An Overview of Apple Silicon M Series Chips

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***Abstract*—Gradually CPU architectures are changing and reaching new performance standards that previously were only dreams. The roll-out of the Apple M1 chips allowed the CPUs (central processing unit) to reach an enormous improvement in performance terms and heat management. Apple managed to make such an innovating ARM chip, that it has surpassed some of the best Intel x86 chips available at the moment in terms of performance and power consumption. In this paper we will address the architecture of the Apple M1 Chip and compare it to the legacy Intel x86 architecture considering the instruction set, the memory design, and the performance of systems integrating them. Apple's release of this cutting-edge ARM-based (Advanced RISC Machine) SoC (system-on-a-chip) CPU has innovated CPU architectures as we know them, and led Google, Nvidia, and other tech giants to follow up, announcing their plans for their custom ARM solutions.**

***Index Terms*—Apple M1, Apple Silicon, ARM, CPU, Intel x86**

I. Introduction

IN June 2020, at their annual Worldwide Developers Conference, Apple went public with an announcement which shocked the entire semiconductor industry: they would be transitioning from Intel x86 silicon to their own custom-designed and internally developed silicon using the ARM64 architecture for their Mac (desktop and laptop) products. Apple has demonstrated it is capable of designing powerful silicon since April 2010, when it released the A4, its first internally developed SoC. At the time of introduction in 2020, Apple stated that the M1 had the world's fastest CPU core "in low power silicon" and the world's best CPU performance per watt.

This is Apple's third change of the instruction set architecture used by Macintosh computers, switching from Intel to Apple silicon 14 years after they switched from PowerPC to Intel, and 26 years after the transition from the original Motorola 68000 series to PowerPC.

This paper proposes a showcase of the Apple's M1 Chip's architecture, while making a comparison to the the Intel x86 architecture in terms of instruction set, memory design, and performance.

The rest of the paper is structured in the following way: Section II presents the Apple M1 SoC architecture. Section III compares the M1 Chip to the Intel x86 architecture, and finally, Section IV exposes the conclusion.

II. Apple M1 Chip

The Apple M1 SoC is implemented using Taiwan Semiconductor Manufacturing Company's (TSMC) 5 nm fin field-effect transistor technology (N5). It has a CPU consisting of 8 CPU cores (4 performance cores and 4 efficiency cores) and a GPU (graphics processing unit) consisting of 8 cores. Each performance core features a dedicated L1 cache consisting of a 192 KB instruction cache and a 128 KB data cache. Each efficiency core features a dedicated L1 cache consisting of a 128 KB instruction cache and a 64 KB data cache. The performance cores share a 12 MB L2 cache and the efficiency cores share a 4 MB L2 cache. The CPU microarhitecture, as well as the GPU one are designed completely by Apple. The SoC features a NPU (neural processing unit), referred by Apple as the Neural Engine, consisting of 16 cores capable of 11 trillion operations per second. [1]

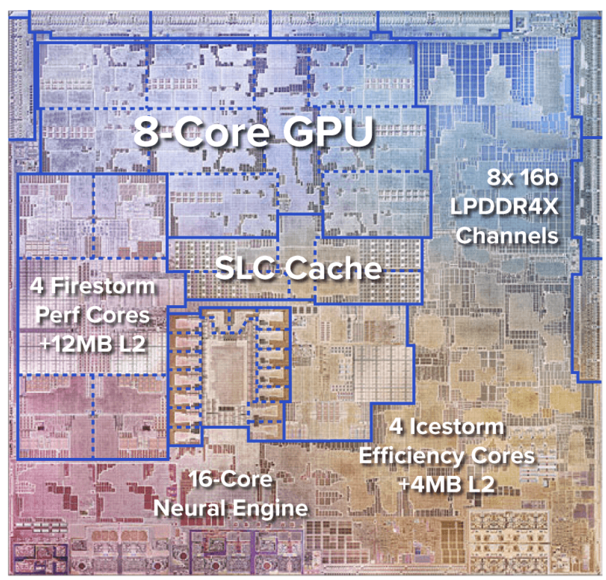

Fig. 1. Apple M1 SoC Architecture [2]

The SoC uses a 128 bit memory bus consisting of 8 LPDDR4X channels of 16 bit. The memory pool is addressable by each component of the SoC, achieving an unified memory architecture. For example, in the context of the GPU, resources, such as textures, images, and geometry data, can be shared between the CPU and GPU without introducing any overhead as it's not necessary to copy data across a PCIe bus. The DRAM, as well as the SoC are packaged using a SiP (System in a Package) design. This chip is designed to reduce latency and enhance the performance of the GPU, but it also generates inconvenience in case of upgrading and replacing the memory. Unfortunately, the GPU only supports 2 independent displays. On devices, such as the 13-inch MacBook Pro and MacBook Air, the integrated display consumes a display pipe which allows only a single external display. [3]

The SoC also features a variety of other specialized hardware:

1) ISP (image signal processor);
2) secure enclave;
3) motion coprocessor;
4) storage controller with accelerated AES encryption/decryption;
5) media encode and decode engines;
6) USB4 controller (backward compatible with Thunderbolt 3).

III. Apple M1 Chip vs Intel x86

A. Instruction Set

In case of x86 and ARM CPUs, the workflows follow a similar course of action, with IF (Instruction Fetch), ID (Instruction Decode), EXE (Execute), MEM (Memory), and WB (Writeback). The ARM CPU is a RISC architecture (Reduce Instruction Set Computer), while the X86 CPU is a CISC architecture (Complex Instruction Set Computer). In comparison to the x86 architecture, the ARM one has some advantages: simplified instructions, simple structure, constant execution time, etc. Although the instructions executed by both after decoding are alike, the ARM architecture is more efficient than the x86 one. The Apple M1 core has a decoder which decodes 8 instructions per cycle, being the decoder with the largest processor specifications at present [4]. This has allowed M1 Firestorm cores to essentially process twice as many instructions as AMD and Intel CPUs at the same clock frequency.

The equivalent of the AVX instruction set of the x86 architecture for the ARM architecture is the Neon instruction set. The M1 has 4 128 bit Neon pipes in each core. The ARM CPU's equally matched the most advanced x86 architectures in terms of floating point performance. Besides, the M1 has an AMX instruction set which allows the floating point unit to associate with the NPU, enhancing its floating point performance even more.

B. Memory Design

Apple M1 uses a shared memory architecture, integrating the RAM, the SSD, the CPU and the GPU in the same chipset (SoC), and having a single pool of memory that all these parts can access.

First, this implies that if the GPU needs more system memory, it can ramp up usage while other parts of the SoC ramp down. Also, there's no need to carve out portions of memory for each part of the SoC and then shuttle data between the two spaces for different parts of the processor. Instead, the GPU, CPU, and other parts of the processor can access the same data at the same memory address, unlike the chips based on the x86 architecture. Now, the RAM can be quickly filled and cleaned up. This allows switching between complex tasks to be made almost instantly. For example, the transition from a software development environment to a browser with many open tabs is seamless.

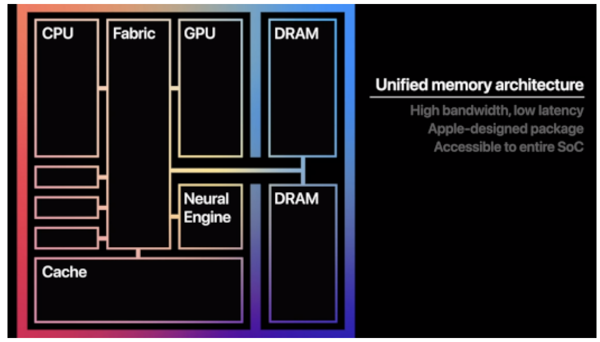

Fig. 2. Apple M1 Unified Memory Architecture [5]

C. Performance

Considering Geekbench 5 as the flagpole for overall system performance, the MacBook Air with a M1 CPU with 16GB of RAM scored a 5,962, topping the latest XPS 13 (5,319) with 11th Generation Intel chips. Even Lenovo's Yoga 9i, which uses the most powerful 11th Generation Intel chips for ultraportable laptops, fell short of the MacBook Air with a score of 5,312.

A 4K movie may be converted to 1080p on the MacBook Air M1 in about 9 minutes and 15 seconds, whereas the XPS 1 accomplished this in 18 minutes and 22 seconds and the Yoga 9i took 14 minutes and 24 seconds, concluding that the M1 laptop being nearly twice as fast as the XPS 1.

On the other hand, Intel excels at some jobs that the M1 doesn't. According to Intel, Google Chrome performs better on the Intel Core i7-1185G7 CPU with 16GB RAM. It also outperforms the M1 regarding Microsoft Office and particular Office activities.

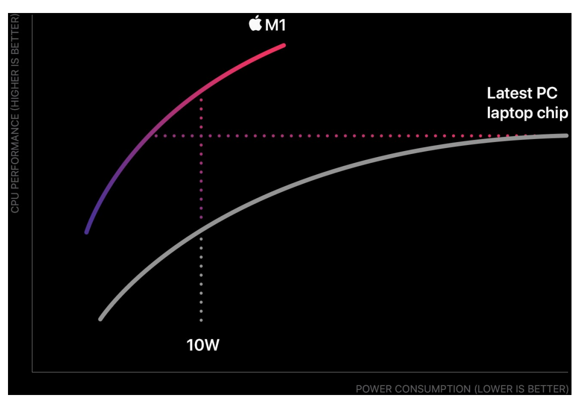

Fig. 3. CPU Performance vs. Power [6]

By the graph from Figure 3 we can conclude that the ARM M1 processor gives up to 2x faster CPU performance and matches peak PC performance using 25% of the power.

IV. Conclusion

In conclusion, Apple has proven the world what they are capable of if they are given full control over the underlying hardware of their products: stronger security, longer battery life, higher performance, smaller carbon footprint. Apple's M1 chip has set a new trend in CPU architectures which has already been followed by Google, Nvidia, and other tech giants, announcing their plans and roadmaps for their own custom ARM solutions. It has also set up great expectations of ARM technologies, and created an urge for investment in research and development (R&D) in this field of technology.

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