Chips Are Everywhere!

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In late 2022, the US Biden administration announced new restrictions on American companies selling advanced semiconductors to China. A number of US allies have joined to control shipment of chips and chip making equipment to China. Thus begins the so called *chip war*. Global politics and struggles among great powers are not our subject here.

We will talk about what chips are, their usefulness in our daily lives, how they are designed, manufactured and distributed, as well as their economic importance, and future directions. Of course, such an understanding is important in the digital age, especially for computational thinkers.

This post is part of our *Computational Thinking* (CT) blog where you can find many other interesting and useful articles.

What Is A Chip?

Needless to say, we are not talking about potato or corn chips.

A *computer chip*, or chip for short, is also known as a microchip, an integrated circuit or IC. It is a collection of electronic circuits built on a small piece of silicon. These chips are critical for modern computing as they can be designed to do different jobs such as logic processing (cpu), storing data (RAM memory), or some other application.

On the chip, transistors act as miniature switches that can turn an electric current on or off. Furthermore, the on/off state of a transistor is also controlled electronically making it the perfect device for building electronic circuits.

A chip usually contains many complicated electronic circuits which are constructed by creating many transistors made of silicon in an interconnected pattern as designed. Chips are usually the size of a fingernail or smaller

(Figure 1). In early January 2023, Intel announced its i9 cpu chip containing 2.95 billion transistors. The chip war only targets the very advanced next generation chips.

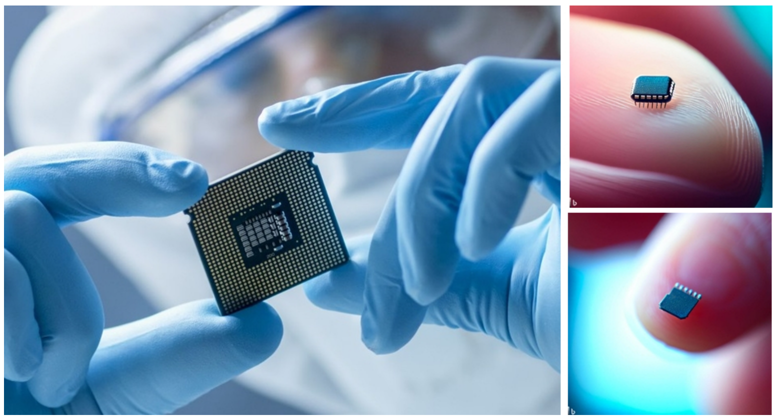

Figure 1: Some Packaged Chips

A Brief History

Chip making dates back to the mid-20th century, when the first electronic computers were being developed. The first computers were built using vacuum tubes, which were bulky, expensive, slow, and generated a lot of heat.

In the late 1940s and early 1950s, researchers began experimenting with using transistors as an alternative to vacuum tubes. Transistors were smaller, more reliable, and used less power than vacuum tubes, which made them ideal for use in electronic devices.

The invention of the integrated circuit in 1958 by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor marked a major milestone in chip research and development. Integrated circuits allowed multiple transistors to be fabricated on a single piece of semiconductor material, making it possible to build smaller and more complex electronic devices.

In the 1960s, the development of large-scale integration (LSI) and very large-scale integration (VLSI) made it possible to fabricate even more transistors on a single chip. This paved the way for the development of microprocessors, which are the central processing units (CPUs) of modern computers.

Throughout the 1970s and 1980s, chip development focused on increasing the speed and performance of microprocessors, as well as reducing their size and power consumption. This led to the development of new materials, such as silicon dioxide, and new manufacturing processes, such as photolithography, that allowed for even more transistors to be packed onto a single chip.

In the 1990s and 2000s, chip research and development continued to focus on increasing performance and reducing power consumption, as well as developing new types of processors, such as graphics processing units (GPUs) and application-specific integrated circuits (ASICs).

Chips Are Everywhere

Nowadays, most devices use chips: computers, cellphones, GPS navigators, smart appliances and objects, networking, cloud computing, Here are a dozen day-to-day objects that often contain chips to make them smart or work better (Figure 2):

Figure 2: Many Objects with Chips

- **Smartphones**: Smartphones contain a wide range of chips, including microprocessors, memory chips, and wireless communication chips, which allow them to perform a variety of tasks, such as accessing the internet, running apps, and taking photos. Most also have receiver chips to process satellite signals from GPS, Beidou, and other GNSS (Global Navigation Satellite Systems).

- **Laptops**: Laptops also contain a variety of chips, including microprocessors, graphics processing units (GPUs), and memory chips, which allow them to run complex software and perform tasks such as video editing and gaming.

- **Smart home devices**: Smart home devices such as smart thermostats, security cameras, and smart speakers often contain chips that allow them to communicate with other devices and perform tasks such as monitoring temperature, detecting motion, and playing music.

- **Automobiles**: Automobiles contain a wide range of chips (Figure 3), including microprocessors and sensors, which are used to control various systems such as the engine, transmission, and brakes.

Figure 3: Inside of A Smart Car

- **Fitness trackers**: Fitness trackers contain chips that allow them to track and monitor physical activity, as well as measure heart rate and other biometric data.

- **Gaming consoles**: Gaming consoles such as the Xbox and PlayStation contain powerful microprocessors and GPUs that allow them to run complex video games.

- **Smartwatches**: Smartwatches contain chips that allow them to perform various tasks, such as displaying notifications, tracking fitness, and making phone calls.

- **Smart TVs**: Smart TVs contain chips that allow them to connect to the internet, run apps, and stream video content.
- **Digital cameras**: Digital cameras contain chips that allow them to capture and process images, as well as store them on memory cards.
- **ATMs**: ATMs contain chips that allow them to connect to banking networks and perform transactions, as well as provide security features such as encryption and authentication.
- **Wearable medical devices**: Wearable medical devices such as pacemakers (Figure 4) and glucose monitors often contain chips that allow them to measure and transmit data about the patient's health to healthcare professionals.

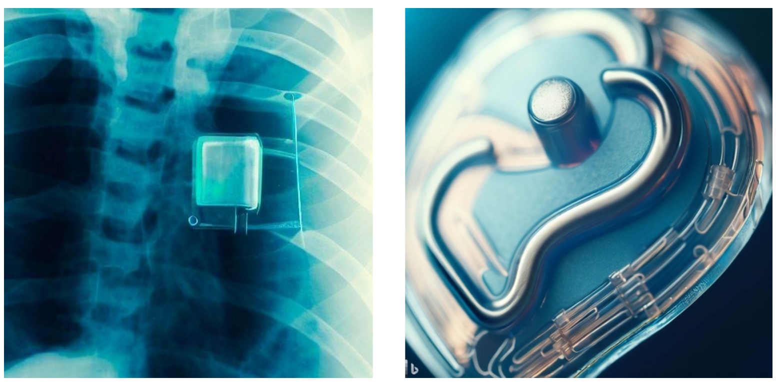

Figure 4: A Pacemaker Implant

- **Smart lighting systems**: Smart lighting systems contain chips that allow them to be controlled remotely via smartphone apps or voice assistants, as well as adjust brightness and color temperature.

No matter which way you turn, you are likely to find chips embeded in something around you. If there were no chips there would not be the digital age. And that is not an exaggeration.

How Are Chips Made?

From idea to product, the process of developing a microchip involves several major steps, including design, fabrication, testing, and packaging:

- **Conceptualization and Design**: The first step in developing a new chip is to conceptualize the idea and create a design. This involves defining the specifications of the chip, selecting the appropriate materials and manufacturing processes, and designing the layout of the chip. The time and cost for this step can vary widely depending on the complexity of the chip and the resources available to the design team.

- **Verification**: Once the design is complete, it needs to be verified to ensure that it meets the required specifications. This involves simulating the behavior of the chip using specialized software tools and identifying any errors or design flaws. The time and cost for this step can also vary widely, depending on the complexity of the chip and the tools available.

- **Fabrication**: After the design has been verified, the chip can be fabricated. This involves using specialized manufacturing processes to etch the design onto a piece of semiconductor material, such as silicon. The time and cost for this step can also vary widely, depending on the complexity of the design and the fabrication processes used.

- **Testing**: Once the chip has been fabricated, it needs to be tested to ensure that it meets the required specifications. This involves using specialized equipment to measure the performance and functionality of the chip. The time and cost for this step can also vary widely, depending on the complexity of the chip and the testing equipment used.

- **Packaging**: After the chip has been tested, it needs to be packaged into a form that can be used in electronic devices. This involves encapsulating the chip in a protective material and connecting it to pins or leads that allow it to be connected to a circuit board. The time and cost for this step can also vary widely, depending on the complexity of the packaging process and the resources available.

Each of these step can take weeks or months. Overall, the process of developing a computing chip from idea to product can take anywhere from months to years.

Chip Manufacture Costs

The mass production of chips is capital intensive and costly. The investments in the construction of fabrication and testing facilities can be especially substantial.

A fabrication facility, also known as a fabrication plant (Figure 5) or "a fab", can cost billions of dollars. A fab—which includes 1,200 multimillion-dollar tools and 1,500 pieces of utility equipment—takes about three years, $10 billion and 6,000 construction workers to complete.

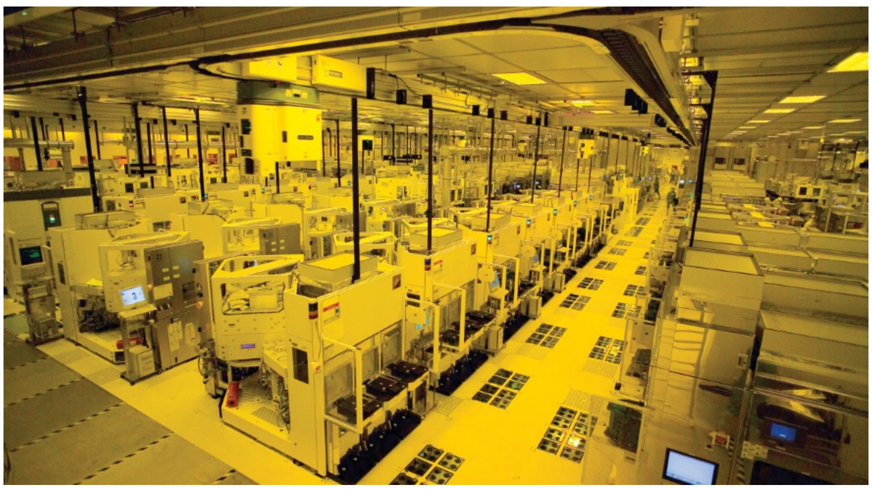

Figure 5: A Chip FAB

Similarly, the cost of building a testing facility can be significant, depending on the complexity of the testing equipment required. For example, a testing facility for advanced microprocessors may require specialized equipment such as electron microscopes, X-ray diffraction machines, and other high-tech tools that can cost millions of dollars each.

Therefore, the cost and time required for the entire chip development process, from concept to mass production, can vary greatly depending on the scale of the operation and the complexity of the chip. For smaller operations or less complex chips, the costs and timelines may be more manageable. However, for larger operations or more complex chips, the costs and timelines can be significant and require substantial investment over an extended period of time.

Here are some of the necessary software, hardware, and manufacturing equipment needed in each step of the chip development process:

1. ***Conceptualization and Design***

   - **Electronic Design Automation (EDA) software**: This is used to create the design of the chip.
   - **Computer-aided design (CAD) software**: This is used to create 3D models of the chip design.
   - **Workstations and high-performance computing (HPC) clusters**: These are used to run simulations of the chip design to test for functionality and performance.

2. ***Verification***

   - **EDA software for verification**: This is used to verify the functionality and performance of the chip design.
   - **Formal verification software**: This is used to verify that the chip design meets the required specifications.
   - **HPC clusters**: These are used to run simulations for verification.

3. ***Fabrication***

   - **Photolithography equipment**: This equipment is key to chip making. It uses light to transfer (print or etch) the circuit patterns for the chip design onto the semiconductor material (Figure 6). ASML, a global industry leader based in the Netherlands, offers one of the best photolithography equipment for chip making that uses EUV (Extreme UltraViolet), an incredibly short wavelength of light to print small, complex designs on microchips.
   - **Chemical vapor deposition (CVD) equipment**: This is used to deposit layers of materials onto the semiconductor material.
   - **Etching equipment**: This is used to remove unwanted material from the semiconductor material.
   - **Ion implantation equipment**: This is used to implant impurities into the semiconductor material to create the necessary electrical properties.

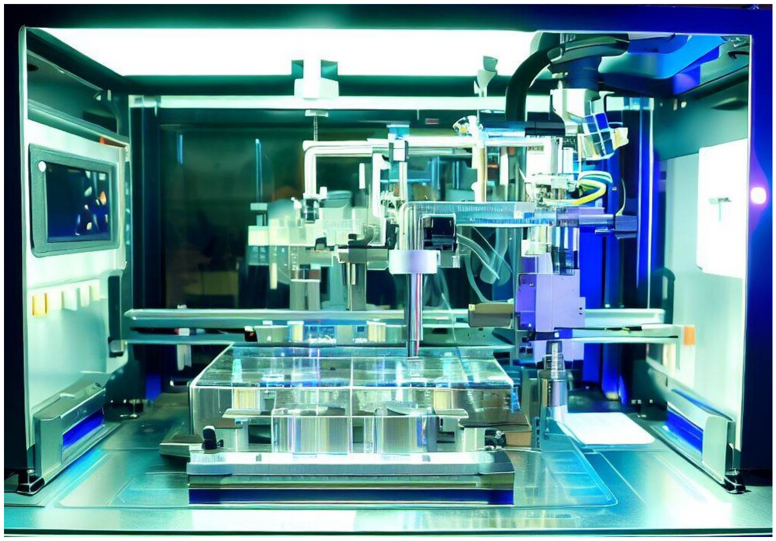

Figure 6: Photolithography equipment for chip making

- **Metrology equipment**: This is used to measure the dimensions and properties of the chip features to ensure they meet the required specifications.

4. ***Testing***

- **Test equipment**: This includes various types of testing equipment, such as oscilloscopes, logic analyzers, and power supplies, which are used to test the functionality and performance of the chip.
- **Probe cards**: These are used to make electrical connections between the chip and the testing equipment.

5. ***Packaging***

- **Wire bonding equipment**: This is used to make connections between the chip and the leads or pins of the package.
- **Molding equipment**: This is used to encapsulate the chip in a protective material, such as plastic.
- **Automated test equipment (ATE)**: This is used to test the packaged chip to ensure it meets the required specifications.

As you can see, the equipment and software required for each step of the chip development process can be quite specialized and expensive. Many of these tools and technologies require specialized knowledge and training to use effectively, which is why chip development often requires a team of experts with diverse skill sets.

Currently, the major directions for chip research and development are in further miniaturization, increasing power efficiency, and special-purpose applications. We can be sure that the future of chips remains bright and exciting.

Chip Inspired Computational Thinking

Looking at the chip technologies we can find several inspirations for computational thinkers:

- *Divide and conquer*—Chip design and manufacturing is a very large and complicated problem, even though the resulting chip is tiny. The problem is broken down into smaller ones and distinct steps to be solved individually.

- *Step-wise refinement*—New generations of chips are created by making improvements and incremental advances to the previous generation of chips. For example, circuit integration have gone through "small-scale integration" (SSI), "medium-scale integration" (MSI), "very-large-scale integration" (VLSI), and "ultra-large-scale integration" (ULSI).

- *Bottom-up problem solving*—Using silicon transistors as basic building blocks, forming logic gates, then up to simple circuits, then eventually to a complete chip.

- *Iteration of a virtuous cycle*—Better chips results in more powerful computers which are used in the design, manufacturing, and testing of new chips. The cycle goes on.

List here are just some ideas. Computational thinkers are sure to learn other lessons from the varied aspects of chip making and apply them in different places.

Careers in the Chip Industry

Many different educational paths can lead to careers in the chip industry. Examples of majors and studies that can be helpful for those looking to enter the field include: electrical engineering, computer science, materials science, physics, and mathematics.

It's important to note that the chip industry is highly technical and specialized, and many roles require advanced degrees or specialized training. Therefore, in addition to choosing an appropriate major or study, individuals interested in pursuing a career in the computing chip industry may also need to seek out internships, certifications, and other opportunities to gain practical experience and skills.

Finally

A chip is tiny, complex, and powerful. With the naked eye, we can hardly see it. Yet a microchip is one of the most wonderful artifacts we have ever made.

Chips are everywhere and affect almost all aspects of our lives. A good understanding of chips is important in the digital age, especially for computational thinkers.

Some may take chips for granted or do not fully appreciate the tremendous creativity, difficulty, effort, time, infrastructure, funding, and rapid evolution required in their design and manufacturing. These are certainly significant challenges.

The matter is further complicated by international factors such as intellectual property rights, manufacturing expertise, technical standards, and trade policies, that affect the development and use of chip technologies. In addition, the chip industry is an important part of the global economy. All these are reasons why international division of labor has been essential in chip R&D and manufacturing.

The micro chip is at the center of the digital revolution and we can look forward to more advances, breakthroughs, applications, and wonderful improvements in our lives brought about by the small but beautiful chips.