Generation: The Ryzen 7 5800X is part of the newer 4th Gen (Zen 3) processor lineup, which offers improved performance and efficiency compared to the Ryzen 5 3400G from the 3rd Gen (Zen+).

TDP: The Ryzen 5 3400G has a lower TDP of 65W, while the Ryzen 7 5800X has a higher TDP of 105W. The higher TDP of the Ryzen 7 5800X is due to its higher core count and performance capabilities.

Price: As processor prices can vary over time and depending on your location, it's essential to consider the current market prices. Generally, the Ryzen 7 5800X is more expensive due to its higher performance and features.

8.4 Conclusion for AMD's 2019 to 2020 processor trends.

In summary, AMD was most hyped processor selling company as because they improved their processor clock cycle and provide less costly processor to the customer like AMD Ryzen 5 3400G. The processor with decent integrated graphics for light gaming and multimedia tasks and have a tighter budget, the AMD Ryzen 5 3400G could be a suitable option. However, if we focus on a high-performance processor for gaming, content creation, and demanding multitasking, the AMD Ryzen 7 5800X is the better choice due to its higher core count, clock speeds, and overall performance for that time. Remember, Ryzen 7 5800X does not have integrated graphics and will require a separate graphics card for any graphical tasks.

8. Period 4: 2021-2023 (continue):

From 2021 to 2023, CPU trends and developments are expected to focus on advancements in process technology, leading to smaller process nodes and improved energy efficiency. CPUs might feature higher core counts, with mainstream consumer CPUs potentially reaching 16 or more cores.

The integration of specialized hardware for AI and machine learning workloads could enhance inferencing and training capabilities. Heterogeneous computing, combining CPUs with specialized accelerators like GPUs, may become more prevalent to improve overall system performance.

Security enhancements, energy efficiency, and sustainable computing practices are likely to remain important considerations. Additionally, there may be continued research and development in quantum computing, edge computing optimization, cloud-optimized designs, and advancements in mobile CPUs and 5G integration.

Below the Intel and AMD's 2021 to 2023 (continue) processor's specification that you can understand what is the improvement in these 3 years.

Table 8.1. Intel's 2020 to 2023 processor's specification comparison:

Introduction date	2021	2022	2023
Model number	i5-11600K	i9-12900KS	i9-13900KS
Maximum base frequency	3.9 GHz / 3900 MHz	3.4 GHz / 3400 MHz	3.2 GHz / 3200 MHz
Maximum turbo frequency	4.9 GHz / 4900 MHz	5.5 GHz / 5500 MHz	6 GHz / 6000 MHz
Bus speed	8 GT/s Direct Media Interface	32 GT/s PCI Express interface 16 GT/s Direct Media Interface 16 GT/s PCI Express interface	32 GT/s PCI Express interface 16 GT/s Direct Media Interface 16 GT/s PCI Express interface
Package	1200-land Flip-Chip Land Grid Array	1700-land Flip Chip Land Grid Array (FC-LGA) with integrated heatspreader	1700-land Flip Chip Land Grid Array (FC-LGA) with integrated heatspreader
Socket	Socket 1200	Socket 1700	Socket 1700
Size	1.48" x 1.48" / 3.75cm x 3.75cm	1.77" x 1.48" / 4.5cm x 3.75cm	1.77" x 1.48" / 4.5cm x 3.75cm
Total number of CPU cores	6	16	24
Total number of threads	12	24	32
Clock multiplier	39	34	32
Level 1 cache size	6 x 32 KB instruction caches 6 x 48 KB data caches	8 x 64 KB instruction caches 8 x 32 KB data caches	16 x 64 KB instruction caches 16 x 32 KB data caches
Level 2 cache size	6 x 512 KB	8 x 1.25 MB	4 x 4 MB
Level 3 cache size	12 MB	30 MB	36 MB
Level 4 cache size	N/A	N/A	N/A
GPU Type	Intel UHD 750	Intel UHD 770	Intel UHD 770
Instruction set	x86	x86	x86
Data width	64 bit	64 bit	64 bit
Supported memory:	128 GB	128 GB	128 GB
Thermal Design Power	125 Watt	150 Watt	150 Watt

8.1 The improvements in-between 2021-2023 for Intel Processors

From **table 8.1** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The Intel Core i9-13900KS significantly outperforms the i5-11600K due to its higher core count (24 cores) and threads (32 threads) with Hyper-Threading enabled. The i9-12900KS is more suitable for heavy multitasking, content creation, gaming, and CPU-intensive tasks compared to the i5-12900KS.

Clock Speed: The i5-has a higher base clock (3.9 GHz) and but i9-13900KS has a much higher max turbo clock (6 GHz) compared to the i5-11600K (4.9 GHz turbo) and i9-12900KS (5.5 GHz Turbo). This makes the i9-13900KS much faster in both single-core and multi-core performance.

Hyper-Threading: The i9-13900KS comes with Hyper-Threading, which allows each core to handle two threads simultaneously. This enables better multi-tasking and boosts overall performance, a feature not available in the i5-11600K.

Integrated Graphics: The i5-11600K includes Intel UHD Graphics 750, which is a decent integrated GPU suitable for light gaming and basic graphical tasks. But the i9-13900KS and i9-13900KS upgrade the integrated graphics with UHD 770.

Generation: The i9-13900KS is from the 13th Gen, which is a recent generation compared to the i9-12900KS, which is from the 12th Gen and i5-11600K is from 11th Generation. Newer generations often bring improvements in architecture, efficiency, and performance.

TDP: The i5-11600K has a lower TDP of 125W, while the i9-12900KS and i9-13900KS has a higher TDP of 150W. The higher TDP of the i9-12900KS is due to its higher core count and clock speeds.

Price: As processor prices can vary over time and depending on location, it's essential to consider the current market prices. Generally, the i9-13900KS is more expensive due to its higher performance and features compare to other processor.

8.2 Conclusion for Intel's 2021 to 2023 processor trends.

In summary, in these three years' time frame Intel mostly focused on more core and thread as well as clock frequency. They also improve the bus speed 8GT to 32GT/s. But this time they increased their price as compare to previous years market. They also increase the cache memory. For general office tasks, light multitasking, and a budget-friendly option, the Intel Core i5-11600K could be sufficient. However, if we look at the a powerful processor for demanding tasks like gaming, content creation, and heavy multitasking, the Intel i9-13900KS is the better choice due to its higher core count, Hyper-Threading, and significantly higher clock speeds as well as Higher memory supported.

Table 8.2. AMD's 2021 to 2023 processor's specification comparison:

Introduction date	2021	2022	2023
Model number _	AMD Ryzen 5 5600G	AMD Ryzen Threadripper PRO 5945WX	AMD Ryzen 9 7900X3D
Maximum base frequency	3.9 GHz / 3900 MHz	4.1 GHz / 4100 MHz	4.4 GHz / 4400 MHz
Maximum turbo frequency	4.4 GHz / 4400 MHz	4.5 GHz / 4500 MHz	5.6 GHz / 5600 MHz
Package	1331-pin lidded micro-PGA package	N/A	1718-pin lidded Land Grid Array (LGA)
Socket	Socket AM4	Socket sWRX8	Socket AM5
Size	1.57" x 1.57" / 4cm x 4cm	N/A	1.57" x 1.57" / 4cm x 4cm
Total number of CPU cores	6	12	12
Total number of threads	12	24	24
Level 1 cache size	6 x 32 KB instruction caches 6 x 32 KB data caches	12 x 32 KB instruction caches 12 x 32 KB data caches	12 x 32 KB instruction caches 12 x 32 KB data caches
Level 2 cache size _	6 x 512 KB	12 x 512 KB caches	4 x 512 KB 8-way set associative caches
Level 3 cache size	16 MB	64 MB shared cache	128 MB shared cache
Level 4 cache size	N/A	N/A	N/A
GPU Type	Radeon	N/A	Radeon
Instruction set	x86	x86	x86
Data width	64bit	64bit	64bit
Supported memory:	64 GB	2 TB	128 GB
Thermal Design Power	65 Watt	280 Watt	120 Watt

8.3 The improvements in-between 2021-2023 for AMD Processors

From **table 9.2** we can identify which one is better and improved in-terms of Performance and other key-points. Which are discussed below:

Performance: The AMD Ryzen 9 7900X3D outperforms the AMD Ryzen 5 5600G by a significant margin due to its higher core count (12 cores vs. 6 cores) and clock speeds. The Ryzen Threadripper PRO 5945WX is designed for high-end gaming, content creation, and CPU-intensive tasks, making it a much more powerful processor overall.

Clock Speed: The AMD Ryzen 9 7900X3D has a higher base clock (4.4 GHz) and a significantly higher max turbo clock (5.6 GHz) compared to the Ryzen 5 5600G (3.9 GHz base, 4.4 GHz turbo). On the other hand AMD Ryzen Threadripper PRO 5945WX has 4.1Ghz base clock frequency and 4.5 GHz turbo clock frequency. This means the AMD Ryzen 9 7900X3D offers better single-core and multi-core performance.

Cores and Threads: The AMD Ryzen 9 7900X3D and comes with 12 cores and 24 threads due to Simultaneous Multithreading (SMT), AMD Ryzen Threadripper PRO 5945WX which allows each core to handle two threads simultaneously. In contrast, the Ryzen 5 5600G has 6 cores and 12 threads.

Integrated Graphics: The AMD Ryzen 9 7900X3D features integrated Radeon RX Vega 11 Graphics with 11 GPU cores, which can handle light gaming and multimedia tasks without the need for a dedicated GPU. The AMD Ryzen 9 7900X3D, has also supports the Radeon Graphics. However, AMD Ryzen Threadripper PRO 5945WX does not have integrated graphics and requires a separate graphics card for any graphical tasks.

Generation: The AMD Ryzen 9 7900X3D is part of the newer Gen (Zen 4) processor lineup, which offers improved performance and efficiency compared to the Ryzen 5 5600G from the 3rd Gen (Zen+).

TDP: The Ryzen 5 5600G has a lower TDP of 65W, while the AMD Ryzen 9 7900X3D and Ryzen Threadripper PRO 5945WX has a higher TDP of 120W and 280 Watt. The higher TDP of the Ryzen Threadripper PRO 5945WX is due to its higher core count and performance capabilities.

Price: As processor prices can vary over time and depending on your location, it's essential to consider the current market prices. Generally, the Ryzen Threadripper PRO 5945WX is more expensive due to its higher performance and features.

8.4 Conclusion for AMD's 2019 to 2020 processor trends

In summary, AMD is most valued processor selling company as because they improved their processor clock cycle and provide more cache memory and improves others technology liked TDP.

The processor with decent integrated graphics for gaming and multimedia tasks and have a tighter budget, the AMD Ryzen 5 5600G was a best option. However, if we focus on a high-performance processor for gaming, content creation, and demanding multitasking, the AMD Ryzen 9 7900X3D is the better choice due to its higher core count, clock speeds, and overall AMD Ryzen Threadripper PRO 5945WX is best option as it is more powerful compare to the others two processors. It supports 2TB of memory which looks awesome to the CPU industry.

8.5 Overall Improvement During the 10 years period of Intel and AMD Processors

In the Table 8.3, we can see the significant improvements and advancement in the processor during the period of 2013 to 2023. First, two column we can see the Intel's 2013 released processor and 2023 released processor. From that we can understand, how they improved and advancement happen during this period time. In the last two column we can see improvements and advancement during the period of 10 years of AMD's 2013 to 2023 processors.

If we look on the table, we can see Intel and AMD both them are trying to have some major improvements in their processors. Its seems a competition between them that who can give us the more powerful, high capability processors. Now, we will look on to the significant improvements for both Intel and AMD's.

Table 8.3 The improvements of Intel and AMD’s 2013 to 2023 processors and specification comparison:

Introduced date	2013	2023	2013	2023
Model number _	i3-3210	i9-13900KS	AMD Athlon II X2 280	AMD Ryzen 9 7900X3D
Maximum base frequency	3.2 GHz / 3200 MHz	3.2 GHz / 3200 MHz	3.6 GHz / 3600 MHz	4.4 GHz / 4400 MHz
Maximum turbo frequency	N/A	6 GHz / 6000 MHz	N/A	5.6 GHz / 5600 MHz
Bus speed	5 GT/s Direct Media Interface	32 GT/s PCI Express interface 16 GT/s Direct Media Interface 16 GT/s PCI Express interface	N/A	32 GT/s PCI Express interface
Package	1155-land Flip-Chip Land Grid Array	1700-land Flip Chip Land Grid Array (FC-LGA) with integrated heat spreader	938-pin organic micro–Pin Grid Array (UOF938)	1718-pin lidded Land Grid Array (LGA)
Socket	Socket 1155 / H2 / LGA1155	Socket 1700	Socket AM2+ Socket AM3	Socket AM5
Size	1.48" x 1.48" / 3.75cm x 3.75cm	1.77" x 1.48" / 4.5cm x 3.75cm	N/A	1.57" x 1.57" / 4cm x 4cm
CPU cores	2	24	2	12
number of threads	4	32	1	24
Clock multiplier	32	32	18	44
L1 cache size	2 x 32 KB instruction caches 2 x 32 KB data caches	16 x 64 KB instruction caches 16 x 32 KB data caches	2 x 64 KB instruction caches 2 x 64 KB data caches	12 x 32 KB instruction caches 12 x 32 KB data caches
L2 cache size	2 x 256 KB	4 x 4 MB	2 x 1 MB	4 x 512 KB 8-way set caches
L3 cache size	3 MB	36 MB	N/A	128 MB shared cache
L4 cache size	N/A	N/A	N/A	N/A
GPU Type	HD 2500	Intel UHD 770	N/A	Radeon
Instruction set	x86	x86	x86	x86
Data width	64 bit	64 bit	64bit	64bit
Supported memory	32GB	128 GB	8/16 GB	128 GB
Thermal Design Power	55 Watt	150 Watt	65 Watt	120 Watt

Processor Family: During this period, Intel mainly focused on core-i3, i5, i7 and i9 family. And they launched the latest generation in each year. And improve the processor family during this period by increasing other things. Whereas AMD focused on Ryzen 3, Ryzen 5, Ryzen 7 and Ryzen 9 and skipped the Athlon family.

Frequency (Clock Speed): Though we can see the base frequencies are same for the Intel's 2013 and 2023 processor. But in case of Maximum Turbo Frequency, it was not available for the 2013 processor whereas for 2023 processor it has been introduced and its maximum turbo frequency is 6000 MHz or 6GHz. On the other hand, AMD's 2013 processor's base frequency was (3.6 Ghz) higher from the intel 2013 processor and in the latest processor, AMD has higher base frequency (4.4 GHz). In-terms of Turbo (Overclocking) Frequency both they could not introduce this technology in the 2013 processors. Now, Intel has higher turbo frequencies (6 GHz), that means Intel is dominating the AMD's turbo frequencies. In case of clock multiplier AMD (44 clock multiplier) is dominating Intel's clock multiplier.

Bus Speed: In terms of Bus Speed, it was only 5GT/s for the Intel 2013 processor, but later on in 2023 the processor bus speed has been increased up to 32GT/s for the boot Intel and AMD's.

CPU Core and Thread: From the table we can see that there is only 2 core is available in the 2013 Intel and AMD's processors and Intel has more thread than the AMD. But after 10 years' time, it has been improved as 24 core and 32 thread for Intel and for AMD it is 12 core and 24 threads.

Cache Size: In this 10 years period, the level 1, level 2 and level 3 cache size has been increased significantly. Which seems 12 times higher from the 2013 processor for both Intel and AMD's processor. Though Intel has much higher cache memory in Level 1 and Level 2 compare to the AMD processors.

GPU: The built in GPU has been also improved in the meantime from HD to UHD for Intel and AMD also improved their Built in GPU with Radeon Technology. In Radeon GPU people can play game and render high resolution video without dedicated Graphics card.

Memory: If we look on the table then we can see that in 2013 the processor can have ability to support the maximum memory was 32GB for Intel and for AMD it was 8/16GB whereas in the latest 2023 processor can support a maximum memory of 128GB for both Intel and AMD.

TDP: In case of Thermal Design and Power It was good for 2013 processor, because, it consumed less power on that time. But after a certain period of improvement, it increased the Power consuming. It is happened due to powerful processor and other features. AMD's 2023 processor has better TDP compare to the Intel's 2023 processor.

9. Conclusion

In the conclusion we can say, the development of the Central Processing Unit (CPU) has been a remarkable journey in the history of computing. CPU is a crucial component that determines the computer's speed, performance, and ability to handle complex tasks. It plays a central role in enabling the computer to function effectively and efficiently for a wide range of applications, from everyday computing to high-performance tasks like gaming and data-intensive workloads. Modern CPUs often have multiple cores, allowing them to execute multiple instructions concurrently, further improving performance and multitasking capabilities.

As technology has advanced, the number of transistors that can be integrated into a single CPU chip has increased dramatically. Modern CPUs contain billions of transistors that work together to perform intricate computations and execute complex software applications. The miniaturization of transistors and the ability to pack more of them into a small space have been key factors in the continuous improvement of CPU performance over the years.

Intel and AMD are the primary manufacturers of CPUs (central processing units) for personal computers. These two are the prominent CPU manufacturers. Intel made their first processor in 1971 where as AMD make its first chip on 1970.

There are several types of processors based on core, such as single core, dual core, quad core, hexa-core, octa core and multi-core. It's worth noting that the number of cores is not the sole determinant of a processor's performance. Other factors, such as clock speed, cache size, architecture, and efficiency, also influence a processor's overall capabilities. It is also required to set the cooling system to reduce the heat which produced by CPU. And it is also helps to improve the performance of the CPU.

In the period of 2013 to 2023 (10 years) the world of CPU has been improved a lot. Such as their performances are higher and processing are faster than the earlier CPU like Pentium. Number of core and thread has been increased as well as the higher clock multiplier. Level of cache memory has been increased to perform the fetch-decode-instruction cycle on less amount of time. The bus speed also increased to transfer the data faster to the CPU and now with huge amount of memory capacity it can load big program or run multiple programs at a time smoothly without any lagging. Still, the CPU development is ongoing and in a continuous process. Both Intel and AMD are trying to improve the AI enable capabilities CPU. Intel will introduce as Meteor Lake which will comes with AI features.

In the future, if engineers can find ways to keep up with Moore's law and processor speed actually doubles every 24 months, by 2050 we'd have a chip capable of running at 5,452,595 gigahertz, or nearly 5.5 petahertz. It's hard to imagine what kind of applications we could direct such a machine to tackle. So, the future of computer will have more powerful alike the super computer we have in 2023.

References

[1] All CPU table data collected from this website:

[https://www.cpu-world.com/Releases/Desktop_CPU_releases_\(2014\).html](https://www.cpu-world.com/Releases/Desktop_CPU_releases_(2014).html)

[2] Figure 4.1 is collected from internet.