# Moore’s Law


The journey of semiconductor and CPU performance growing

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# Path and Challenge

For the first two weeks, we brainstormed various potential topics for our project. Ultimately, we decided to focus on the development of CPUs as the main storyline. We chose this topic because while CPUs are remarkable intellectual products, they have certain knowledge boundaries and may be perceived as less interesting by most people. Our aim is to utilize visual aids to engage even those without extensive knowledge (though some basic computer science understanding is required) and demonstrate that this subject can be fascinating.

After selecting the topic, we embarked on a search for the necessary data to support our story. Simultaneously, we began discussing the types of visualizations that would enhance our storytelling. This process quickly became iterative as new data emerged, presenting us with additional visualization possibilities. Likewise, as new plots or elements arose, we had to identify and obtain the relevant data required to effectively incorporate them. In the end, we accumulated two datasets based on data: one dataset included the evolution of semiconductor technology on a single chip, while the other was manually collected by us, containing data on classic Intel and AMD CPUs from 1995 to 2022. In addition to the data-based datasets, we also collected 12 figures (e.g., images of transistors) that we will later utilize to demonstrate the inner structure of transistors and various famous CPU architectures. The main challenge in this part mostly stems from the lack of data sources, particularly for older CPUs. Additionally, the diversity of the available data is somewhat limited. We will likely rely on multiple line or scatter plots to describe the information obtained from the data, which is informative but may be too tedious for the audience. To overcome this, we found a solution by incorporating some static figures we discovered (the figure-based datasets). By making these figures more interactive, we ensured the richness and diversity of content on our website, making the story far more interesting than simply describing the data.

With the data ready, we began transforming our story sketch into a well-structured introductory journey. The core of our story is based on the famous Moore's Law, which has served as a guiding principle in microprocessor development. The entire development trend of microprocessors can be divided into four stages: Manually Designed CPUs, Architecture Innovation for Single Core Performance, Parallel Processors, and Specialized CPUs (we skipped the first stage due to a lack of data). We decided to take the audience on a journey where they can easily understand the developments in CPU design without being overwhelmed by technical terminology. For certain concepts that are unavoidable (e.g., Instruction-Level Parallelism), we want the audience to perceive them as a "black box" (i.e., they don't necessarily need to know the exact details, just a general understanding is sufficient). The ultimate goal of the website is not to ensure that everyone comprehends the essence of each aspect of CPUs or the intricacies of the development process. Rather, we aim to create a "museum" that sparks people's interest in this field and provides a place they can revisit to gain new knowledge with each visit. To achieve this effect, we drew inspiration from our undergraduate computer architecture courses to ensure a smoother flow in the storytelling. Before delving into the development of CPUs, we start with a preliminary introduction to integrated circuits and transistors. Familiarizing the audience with the fundamental components of microprocessors will enable them to have a more complete understanding of the overall picture. The details of the visualizations will be explained in the "Sketch" section.

Finally, we reached the implementation stage. In this phase, we took cues from "Wine101" on how to structure our website. The challenges in this part are primarily technical. Although we know which widgets we may use most of the time, adapting them to the website is another story. Many adjustments and laborious work are required. Thanks to our persistence, we finally achieved a nice and clean version.

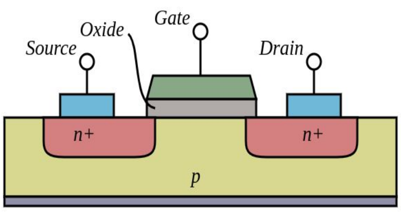
# Sketches

## 01. Transistor

Here we show how the CMOS work by visualizing the movement of the charge carriers inside the CMOS, and how the gate turns accordingly.

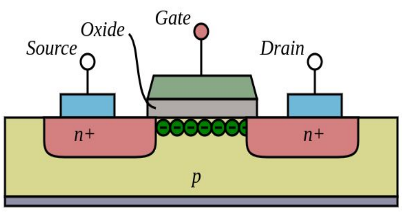
### Effects

Original



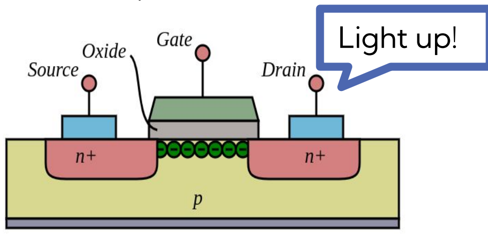

"Drain" voltage is low

Click "Gate"




Carriers appear

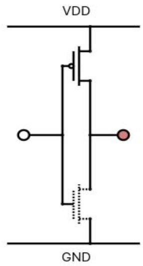
Then, click "Source"




"Drain" voltage gets high

## 02. Gate

Here we show how the three gates work (NOT, AND, OR). Users can learn the knowledge by interacting with the inputs, and checking the outputs.

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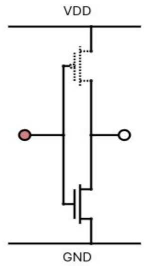
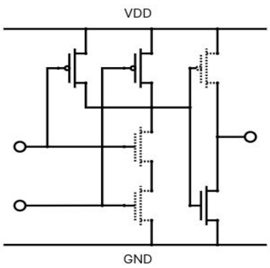
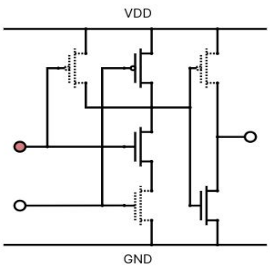



~1 = 0

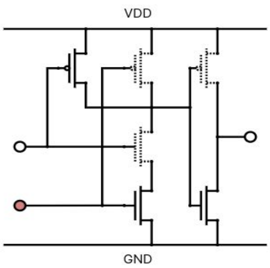
### Effects



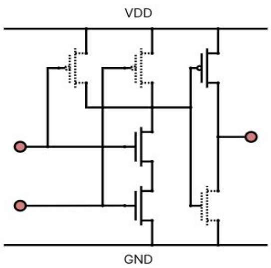

0 & 0 = 0



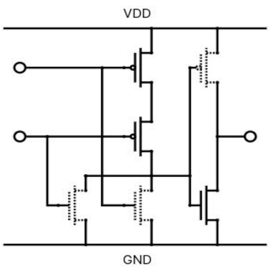

1 & 0 = 0




0 & 1 = 0




1 & 1 = 1

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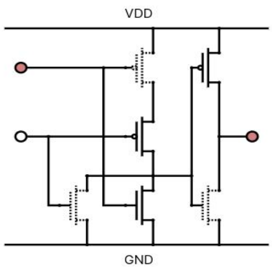
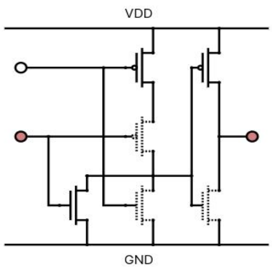
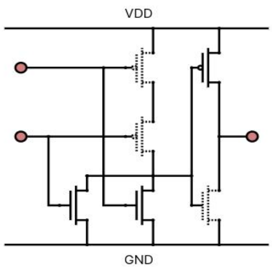



1 | 0 = 1




0 | 1 = 1



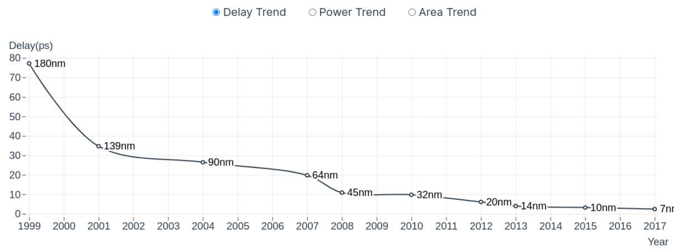

1 | 1 = 1

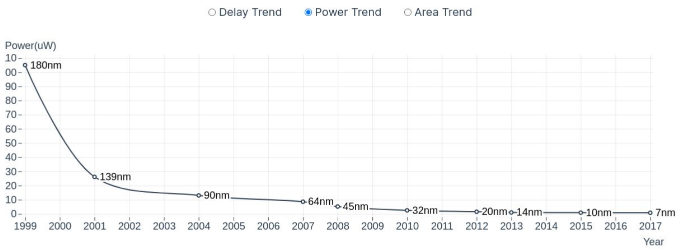
# 03. Trends of Transistor Delay, Power, and Area

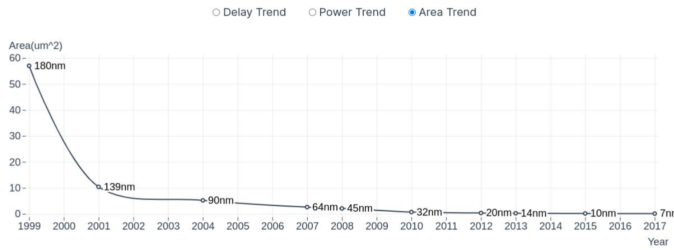
Here we give the user an overview of the trends of transistor delay, power, and area, which is the rationale behind Moore's Law.

### Effects

Click an item, then dots would be connected one by one, which gives the user an impression of the trends.



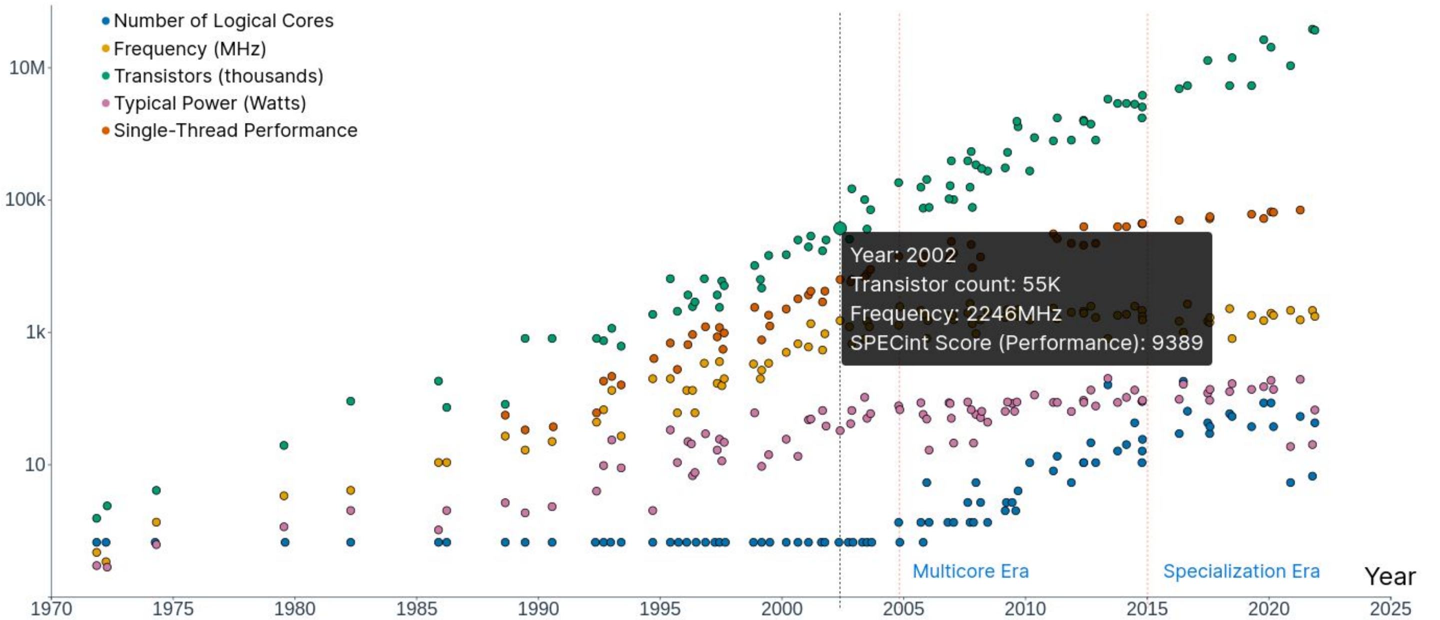




# 04. 50-Year Trend of CPU Design

Here we show the development trend of microprocessors during the past 50 years. Data included are CPU's frequency, number of logical cores, single-thread performance, number of transistors, and typical power consumption. Users can grasp an overview of how CPU has developed over the years, and the development patterns.

### Effects

Hovering on each dot, you will see the details of the feature value. The chosen dot would become bigger as indication. For the ease of distinguishing the dots, we use a color set that is friendly for the color-blind group, and add a black stroke. The red dashed lines separate different stages of microprocessor development.

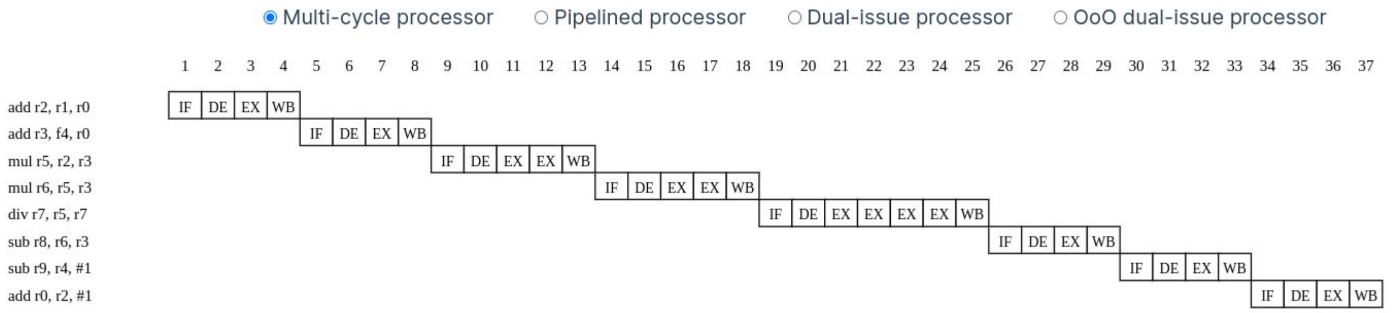


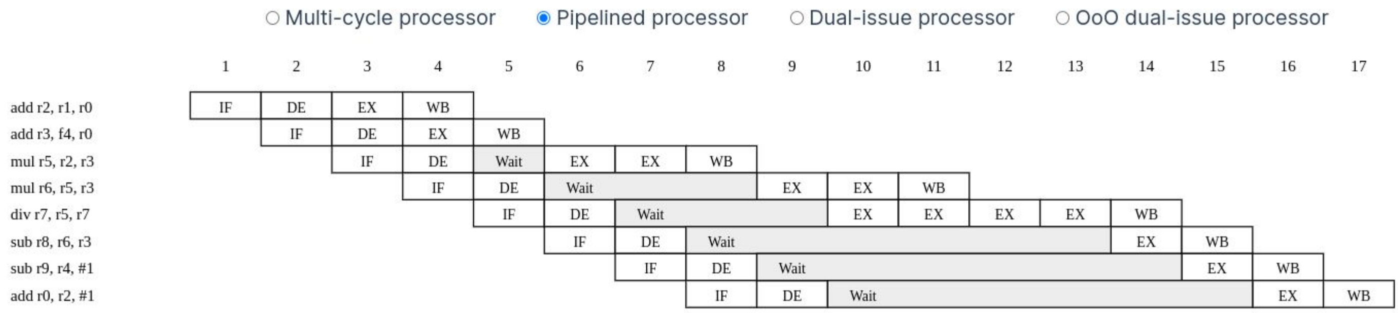
# 05. Microarchitecture Optimization

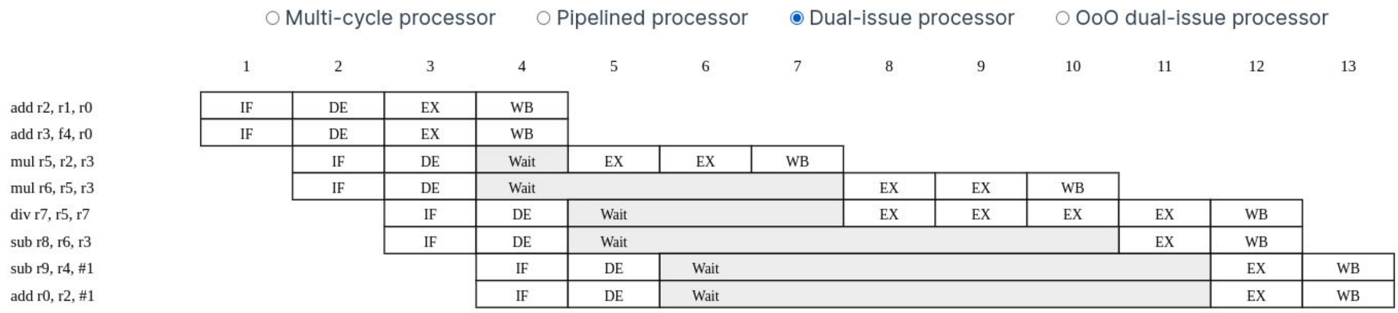
Here we show four different optimizations of microarchitectural improvement with a developmental view, indicating their execution time differences through a code example.

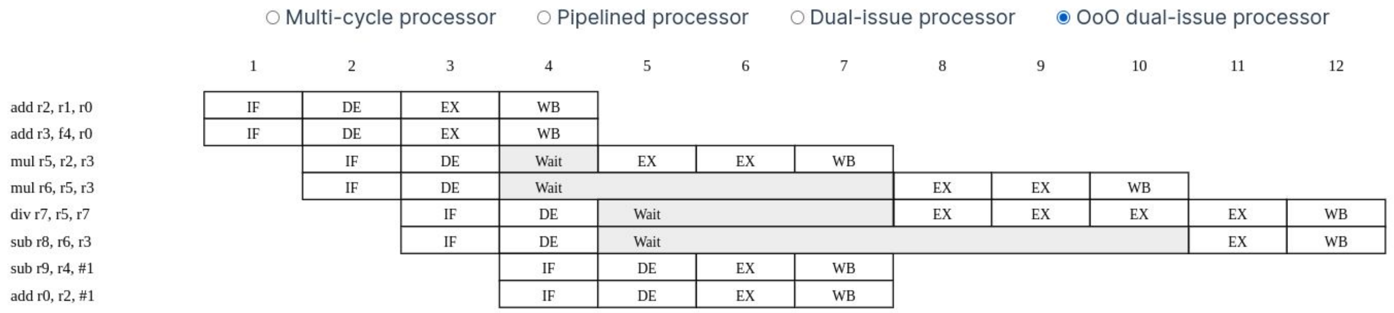
## Effects

Users can choose between different structures. An animation of the phases' flow would start after an optimization is chosen.



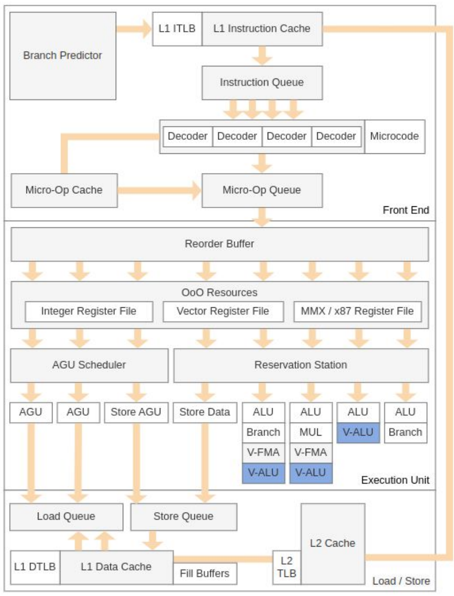



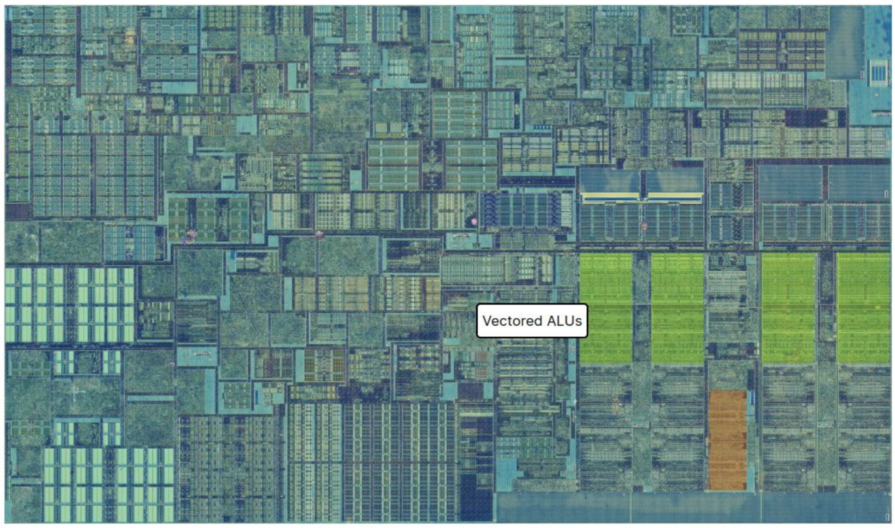
# 06. A Real Processor: Intel Skylake

Here we dissect the parts of a Skylake processor, to show the users the functionality of each part of the CPU.

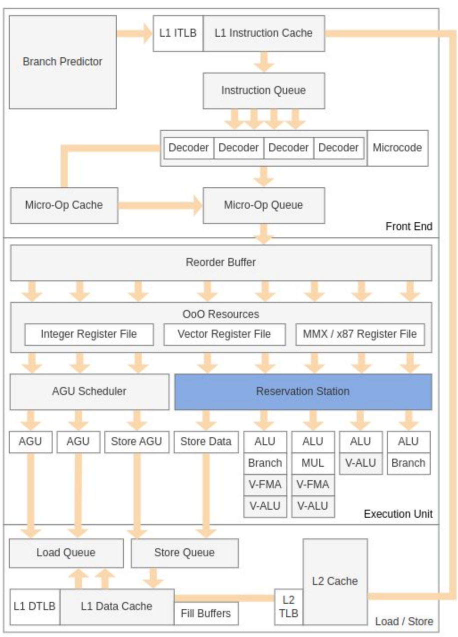
## Effects

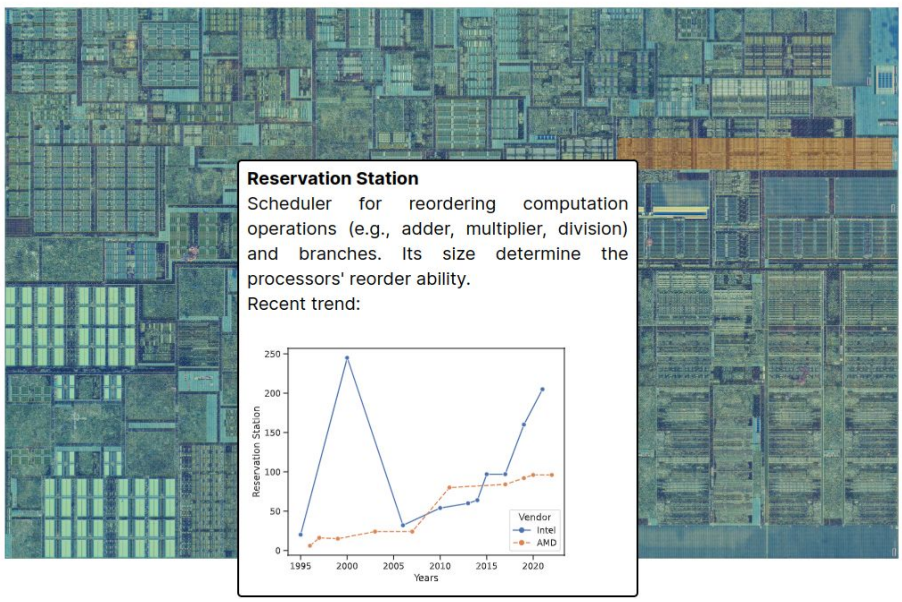
When the user hovers over an area in the die shot figure (figure on the right), the corresponding area in the architecture figure (figure on the left) would be lightened, and vice versa. When hovering on a component, the user would see a brief description of the item's functionality.




For 12 key components (e.g., AGU, ALU, load/store queue, fill buffer, micro-op cache), we also show a line plot of their development trend over years.



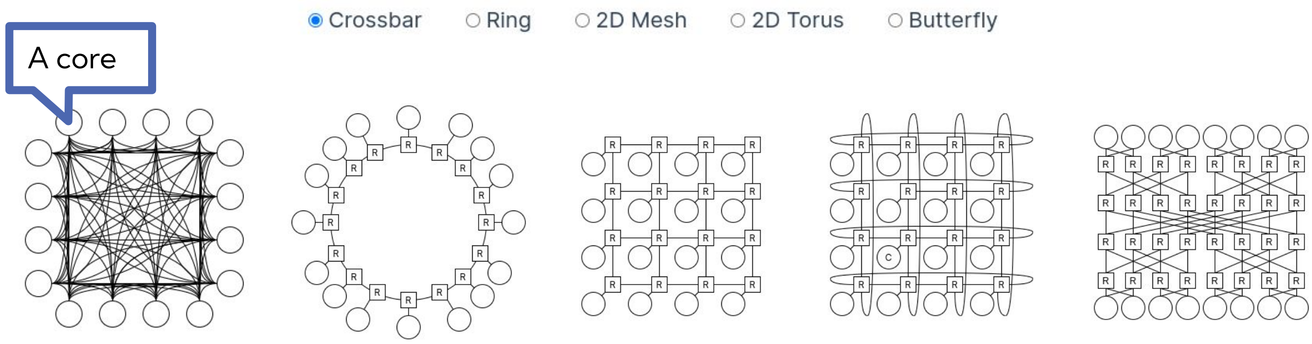



## 06. Interconnect Topology of Cores

Here we show some classic ways of how multiple cores are connected in a single microprocessor. The users can choose between different kinds of interconnections among the 5 types.

### Effects

When changing between the options, the "mesh of cores" would reform from the current structure to the newer one. With the supplemented texts, the users can have an impression of the differences between the different topologies.

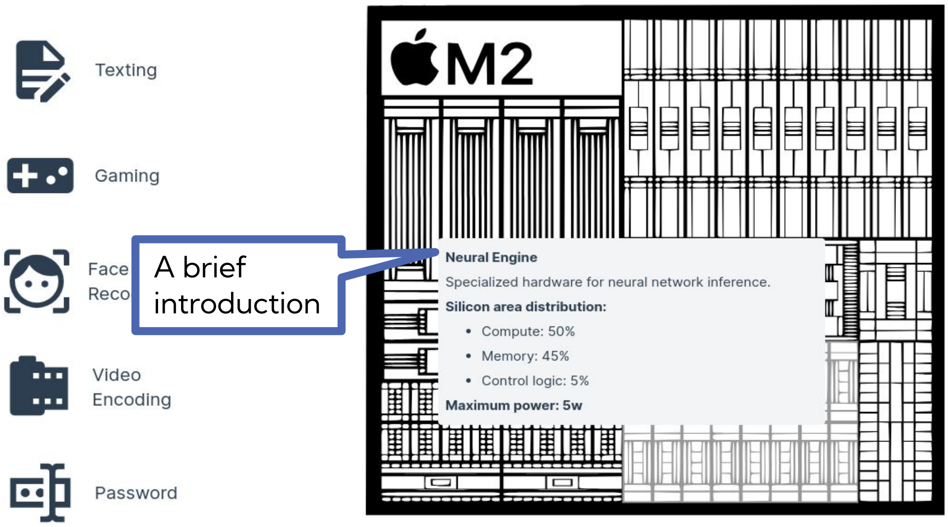



## 07. An Example: Apple M2

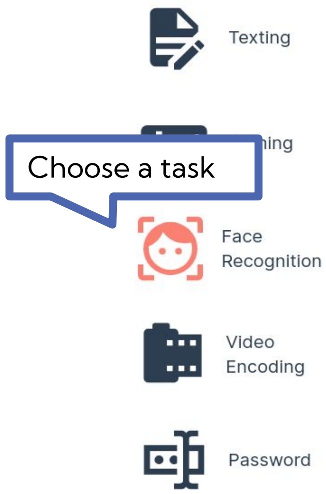
Apple M2 is a typical specialized microprocessors, which integrates CPU, GPU, and a neural engine. We would like to give the audience a concrete example of a specialized microprocessor. Here we have a dissected image of the Apple M2 chip.

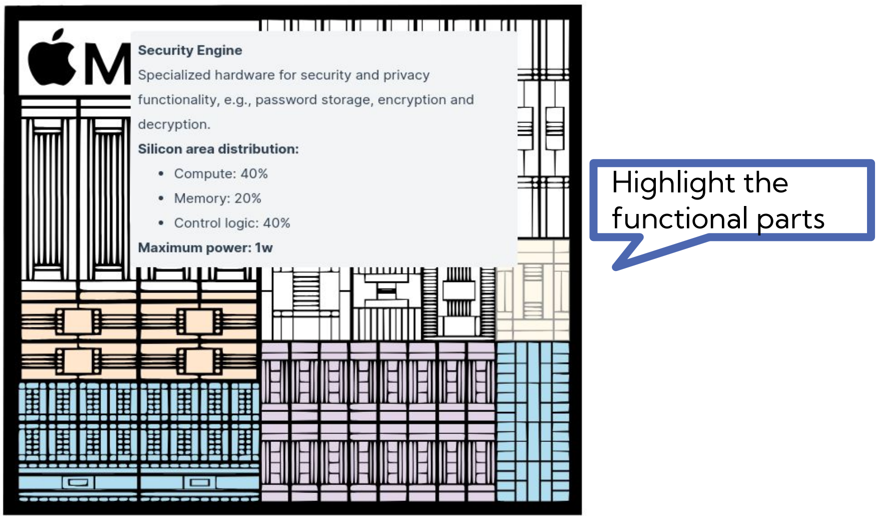
### Effects

When the mouse is hovered on a part of the chip, related information would be shown.



On the left side, there are five tasks the computer typically execute. When clicking on the task, the active parts of the CPU would be filled with color, indicating it is functioning. Multiple tasks can be chosen simultaneously. If you choose all tasks, the whole CPU would be lightened.




# Peer Assessment

During the whole project, we always tried to think and take all the important decisions together. Each one of us always brought new ideas which helped a lot always going forward. We call each other very frequently in order to debate and take the best decisions.

Then, we split the actual implementation work between each one of us. Here is a breakdown:

### Duo Xu

- Collect datas and scatter plots of the transistor trend and 50-year trend of CPU.
- Connected lineplot of trends of CPU's delay, power, and area.
- I enjoyed quite a lot working with both Shanqing and Zhiyao. They were both amazing teammates and have great patience when helping me with my bugs.

### Shanqing Lin

- Come up with the idea of visualization of CPU and Moore's law
- Provide layout and text.
- Do auxiliary animations (transistors, gate, microarchitectural optimization, topology type, Apple M2).
- Both Duo and Zhiyao are hardworking guys. They can quickly form a plan on how to visualize a chart and make them into practice!

### Zhiyao Feng

- Plot the Skylake's mapping between logic pipeline and dieshot.
- Draw all static figures
- Apply fullpage.js to organize the content.
- I appreciate Duo and Shanqing's help on understanding how DOM event works and debugging my code. I enjoy the process of cooperating with them!

**Hope the website gives you interest to learn more knowledge in CPU design!**