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Apple

DR JEFF SOFTWARE
INDIE APP DEVELOPER

Rev. 6-5-23

Computer Org &

ASSEMBLY Programming

Apple SoC

Dr Jeff Drobman

website → drjeffsoftware.com/classroom.html

email → jeffrey.drobman@csun.edu

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Section

Early Apple Computers

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Original Apple I

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Apple I Computer

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Robert Mudry, Retired Silicon Valley engineering geek.
Shared Feb 6

A Hand-Built, Original Apple 1 Computer Is Yours for Just 1.5 Million Dollars

Early PC's

Commodore PET

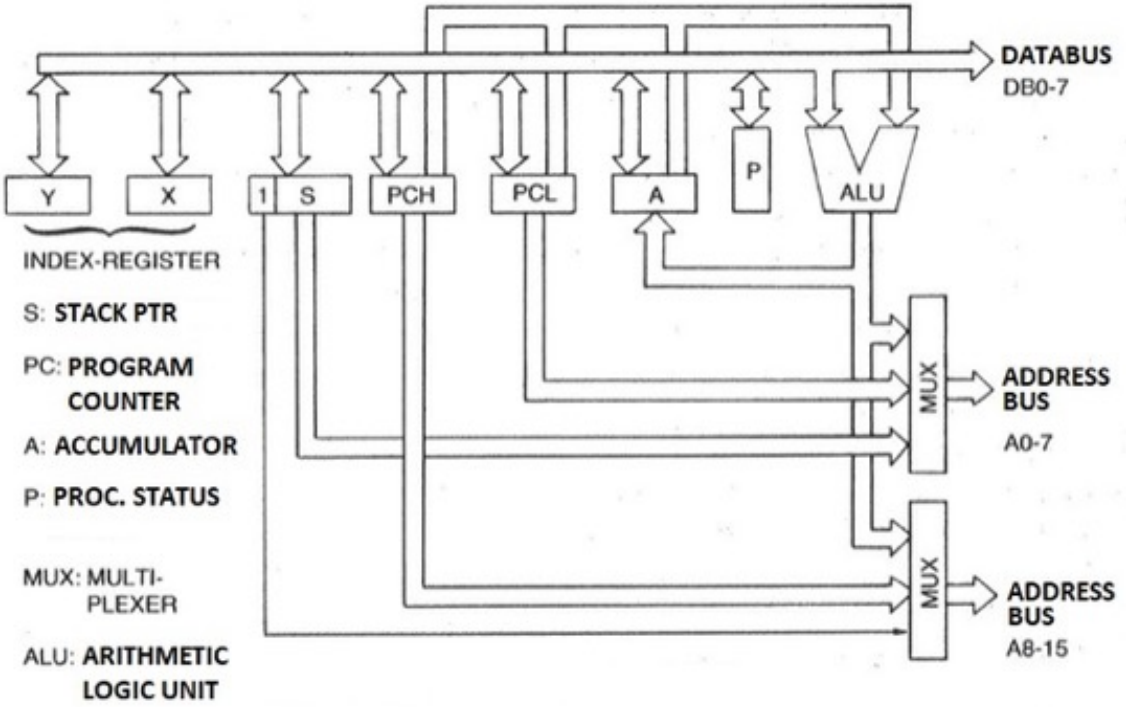
The Commodore PET 2001-8 alongside its rivals, the Apple II and the TRS-80 Model I

6502 8-bit MPU

Apple II in 1977 | CISC

Other than ALU, what are the basic components of a CPU?

Most of the answers are for more complicated CPUs, with caches, pipelines, DMA etc. But the basic components for a working CPU are much fewer. The 8-bit 6502 microprocessor, introduced in 1975 and used in the Apple][computer and other early personal computers, had only 3510 transistors (compared to the many billions in today's CPUs). Its basic block diagram was fairly simple and easy to understand:



Not shown is the Instruction Register (IR) and decoder logic, which holds the instruction being executed which was fetched from memory.

6502 8-bit MPU

CISC Apple II in 1977

The 6502 had one 8-bit accumulator, and two 8-bit index registers, 8-bit stack pointer, and a 16-bit program counter so it could address a maximum of 65536 bytes.

MOS 6502 registers

F E D C B A 9 8	7 6 5 4 3 2 1 0	*(bit position, hex)*
Main registers		
	A	**A**ccumulator
Index registers		
	X	**X** index
	Y	**Y** index
0 0 0 0 0 0 0 1	S	**S**tack **P**ointer
Program counter		
PC		**P**rogram **C**ounter
Status register		
	N V - B D I Z C	**P** Processor flags

The high byte of the stack address is hardwired to 1, so stack addresses ranged from 0x1FF (initial value) to 0x100.

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6502 8-bit MPU

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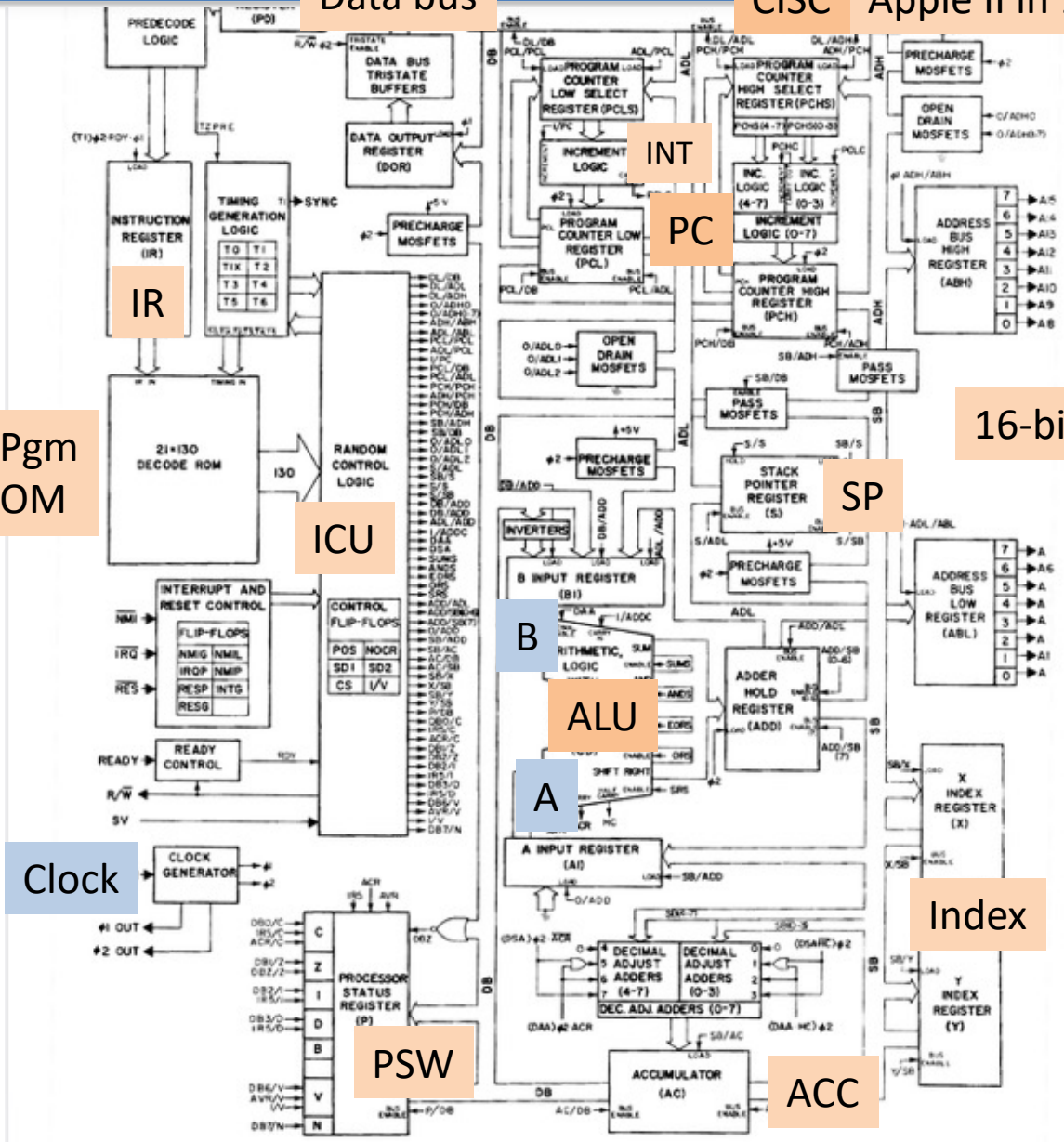
Data bus

CISC

Apple II in 1977



IR

uPgm ROM

ICU

INT

PC

16-bit Address bus

SP

B

ALU

A

Clock

Index

PSW

ACC

Section

Apple

Apple

1984

The MacIntosh

CPU: MT6502
(8-bit)

Wozniak

Steve Jobs

CPU: M68000
(16-bit)
RAM: 1MB

GUI: Xerox PARC (Alan Kay)

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AAPL

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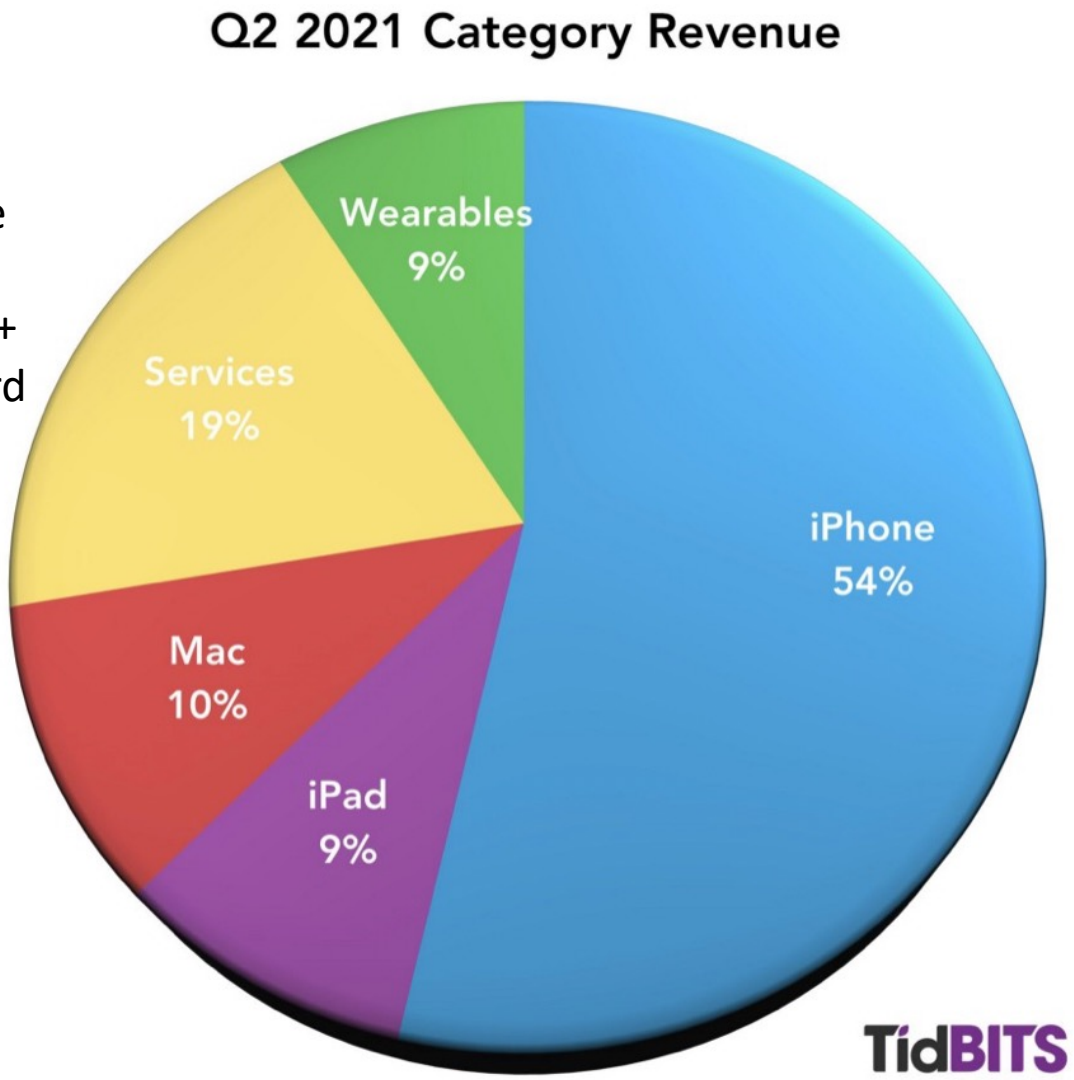
Apple Segments

- App store
- iTunes
- Apple TV+
- Apple card



Section

Apple Events

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Apple Events

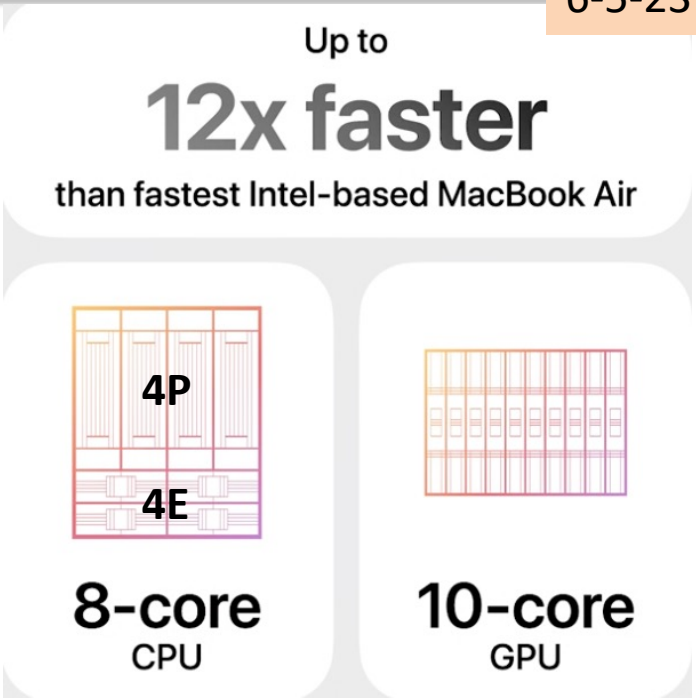
Apple M2 Event

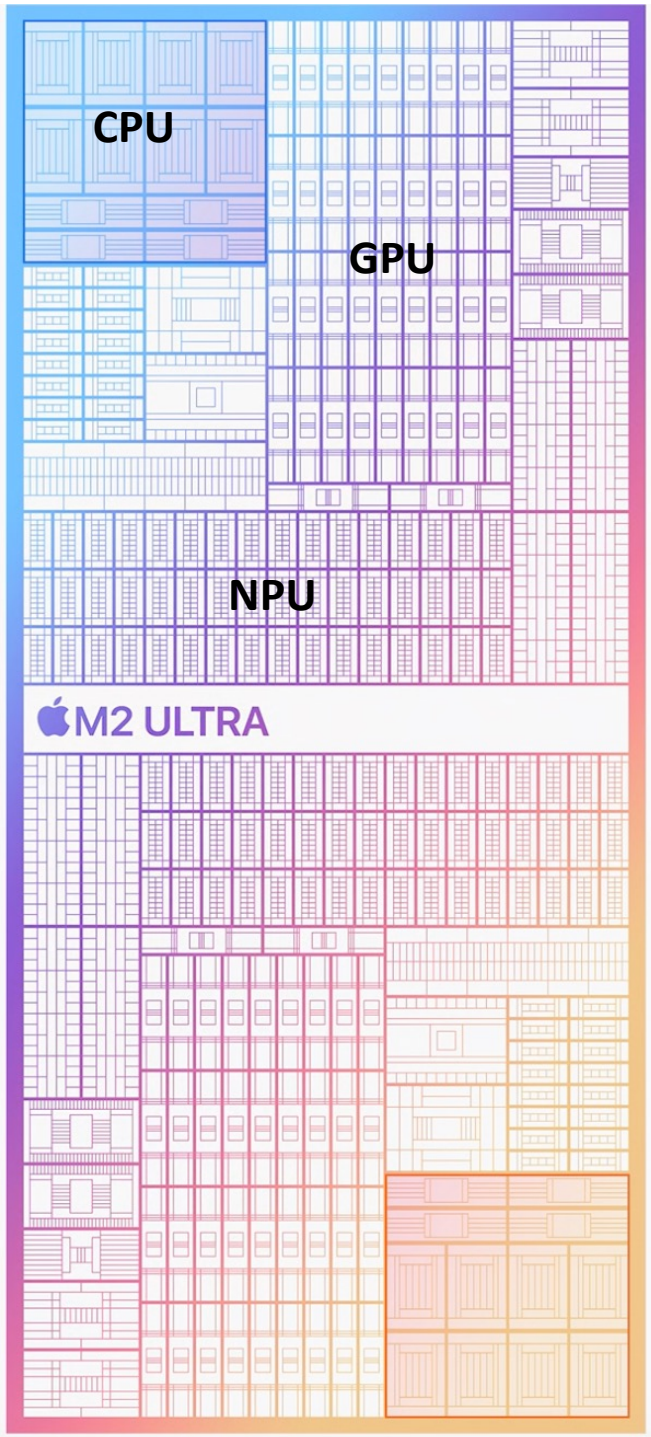
6-5-23

Apple Events

Apple M2 Event

6-5-23





M2 Event

6-5-23

- Each die (x2)
  - 12 **CPU** cores (8P+4E)
  - 38 **CPU** cores
  - 16 **NPU** cores
  - 67B transistors

M2 ***Ultra*** = 2x M2 ***Max***

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WWDC23

Apple M2 Event

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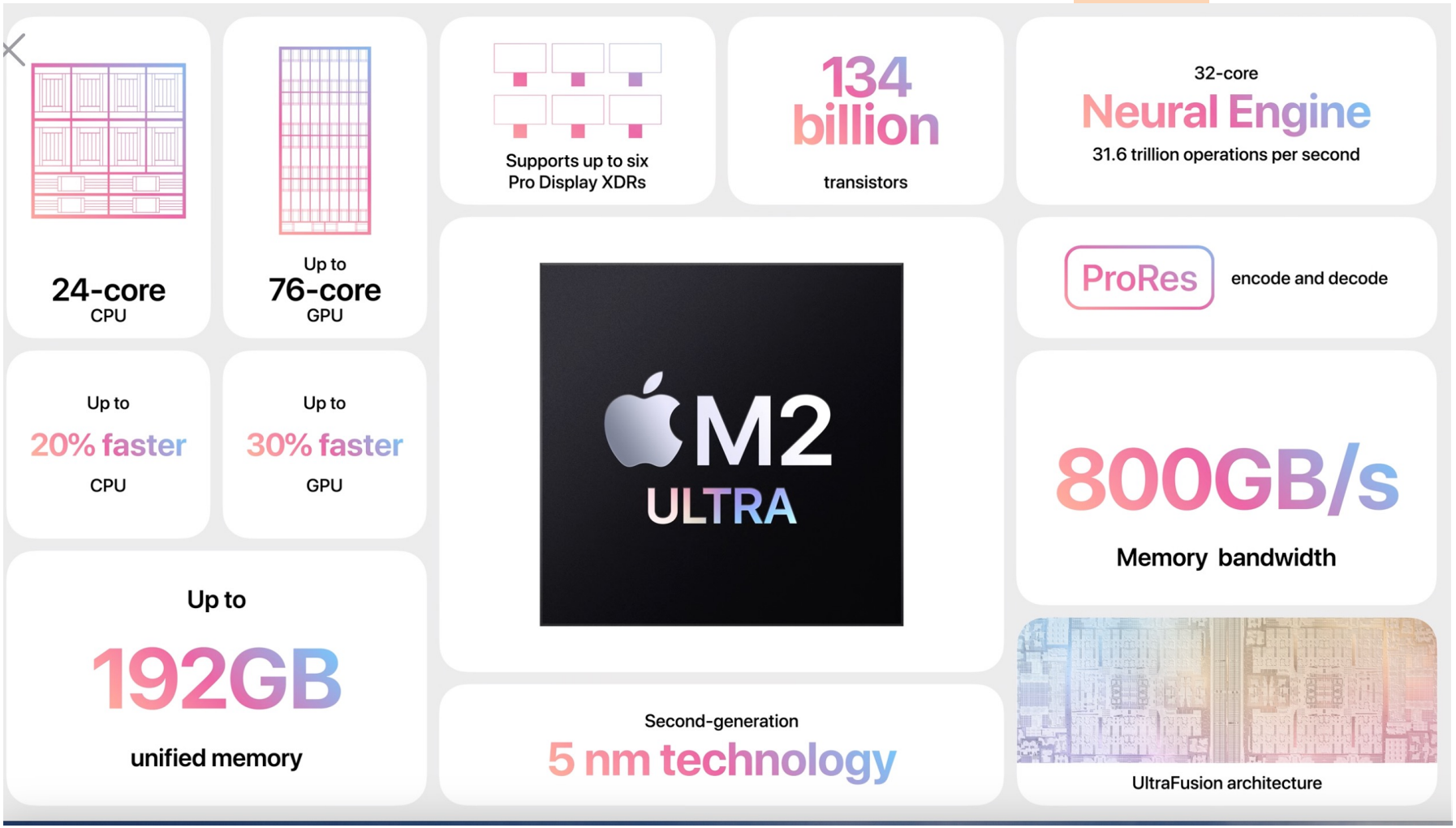

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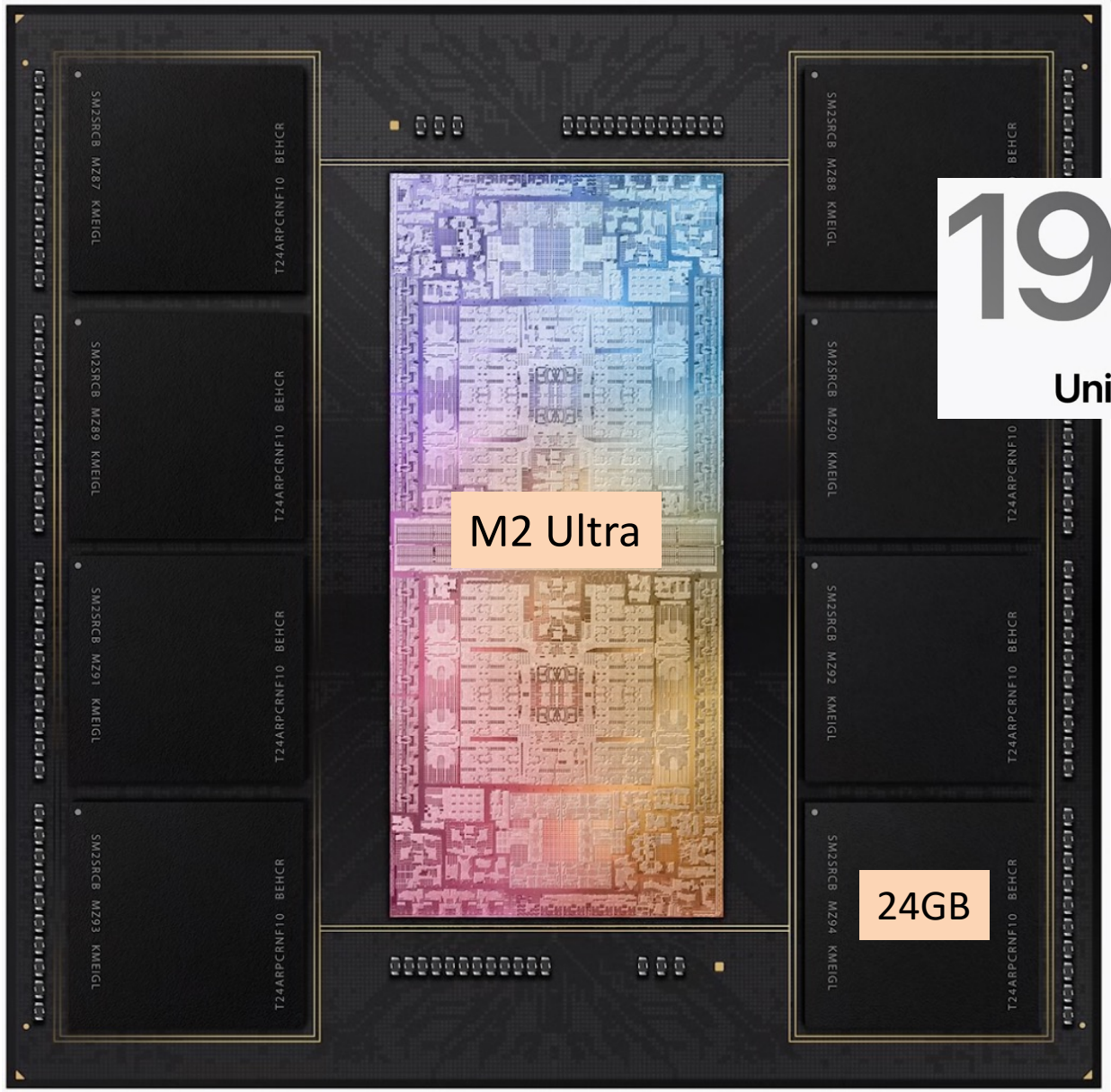

192GB
Unified memory

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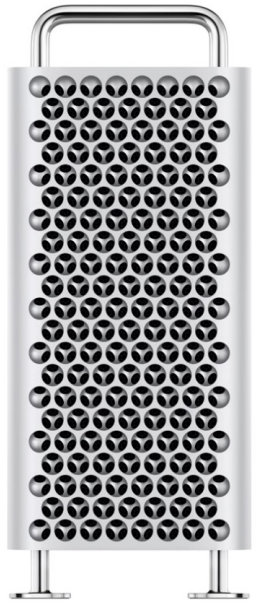
M2 ULTRA

Two HDMI ports

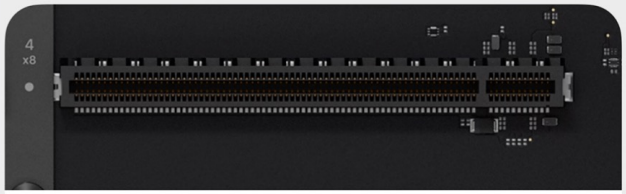
Dual 10Gb Ethernet



Supports up to six Pro Display XDRs

Eight Thunderbolt 4 ports

Up to **192GB** unified memory



Six open PCIe gen 4 slots

Up to **24-core** CPU

Up to **76-core** GPU

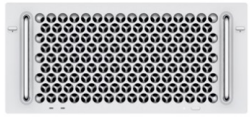
Up to **3x faster** than fastest Intel-based Mac Pro

Up to **7x faster** than starting config of Intel-based Mac Pro

32-core **Neural Engine** 31.6 trillion operations per second

Wi-Fi 6E

Bluetooth 5.3



Rack mount available

Up to **22 streams** of 8K ProRes

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Apple M2 Event

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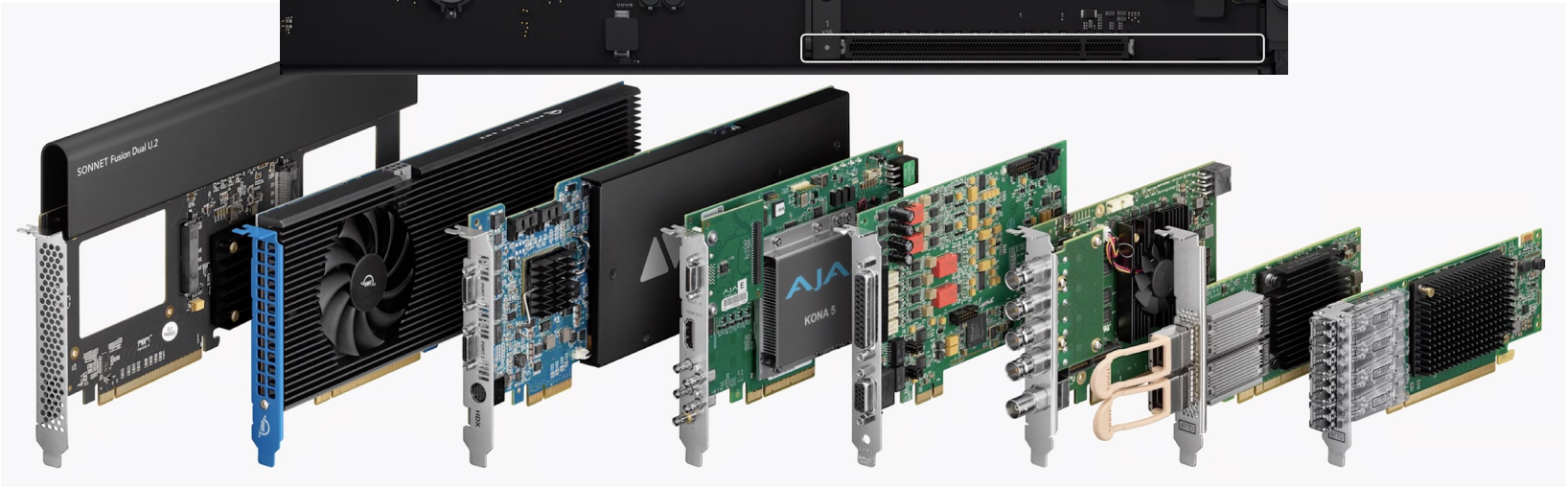
2016-2023

6-5-23

PCIe 4



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Vision Pro

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9-7-22

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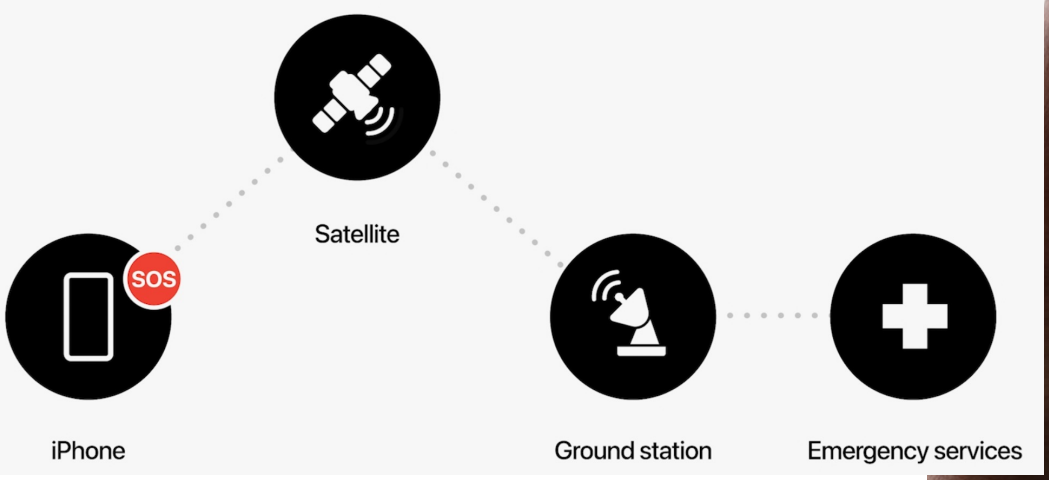
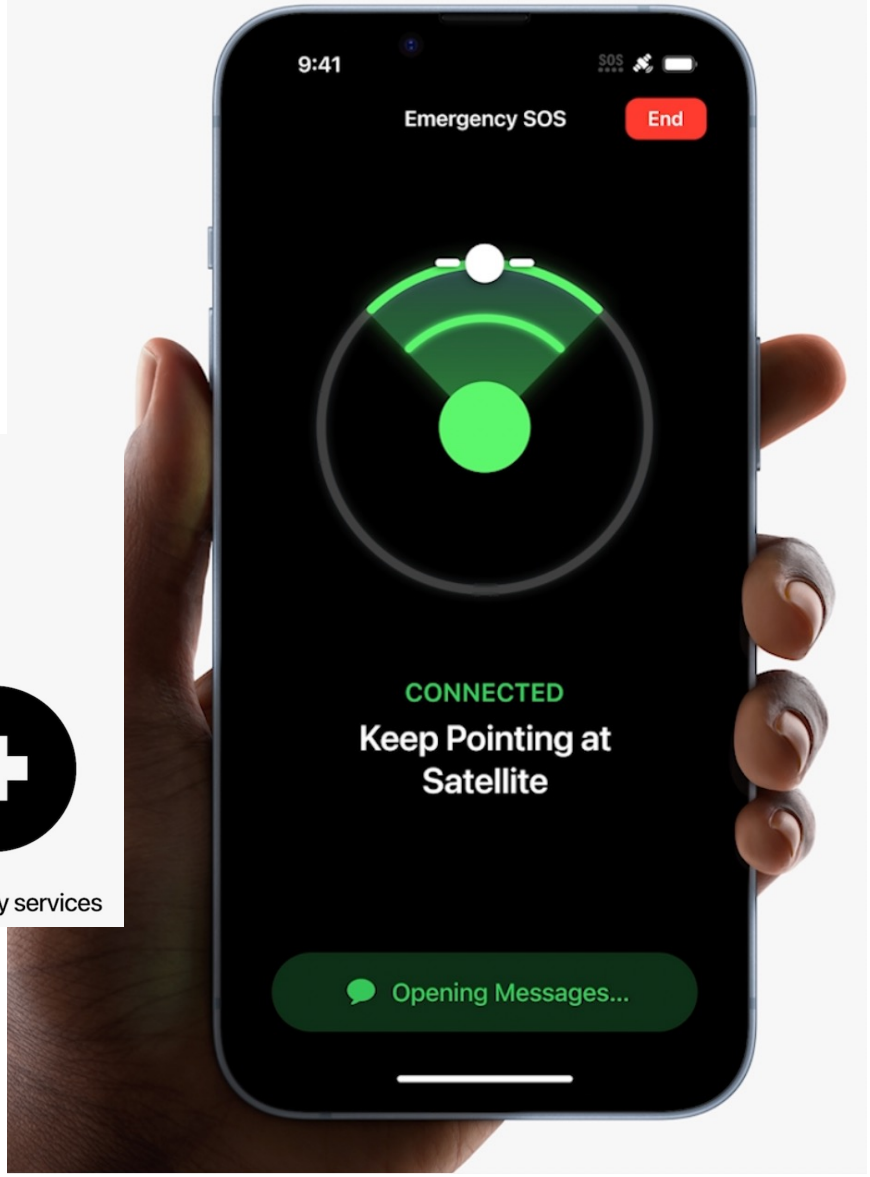
Apple Event

Emergency SOS

via satellite





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9-7-22

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Apple Event

9-7-22

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WWDC Apple Event

June 6, 2022

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New Apple Event

March 8, 2022

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Apple Event

Sep 14, 2021

iPads

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Apple Buildings

DR JEFF
SOFTWARE
INDIE APP DEVELOPER

October 13, 2020

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Apple Buildings

October 13, 2020

DR JEFF
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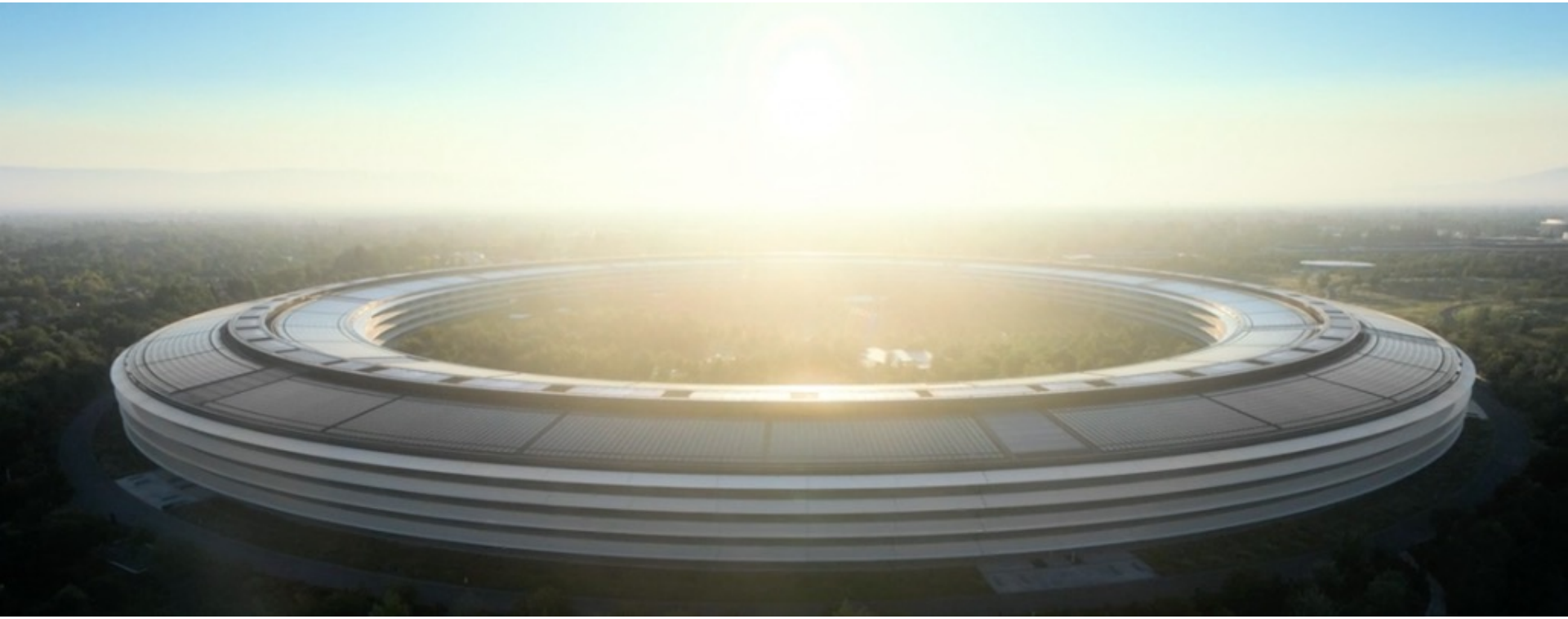

Section

Apple Phones

ARM Chips (SoC)

Quora

Joe Zbiciak
Developed practical algorithms actually used in production. · 6mo

Who makes the ARM processor?

Just about everybody *but* ARM.

ARM develops the architecture, and develops its own RTL implementations. But outside of a handful of test chips, ARM does not manufacture any of the volume production ARM products out there.

I know of a few custom microarchitectures that implement the ARM ISA other than Apple.

- Qualcomm Krait and Kryo
- Fujitsu A64FX
- Cavium Vulcan
- Samsung Exynos M1 through M4
- Ampere Siryn.
- Marvell ThunderX3 (canceled)
- AppliedMicro Storm, Shadowcat, and Skylark

All the production ARM processors come from:

- Apple
- Samsung
- Qualcomm
- Amazon
- Texas Instruments
- Microchip
- NXP / Freescale
- ST Microelectronics
- Broadcom
- AMD ?
- Intel®
- ...and many more.

- Google
- Tesla

1st iPhone

iPhone

ANNOUNCED: Jan. 9, 2007

RELEASED: June 29, 2007

KEY FEATURES:
3.5-inch diagonal screen;
320 x 480 pixels at 163 ppi;
2-megapixel camera

PRICE: 4GB model, $499;
8GB version, $599 (with
a two-year contract)

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Apple Event: iPhone 14

9-7-22

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Apple Event

9-7-22

iPhone 14

Two great sizes: 6.1″ and new, larger 6.7″ Super Retina XDR displays.

Our best battery life ever on iPhone 14 Plus. And all-day battery life on iPhone 14.[4]

Emergency SOS via satellite[2] and Crash Detection[3] for help when you need it most.

Industry-leading durability features like Ceramic Shield and water resistance.[6]

Advanced dual-camera system for more detailed, colorful shots. Sharper selfies.

Action mode takes smooth handheld videos when you're on the move.

Superspeedy A15 Bionic chip with 5-core GPU.

5G cellular for superfast streaming, gaming, downloading, and more.[5]

iPhone 14 *Pro*

Dynamic Island, a magical new way to interact with your iPhone.

Always-On display — the info you want, at a glance.

Emergency SOS via satellite[2] and Crash Detection[3] for help when you need it most.

Amazing all-day battery life, even with so many new capabilities.[4]

Pro camera system with 48MP Main camera. Four zoom options. Sharper selfies.

Action mode takes smooth handheld videos when you're on the move.

A16 Bionic — the ultimate smartphone chip.

5G cellular for superfast streaming, gaming, downloading, and more.[5]

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Apple Event

Sep 14, 2021

iPhone 13 mini
From
$699

iPhone 13
From
$799

Apple

October 13, 2020

- iPhone 12
  - 5G
    - 2x peak data rate
  - Camera (4)
  - Mag interface
  - Colors (5)

iPhone 12

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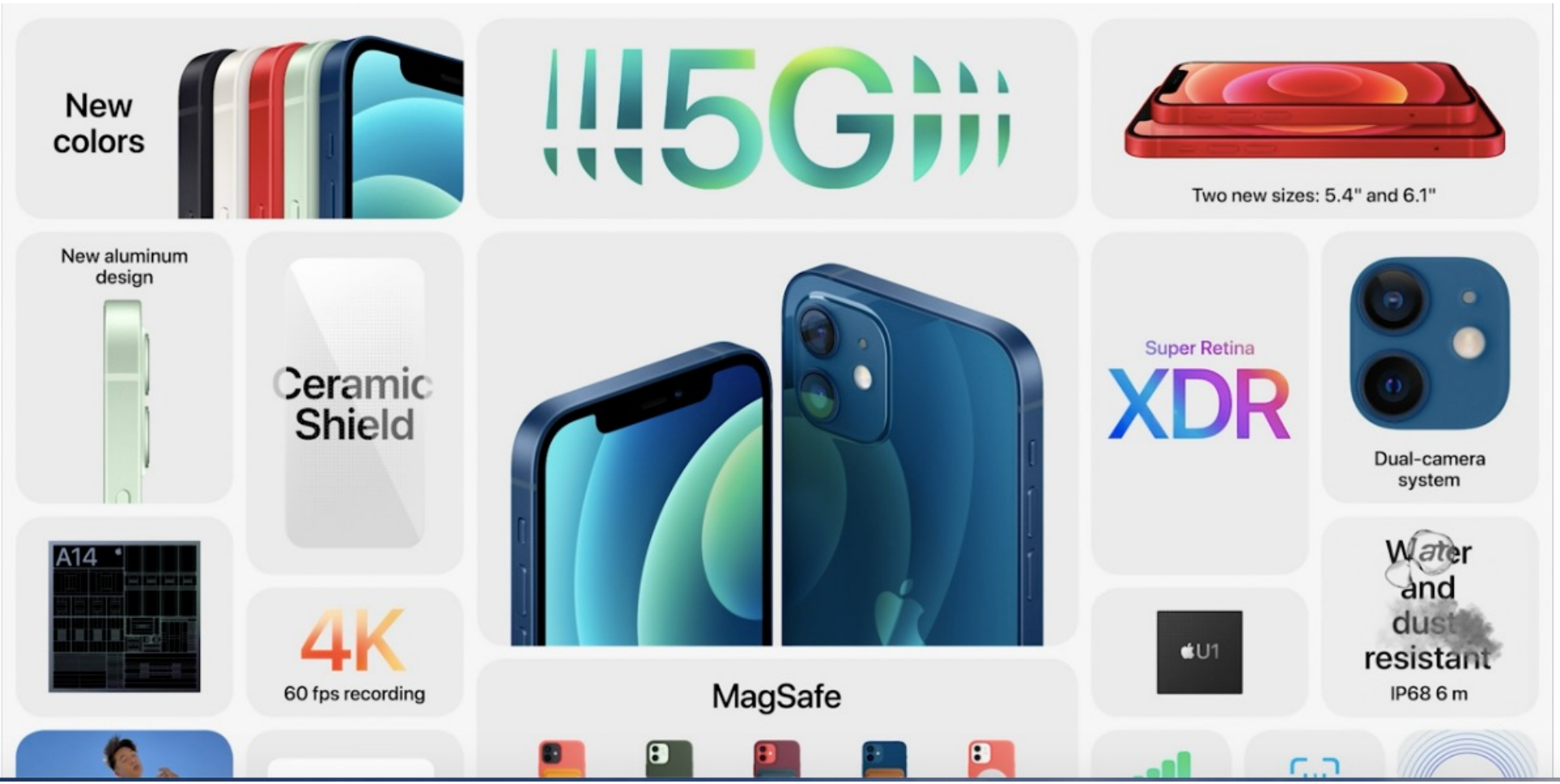
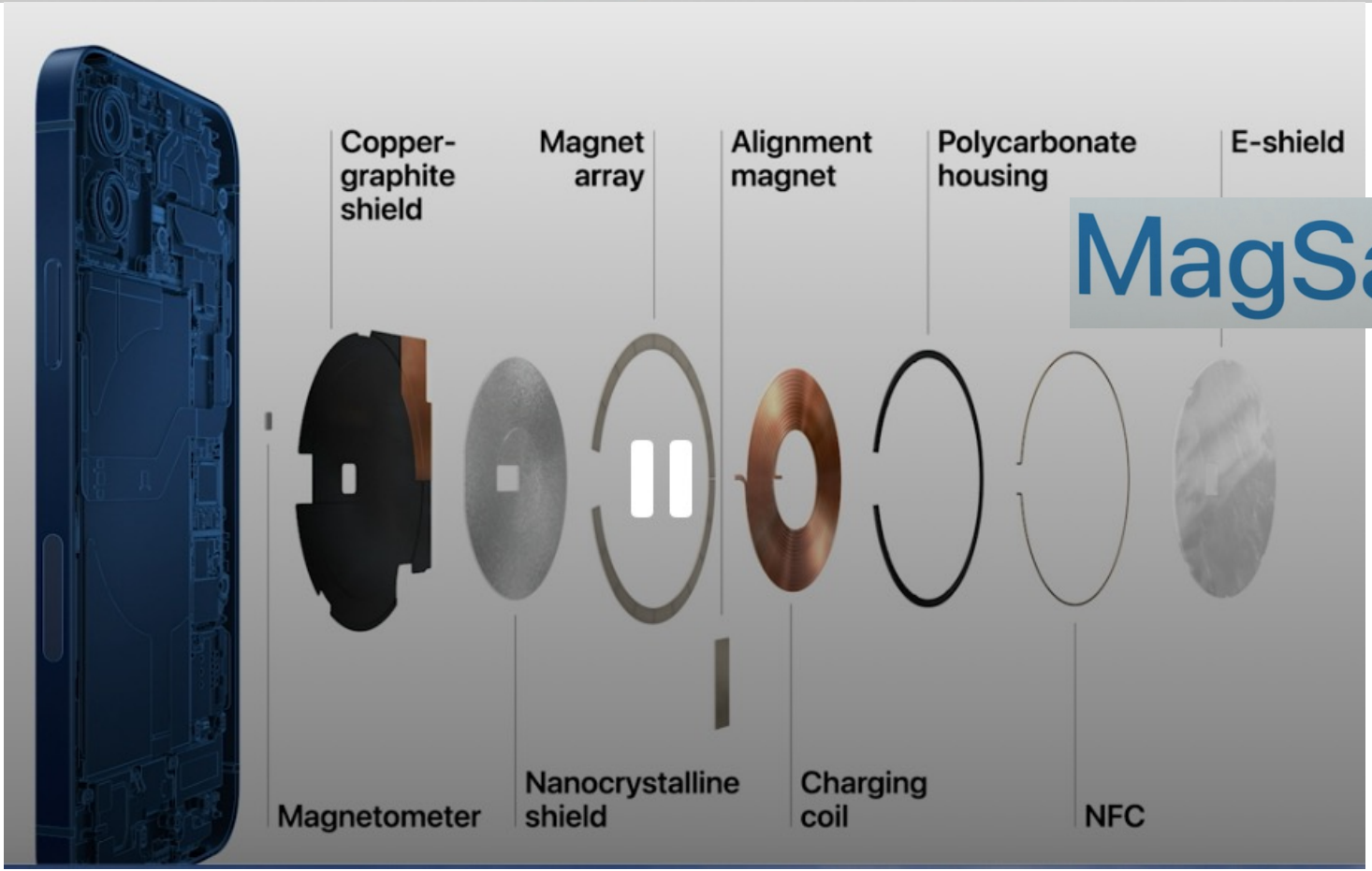
iPhone 12



iPhone 12



Section

Apple
iPads

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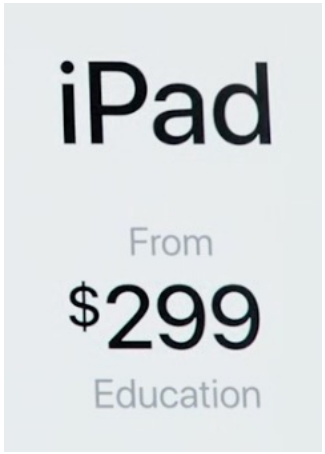
Apple Event

Sep 14, 2021

iPads



New Apple A14/iPads

Find the right iPad for you.

Compare iPad models >

iPad Pro

The ultimate
iPad experience.

From $799

Buy

Available in October

iPad Air

Powerful. Colorful.
Wonderful.

From $599

View pricing

New

iPad

Delightfully capable.
Surprisingly affordable.

From $329

Buy

iPad mini

Small in size.
Big on capability.

From $399

Buy

New Apple A14/iPads

The new

iPad

The new iPad is more capable than ever.
Now with the faster A12 Bionic chip,
support or Apple Pencil, and the
amazing features of iPadOS 14.

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New Apple A14/iPads

Available in October

iPad Air features an all-screen design with a 10.9-inch Liquid Retina display. The new A14 Bionic chip. And support for Apple Pencil and Magic Keyboard. Available in five finishes.

New Apple A14/iPads

Chip

40% FASTER CPU PERFORMANCE

30% FASTER GRAPHICS

A14

A14 Bionic chip with 64-bit architecture

Neural Engine

A14 Bionic chip featuring 40% faster CPU, 30% faster graphics, and 2x faster machine learning with next-generation Neural Engine.[5]

Camera

12MP Wide camera

ƒ/1.8 aperture

Five-element lens

Hybrid IR filter

Backside illumination sensor

Live Photos with stabilization

Autofocus with Focus Pixels

Tap to focus with Focus Pixels

Wide color capture for photos and Live Photos

Panorama (up to 63MP)

Exposure control

60% FASTER LTE

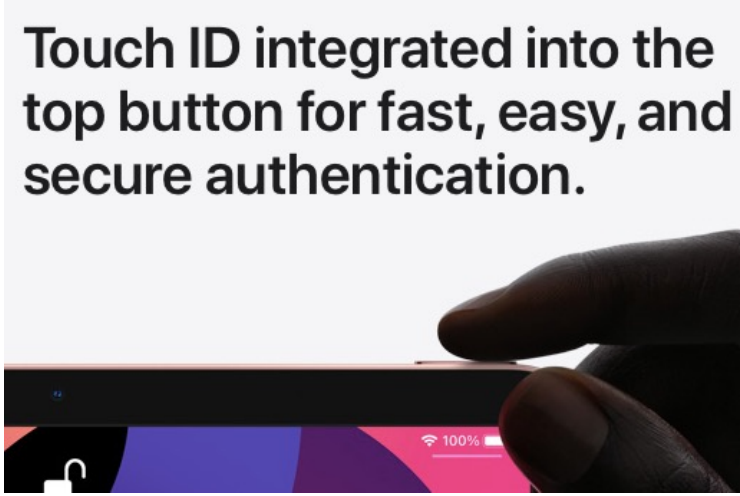
WI-FI 6

New Apple A14/iPads

Available in October

iPad Air

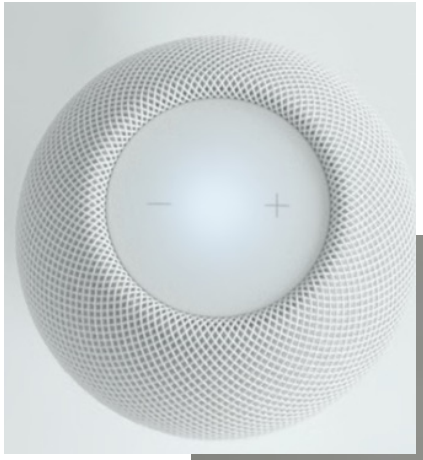
Location	**All models**
	Digital compass
	Wi-Fi
	iBeacon microlocation
	Wi-Fi + Cellular models
	Built-in GPS/GNSS
	Cellular
Sensors	Touch ID
	Three-axis gyro
	Accelerometer
	Barometer
	Ambient light sensor

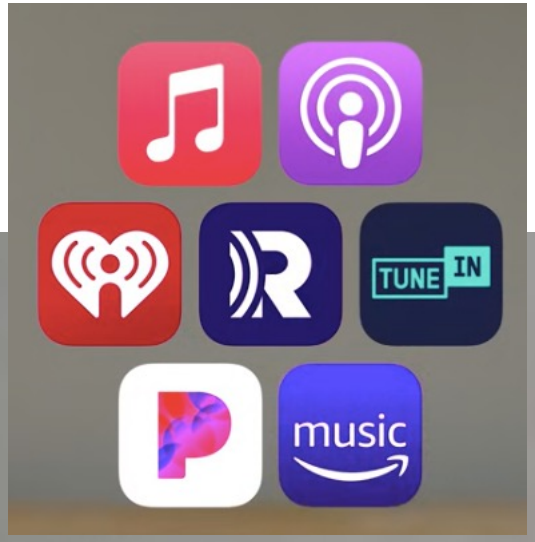


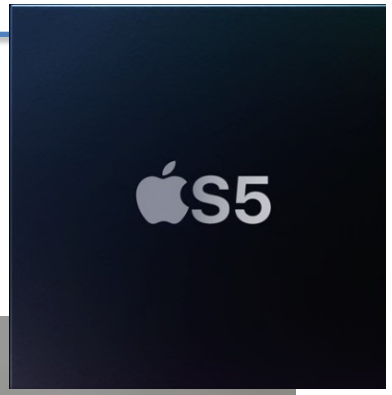
Apple Mini

October 13, 2020

Smart speaker/assistant







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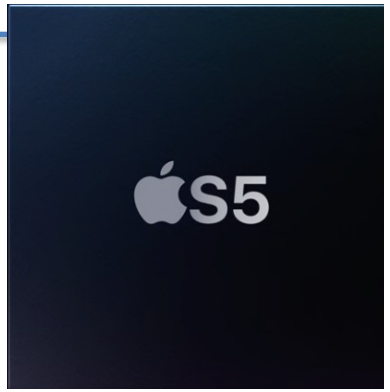
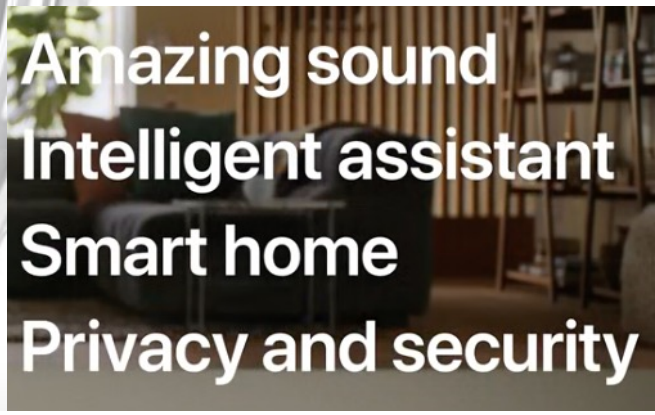
Apple Mini

October 13, 2020

Smart speaker/assistant





Section

Apple Mac

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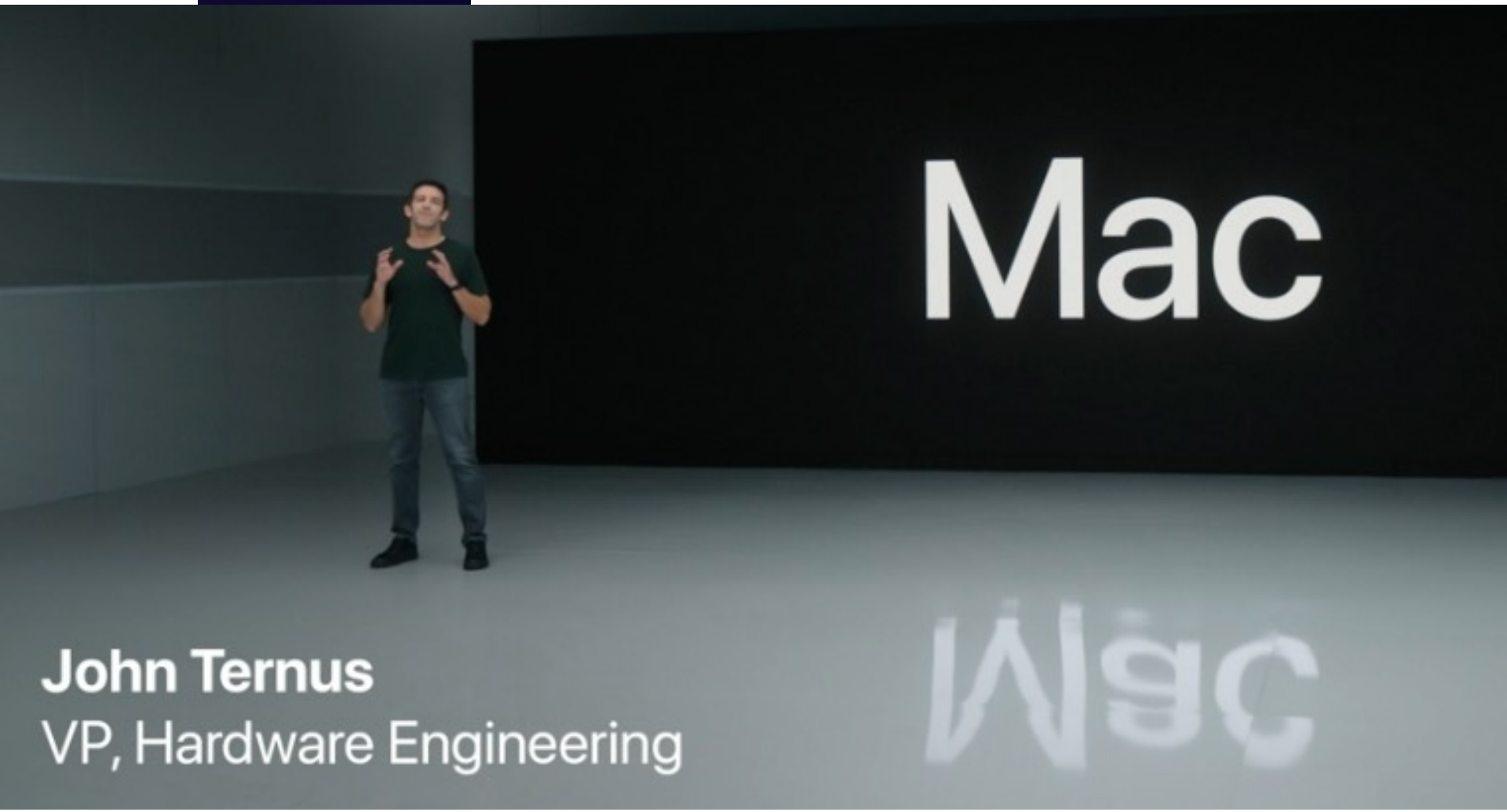
Apple Event

November 10, 2020



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Apple WWDC

June 6, 2022

New MacBooks

MacBook Air
M1
From
$999

M1

MacBook Air
M2
From
$1199

M2

MacBook Pro
M2
From
$1299

M2

Education discount = $100

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Apple WWDC

June 6, 2022

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New M2 MacBook Air Features

13.6″ Liquid Retina display

8K video playback

ProRes encode and decode

Touch ID

Up to 18 hours battery life

MagSafe

Four-speaker sound system

Up to 500 nits brightness

8-core CPU

Up to 10-core GPU

Up to 2TB SSD

Up to 24GB memory

2.7 pounds
11.3 mm

Fanless design

1080p FaceTime HD camera

Magic Keyboard

1 billion colors

M2

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Apple WWDC

June 6, 2022

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New M2 MacBook Pro Features

Up to
20 hours
battery life

Thunderbolt

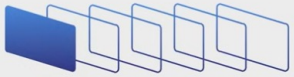
Wi-Fi 6

Up to
500
nits
brightness

P3
wide color


Magic Keyboard + Touch Bar

Retina display



Advanced camera ISP

8-core
CPU

10-core
GPU

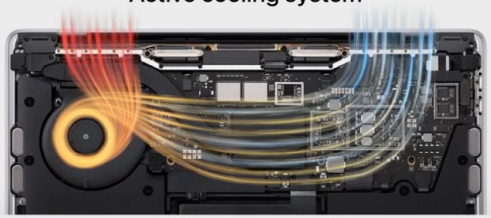
Up to
24GB
memory

Up to
2TB
SSD

M2

Studio-quality mics

ProRes
encode and decode

Active cooling system


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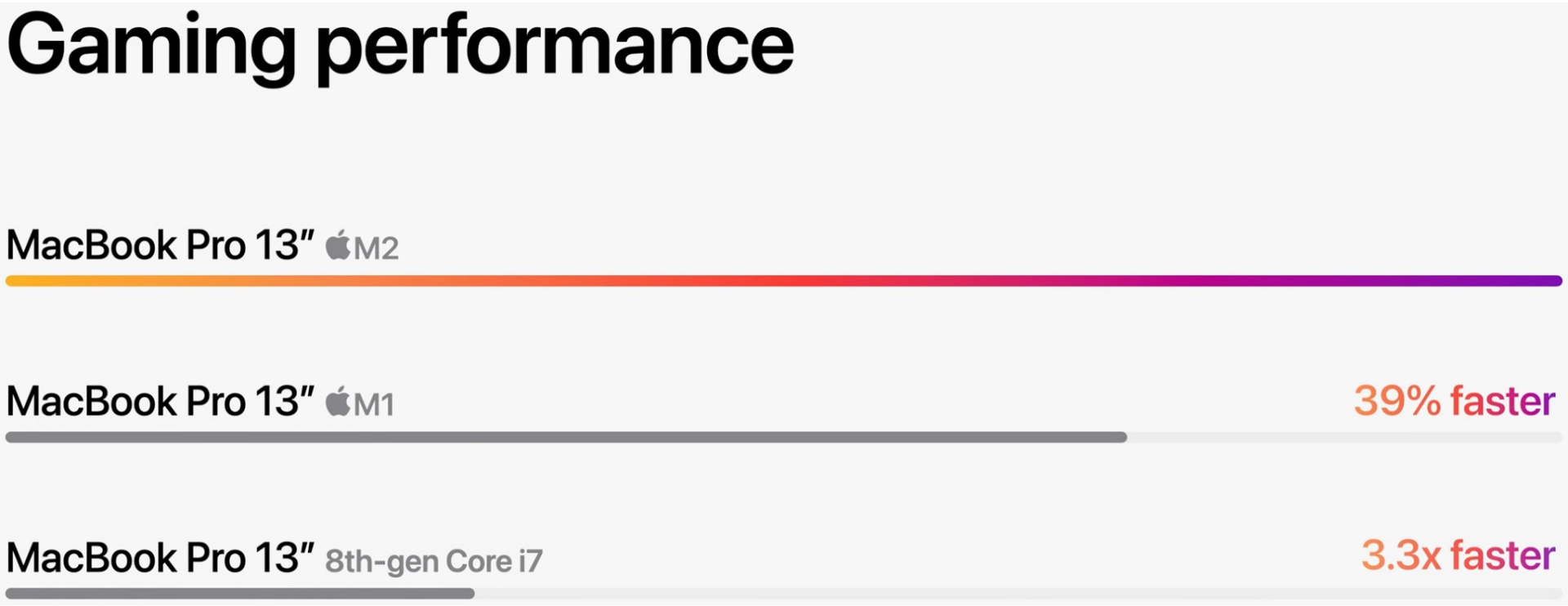
Apple WWDC

June 6, 2022

New **M2** MacBook **Performance**



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New Apple Event

March 8, 2022

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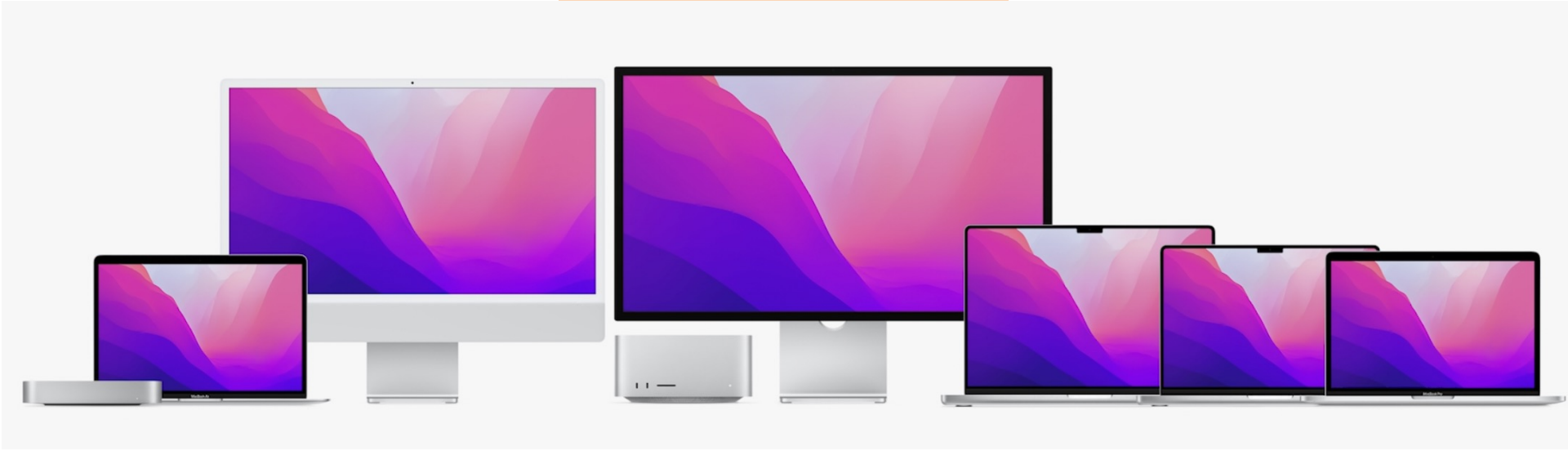
New Mac Lineup



Mac Studio

M1 Ultra
64GB unified memory
1TB SSD

Starting at
$3999

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New Apple Event

March 8, 2022

DR JEFF SOFTWARE
INDIE APP DEVELOPER

New Mac Studio

Wi-Fi 6

Bluetooth 5.0

Up to
8TB
SSD

10Gb Ethernet

Thunderbolt 4

HDMI

SDXC card slot

Up to
7.4GB/s
storage performance

Up to
20-core
CPU

Up to
128GB
unified memory

Up to
64-core
GPU

Up to
800GB/s
memory bandwidth

M1 MAX

M1 ULTRA

Media engine with H.264, HEVC, ProRes encode and decode

Drives over
90 million pixels

macOS Monterey

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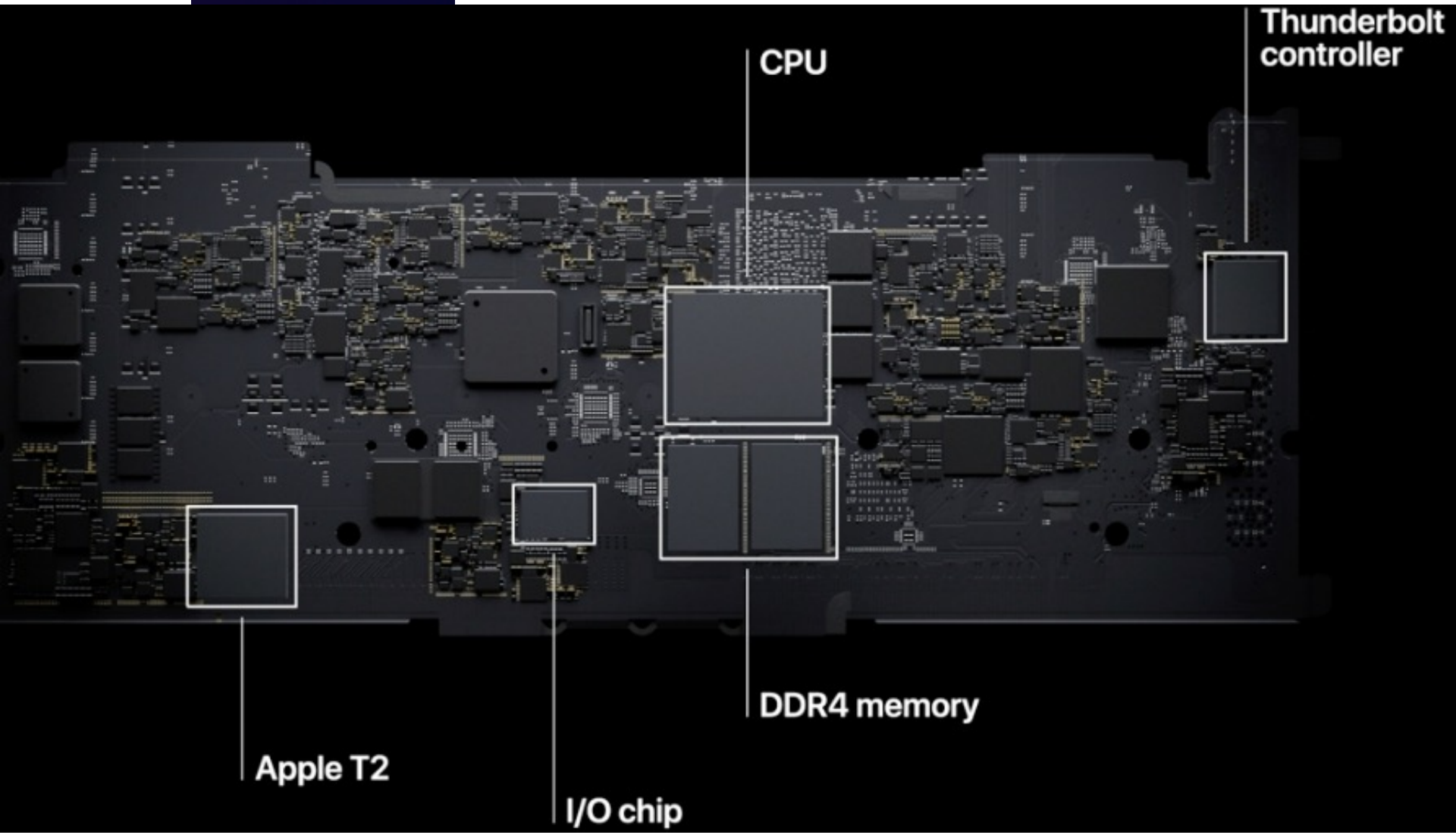
Apple Event

November 10, 2020



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Apple Event

November 10, 2020

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INDIE APP DEVELOPER

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Section

Apple Chips

A-series

(ARM v8)

Apple's ARM License

Apple's ARM license is beyond architectural?

it look like Apple is allowed to add **proprietary ISA extensions** -- as long as they are ARM ISA compatible.
And apparently in Apple's case, they get to be a little bit incompatible (no **nVHE** mode, crazy **custom ISA extensions**, ...)
Which is also obvious proof that they're their own designs, because literally nobody else could or would implement the same Apple-proprietary ISA extensions. Here, we use some of the custom instructions in **m1n1**

> Nope, you need to be compatible with the **architecture specification**, and it lays out exactly what can be implementation defined and what can't. E.g. you're allowed some freedom in what features to implement (Apple doesn't implement **EL3** and this is fine), and you can add implementation defined system **registers** (Apple has a huge number of them, e.g. to implement TSO for ***Rosetta***). But you can't decide not to support **mandatory features** (Apple forces on **VHE mode**, which is not legal - VHE is optional, non-VHE mode isn't), nor can you add **extensions** to the core ISA. Apple added **AMX**, memory compression/decompression, a variant of the AT instructions that outputs to a GPR, and the whole **Guarded Execution** feature (two new parallel **exception levels** and machinery to call to/from them and lock down things to them), and possibly more, all of them in **reserved instruction encoding space**.

New Apple A16

Quora

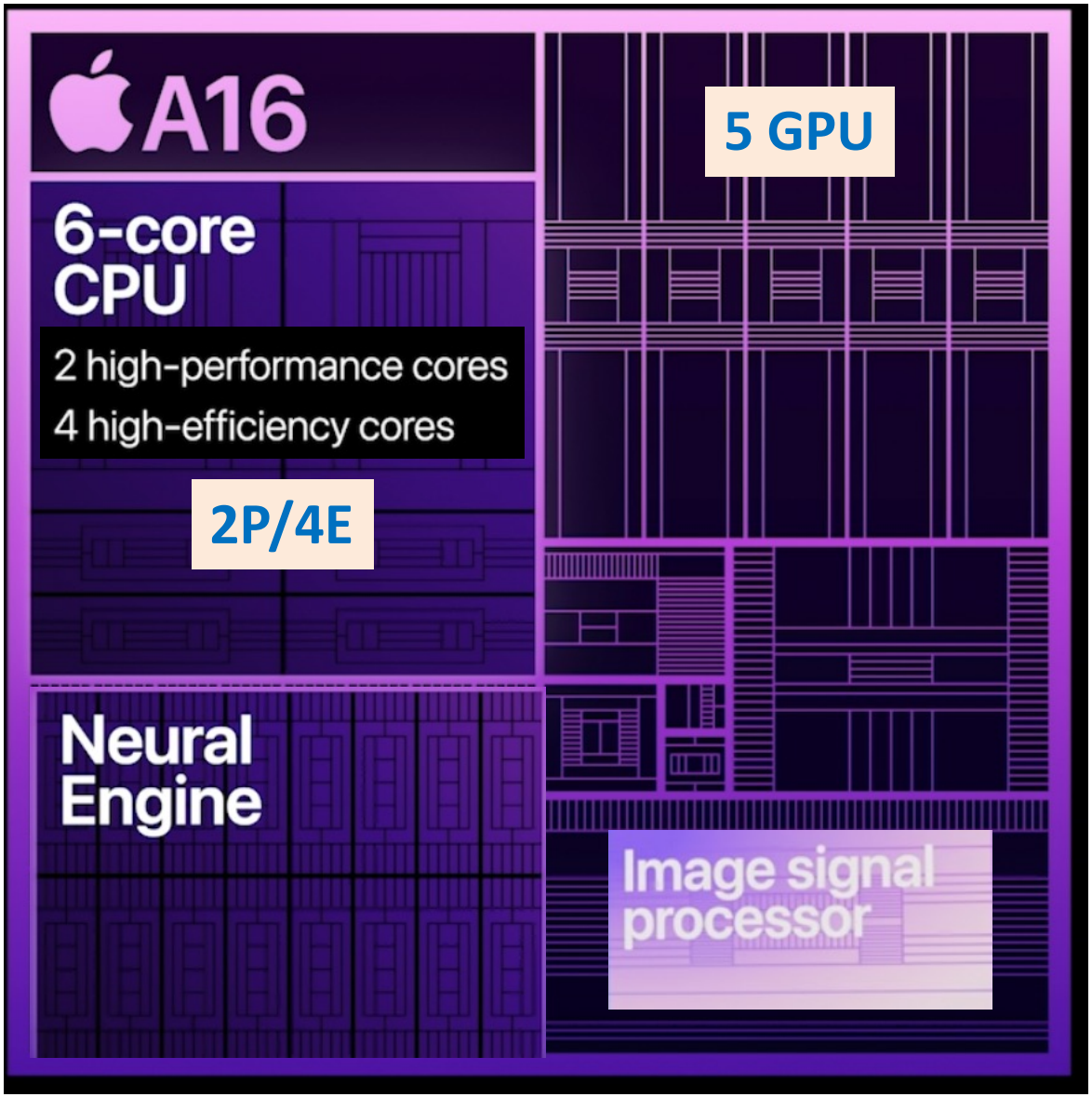
Why did Apple's mobile processor speed growth become slower compared to their early processor which usually doubled the performance compared to its previous generation?

Jeff Drobman
Lecturer at California State University, Northridge (2016–present) · Just now

the new A16 is the 1st Apple chip to use the latest 4nm process from TSMC. that allows more transistors on the same size die. but Apple chose to use the same number of CPU and GPU cores as for the A15 SoC, and instead uses the extra transistors for other functions like media and AI/ML. so we won't see much difference in benchmarked performance vs the A15. Apple shows a performance improvement vs their A13 chip.

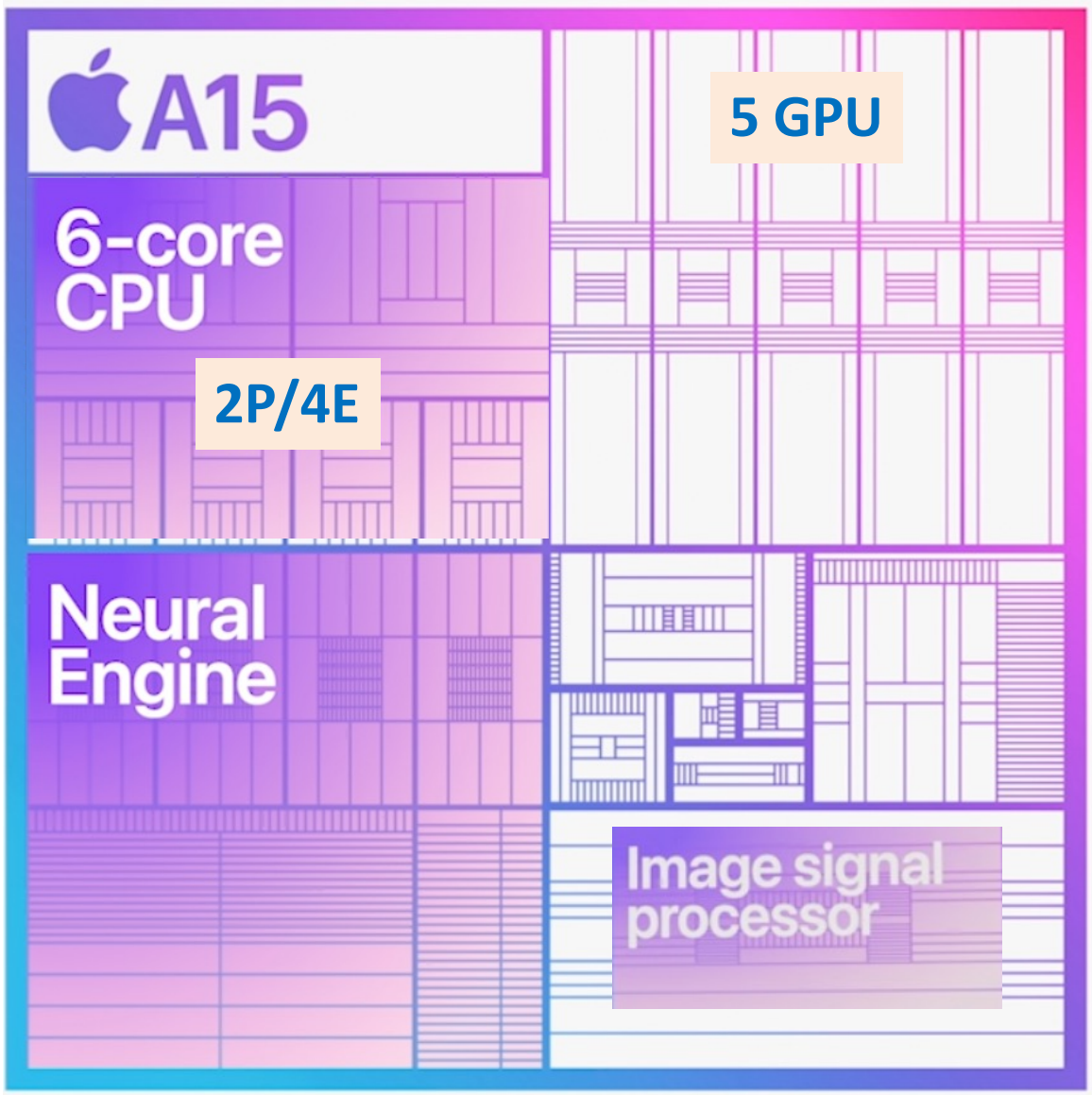
Apple Event

9-7-22



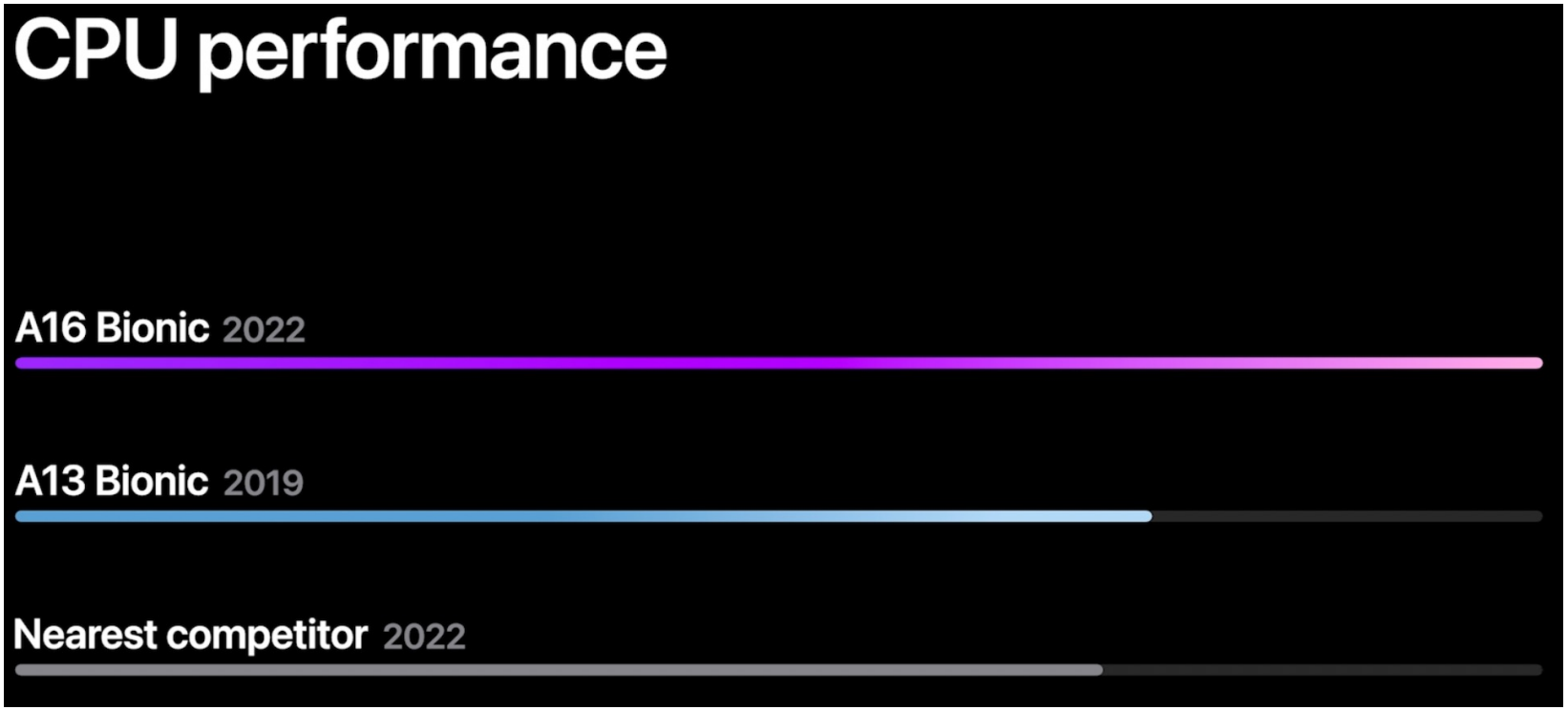
Apple Event

9-7-22



Apple Event

9-7-22



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Apple Event

Sep 14, 2021

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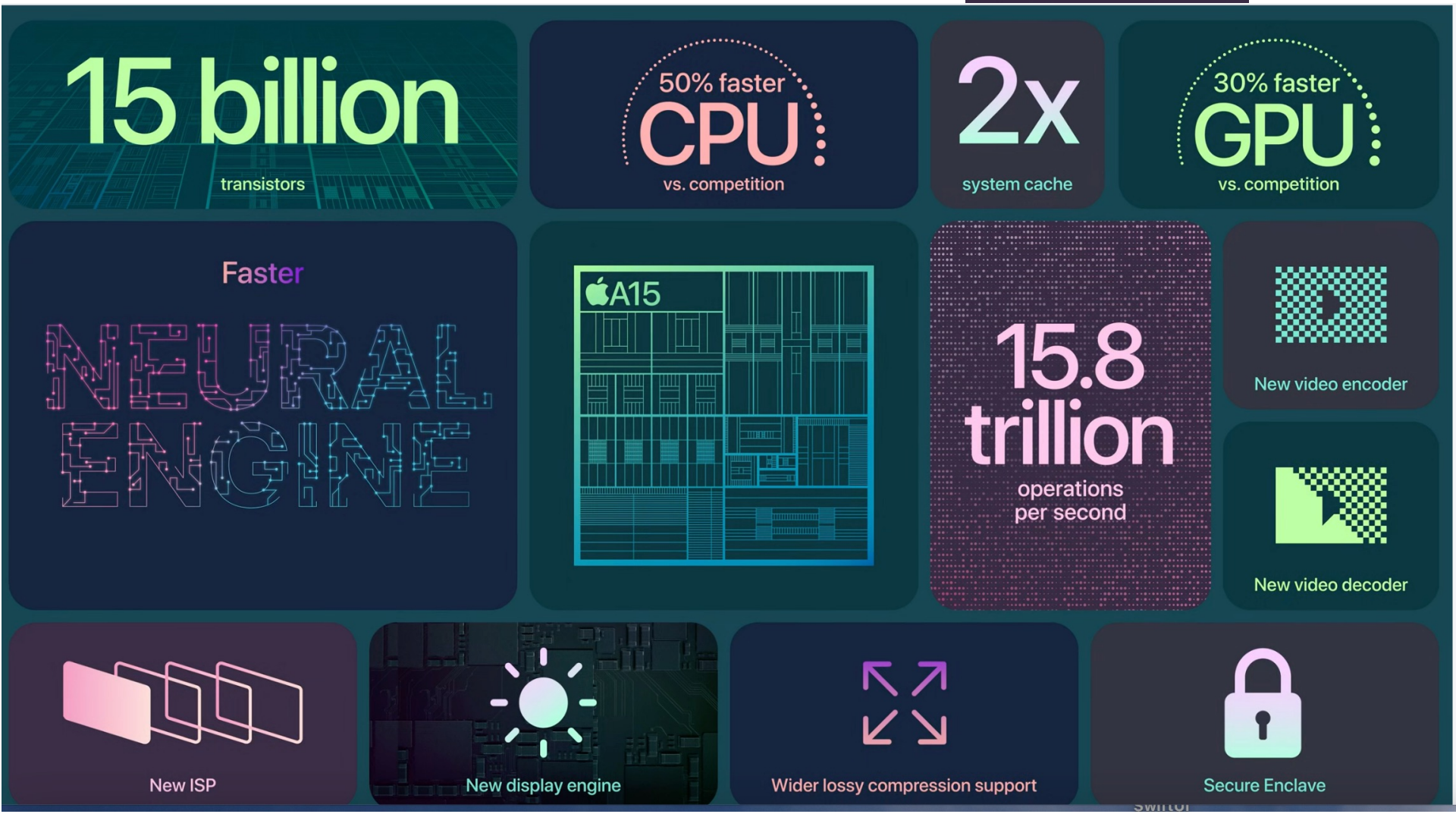
iPhone 13



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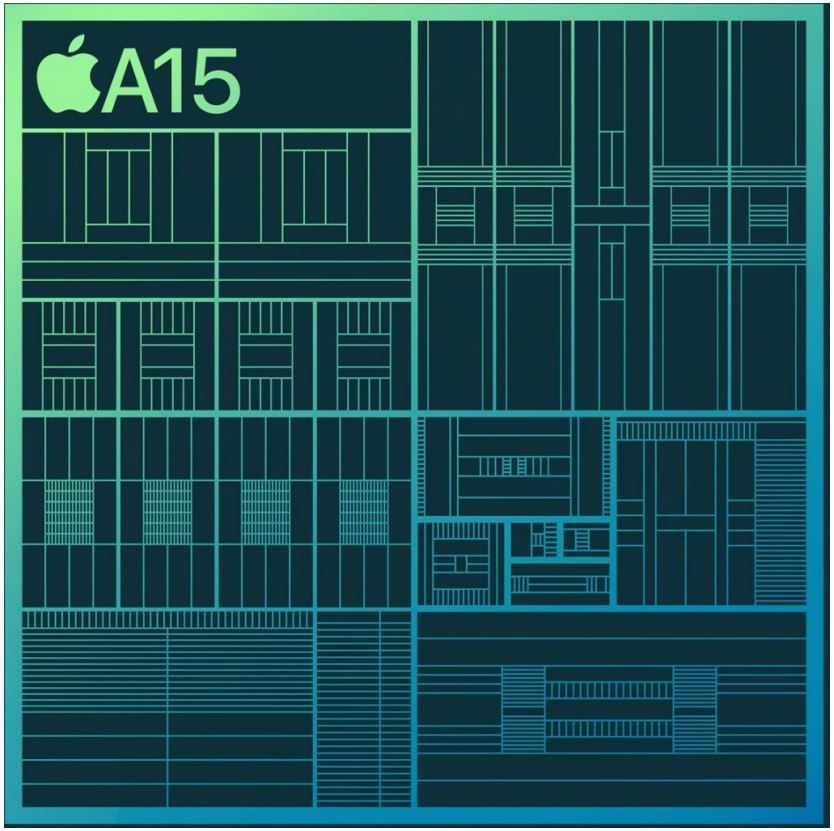
Apple Event

Sep 14, 2021

iPhone 13



6-core CPU

2 high-performance cores

4 high-efficiency cores

4-core GPU

16-core Neural Engine

15 billion

transistors

50% faster CPU

vs. competition

New Apple A14/iPads

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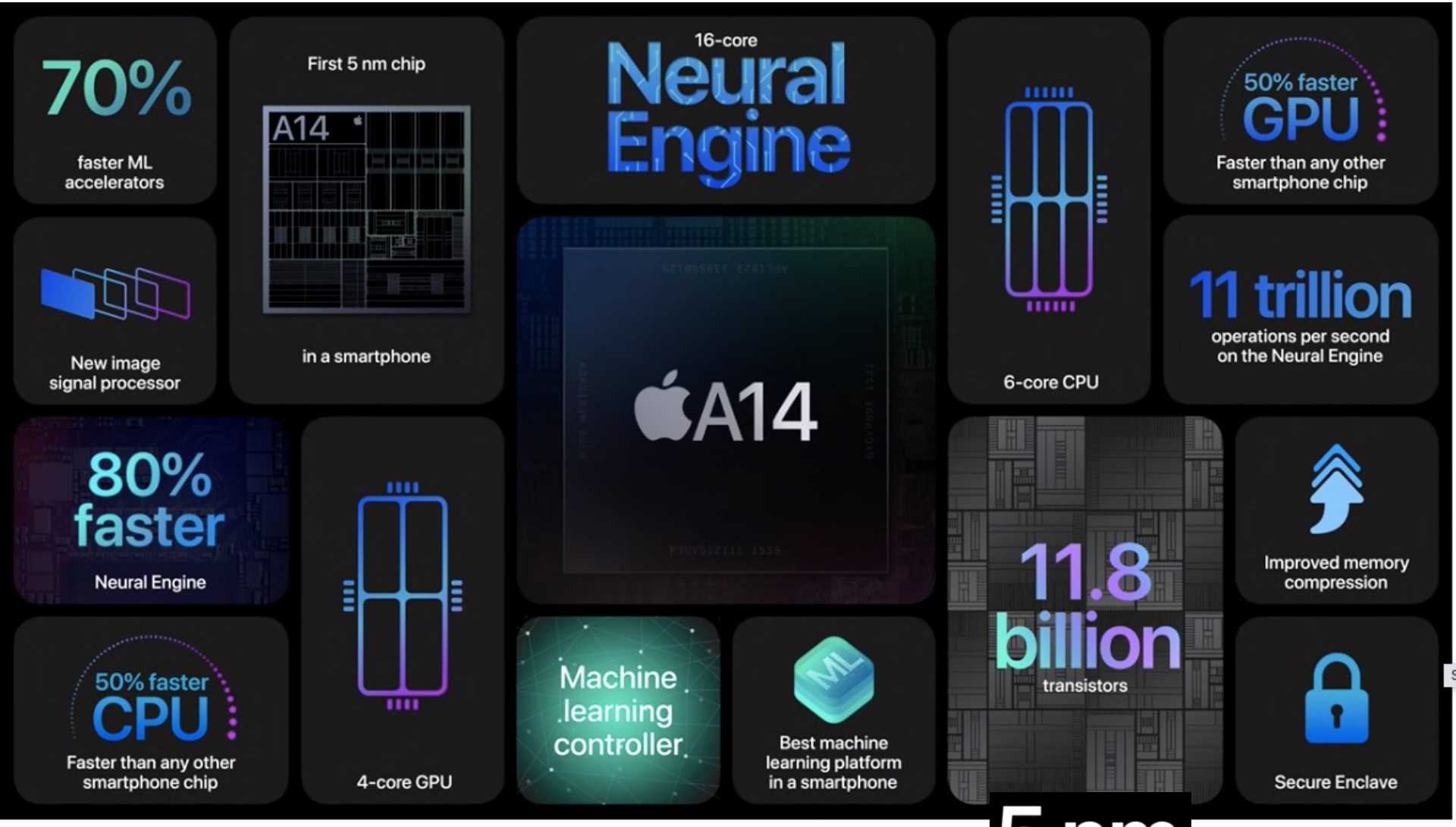
Apple A14

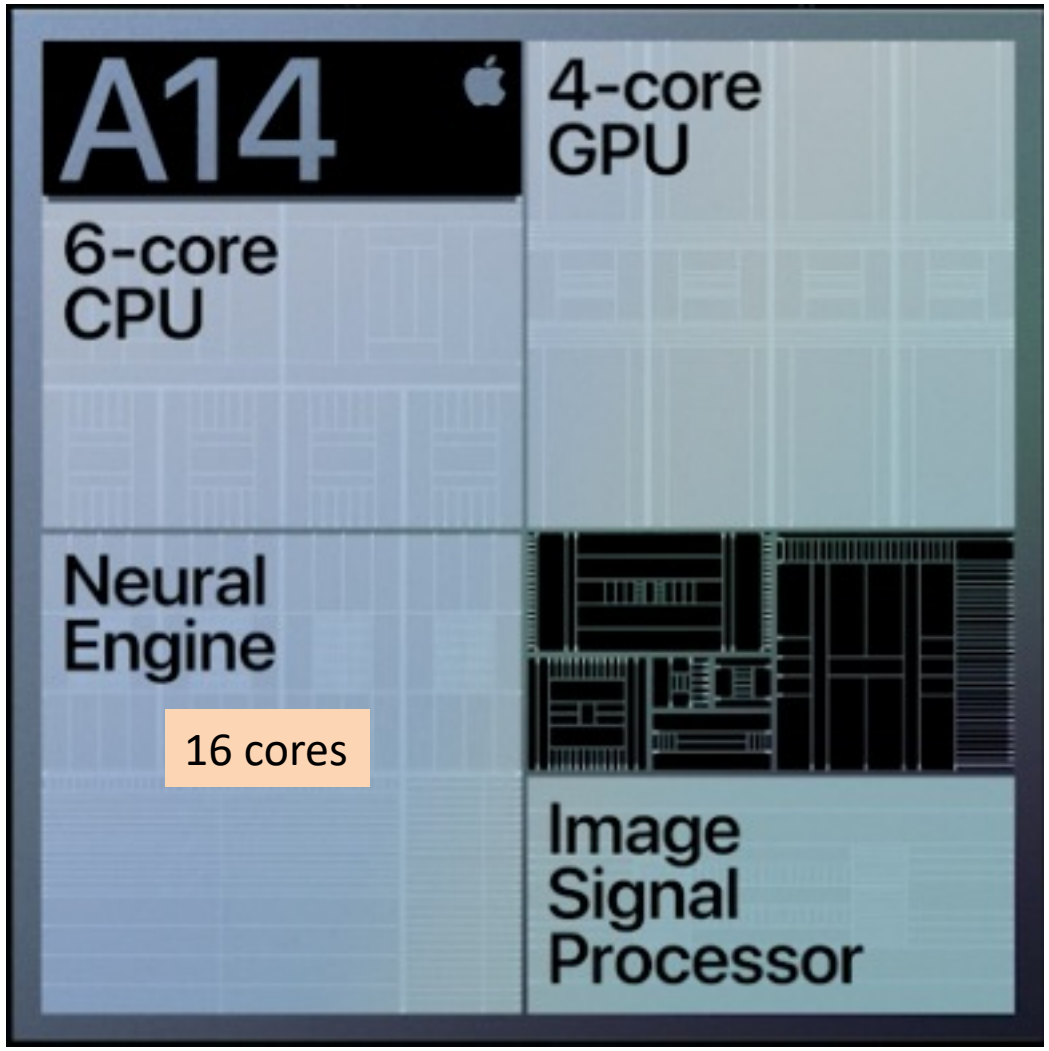
October 13, 2020

A14 Bionic



Apple A14

October 13, 2020



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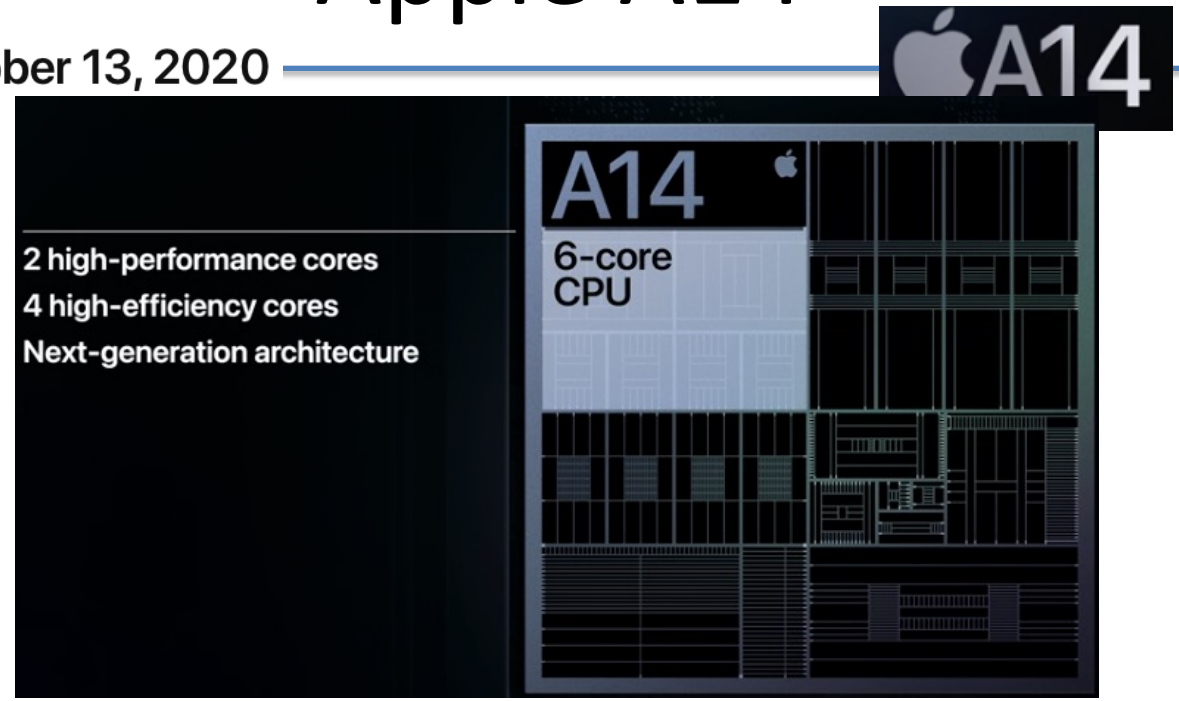
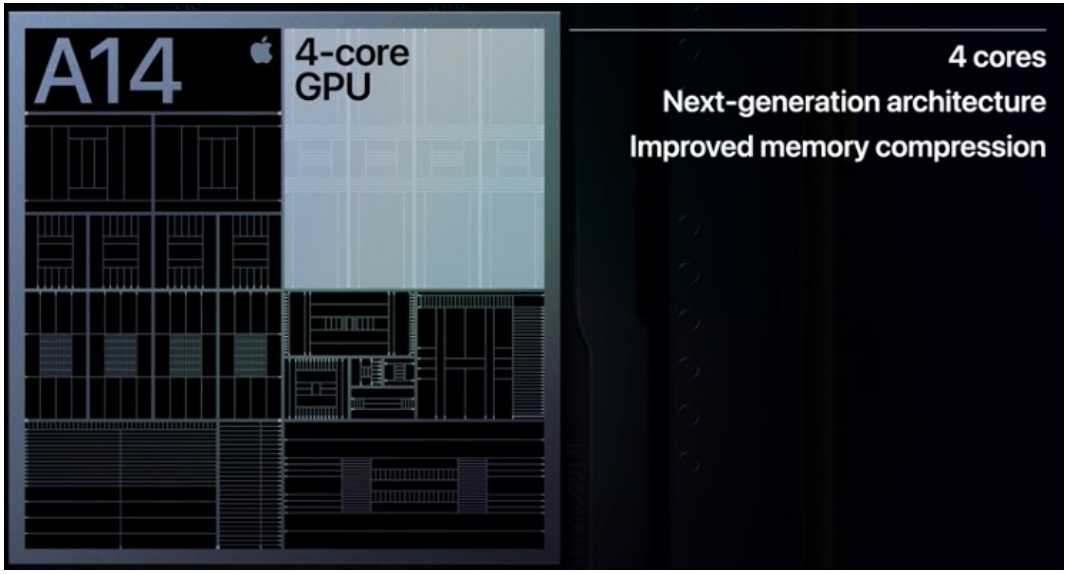
Apple A14

October 13, 2020





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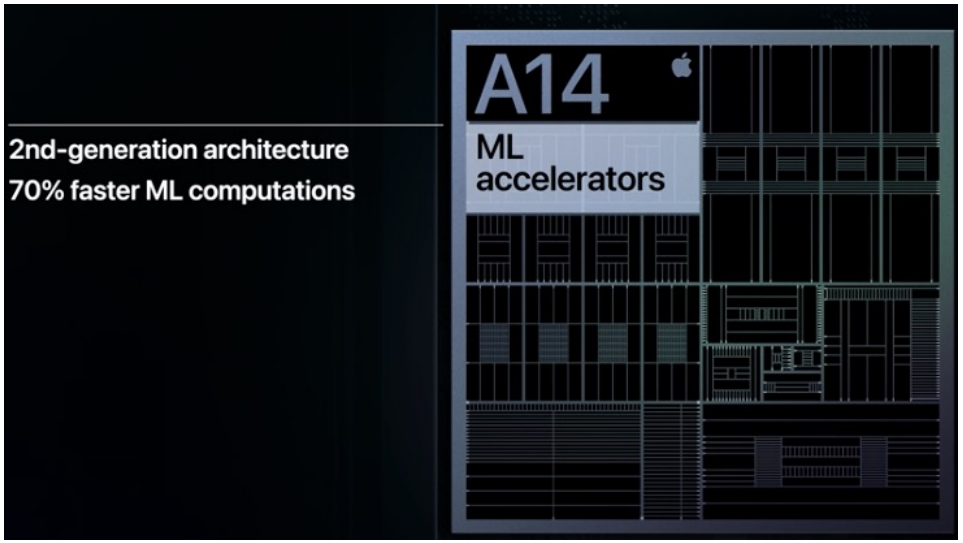
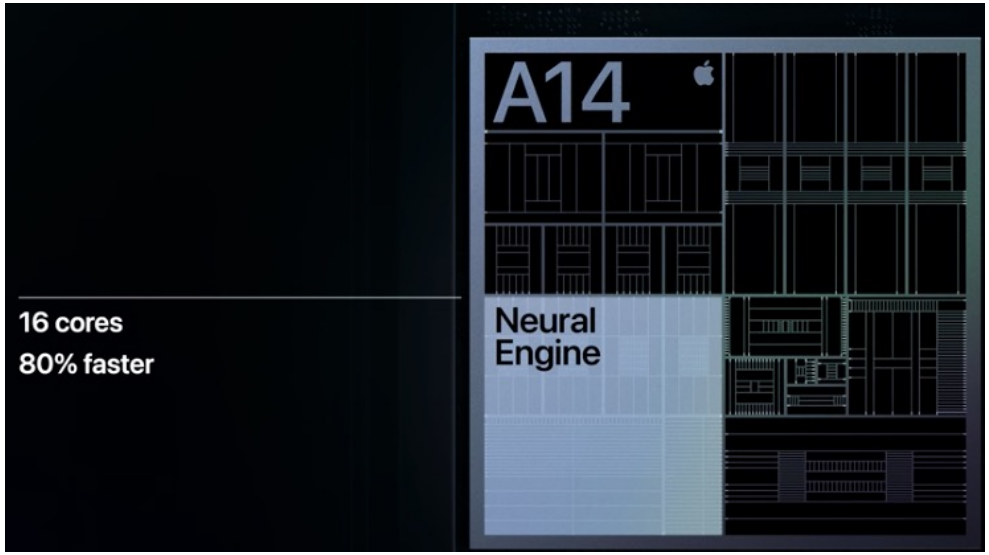
Apple A14

October 13, 2020

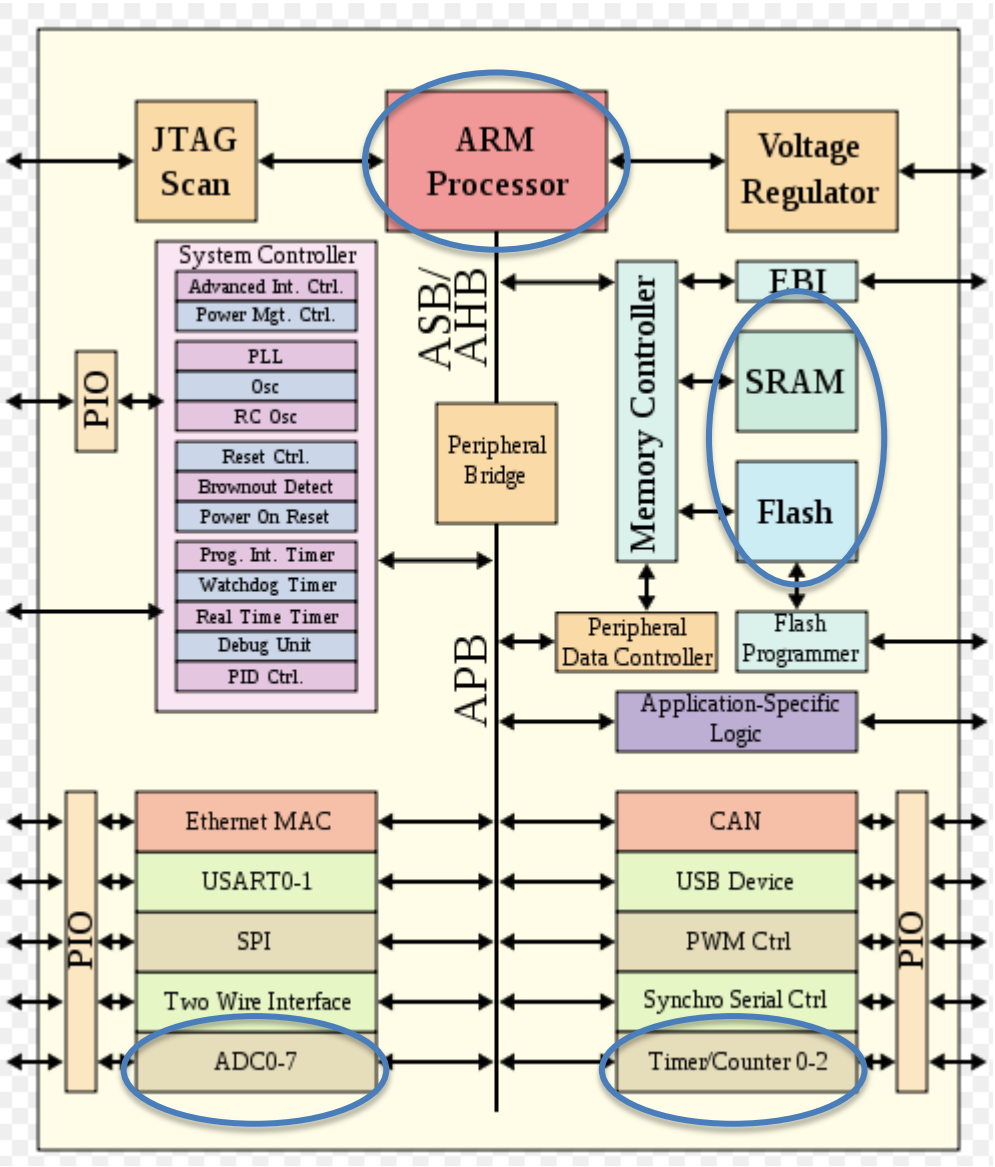


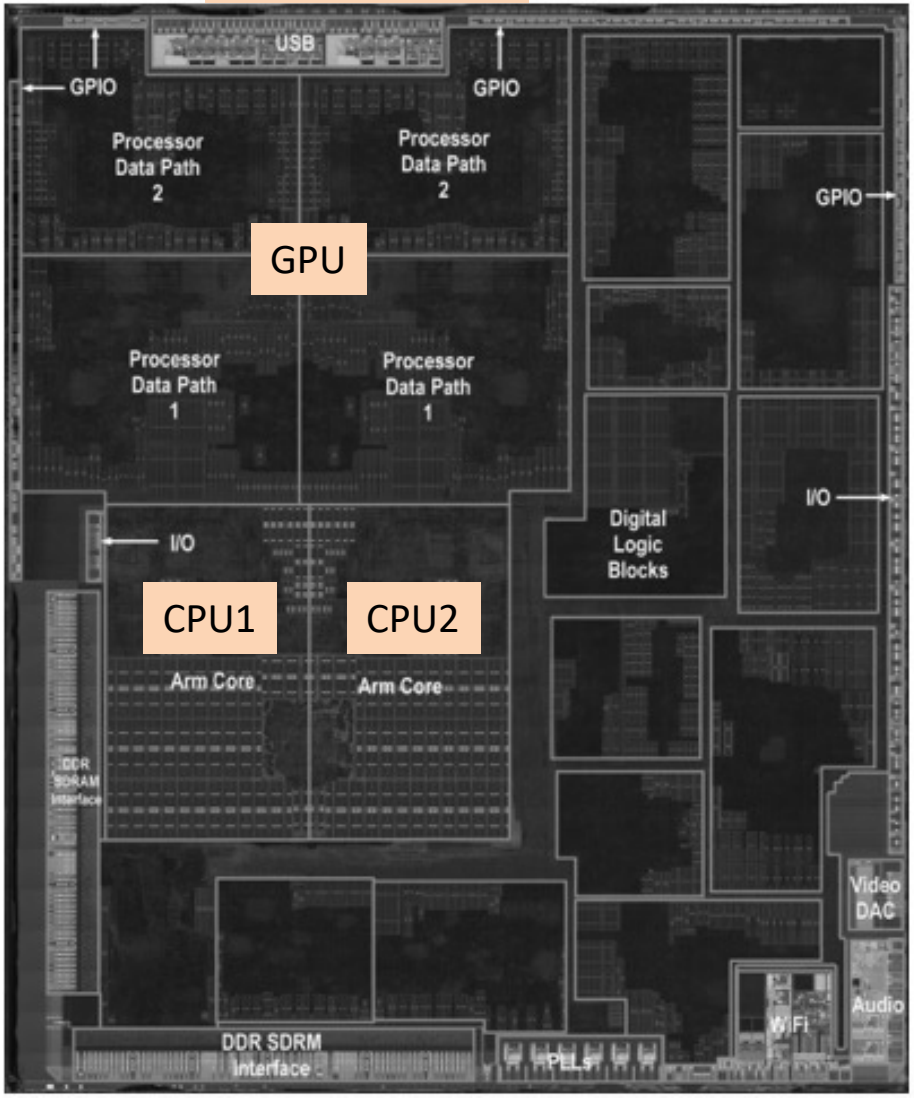


ARM SoC/A5

Hennessy & Patterson

Apple ARM **A5** 12.1x10.2mm





Apple ARM SoC

Apple ARM SoC

the first ARM designs were for LOW POWER for portable devices. to achieve low power, the CPU was designed as simple RISC ISA and low clock frequency. Apple iPhones have used ARM from day 1, since they too initially didn't need high compute performance. over time, ARM models have evolved into more powerful models, including a 64-bit ISA -- necessary for today's computers. so now the time has come to start switching to ARM, mainly due to ARM being a licensable ISA and core that can be designed into anyone's SoC like Apple and many others do. I also note that the ARM ISA has evolved from a simple RISC to a more complex, CISC-like one.

Apple has just announced they will replace x86 CPU's on their **Macs** with their own ARM-based **A13** (or next generation A14/15). makes sense for them to use their own chips now that they are powerful enough. this will also give Apple the same **AI** performance capabilities across all their hardware devices (e.g., Siri) -- way more AI power than any x86 chips.

The reason -- historically: Apple has upgraded their Macs for the same reason any company does: to be competitive they have to use a top performance CPU. so Apple switched from the 6502 (Apple II) to the M68000 in the 1st Mac, then upgraded to the Mot PPC. but then Mot stopped making PPC's, so Apple had nowhere else to go but x86 (Intel or AMD) – for Macs. note they have been making their own custom ARM-based chips (A series) for their phones.
Apple has long made their own chips with ARM CPU's since 2007 in their iPhones, designing an ever more powerful SoC (A4-A13). These new **A13** SoC's are now much better than the Intel x86 chips in overall performance -- including machine learning (ML) via on-chip GPU cores plus neural engine -- and with superior power management.

Apple A1-5

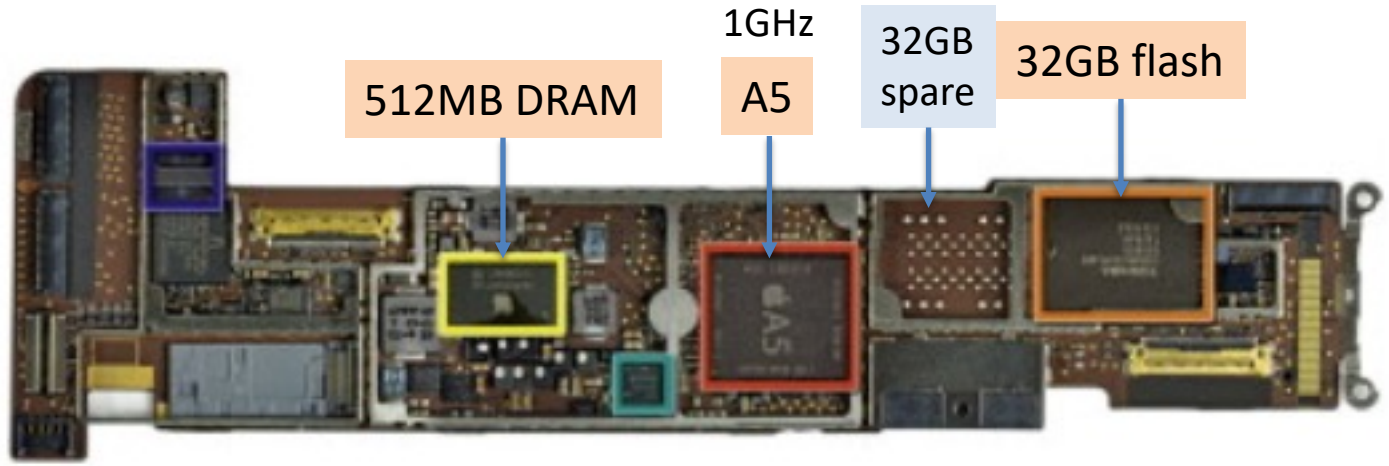
2007-10

Name	Model no.	Image	Semiconductor technology	Die size	Transistor count	CPU ISA	CPU	CPU cache	GPU
	APL0098		90 nm[9]	72 mm²[6]		ARMv6	412 MHz single-core ARM11	L1i: 16 KB L1d: 16 KB	PowerVR MBX Lite @ 103 MHz
	APL0278		65 nm[6]	36 mm²[6]		ARMv6	412–533 MHz single-core ARM11	L1i: 16 KB L1d: 16 KB	PowerVR MBX Lite @ 133 MHz
	APL0298		65 nm[9]	71.8 mm²[19]		ARMv7	600 MHz single-core Cortex-A8	L1i: 32 KB L1d: 32 KB L2: 256 KB	PowerVR SGX535
	APL2298		45 nm[6]	41.6 mm²[6]		ARMv7	600–800 MHz single-core Cortex-A8	L1i: 32 KB L1d: 32 KB L2: 256 KB	PowerVR SGX535 @ 200 MHz
A4	APL0398		45 nm[6][19]	53.3 mm²[6][19]		ARMv7	0.8–1.0 GHz single-core Cortex-A8	L1i: 32 KB L1d: 32 KB L2: 512 KB	PowerVR SGX535[128]
	APL0498		45 nm[38]	122.2 mm²[38]			0.8–1.0 GHz dual-core Cortex-A9	L1i: 32 KB L1d: 32 KB L2: 1 MB	PowerVR SGX543MP2 (dual-core) @ 200 MH (12.8 GFLOPS)[129]

A5 CPU on iPad2

Hennessy & Patterson

The logic board of Apple iPad 2 in the previous figure. The photo highlights five integrated circuits. The large integrated circuit in the middle is the Apple A5 chip, which contains dual ARM processor cores that run at 1 GHz as well as 512 MB of main memory inside the package. The next figure shows a photograph of the processor chip inside the A5 package. The similar-sized chip to the left is the 32GB flash memory chip for non-volatile storage. There is an empty space between the two chips where a second flash chip can be installed to double storage capacity of the iPad. The chips to the right of the A5 include power controller and I/O controller chips. (Courtesy iFixit, www.ifixit.com)



A Series: A4-7

32/64-bit

The **Apple A4** is a 32-bit package on package (PoP) system on a chip (SoC) designed by Apple Inc. and manufactured by Samsung. It was the first SoC Apple designed in-house. The first product to feature the A4 was the first-generation iPad, followed by the iPhone 4, fourth-generation iPod Touch, and sec

1st Apple design

- iPad 1
- iPhone 4

The **Apple A5** is a 32-bit system on a chip (SoC) designed by Apple Inc. and manufactured by Samsung. The first product Apple featured an A5 in was the iPad 2. Apple claimed during their media event on March 2, 2011 that the ARM Cortex-A9 central processing unit (CPU) in the A

- iPad 2

The **Apple A7** is a 64-bit system on a chip (SoC) designed by Apple Inc. It first appeared in the iPhone 5S, which was announced on September 10, 2013, and the iPad Air, announced October 22, 2013. Apple states that it is up to twice as fast and has up to twice the graphics power compared

- iPhone 5S

A8-11

64-bit

The **Apple A8** is a 64-bit ARM-based system on a chip (SoC) designed by Apple Inc. It first appeared in the iPhone 6 and iPhone 6 Plus, which were introduced on September 9, 2014. Apple states that it has 25% more CPU performance and 50% more graphics performance while

- iPhone 6

The **Apple A10 Fusion** is a 64-bit ARM-based system on a chip (SoC), designed by Apple Inc. and manufactured by TSMC. It first appeared in the iPhone 7 and 7 Plus which were introduced on September 7, 2016, and is used in the sixth-generation iPad, seventh-generation iPad, and

- iPhone 7

- iPhone 6S

The **Apple A9** is a 64-bit ARM-based system-on-chip (SoC), designed by Apple Inc. Manufactured for Apple by both TSMC and Samsung, it first appeared in the iPhone 6S and 6S Plus which were introduced on September 9, 2015. Apple states that it has 70% more CPU

- iPhone 8

The **Apple A11 Bionic** is a 64-bit ARM-based system on a chip (SoC), designed by Apple Inc. and manufactured by TSMC. It first appeared in the iPhone 8, iPhone 8 Plus, and iPhone X which were introduced on September 12, 2017. Apple states that the two high-performance cores are 2

A12-14 + M1

64-bit

The **Apple A12 Bionic** is a 64-bit ARM-based system on a chip (SoC) designed by Apple Inc. It first appeared in the iPhone XS, XS Max, XR, the 2019 versions of the iPad Air and iPad Mini, and the iPad (2020). Apple states that the two high-performance cores are 15% faster and 50% more energy-ef

- iPad Air/Mini
- iPhone XS

The **Apple A13 Bionic** is a 64-bit ARM-based system on a chip (SoC), designed by Apple Inc. It appears in the iPhone 11, 11 Pro/Pro Max and the iPhone SE. Apple states that the two high performance cores are 20% faster with 30% lower power consumption than the Apple

- iPhone 11 — 8.5B Tx

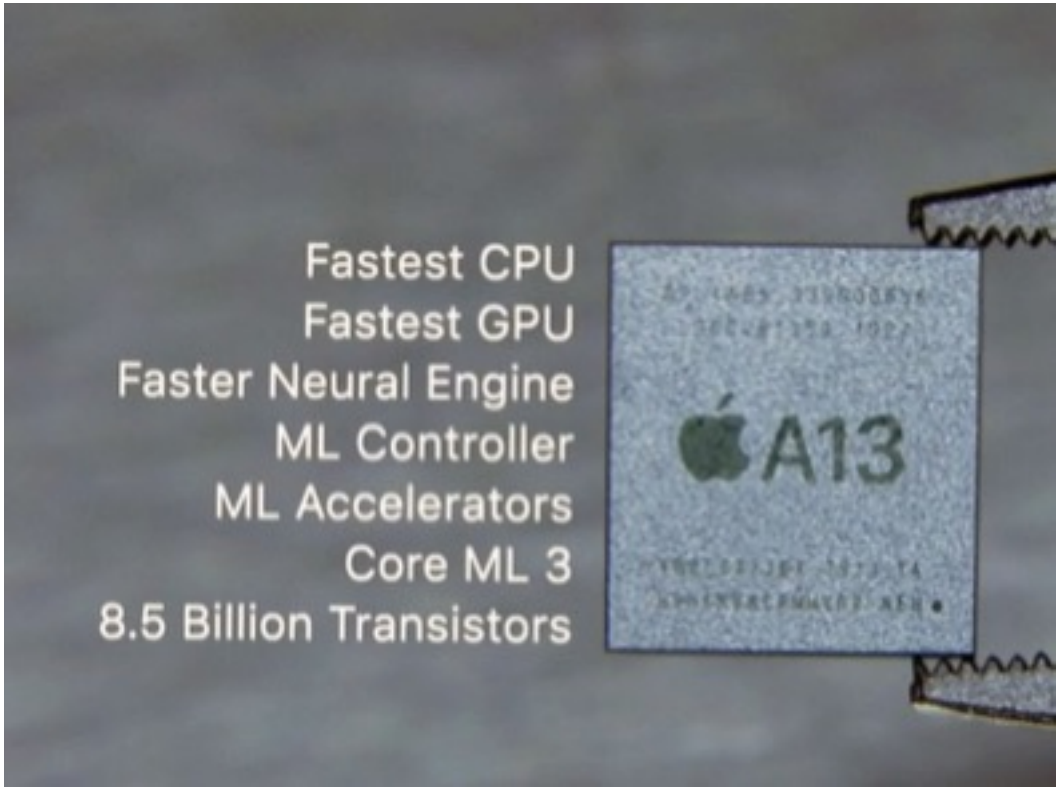
- iPhone 12 — 11.8B Tx

The **Apple A14 Bionic** is a 64-bit ARM-based System on a Chip (SoC), designed by Apple Inc. It appears in the fourth generation iPad Air, as well as iPhone 12 Mini, iPhone 12, iPhone 12 Pro, and iPhone 12 Pro Max. Apple states that the Central Processing Unit (CPU) performs up to 40

- MacBook Air/Pro — 16B Tx

The **Apple M1** is the first ARM-based system on a chip (SoC) designed by Apple Inc. as a central processing unit (CPU) for its line of Macintosh computers. It is deployed in the MacBook Air, Mac mini, and the MacBook Pro. It is the first personal computer chip built using a 5 nm process. Ap

Apple A13



Apple A13

iPhone12,3

Single-Core Score	Multi-Core Score
5472	13769

Geekbench 4.4.1 for iOS AArch64

Result Information

Upload Date	September 11 2019 11:03 PM
Views	3591

System Information

System Information	
Operating System	iOS 13.0
Model	iPhone12,3
Motherboard	D421AP
Memory	3759 MB

Processor Information	
Name	ARM
Topology	1 Processor, 6 Cores
Identifier	ARM
Base Frequency	2.66 GHz
L1 Instruction Cache	48.0 KB x 1
L1 Data Cache	48.0 KB x 1
L2 Cache	4.00 MB x 1

Apple ARM A Series

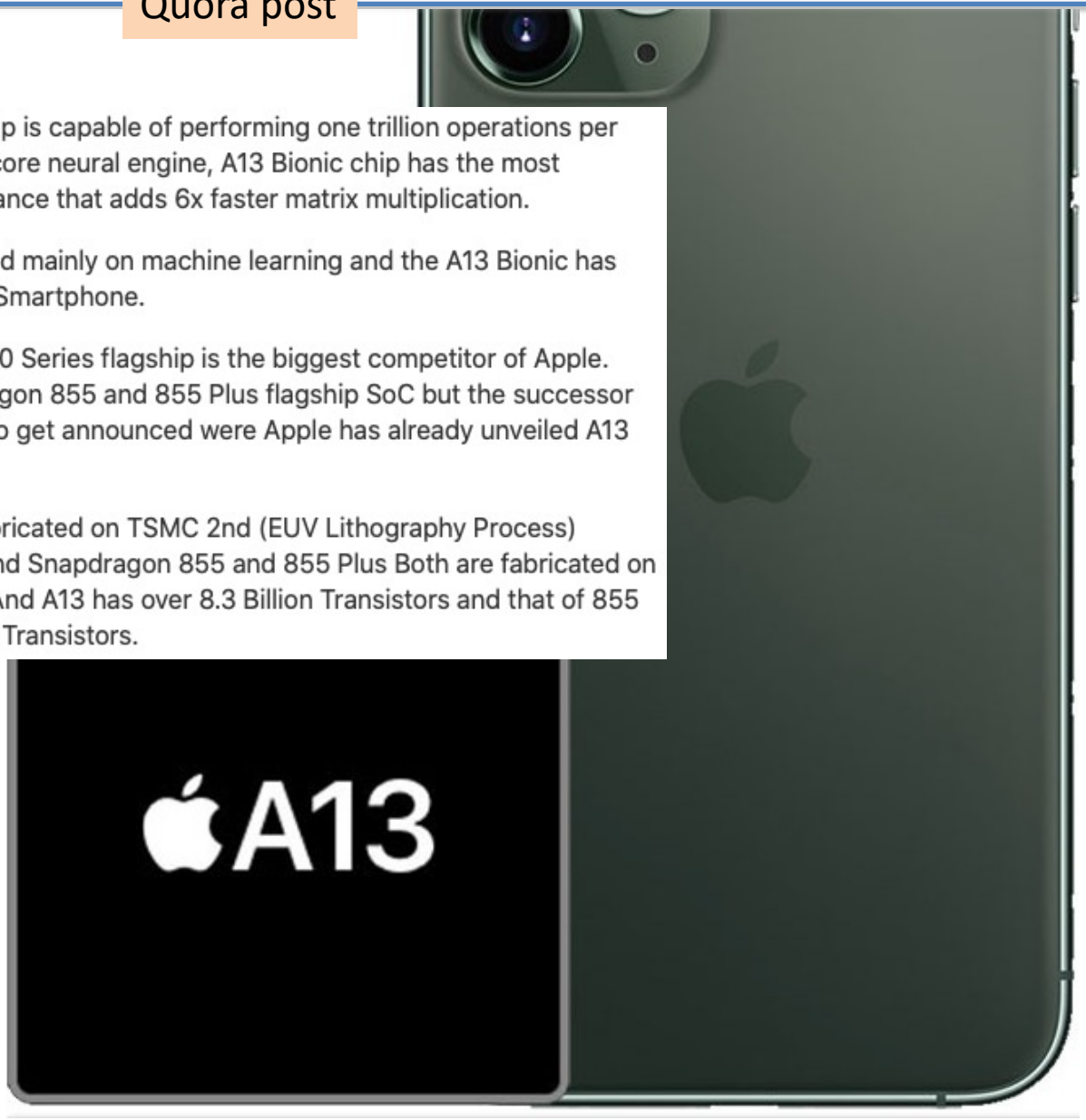
Quora post

According to Apple, the chip is capable of performing one trillion operations per second and with an eight-core neural engine, A13 Bionic chip has the most Machine Learning performance that adds 6x faster matrix multiplication.

This time Apple has focused mainly on machine learning and the A13 Bionic has Fastest CPU and GPU in a Smartphone.

Qualcomm Snapdragon 800 Series flagship is the biggest competitor of Apple. Qualcomm has its Snapdragon 855 and 855 Plus flagship SoC but the successor to Snapdragon 855 is yet to get announced were Apple has already unveiled A13 Bionic.

The Apple A13 Bionic is fabricated on TSMC 2nd (EUV Lithography Process) Generation 7nm process and Snapdragon 855 and 855 Plus Both are fabricated on TSMC 7nm DUV process. And A13 has over 8.3 Billion Transistors and that of 855 Snapdragon has 6.9 Billion Transistors.



Apple ARM A*12/13* SoC

- 8 CPU
- 7 GPU
- 1 NPU
- 2 MCU

This is a block diagram of the Apple A12X with 10 billion transistors. Of that amount, only 25% is dedicated to the two CPU clusters:

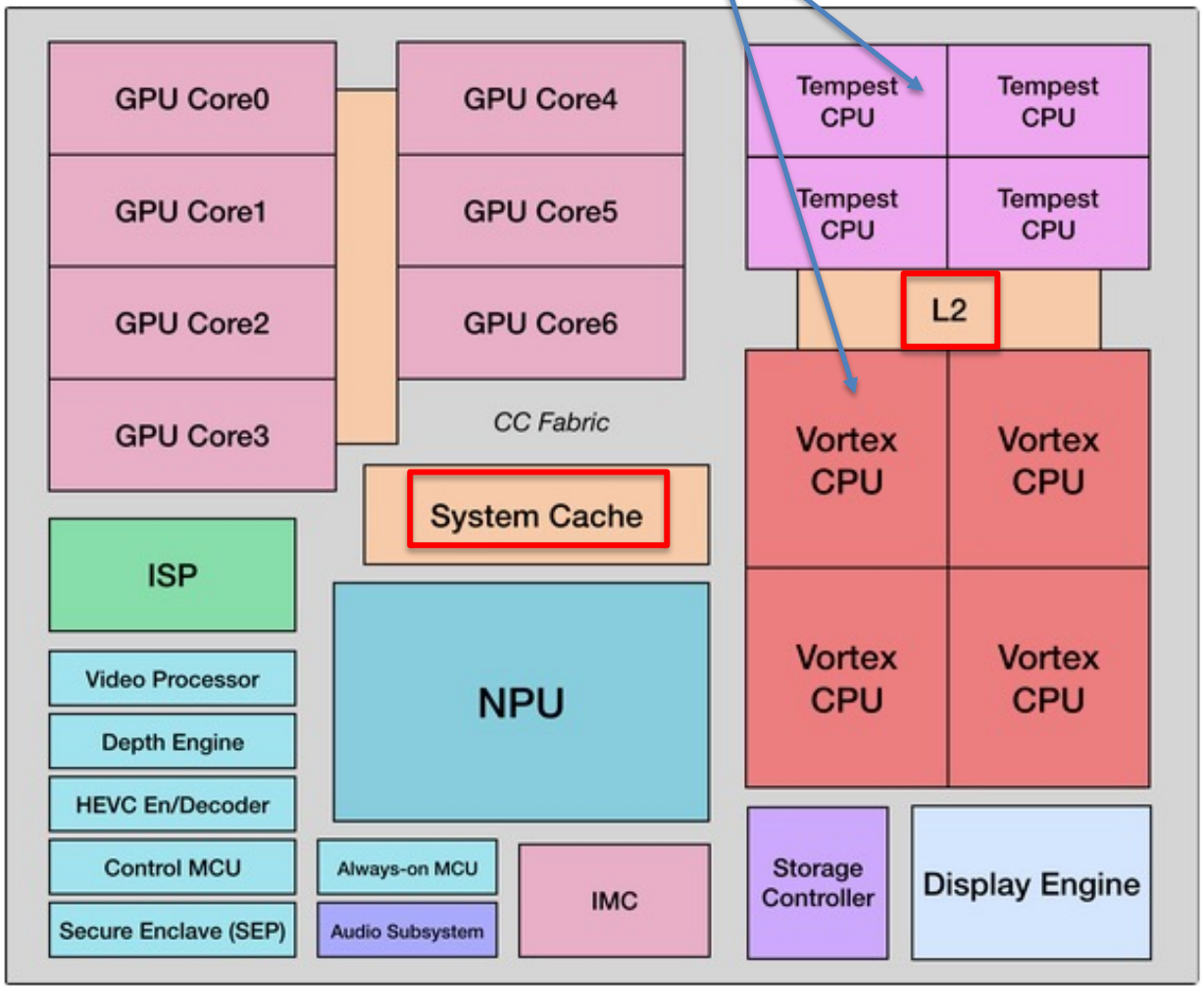


Image source: A12X Bionic - Apple - WikiChip

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Apple A11/12/13

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Name	Model no.	Image	Semiconductor technology	Die size	Transistor count	CPU ISA	CPU	CPU cache	GPU
A11 Bionic	APL1W72		10 nm FinFET (TSMC)	87.66 mm²[162]	4.3 billion	ARMv8.2-A[163]	2.39 GHz hexa-core (2× Monsoon + 4× Mistral)	L1i: 64 KB L1d: 64 KB L2: 8 MB L3: *none*[164]	Custom design (triple-core)
A12 Bionic	APL1W81		7 nm FinFET (TSMC N7)	83.27 mm²[167]	6.9 billion	ARMv8.3-A[168]	2.49 GHz hexa-core (2× Vortex + 4× Tempest)[169]	L1i: 128 KB L1d: 128 KB L2: 8 MB L3: *none*[169]	Custom design (quad-core)
A12X Bionic	APL1083		7 nm FinFET (TSMC N7)	≈135 mm²[172]	10 billion	ARMv8.3-A[168]	2.49 GHz octa-core (4× Vortex + 4× Tempest)	L1i: 128 KB L1d: 128 KB L2: 8 MB L3: *none*[173]	Custom design (hepta-core)
A12Z Bionic									Custom design (octa-core)
A13 Bionic	APL1W85		7 nm FinFET (TSMC N7P)	98.48 mm²[174]	8.5 billion	ARMv8.4-A[175]	2.65 GHz hexa-core (2× Lightning + 4× Thunder)	L1i: 128 KB L1d: 128 KB L2: 8 MB L3: *none*[176]	Custom design (quad-core)

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Apple A12X

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Apple A12X Bionic

General Info	
Launched	October 30, 2018
Discontinued	March 18, 2020
Designed by	Apple Inc.
Common manufacturer(s)	TSMC[1]
Product code	APL1083[2]
Max. CPU clock rate	to 2.49[3] GHz
Cache	
L1 cache	128 KB instruction, 128 KB data
L2 cache	8 MB
Architecture and classification	
Application	Mobile
Min. feature size	7 nm[4]

Apple A12X

Design [edit]

The A12X features an Apple-designed 64-bit ARMv8.3-A octa-core CPU, with four high-performance cores called **Vortex** and four energy-efficient cores called **Tempest**.[4][1] The Vortex cores are a 7-wide decode out-of-order superscalar design, while the Tempest cores are a 3-wide decode out-of-order superscalar design. Like the Mistral cores, the Tempest cores are based on Apple's Swift cores from the Apple A6, and are similar in performance to ARM Cortex-A73 CPU cores.[5][6] It is Apple's first SoC with an octa core CPU.[1]

The A12X integrates an Apple-designed septa core graphics processing unit (GPU) with twice the graphics performance of the A10X.[4] Embedded in the A12X is the M12 motion coprocessor.[7] The A12X includes dedicated neural network hardware that Apple calls a "Next-generation Neural Engine".[4] This neural network hardware, which is the same as found in the A12,[1] can perform up to 5 trillion operations per second.[4]

The A12X is manufactured by TSMC using a 7 nm FinFET process, and it contains 10 billion transistors[1][4] vs. the 6.9 billion on the A12.[8] The A12X is paired with 4 GB of LPDDR4X memory in the third-generation 12.9" iPad Pro and the 11" iPad Pro or 6 GB in the 1TB storage configurations.[9][2]

Products that include the Apple A12X [edit]

- iPad Pro 2018 11-inch (First-generation)
- iPad Pro 2018 12.9-inch (Third-generation)

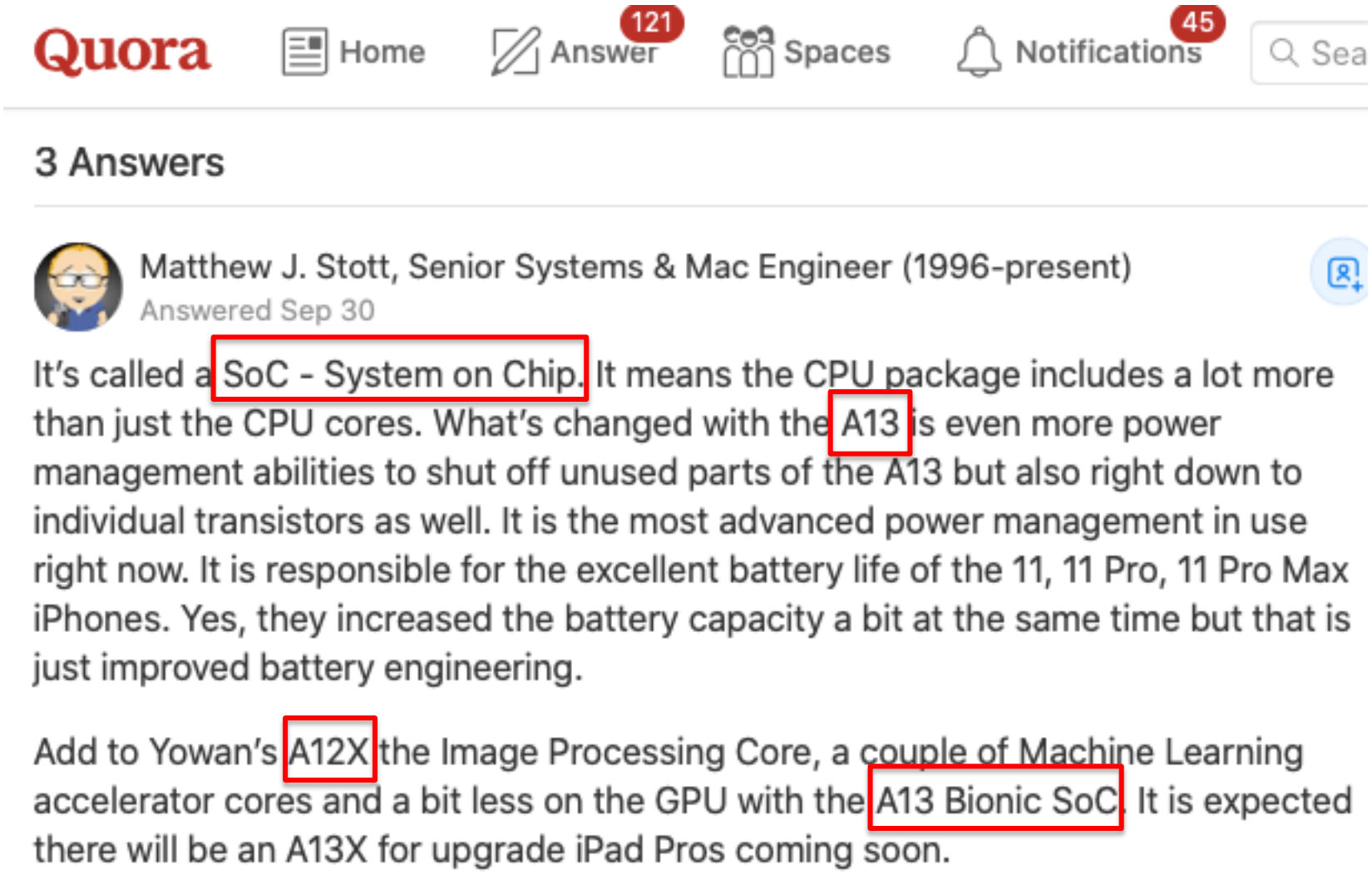
Apple ARM A13

Intel chips are **x86** ISA and multi-core CPU (only). Apple chips are **ARM** ISA with multi-core CPU's, GPU's, and NPU, MCU's. The latest Apple chip is the **A13**, succeeding the powerful **A12X** as the first "bionic" SoC.

A13: The A13 is the latest multi-core architecture designed by Apple with 8.5B transistors manufactured at TSMC (7nm EUV) -- extremely state-of-the-art. The A13 was released Sept. **2019** and is used in the iPhone **11**.

It contains a large number of **ARMv8** ISA cores: 6 CPU (2.65GHz) + 4 GPU + 8 NPU + 2 MCU. (Note that the A12X/Z has 8 CPU cores + 8 GPU's). All cores are Apple designed (ARM 64-bit v8 ISA is licensed). It includes a Neural engine (8x NPU) with machine learning (core ML 3 at 6x faster matrix multiply) -- which sets it apart from Intel chips without GPU's or an NPU. The GPU's can perform 1 trillion operations per second (1 Tflops=1000 Gflops), and the NPU may hit 5 Tflops. It has extreme power management as well (so good for portables and mobile).

Apple ARM A*12/13* SoC



Apple A13

Quora post

And I think iPhones are going to be more power-efficient than Snapdragon 855 powered Android Phones. If you are asking about CPU, then the A13 Bionic is based on 64-bit Fusion Architecture. It is a Hexa-Core CPU with 2 Performance cores and 4 Efficiency cores. And it consumes 40% less power than the A12 Bionic. Coming to 855 Snapdragon, both Snapdragon 855 and 855 Plus is an ARM 64-bit SoC with Kryo 485 Octa-Core CPU. And it has Three CPU Clusters: 1 Cortex-A76 Prime Core, 3 Cortex-A76 Performance Cores and 4 Cortex-A55 Efficiency Cores. From these it seems Snapdragon 855 will definitely be a strong competitor for the Apple A13 Bionic Chip.

Moreover, while talking about GPU, for Apple, it is an Apple-designed Quad Core GPU and Snapdragon 855 has Adreno 640 GPU. And I don't think the Snapdragon will beat the performance of Apple's A13 bionic chip.

A Series: ARMv7/8

	ISA		Cores	Cache	Speed
Ax (Apple)	ARMv7-A	Swift[73]	2 cores. ARM / Thumb / Thumb-2 / DSP / SIMD / VFPv4 FPU / NEON	L1: 32 KB / 32 KB, L2: 1 MB	3.5 DMIPS/MHz per core
	ARMv8-A	Cyclone[74]	2 cores. ARM / Thumb / Thumb-2 / DSP / SIMD / VFPv4 FPU / NEON / TrustZone / AArch64. Out-of-order, superscalar.	L1: 64 KB / 64 KB, L2: 1 MB, L3: 4 MB	1.3 or 1.4 GHz
	ARMv8-A	Typhoon[74][75]	2 or 3 cores. ARM / Thumb / Thumb-2 / DSP / SIMD / VFPv4 FPU / NEON / TrustZone / AArch64	L1: 64 KB / 64 KB, L2: 1 MB or 2 MB, L3: 4 MB	1.4 or 1.5 GHz
	ARMv8-A	Twister[76]	2 cores. ARM / Thumb / Thumb-2 / DSP / SIMD / VFPv4 FPU / NEON / TrustZone / AArch64	L1: 64 KB / 64 KB, L2: 2 MB, L3: 4 MB or 0 MB	1.85 or 2.26 GHz
	ARMv8.1-A	Hurricane and Zephyr[77]	Hurricane: 2 or 3 cores. AArch64, 6-decode, 6-issue, 9-wide, superscalar, out-of-order Zephyr: 2 or 3 cores. AArch64.	L1: 64 KB / 64 KB, L2: 3 MB or 8 MB, L3: 4 MB or 0 MB	2.34 or 2.38 GHz
	ARMv8.2-A	Monsoon and Mistral[78]	Monsoon: 2 cores. AArch64, 7-decode, ?-issue, 11-wide, superscalar, out-of-order Mistral: 4 cores. AArch64, out-of-order, superscalar. Based on Swift.	L1I: 128 KB, L1D: 64 KB, L2: 8 MB, L3: 4 MB	2.39 GHz
	ARMv8.3-A	Vortex and Tempest[79]	Vortex: 2 or 4 cores. AArch64, 7-decode, ?-issue, 11-wide, superscalar, out-of-order Tempest: 4 cores. AArch64, 3-decode, out-of-order, superscalar. Based on Swift.	L1: 128 KB / 128 KB, L2: 8 MB, L3: 8 MB	2.5 GHz
	ARMv8.4-A	Lightning and Thunder[80]	Lightning: 2 cores. AArch64, 7-decode, ?-issue, 11-wide, superscalar, out-of-order Thunder: 4 cores. AArch64, out-of-order, superscalar.	L1: 128 KB / 128 KB, L2: 8 MB, L3: 16 MB	2.66 GHz

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Apple T1/2 SoC

MacBook Pro

T series list [edit]

Name	Model no.	Image	Semiconductor technology	Die size	CPU ISA	CPU	CPU cache	GPU	Memory technology	Introduced	Utilizing devices
T1	APL1023[190]				ARMv7			TBD		October 2016	• MacBook Pro (13-inch, 2016, Four Thu • MacBook Pro (15-inch, 2016) • MacBook Pro (13-inch, 2017, Four Thu • MacBook Pro (15-inch, 2017)
T2	APL1027[191]				ARMv8-A			TBD	LPDDR4	December 2017	• iMac Pro 2017 • MacBook Pro (13-inch, 2018, Four Thu • MacBook Pro (15-inch, 2018) • Mac mini (2018) • MacBook Air (2018) • MacBook Pro (15-inch, 2019) • MacBook Pro (13-inch, 2019) • MacBook Air (2019) • MacBook Pro (16-inch, 2019) • Mac Pro (2019) • MacBook Air (2020)

Apple Special Processor

The **Apple M-series coprocessors** are motion coprocessors used by Apple Inc. in their mobile devices. First released in 2013, their function is to collect sensor data from integrated accelerometers, gyroscopes and compasses and offload the collecting and processing of sensor data from the main

Section

Apple Chips

M1

(ARM v8)

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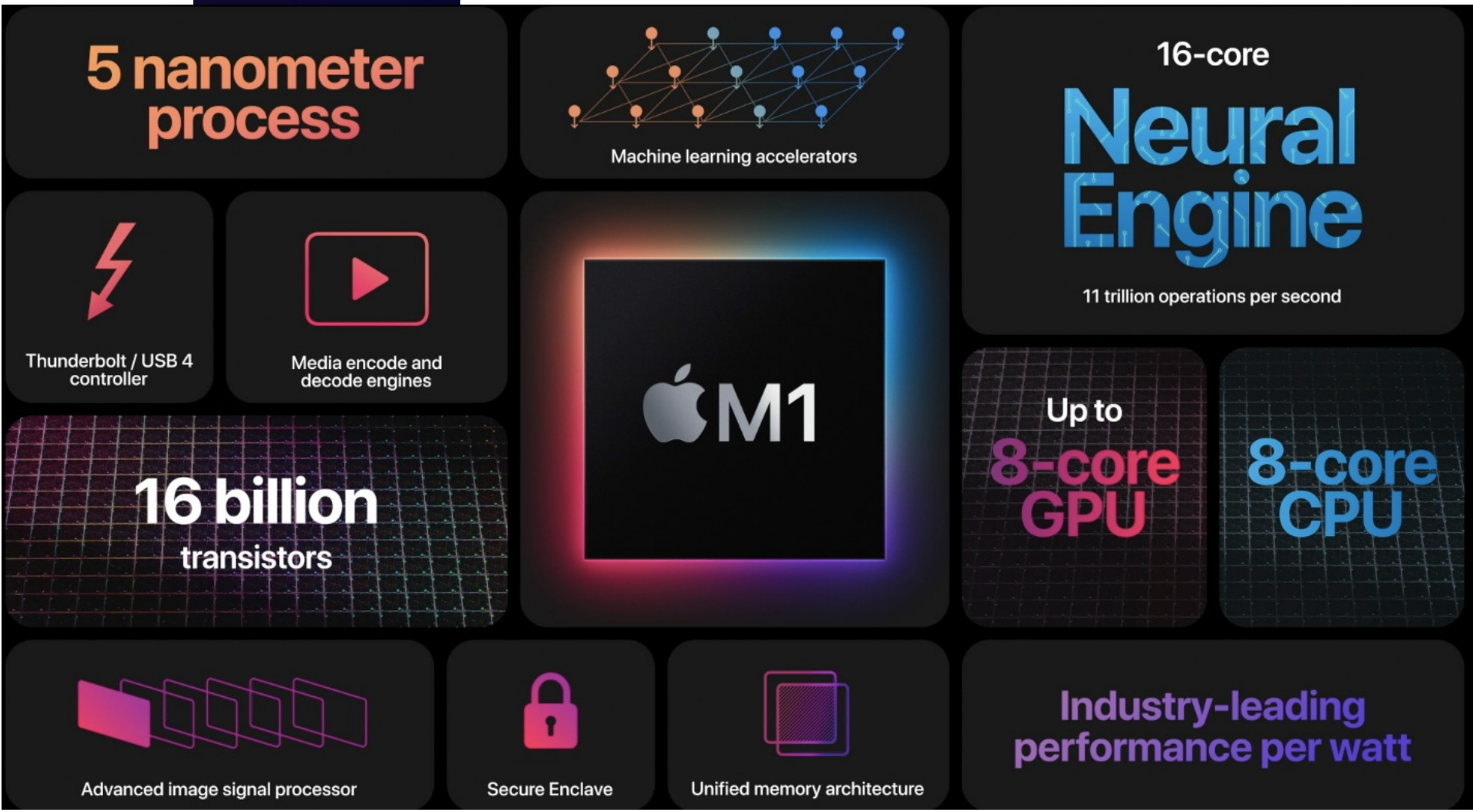
Apple M1

November 10, 2020



Apple M1

5-nanometer process

The first personal computer chip built with this cutting-edge technology.

16 billion transistors

The most we've ever put into a single chip.

Apple M1 Module

Apple M1

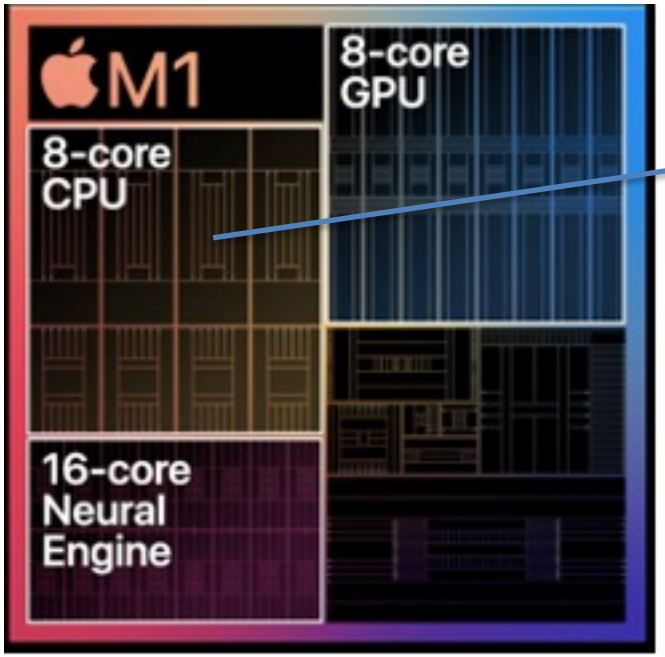
November 10, 2020

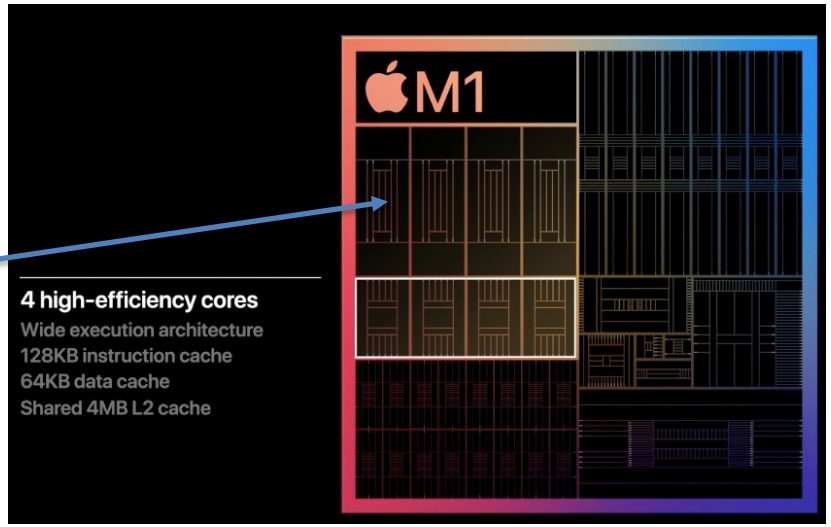
11 trillion
Operations per second

11 Tera FLOPS

- Cores
  - 8 CPU
  - 8 GPU
  - 16 NPU

- CPU cores
  - 4 Hi Perf (20W **P**)
  - 4 Hi Efficiency (1.3W low power **E**)





Apple M1 vs x86 CPUs

Why is the Intel microchip inferior to the MacBook M1 microchip, in average-user, normal-computing terms?

Jeff Drobman, Lecturer at California State University, Northridge (2016-present)

Answered just now

core count. Intel *microchips* come in a broad array of core counts, both CPU and GPU. the Apple M1 has 8 CPU, 8GPU and 16 NPU cores. it would perform comparable to any other such chip — with same number of cores. high-end x86 chips from Intel (Xeon) and AMD (Epyc) will outperform the M1 by a lot, but low end ones will not.

Apple M1 SoC

What's the architectural difference between the low-power and high-performance Apple M1 cores, and can both execute the same instruction sets?

Jeff Drobman, Lecturer at California State University, Northridge (2016-present)
Answered just now

the Apple M1 SoC has 8 CPU cores plus 8 GPU, 16 NPU cores. the CPU cores all run the ARMv8 64-bit ISA. while I don't know the specifics, a CPU core can lower its power consumption by lowering its frequency, and maybe by low powering (Sleep) some less often used functions like L2 or L3 cache. A CPU core can only increase its performance via parallelism. SMT with superscalar is the usual way, along with parallel data via SIMD extensions.

Apple M1

Shresth Sonkar, Mac User since 2014

Answered December 20

1. The M1 has a max TDP of 20W and a nominal TDP of 15W. This is way lesser than the previous intel chips used in previous generation — which had 28W nominal TDP. Thus, the heat generation itself is lower
2. Since the heat generation is lower, the MacBook Air can handle it via passive cooling using a aluminium heat spreader which carries heat away from processor via conduction instead of convection cooling which uses a fan to blow cool air over the CPU.
3. The M1 has asymmetric cores — 4 efficiency cores of the octa core design are working on barely 1.3W of power while the rest 4 performance cores are working at 13.8W. This means that the M1 generates less heat in day to day usage to require cooling. Only when the performance cores and GPU are being used, does the power spike up to the 20W figure.

All this makes the M1 a rather highly thermally efficient processor — which doesn't waste energy as heat. It is producing way less heat than intel processors in the same segment of laptops and thus doesn't need a fan.

For comparison, the A14 powering iPhone 12 lineup has 5W TDP, about a third of the Macs. So 5W is not much for a smart phone and 15 is definitely not much for a laptop which has way more surface area for dissipating heat than a smartphone.

SoC's

Why don't electronic chip manufacturers have most of the features of a whole computer on one chip similar to the Apple M1 SoC? Is it cost or problems manufacturing it?

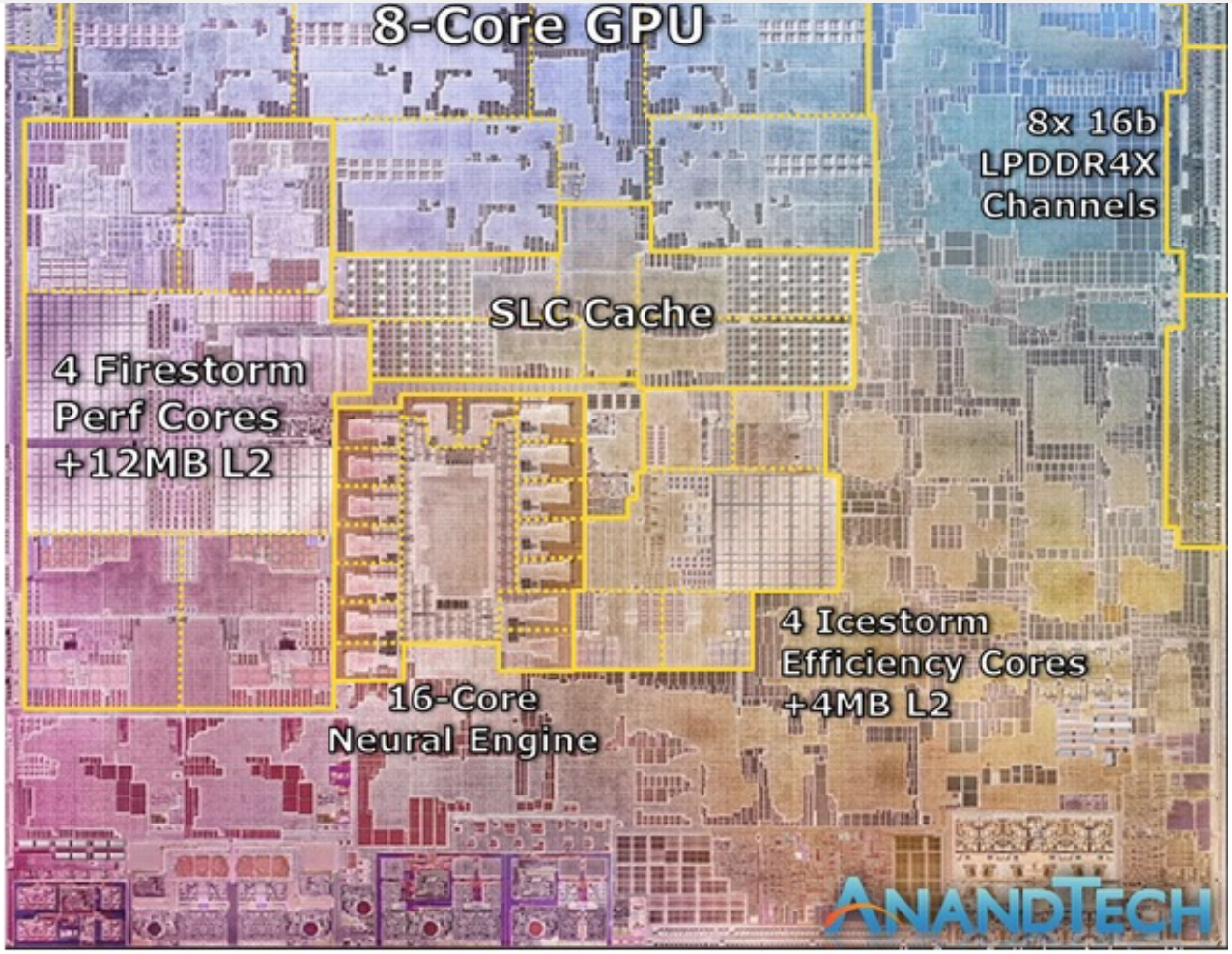
Jeff Drobman, Lecturer at California State University, Northridge (2016-present)
Answered just now

manufacturers? even Apple does not manufacture chips. if you mean *designers*, like Apple, then many do have multi-core SoC's. Intel is the only *desktop* CPU supplier that also manufactures their own chips. Samsung is the only *mobile* CPU supplier that also manufactures their own chips.

the parts of a "whole computer" that might not fit onto an SoC are large DRAM (best left to separate chips) and I/O devices like sensors. mobile CPU's or SoC's are designed by Qualcomm

Apple M1

- I don't know how big SLC is.
  - It looks physically smaller than the 12MB L2 in the Firestorm cores, but it probably uses noticeably denser SRAM cells. L2 may be optimized for very low latency.
  - The memory latency numbers measured by AnandTech show drop-offs at 8MB and 32MB.
  - Drop off ar 8MB is probably L2 capacity. However, Firestorm supposedly has 12MB L2, so that suggests some partitioning. I wouldn't be surprised to learn that 4MB is instruction-only to help Rosetta.
  - Drop off ar 32MB is likely SLC capacity. 32MB sounds reasonable actually.



Apple M1

Joe Zbiciak replied to your comment on an answer to: "If putting two GPUs in a computer is normal, why isn't putting two CPUs?"

I found an actual picture (rather than illustration) of the M1 with its heat spreader removed. You can see it in the middle-left. It looks a lot like the illustration. Link.

M1 SoC exposed and ready to test (photo credit: Don Scansen)

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Apple Event

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November 10, 2020

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Apple M1

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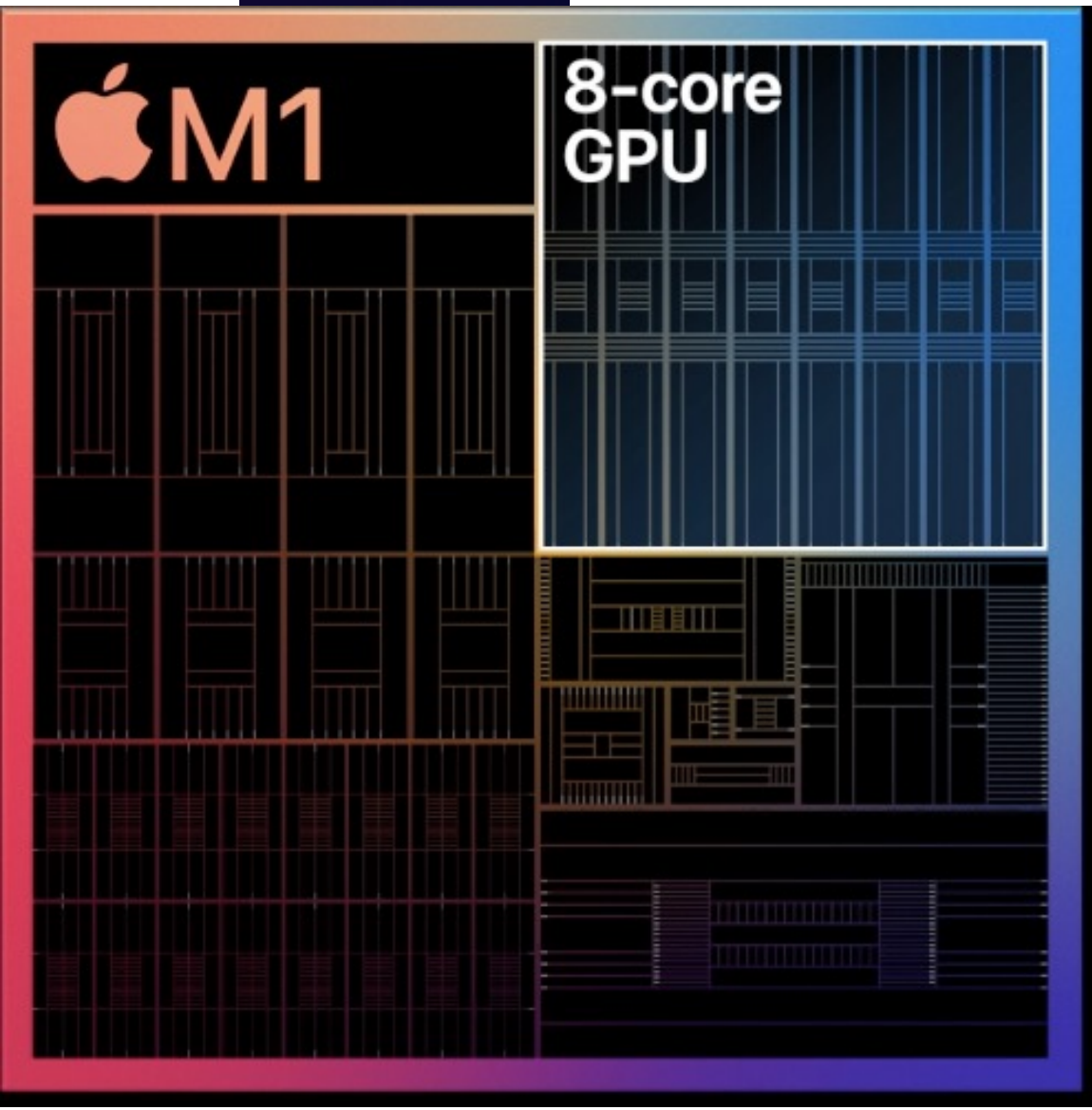

Up to 8 cores
128 execution units
Up to 24,576 concurrent threads
2.6 teraflops
82 gigatexels/second
41 gigapixels/second

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Apple M1

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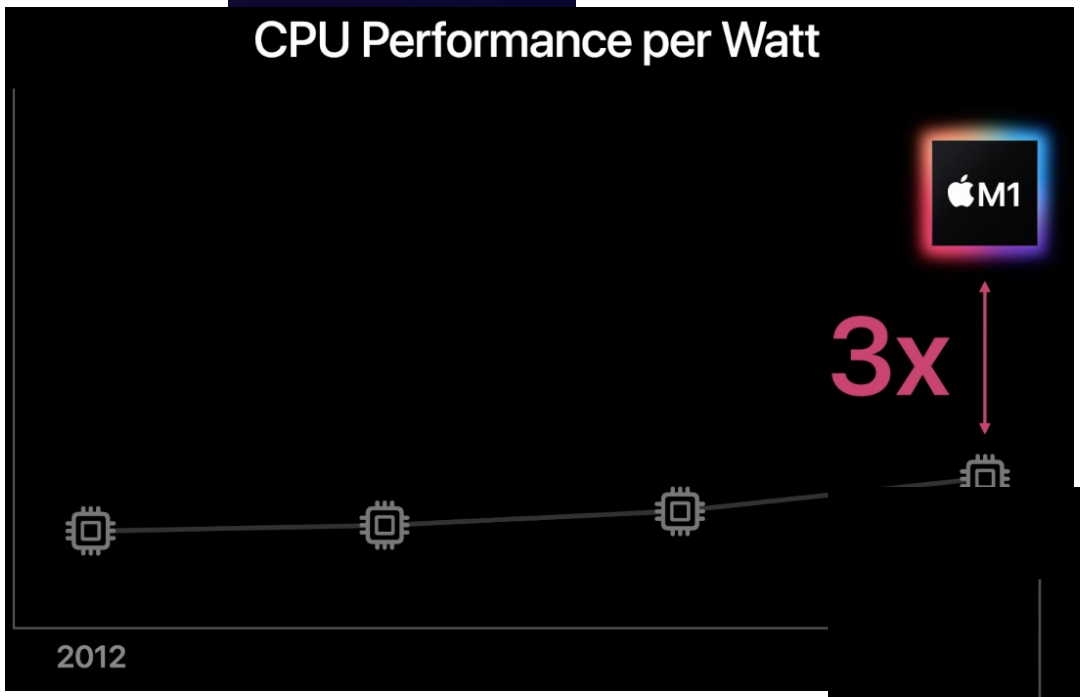

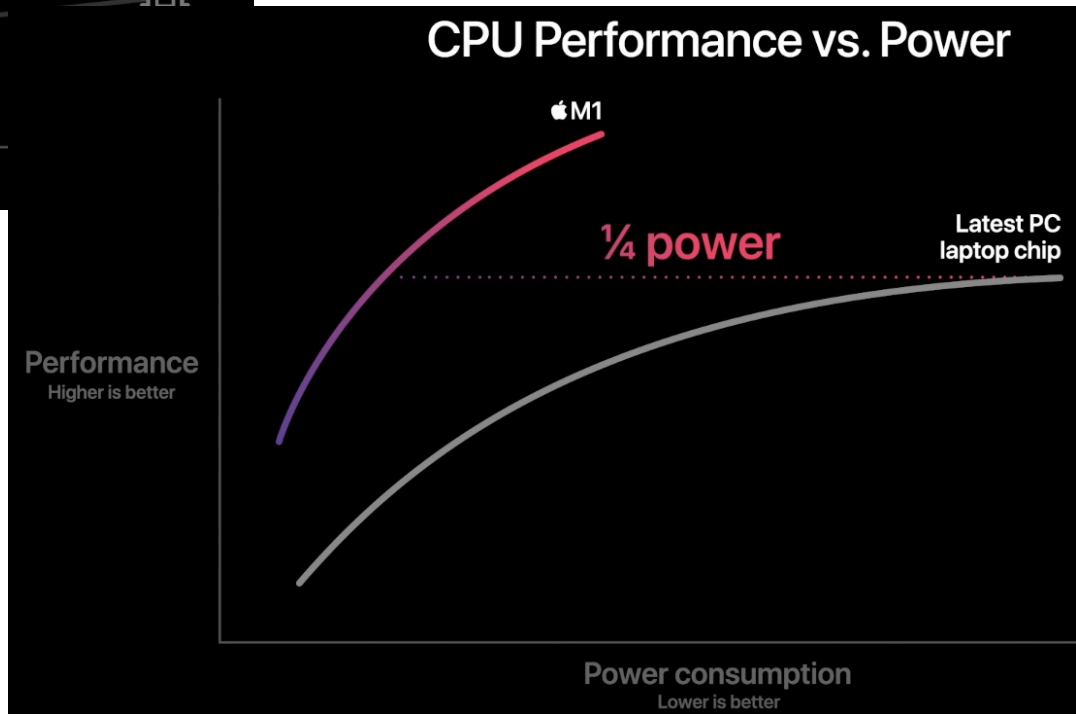

Apple M1

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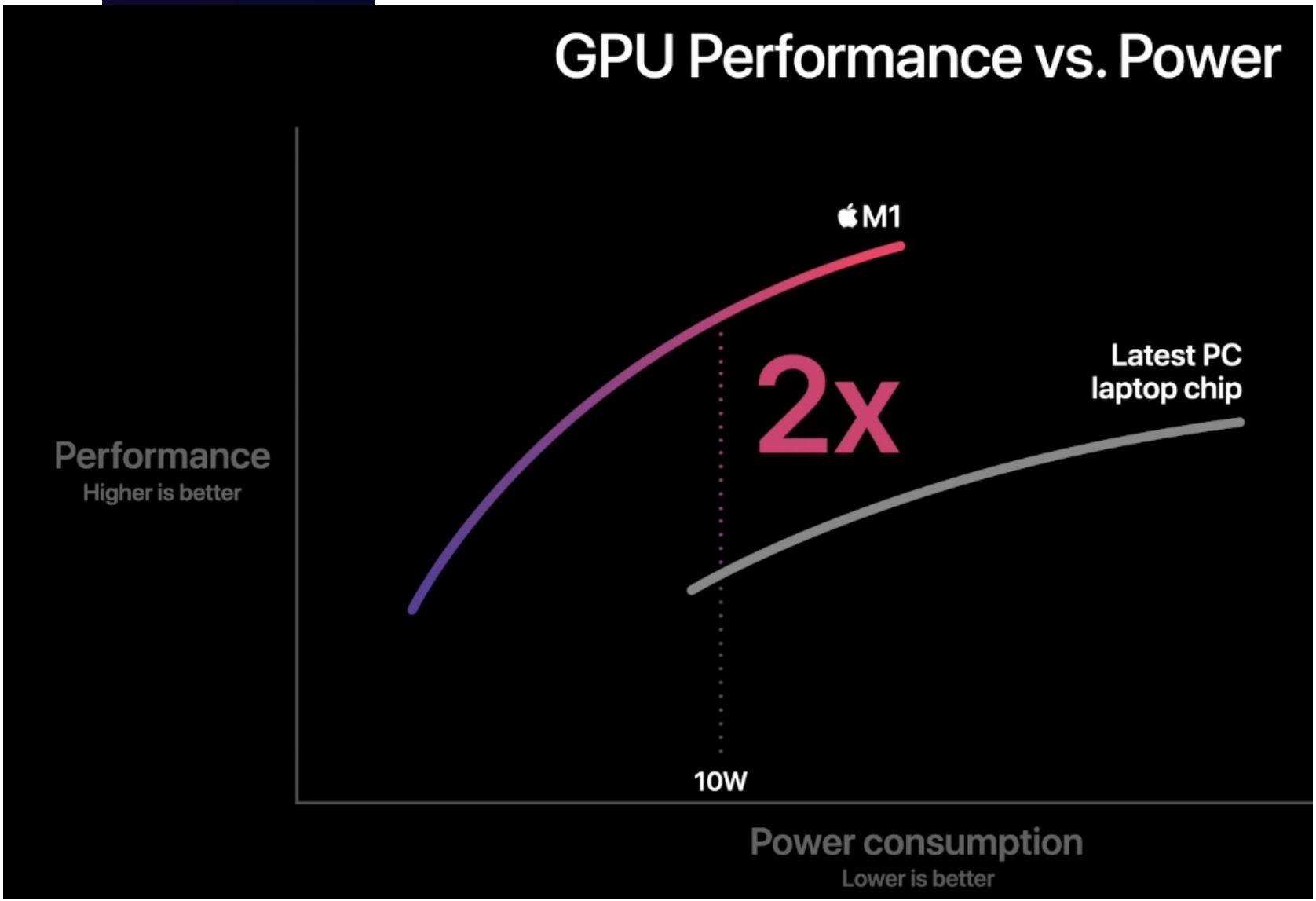

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Apple M1

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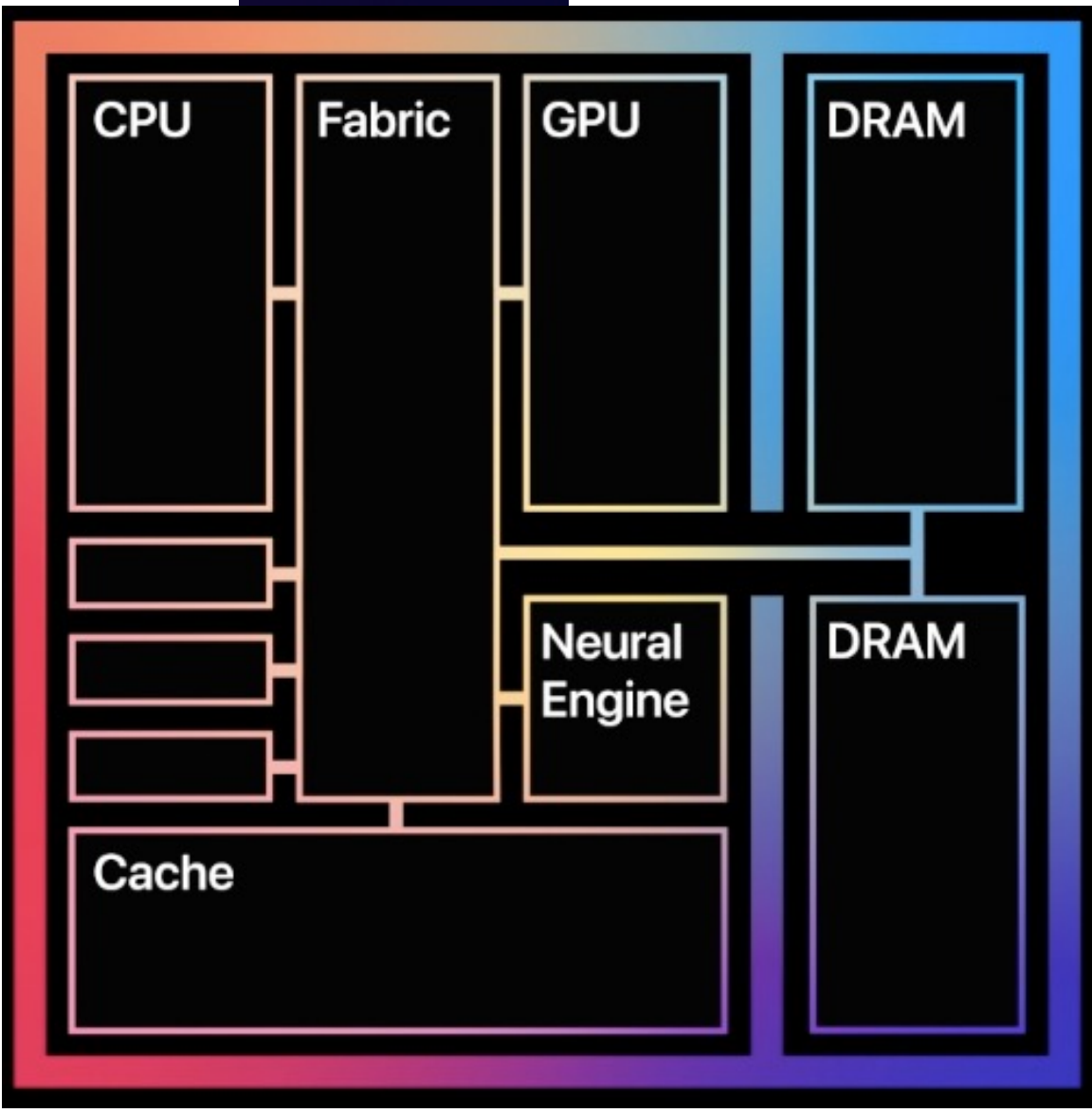
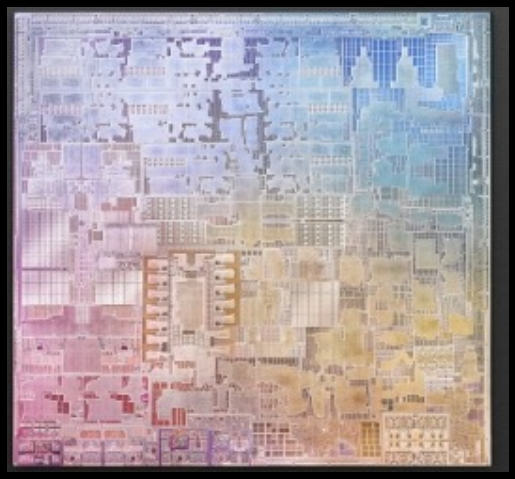
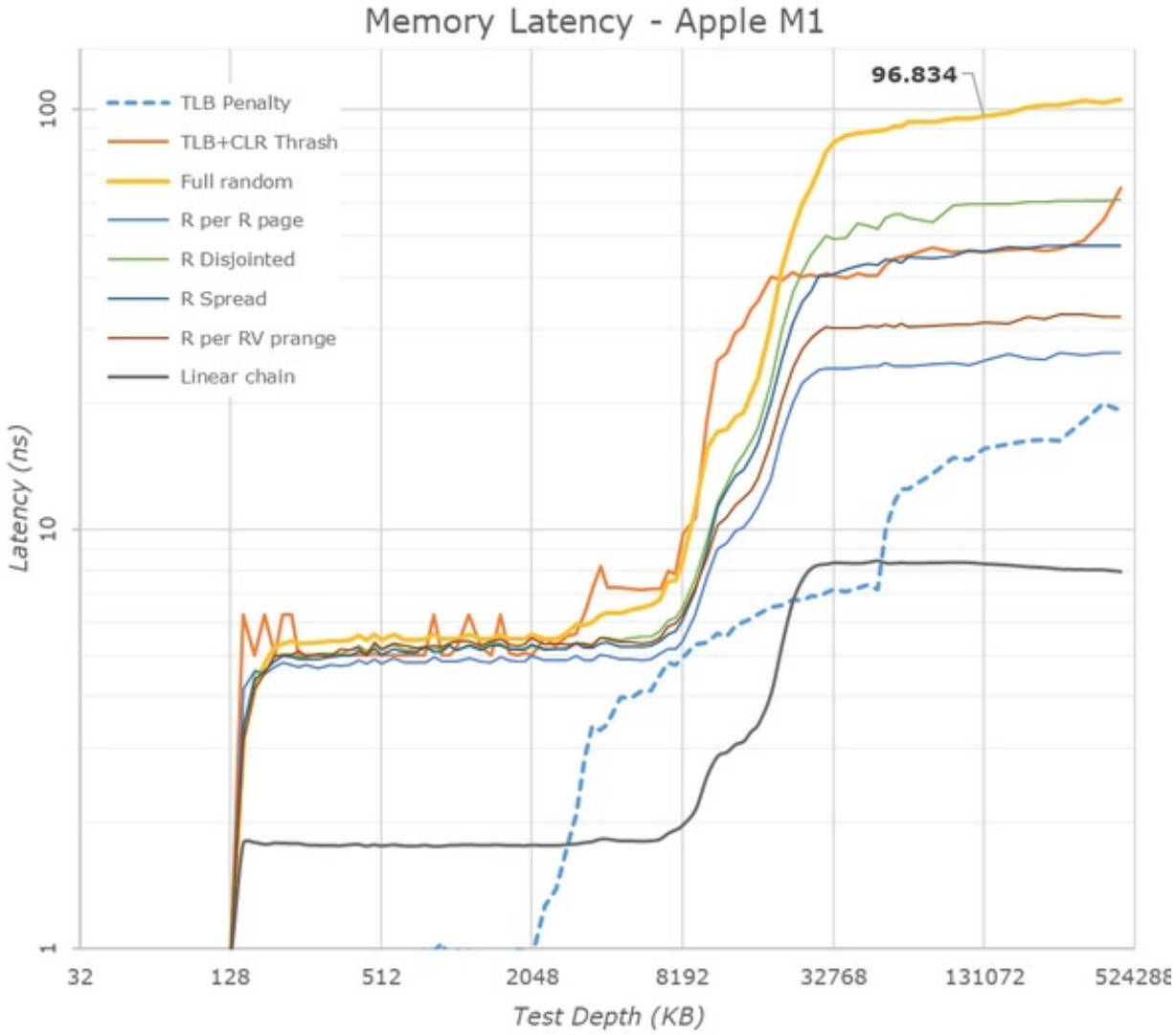


Unified memory architecture

High bandwidth, low latency
Apple-designed package
Accessible to entire SoC



M1 Memory



- There's a lot of unknown in AnandTech's die labeling. Also, we don't know Apple's SLC policy or interconnect architecture. Apple has demonstrated repeatedly that they're more than happy to ignore ARM's standard mechanism and methodologies.

M1 Benchmark

	Apple iPad pro 12.9 (M1)	MacBook Air M1	Microsoft Surface Pro 7 (Intel Core i5-1035G4 10th Gen)
Single-Core	**1714**	1740	862
Multi-Core	**7272**	7694	3104
OpenCL Score	**20887**	18347	7801

Apple's M1-based iPad Pro's benchmarks are in line with other M1-based systems.

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Apple M1 Pro

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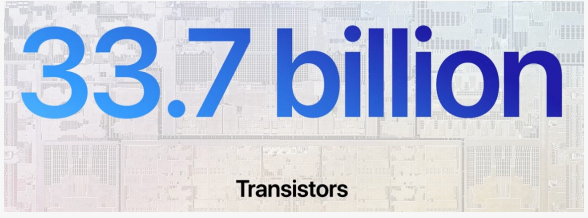
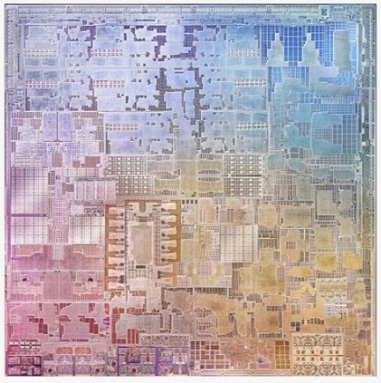
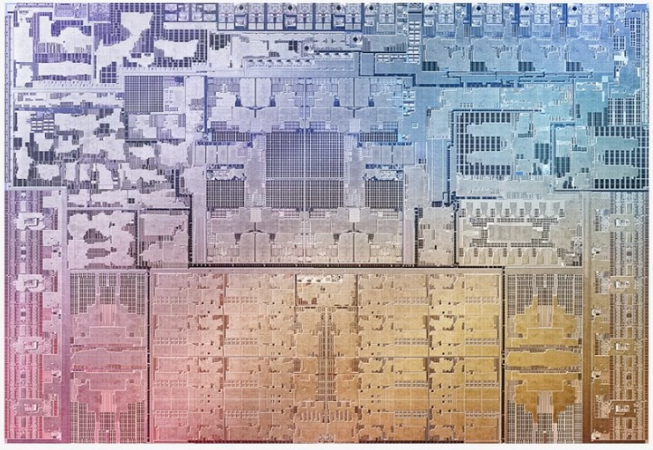
Apple M1 Pro/Max

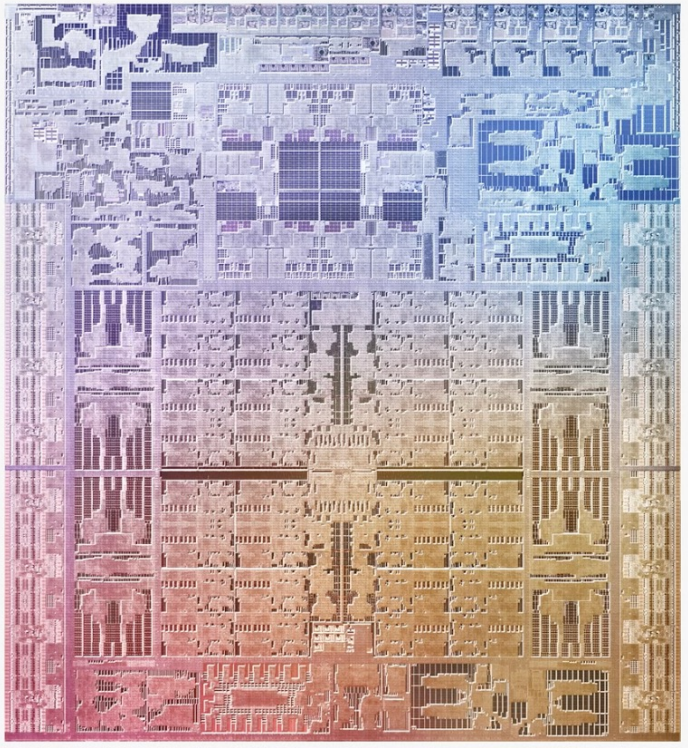




M1

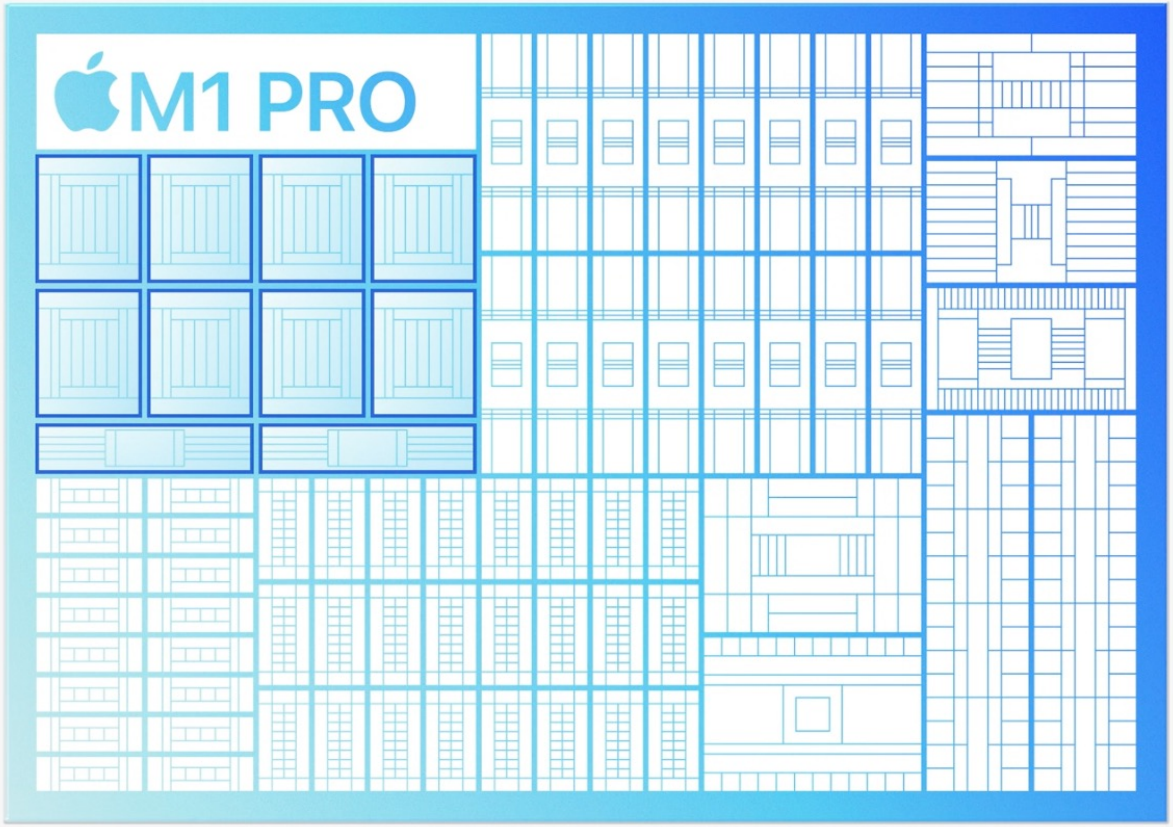


M1 Pro



M1 Max

Apple M1 Pro



8 high-performance cores

Ultra-wide execution architecture
192KB instruction cache
128KB data cache
24MB L2 cache

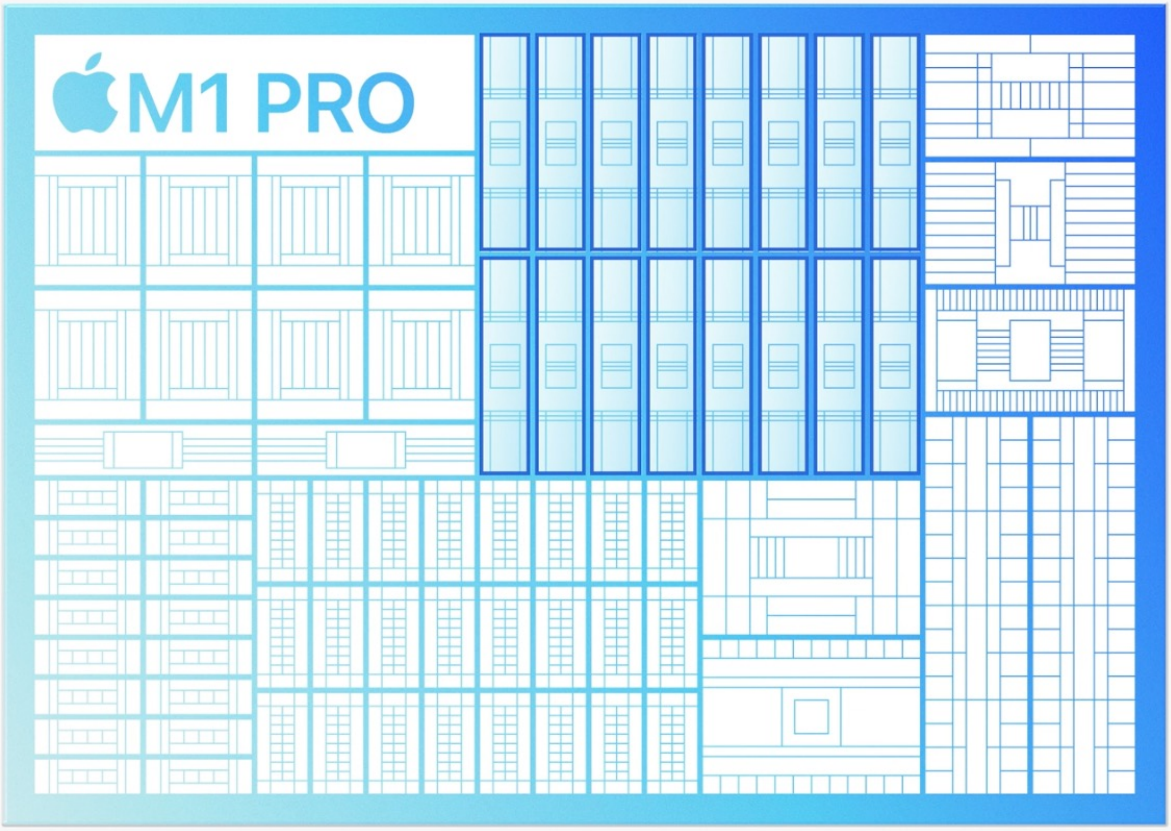
2 high-efficiency cores

Wide execution architecture
128KB instruction cache
64KB data cache
4MB L2 cache

70%

Faster CPU performance than M1

Apple M1 Pro



16-core GPU

2048 execution units

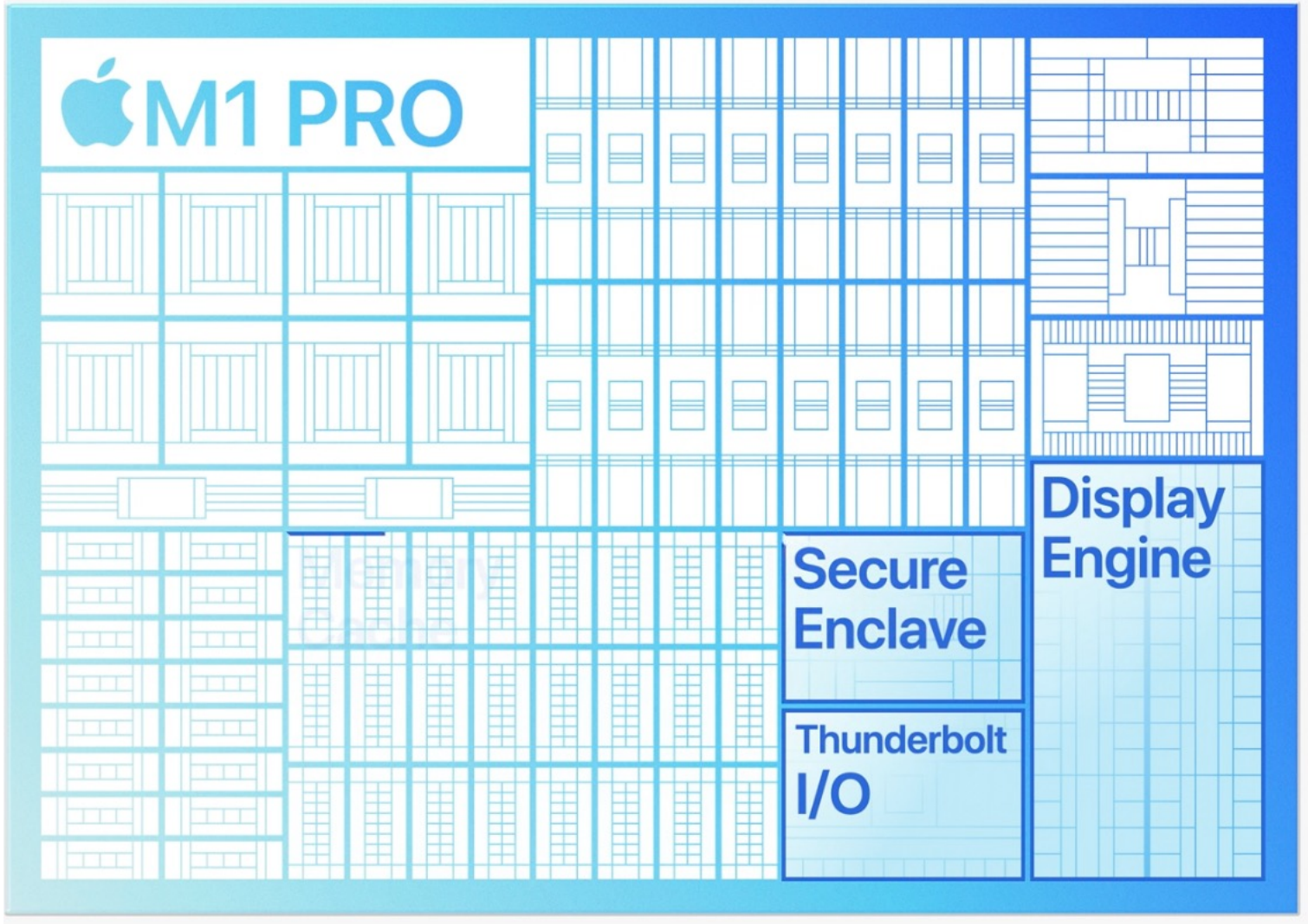
Up to 49,512 concurrent threads

5.2 teraflops

164 gigatexels/second

82 gigapixels/second

Apple M1 Pro



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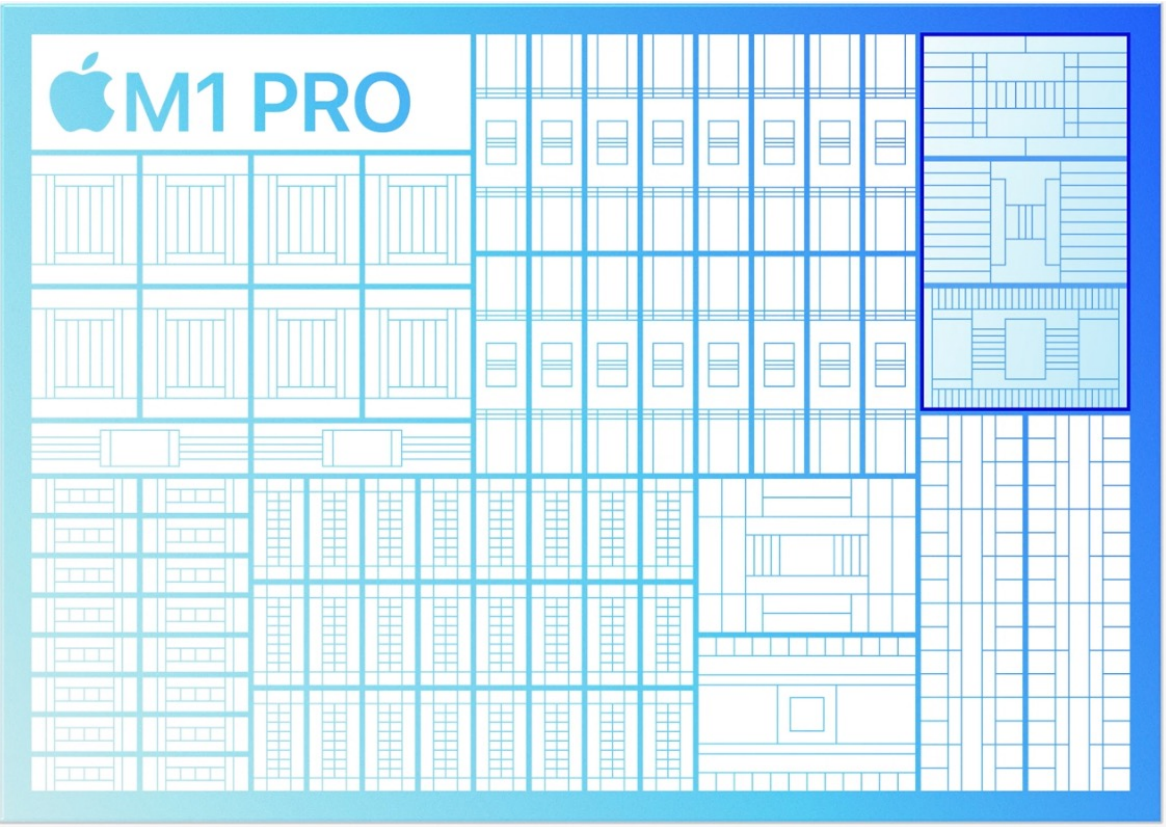
Apple M1 Pro



Media Engine

Hardware-accelerated H.264, HEVC, ProRes, and ProRes RAW

Video decode engine

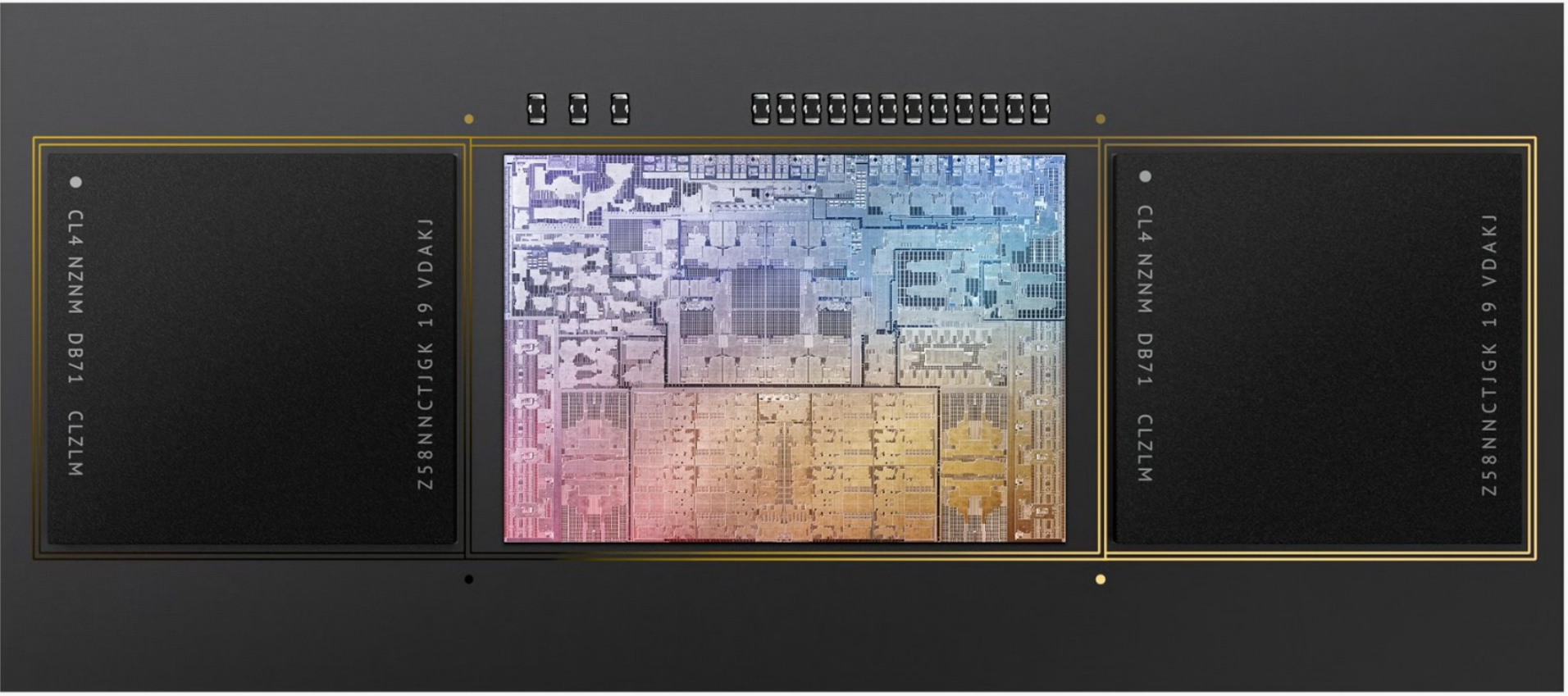
Video encode engine

ProRes encode/decode engine

Multiple streams of 4K and 8K ProRes video

Apple M1

Apple M1 Pro



32GB unified memory

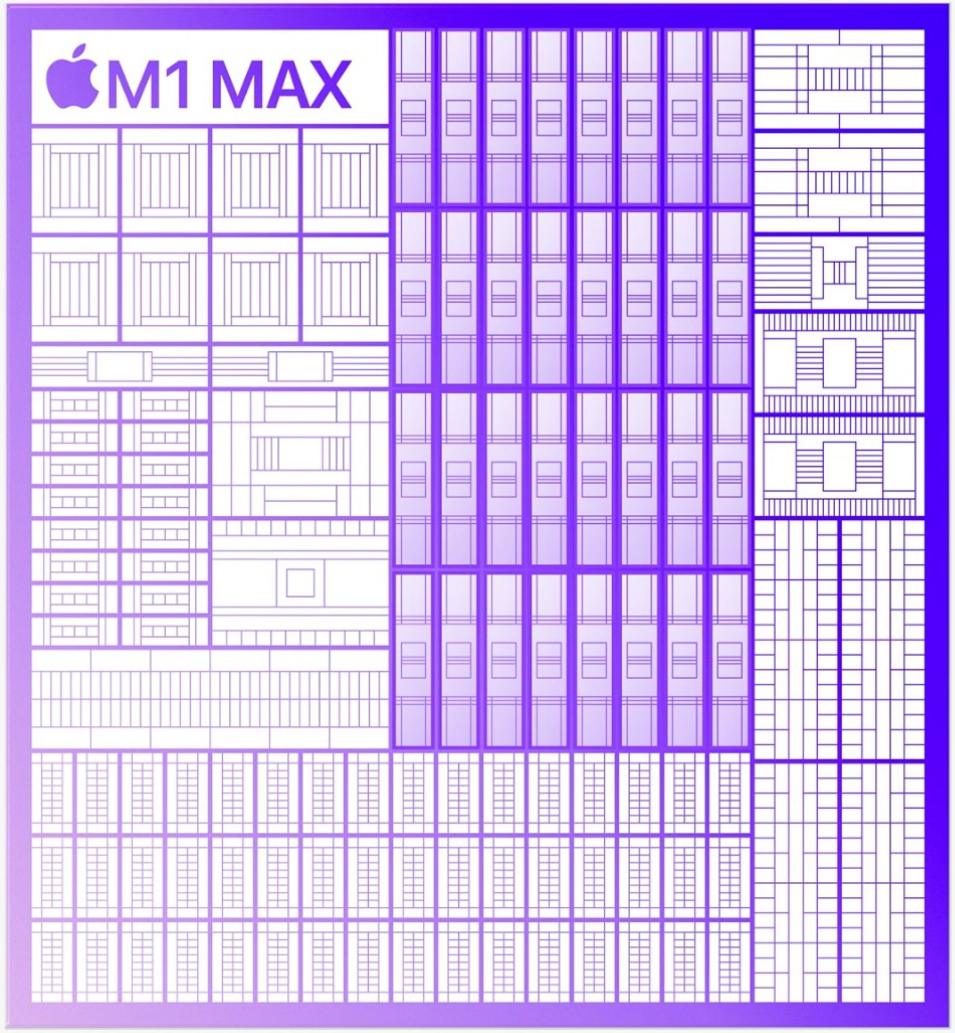
High bandwidth, low latency

256-bit LPDDR5 interface

Apple-designed custom package

Apple M1 Max

Apple M1 Max



32-core GPU

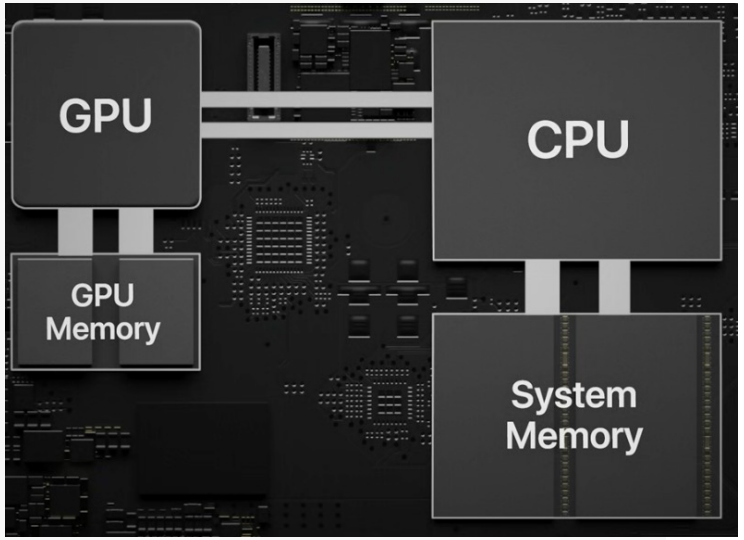
4096 execution units

Up to 98,304 concurrent threads

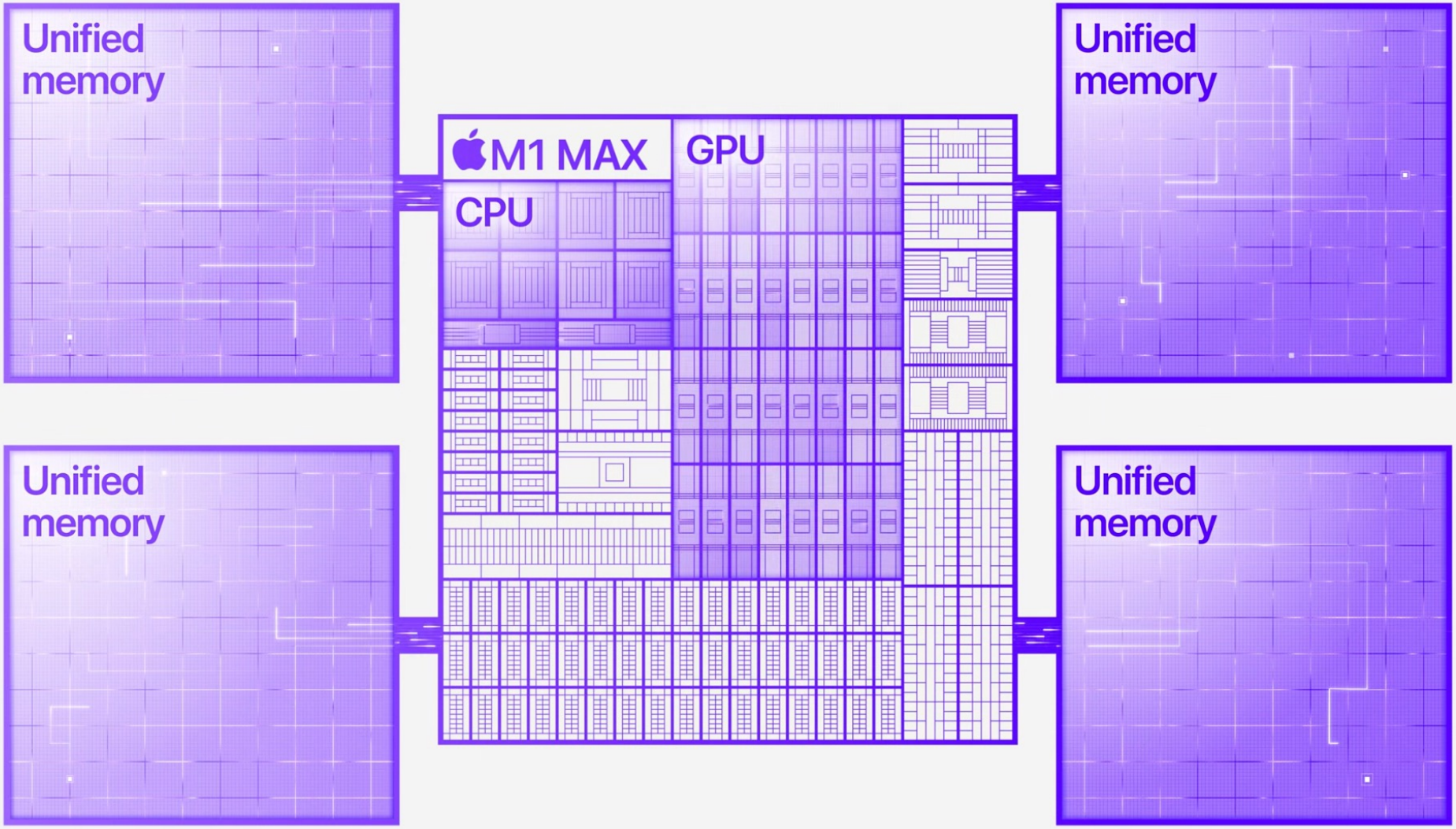
10.4 teraflops

327 gigatexels/second

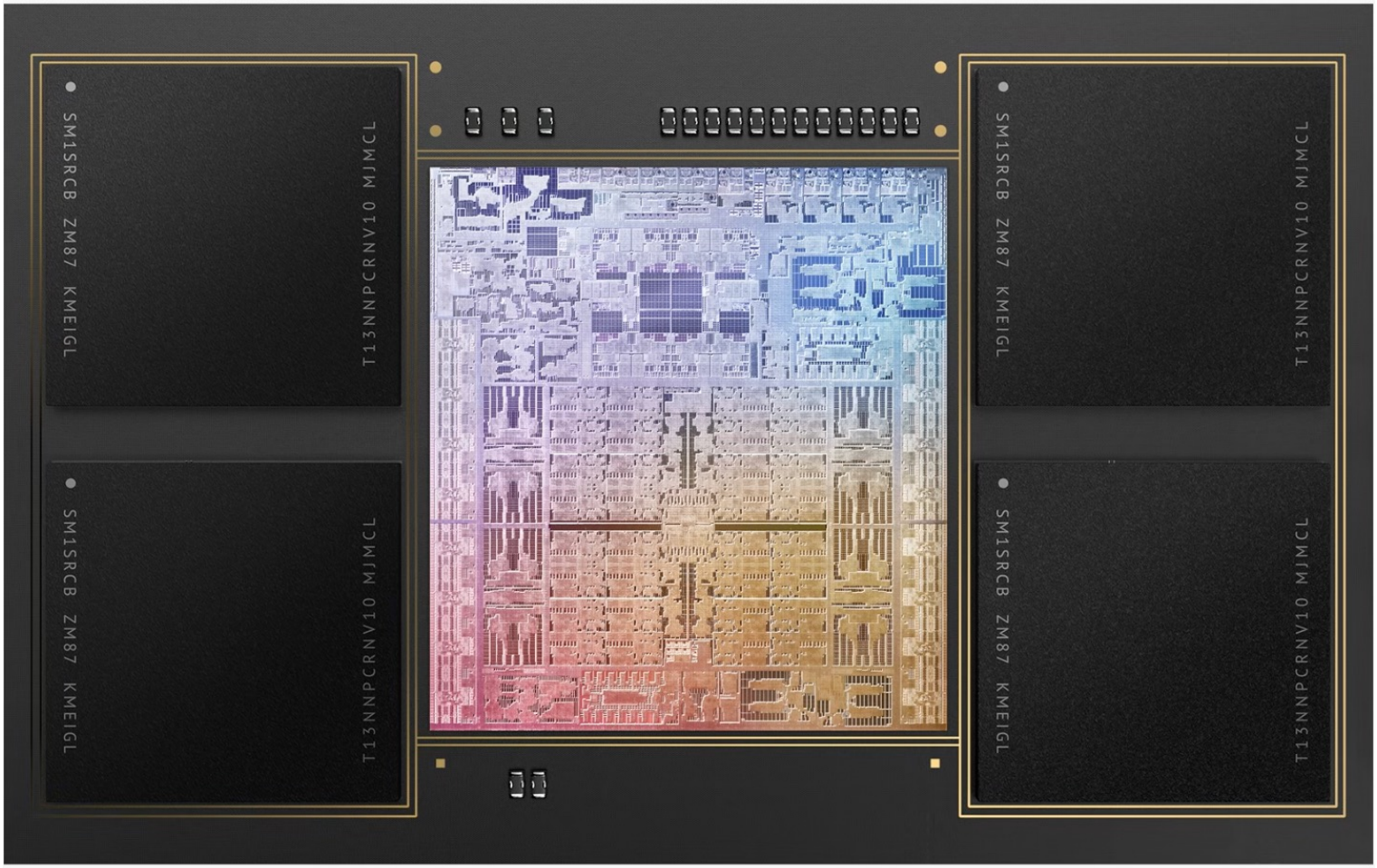
164 gigapixels/second



Apple M1 Max



Apple M1 Max



64GB unified memory

High bandwidth, low latency

512-bit LPDDR5 interface

Apple-designed custom package

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Apple M1 Max

ProRes
encode and decode

Thunderbolt 4

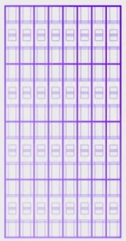
Secure Enclave

Support for four external displays

Up to
64GB
Unified memory

57 billion
Transistors

10-core
CPU



Up to
32-core
GPU

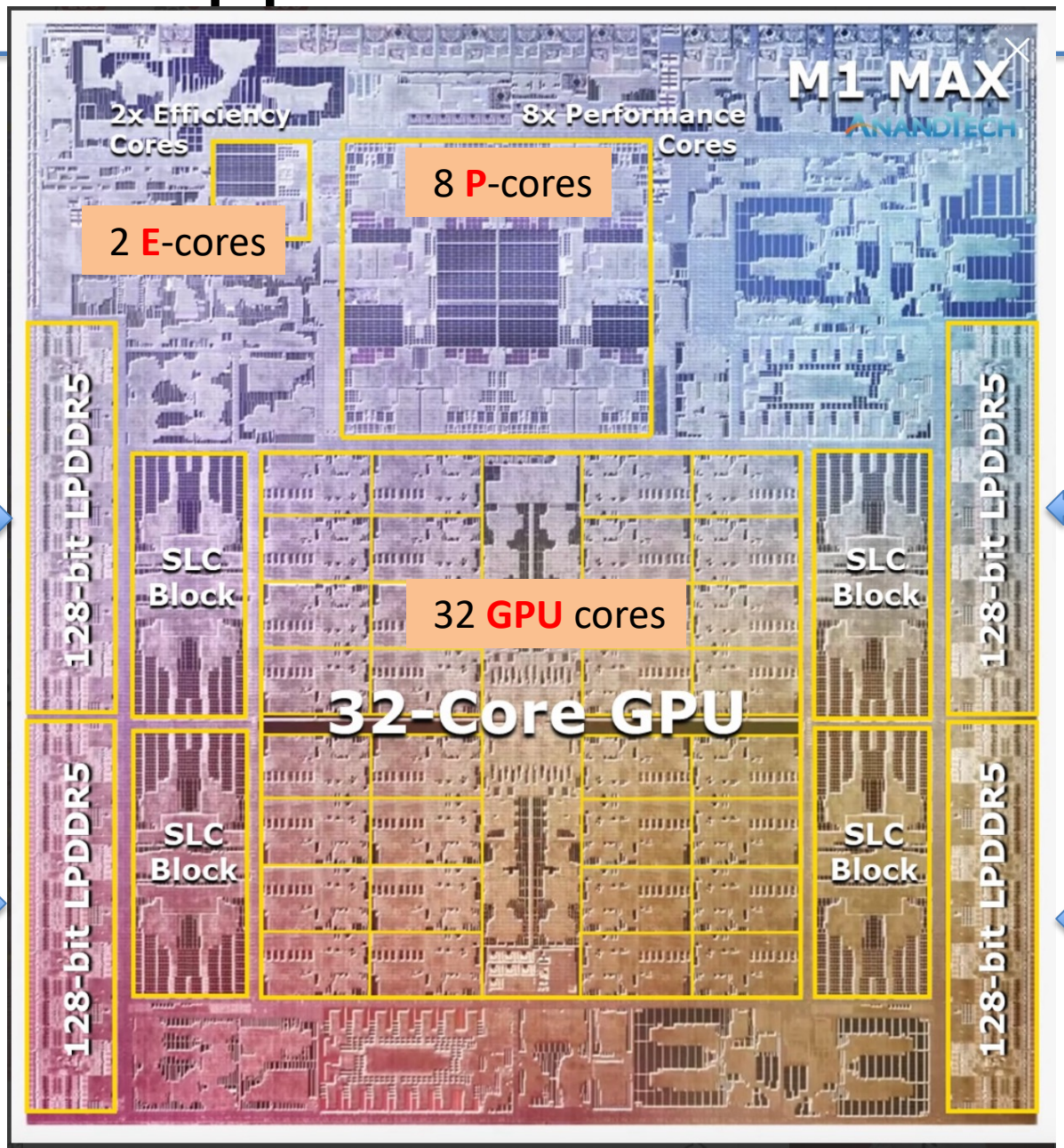
16-core
Neural Engine
11 trillion operations per second

Industry-leading
performance per watt

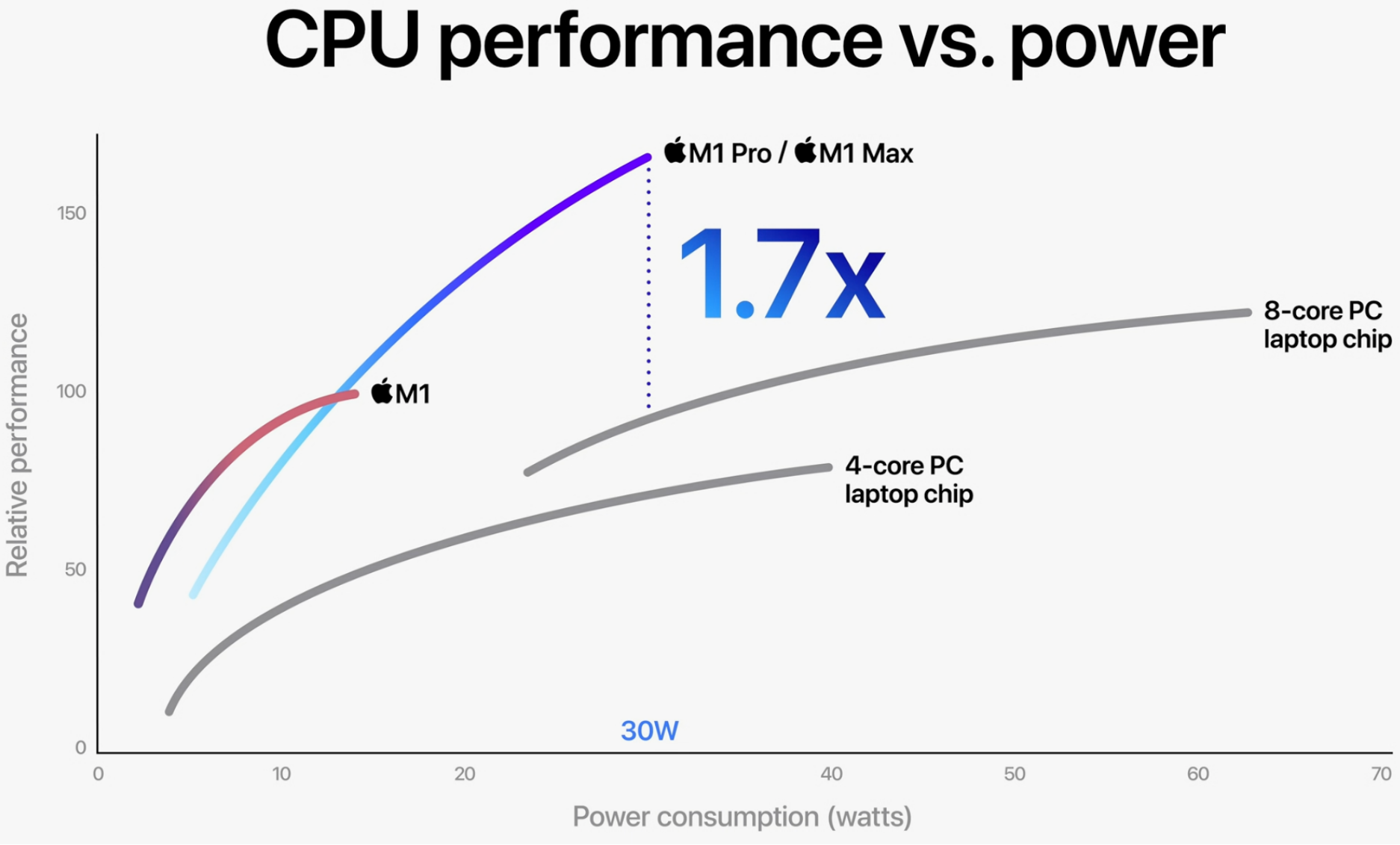
5 nm process

400GB/s
Memory bandwidth

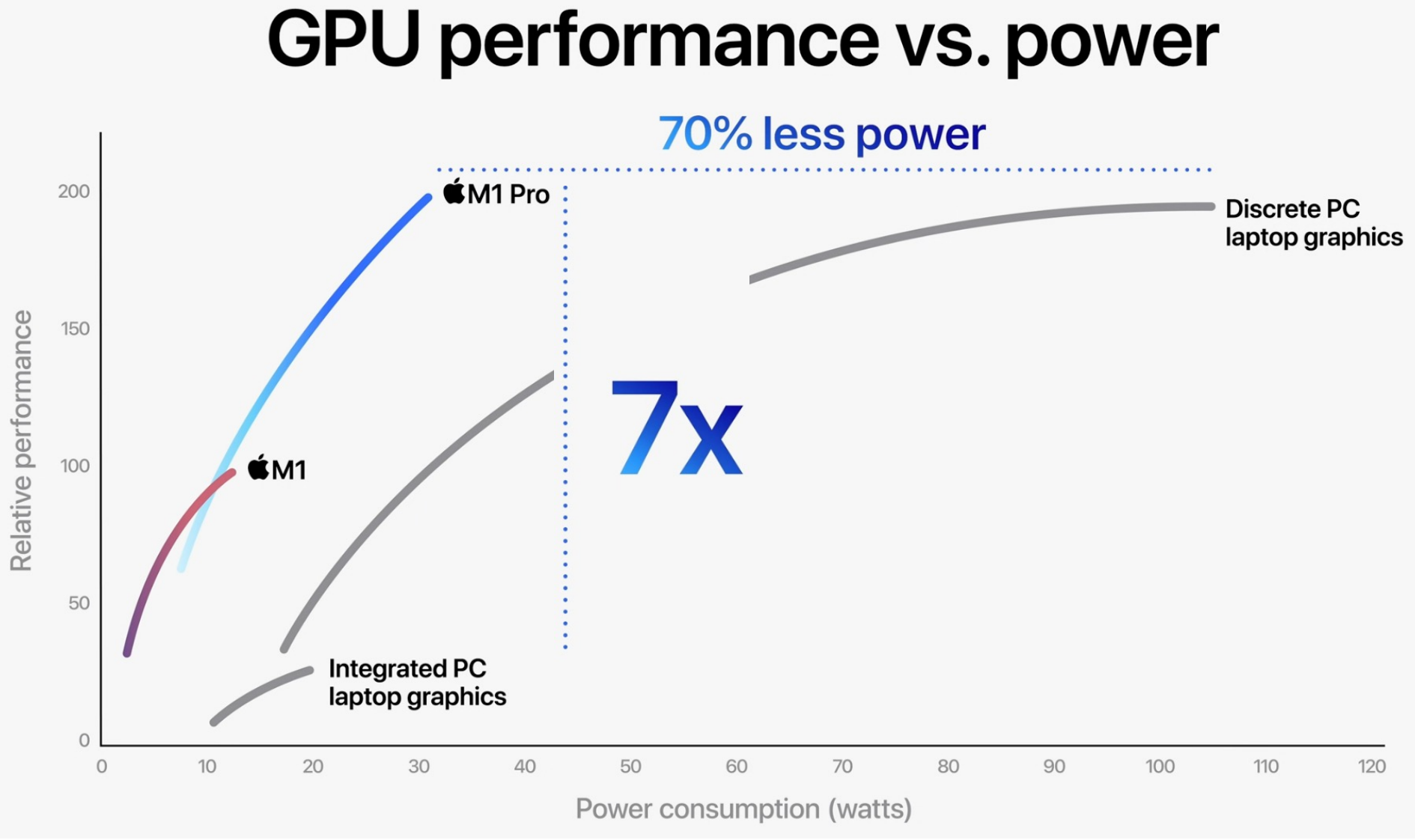
Apple M1 Max Die



Apple M1 Max



Apple M1 Max



Apple M1 Max

Hardware-verified secure boot

Runtime anti-exploitation

Fast in-line encryption

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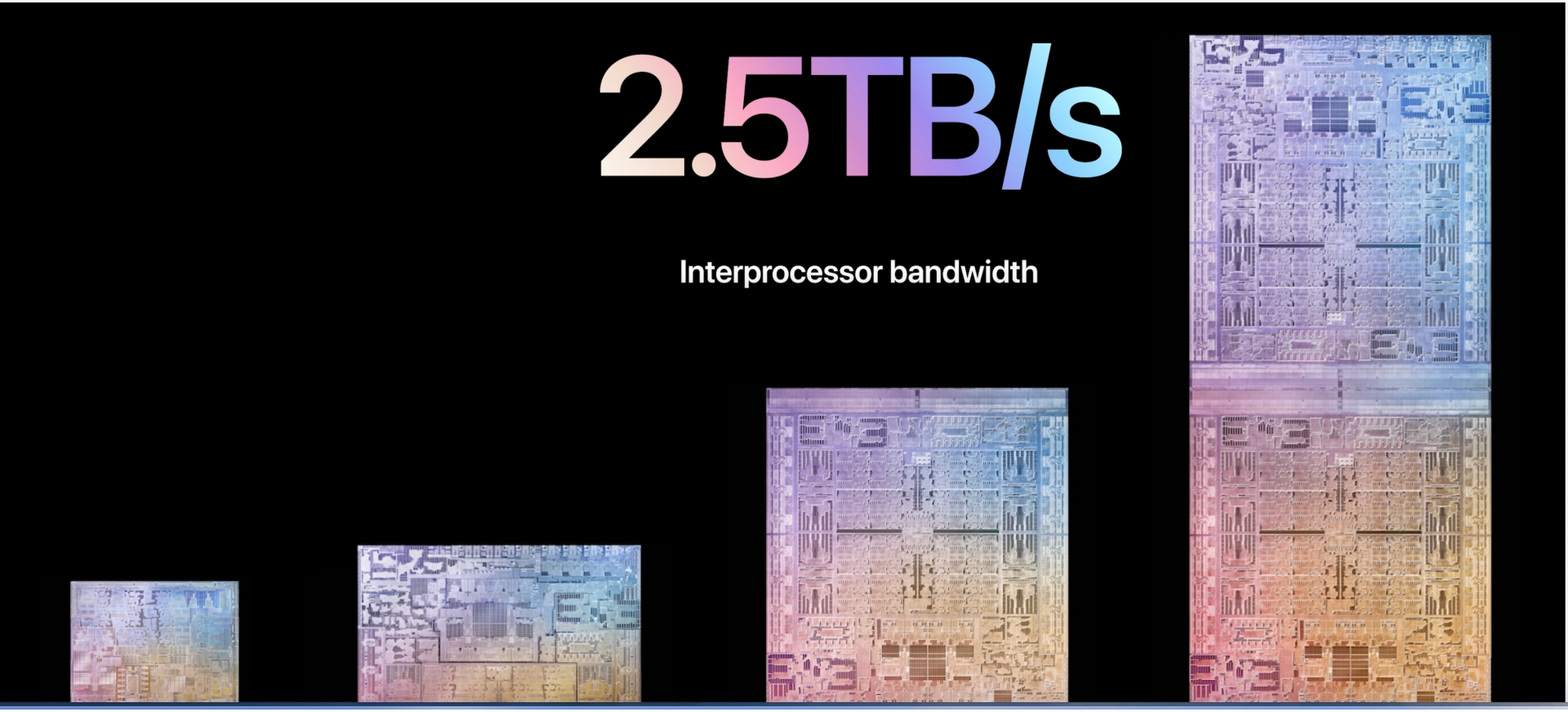
New Apple Event

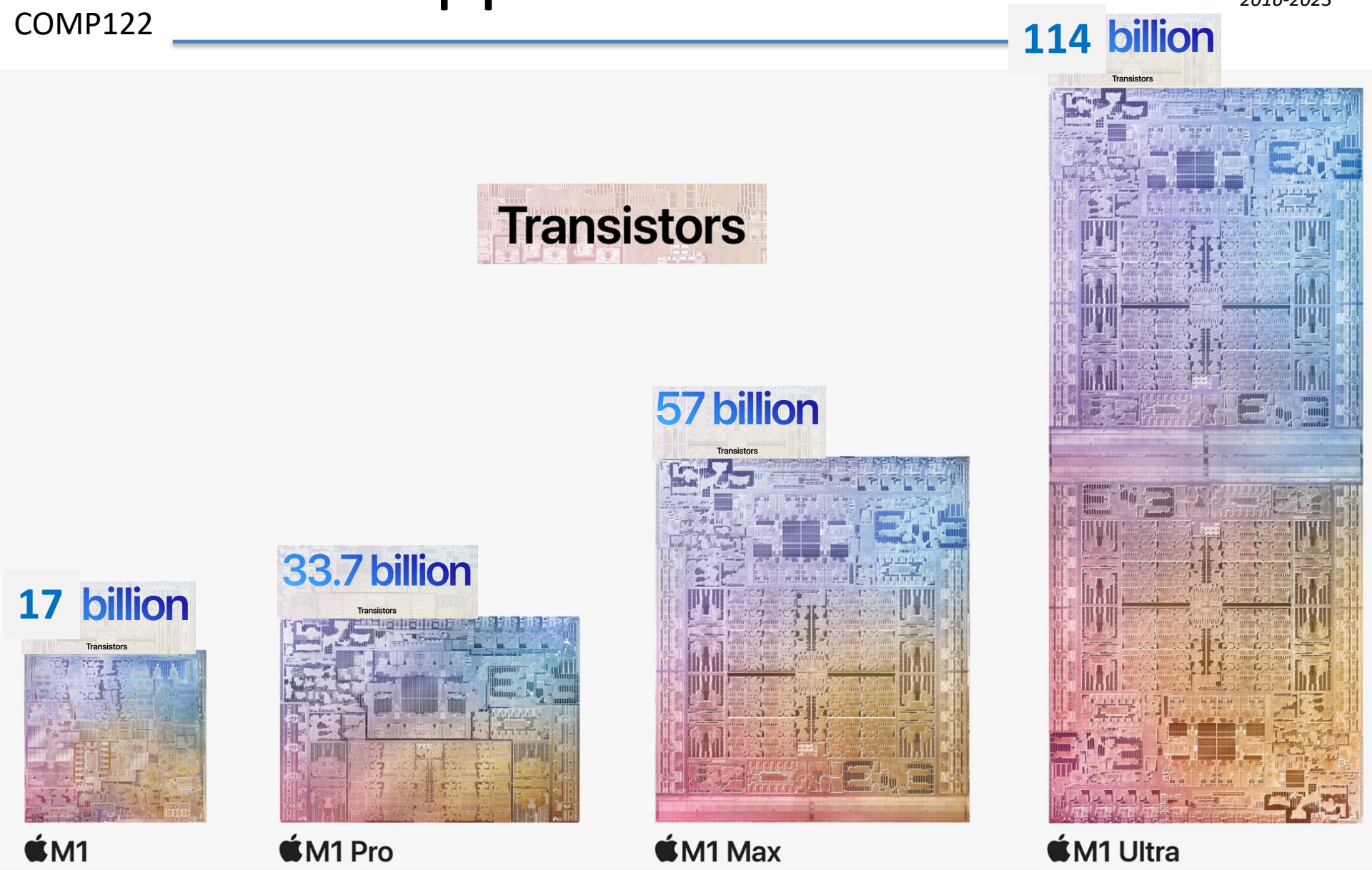
March 8, 2022

New Chip: M1 Ultra

March 8, 2022



Apple M1 Models



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New Chip: M1 Ultra

March 8, 2022

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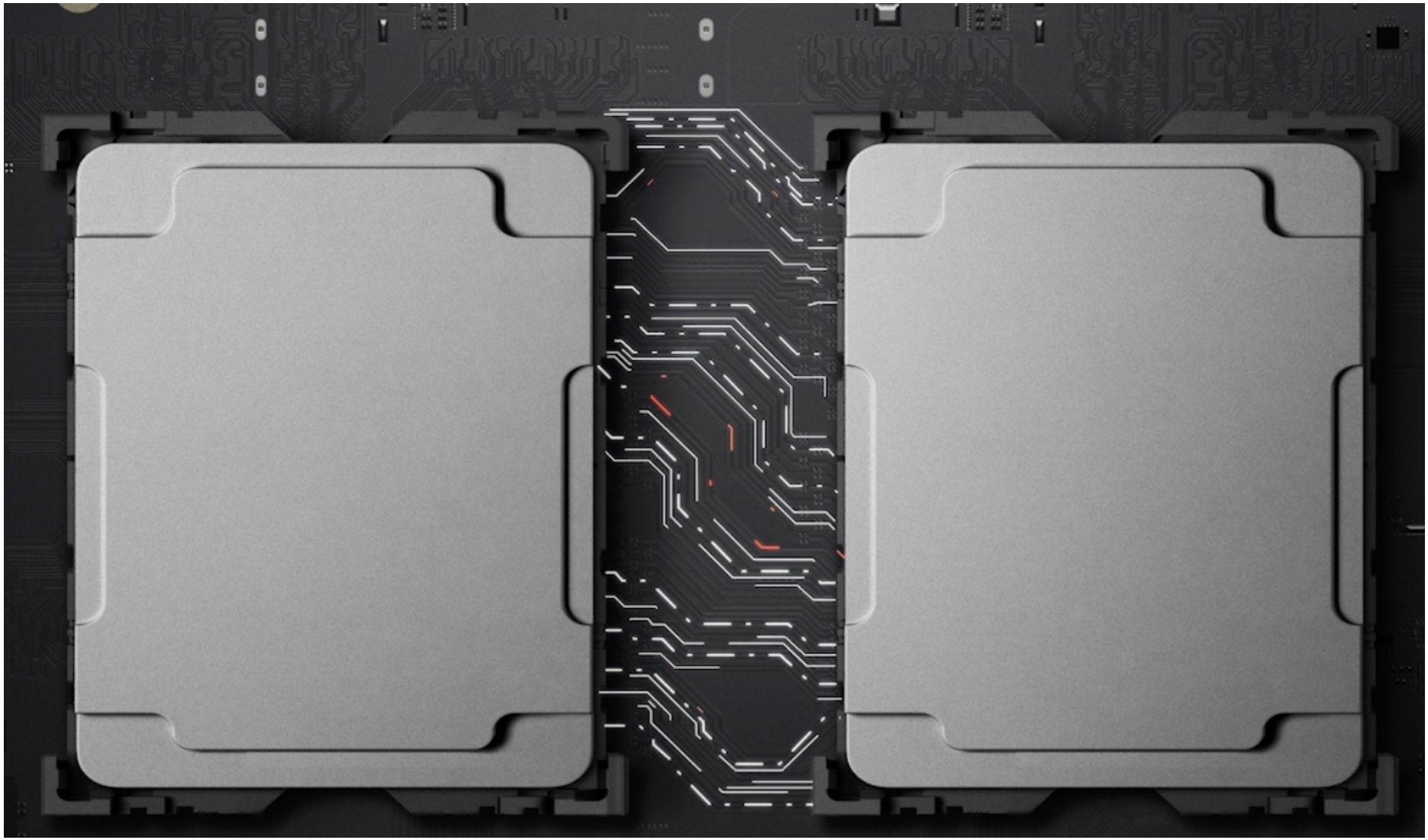
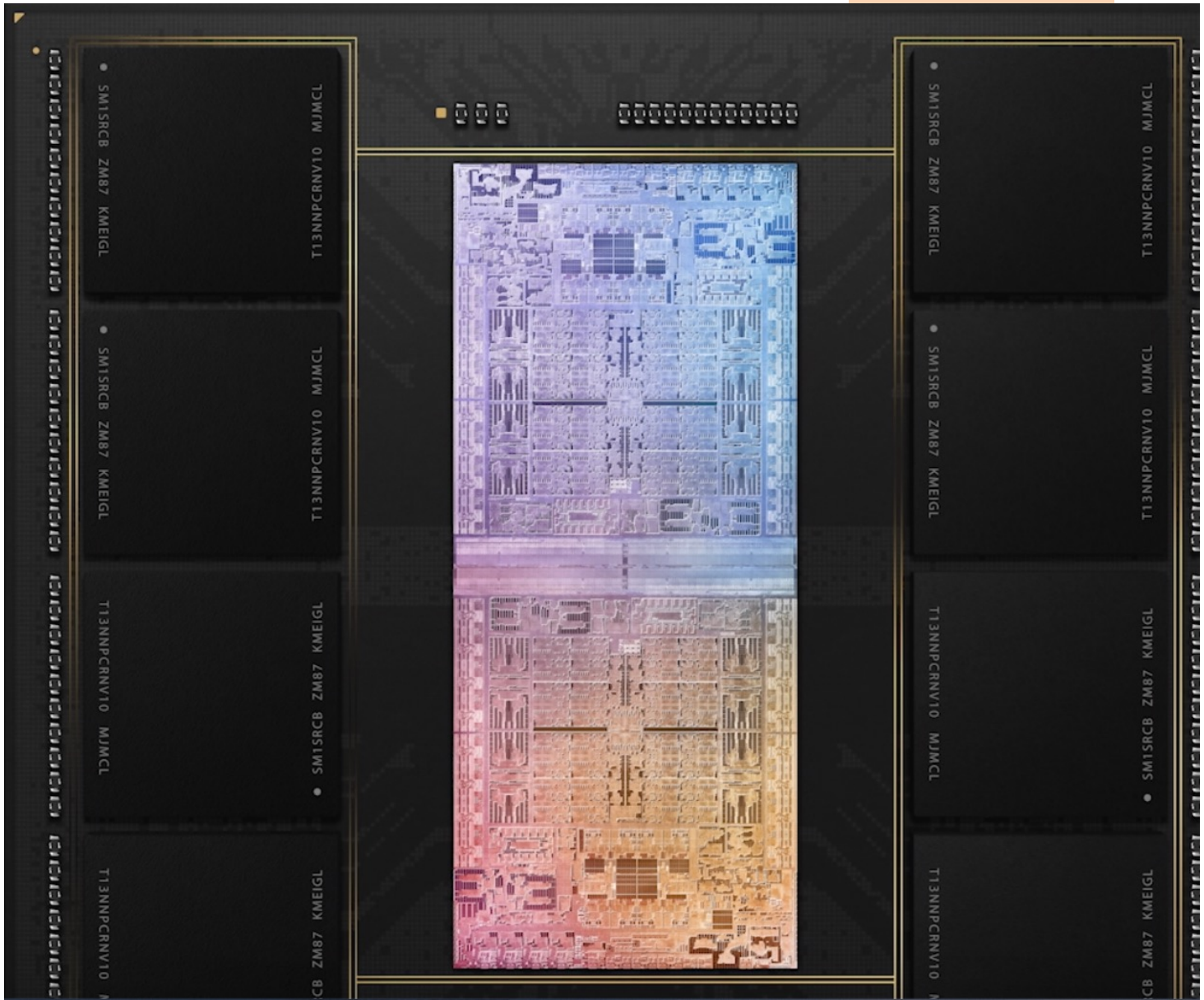


New Chip: M1 Ultra

March 8, 2022



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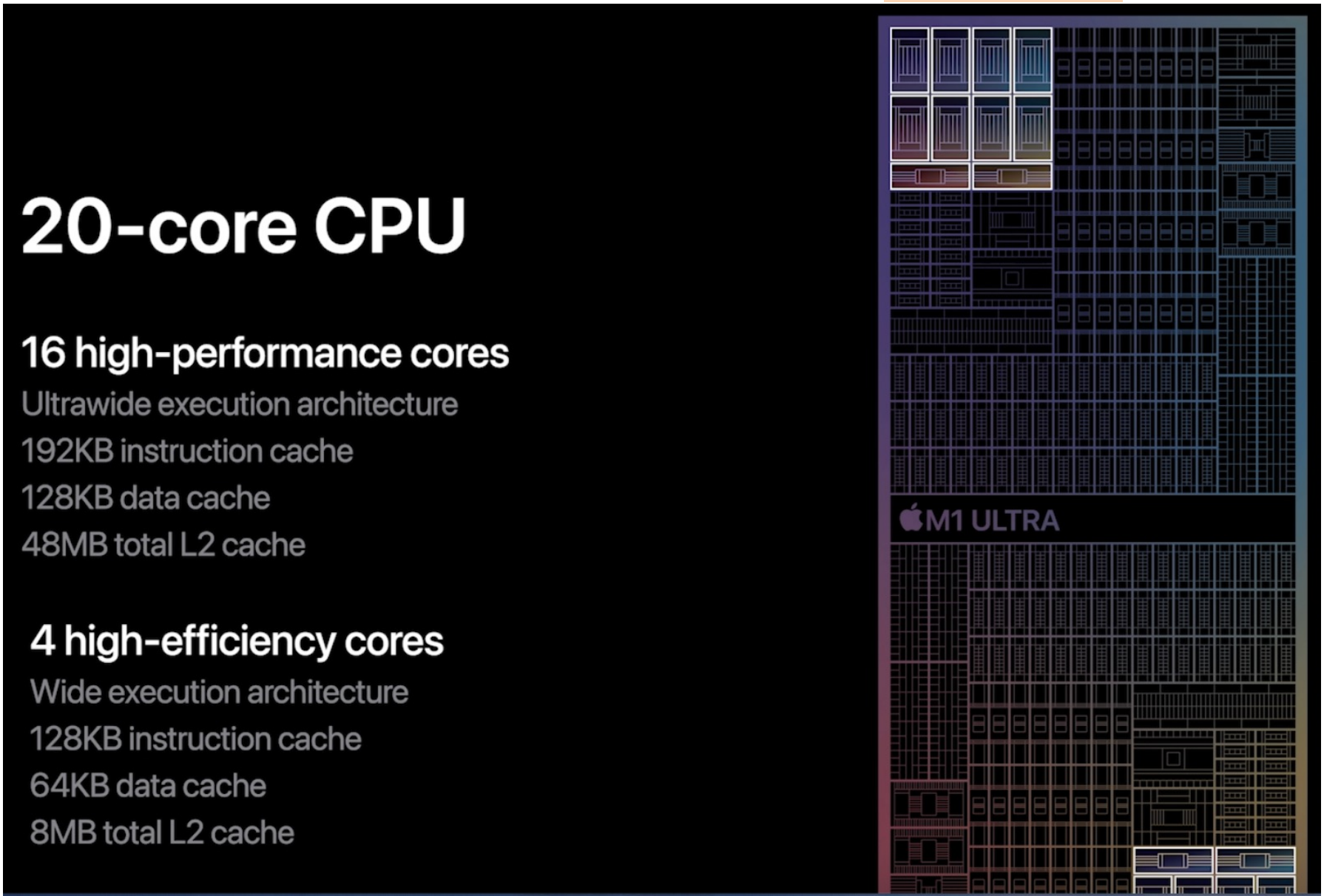
New Chip: M1 Ultra

March 8, 2022

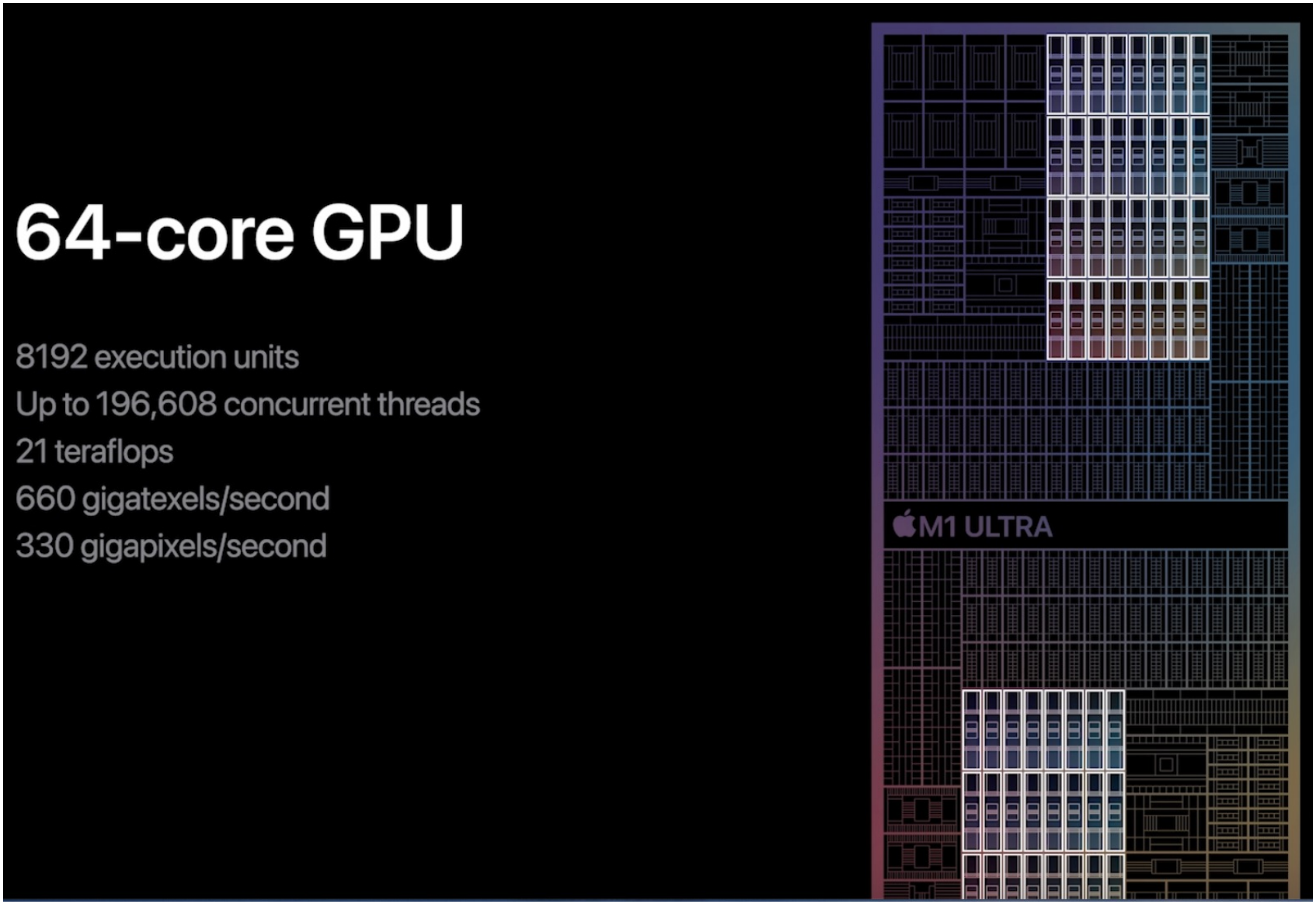
New Chip: M1 Ultra

March 8, 2022



New Chip: M1 Ultra

March 8, 2022



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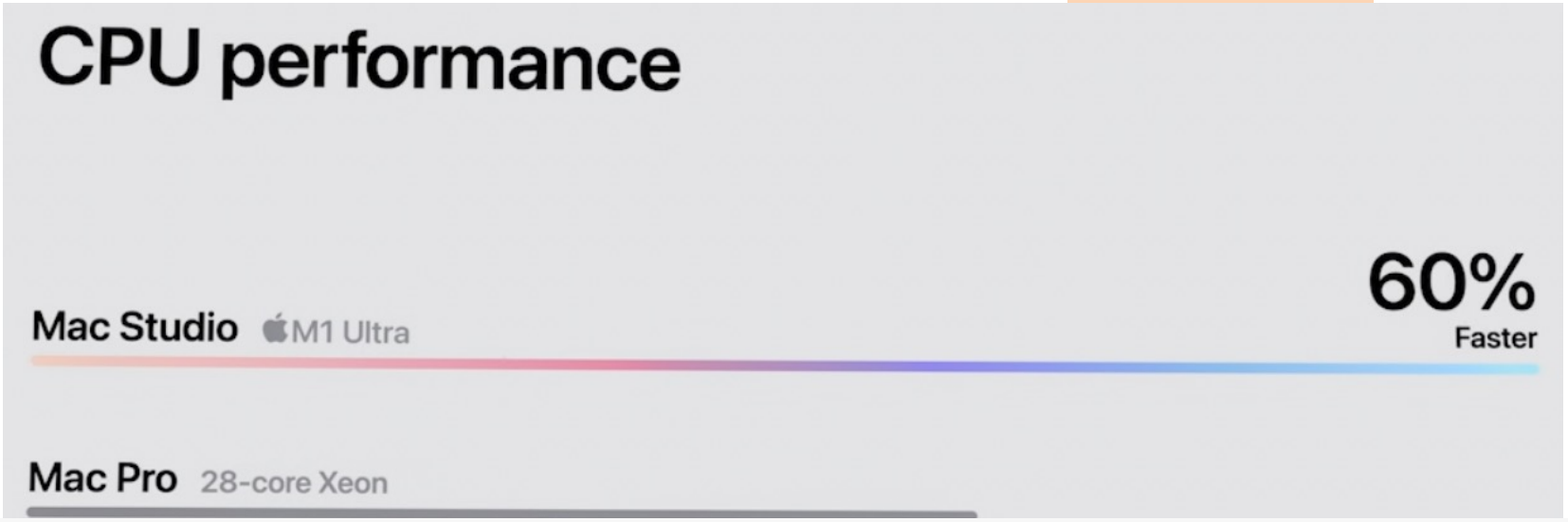
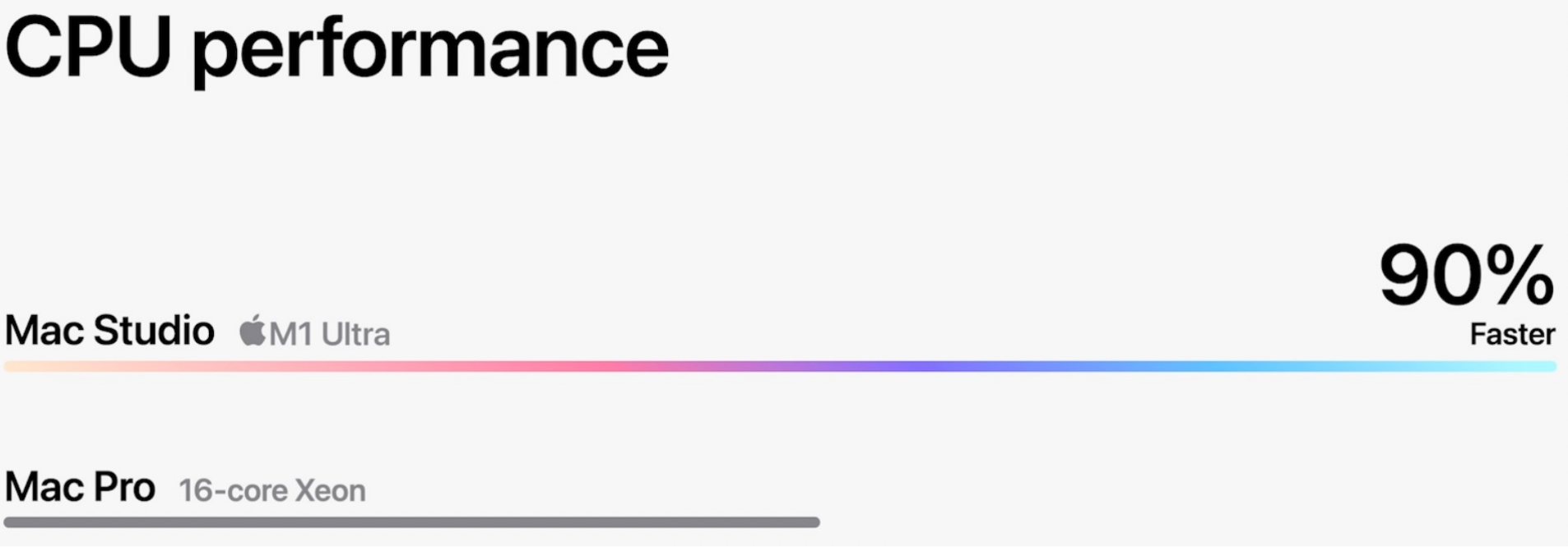
M1 Ultra: CPU Performance

March 8, 2022





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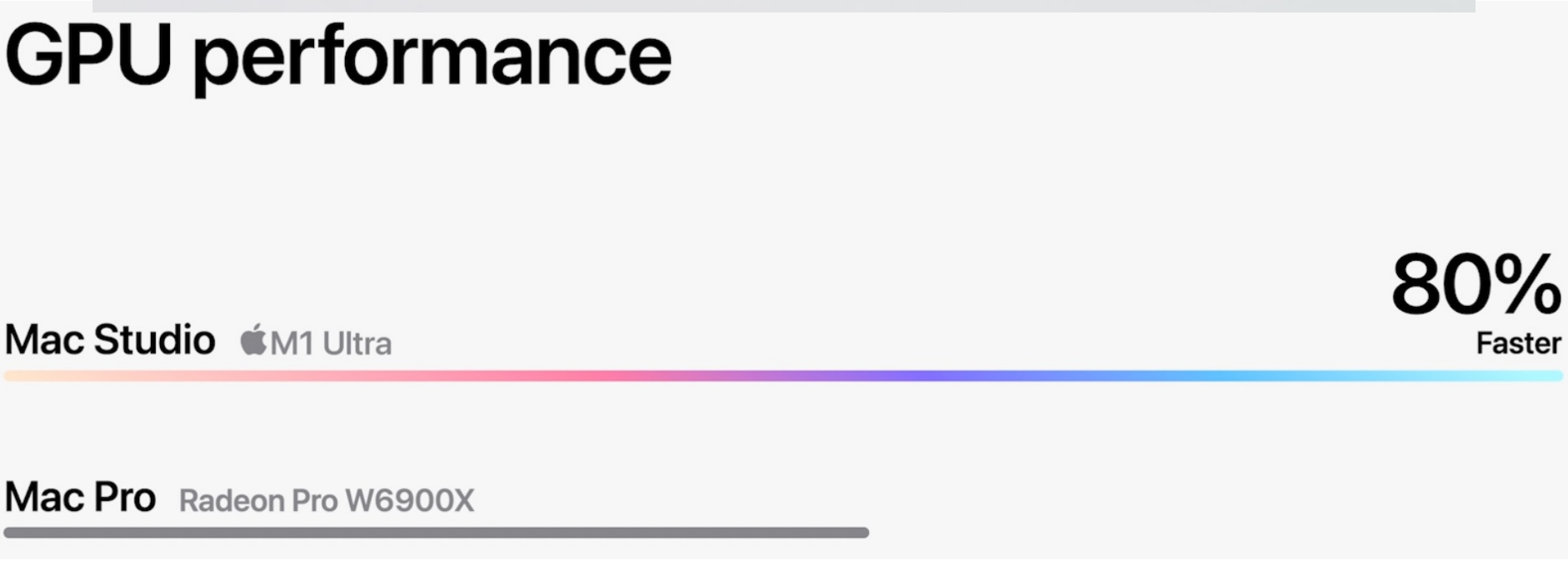
M1 Ultra: GPU Performance

March 8, 2022



Section

June 6, 2022

Apple Chips

Second-generation
5 nanometer

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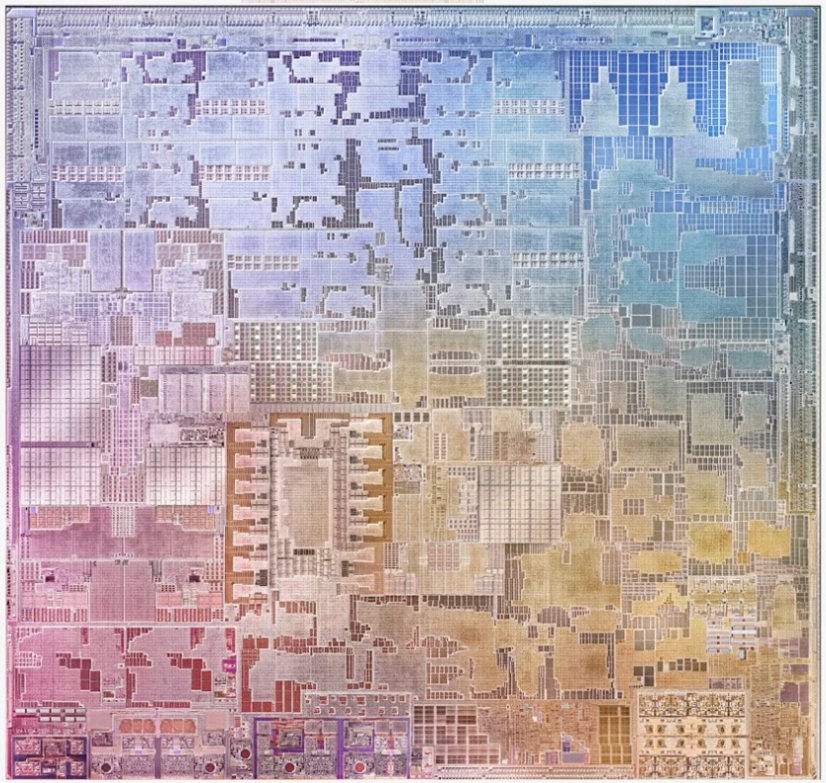
Apple M2 Die

DR JEFF SOFTWARE
INDIE APP DEVELOPER

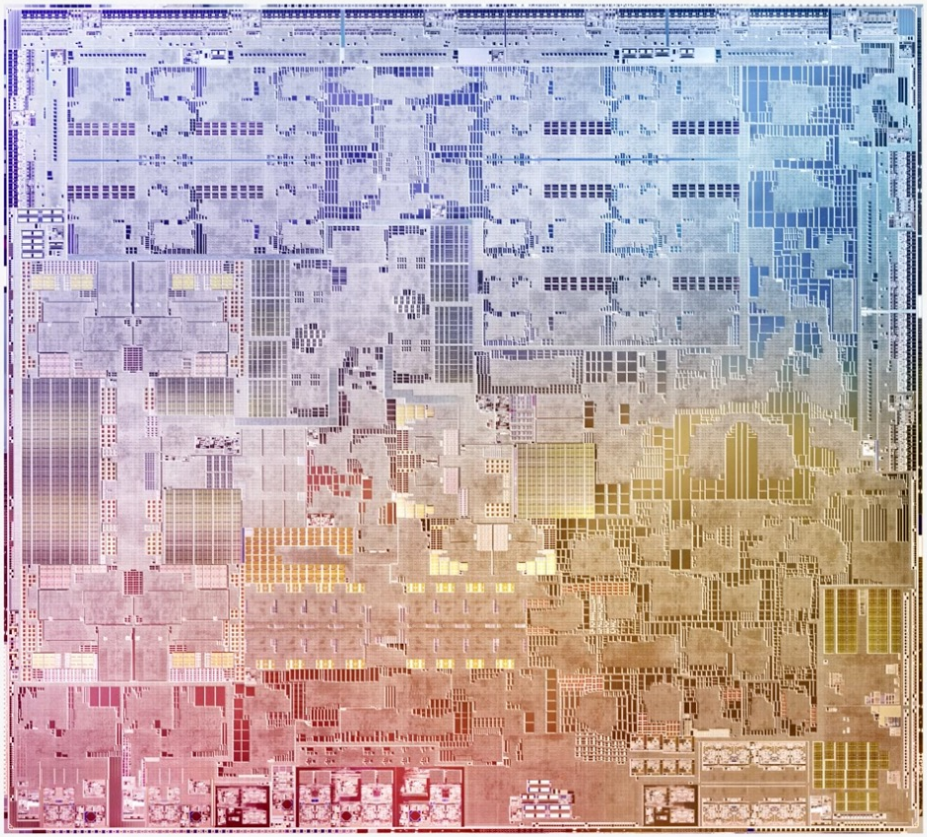
June 6, 2022

Second-generation
5 nanometer

17 billion
Transistors



M1



M2

20 billion
Transistors

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Apple M2

June 6, 2022

Up to
24GB
LPDDR5 memory

High-performance media engine

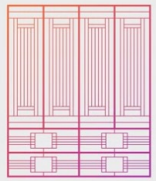
40%
Faster Neural Engine

Up to
15.8 trillion
operations per second
16-core Neural Engine

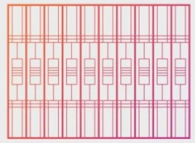
Second-generation 5 nm technology

ProRes
encode and decode

6K external display support



8-core
CPU



Up to
10-core
GPU

Over
20 billion
transistors

18%
Faster CPU

35%
Faster GPU

Industry-leading performance per watt

50%
More memory bandwidth

100GB/s
Memory bandwidth

Apple M2

8-core CPU

P

4 high-performance cores

Ultrawide microarchitecture

192KB instruction cache

128KB data cache

Shared 16MB cache

E

4 high-efficiency cores

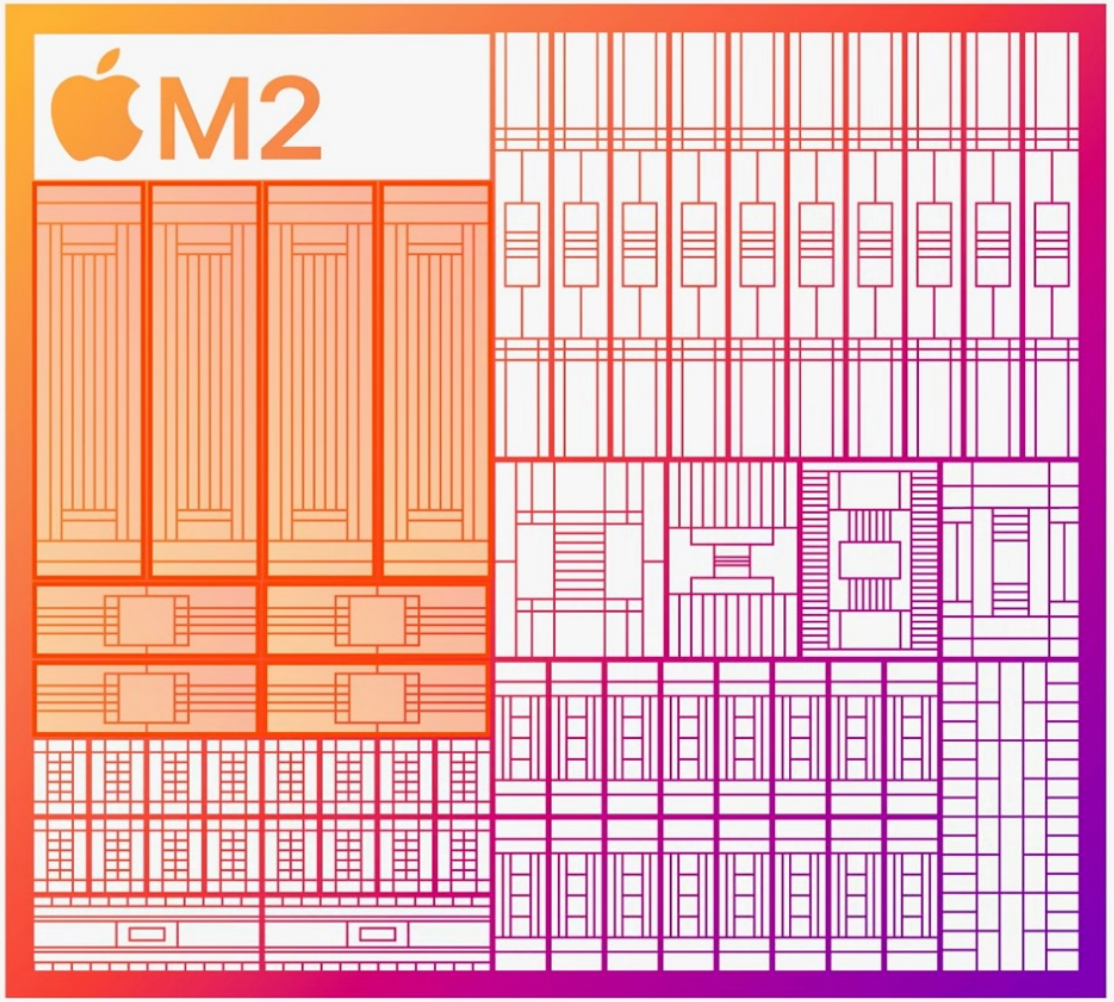
Wide microarchitecture

128KB instruction cache

64KB data cache

Shared 4MB cache

10 GPU cores



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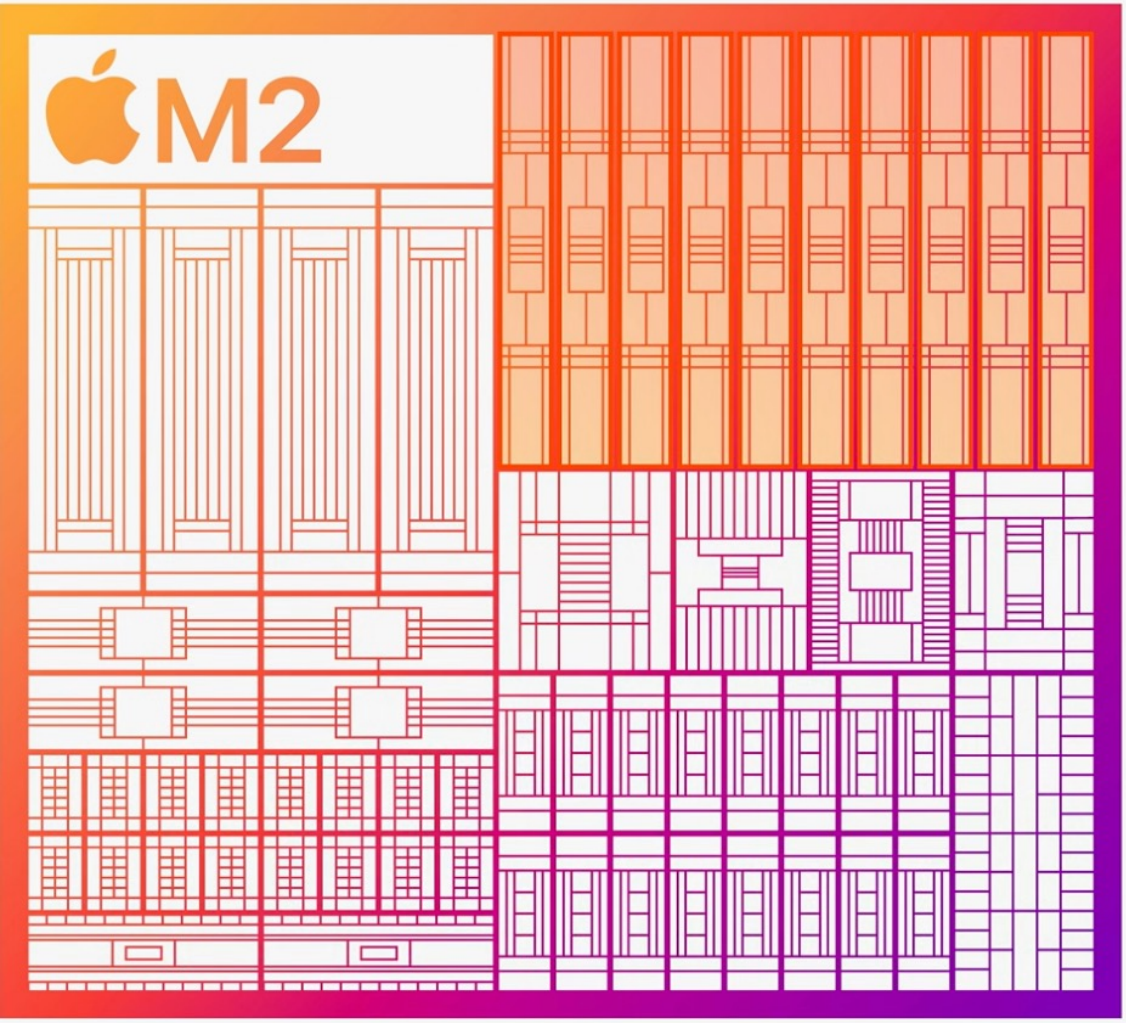
Apple M2

June 6, 2022



10-core GPU

Larger L2 cache

3.6 teraflops

111 gigatexels per second

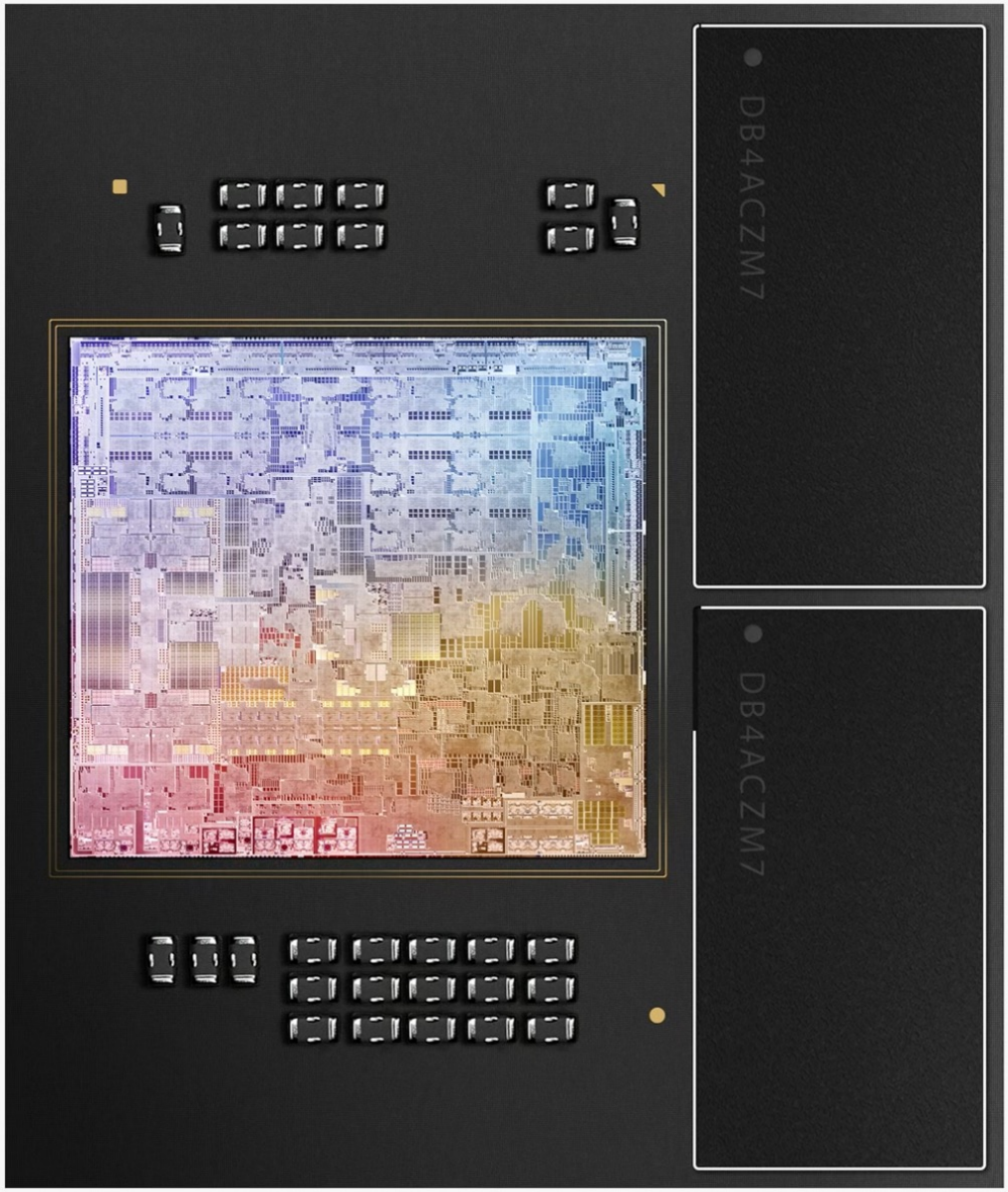
55 gigapixels per second

20 billion

Transistors

Apple M2 Module

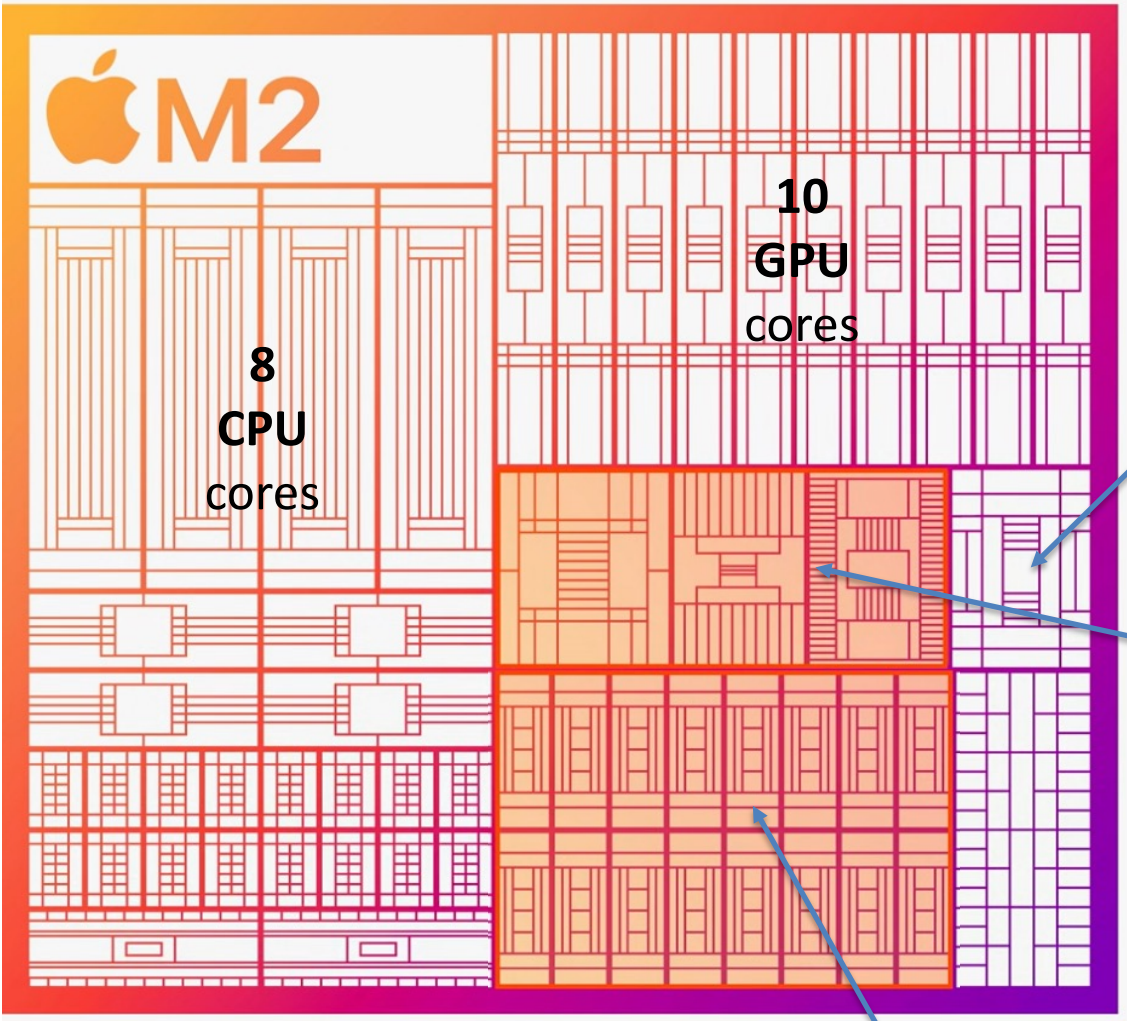
June 6, 2022



24GB unified memory

Apple M2

June 6, 2022



Secure Enclave

Media engine

8K H.264, HEVC, ProRes

Video decode engine

Video encode engine

ProRes encode/decode engine

Neural Engine

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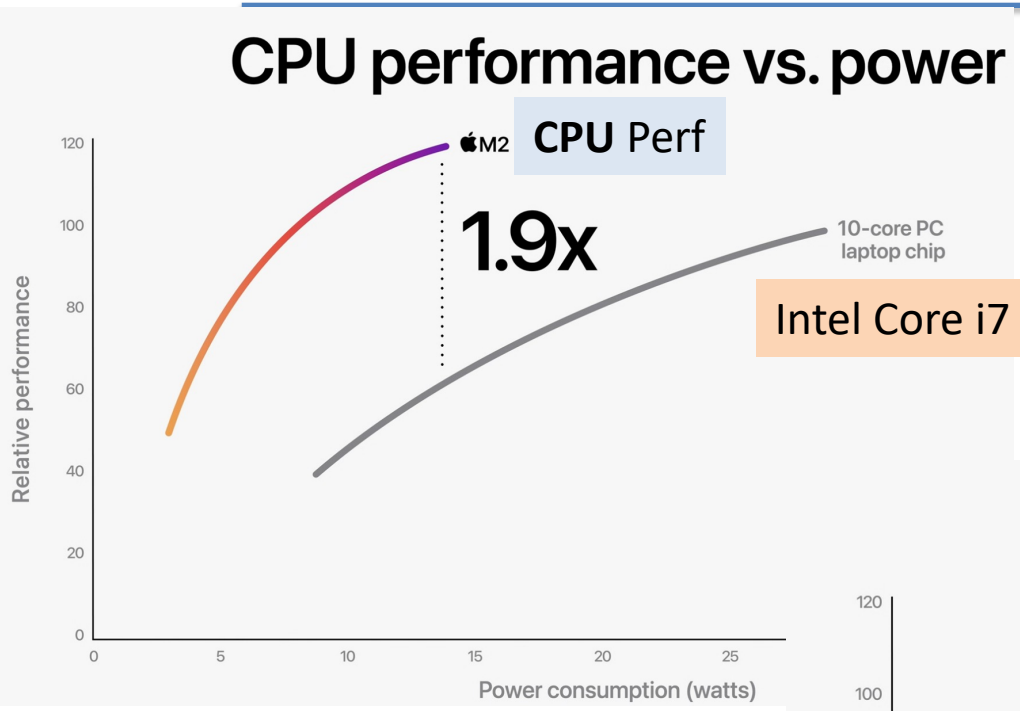
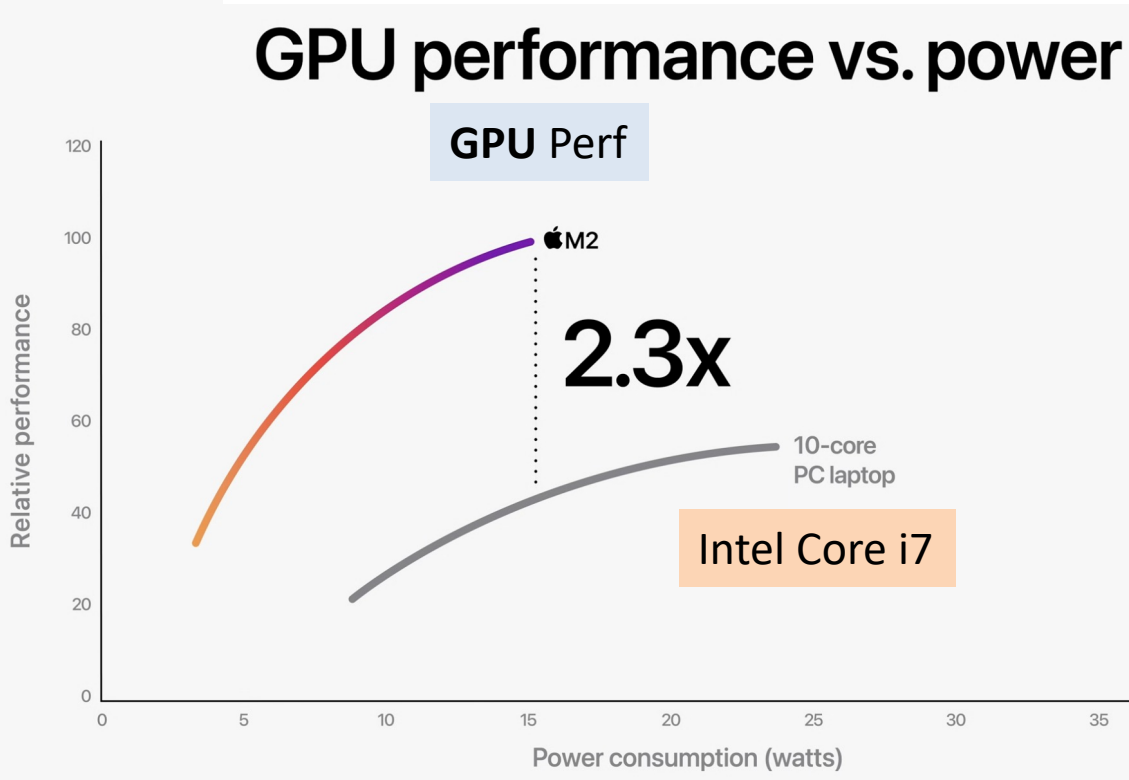
Apple M2 v Intel

June 6, 2022





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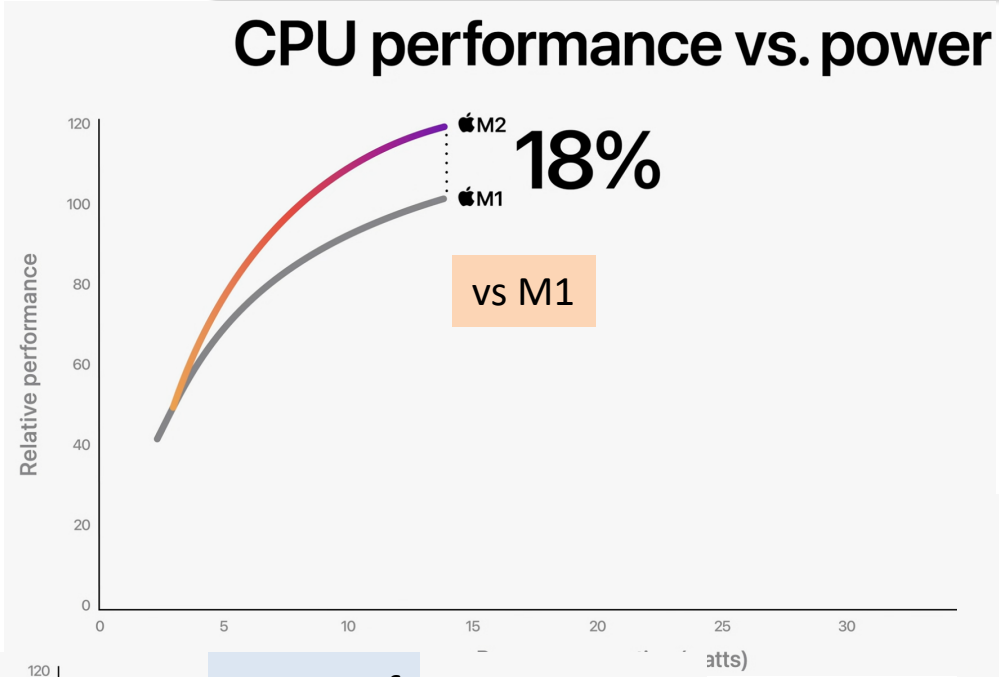
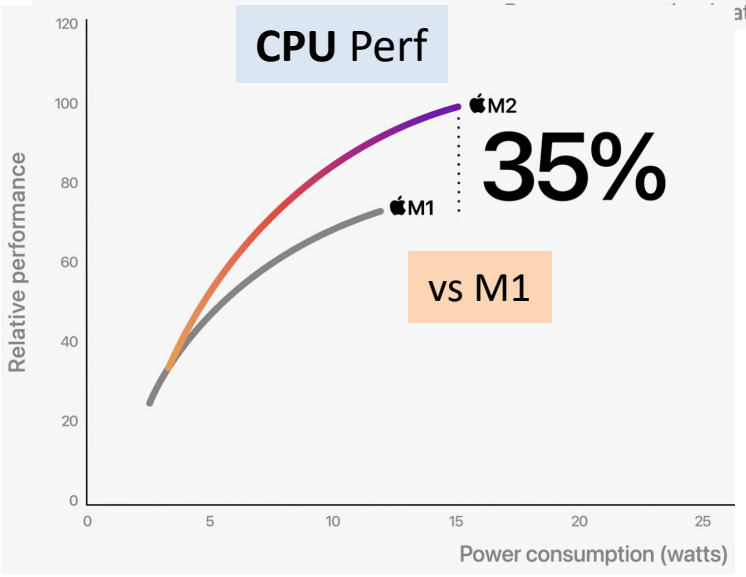
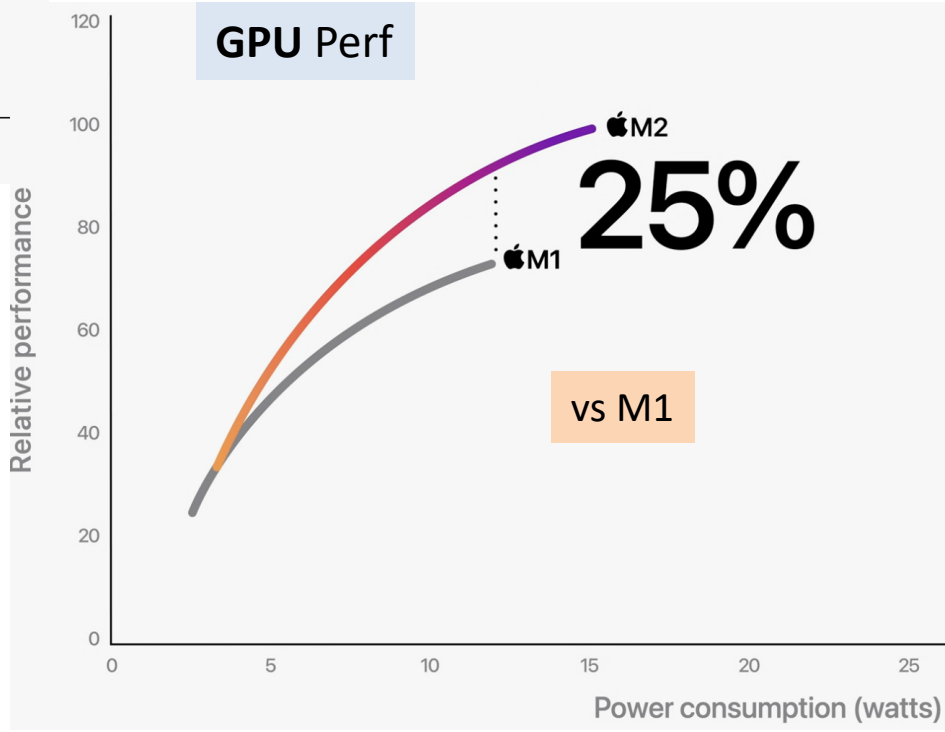
Apple M2 v M1

June 6, 2022







Section

Apple Chip

Fab/Mfg

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TSMC 4nm

Apple Orders 4nm Chip Production for Next-Generation Macs

Tuesday March 30, 2021 12:35 am PDT by Sami Fathi

Apple has booked the initial production capacity of 4nm chips with long-time supplier TSMC for its next-generation Apple silicon, according to industry sources cited in a new report today from *DigiTimes*.

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Apple & TSMC

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> *Apple has already booked the initial capacity of TSMC's N4 for its new-generation Mac series, the sources indicated. Apple has also contracted TSMC to make its next-generation iPhone processor dubbed A15, built using the foundry's N5 Plus or N5P process node, the sources said.*
>
> *TSMC is expected to kick off production for Apple's A15 chip that will power the upcoming iPhone 13 series by the end of May, the sources noted.*

The latest Apple silicon, the M1 chip, is the first of its kind in the industry based on the 5nm process. The A14 Bionic chip in the iPad Air and iPhone 12 lineup is also based on the 5nm process. According to the report, Apple is already looking to the 4nm chip process for its next-generation Apple silicon.

A timeframe for when these new 4nm chips will debut isn't provided, but *DigiTimes* does report that TSMC will move to volume production of the new process in Q4 of 2021, ahead of the previously set 2022 timeframe. Additionally, Apple plans to use an enhanced version of the 5nm process for the A15 chip in the iPhone 13, with production set to get underway by the end of May.

The smaller process reduces the chips' actual footprint and provides better efficiency and performance. Apple's expected to launch multiple new Macs this year with more powerful Apple silicon chips; however, there's no indication that any will be based on the 4nm process.

TSMC $ Apple

Taiwan Semiconductor asked for 2023 price increase from Apple, tech giant said no: report

Sep 28, 2022 11:23 AM ET | **Taiwan Semiconductor Manufacturing Company Limited (TSM)** | Chris Ciaccia, SA News Editor

Taiwan Semiconductor (NYSE:TSM) is slated to raise prices on its customers starting in 2023, but the company's largest customer, Apple (NASDAQ:AAPL), has reportedly told the global foundry no deal.

According to Chinese news outlet Economic Daily News, Taiwan Semiconductor (TSM) wanted to increase the price of the process for its 3 nm process by 3%, which may be used in the A17 chip in some of Apple's (AAPL) Mac computers and perhaps next year's iPhone. However, the tech giant refused and said no, the news outlet said, citing sources.

In May, it was reported that Taiwan Semiconductor Manufacturing (TSM) had started to tell some of its customers that it will raise its prices between 5% and 9%, starting next year, due to inflation concerns, rising costs and its expansion.

Cupertino, California-based Apple (AAPL) is Taiwan Semiconductor's (TSM) largest customer and some reports have suggested that it accounts for as much as 25% of the global foundry's annual revenue.

25%

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TSMC 3nm

SemiWiki.com
The Open Forum for Semiconductor Professionals

8-17-22

TSMC's Initial 3nm HVM Yield To Be Better Than Its 5nm

TSMC **N3e** is the HPC version for Intel, AMD, Nvidia, etc... The SoC companies Apple, Mediatek, will use **N3**. Please remember that TSMC sets expectations on the conservative so they don't disappoint. According to my sources N3 for Apple was frozen in December and the N3e process is now frozen with HVM starting in 1H 2023.

- Apple now in production (HVM) with **4nm**

Software

Apple MacOS

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New Mac OS

November 10, 2020

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New Mac OS

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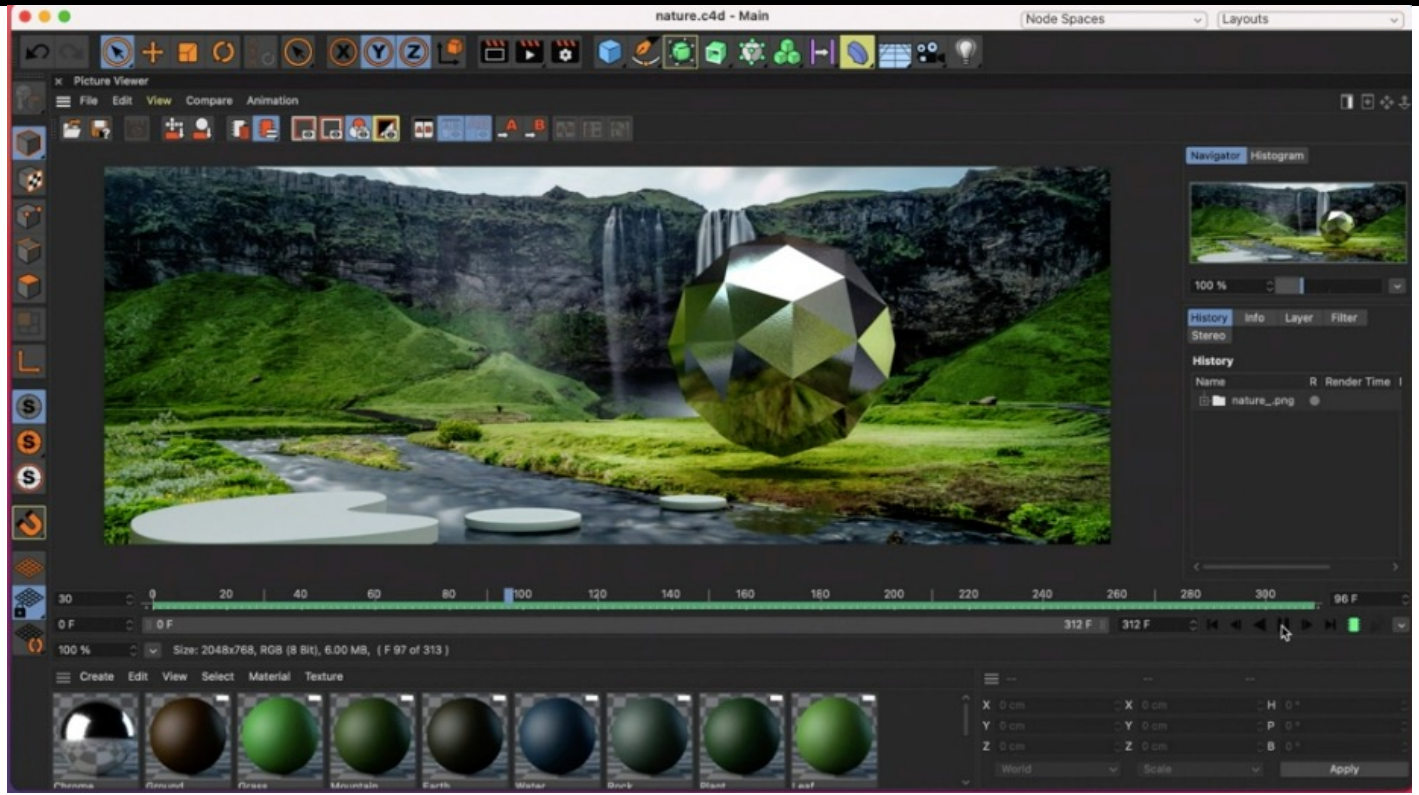
November 10, 2020

Hardware-verified secure boot

Automatic high-performance encryption

macOS run-time protections



Software

Apple Software

iOS

6-7-21

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WWDC 21

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iOS 15