SUMMARY

MOORE'S LAW

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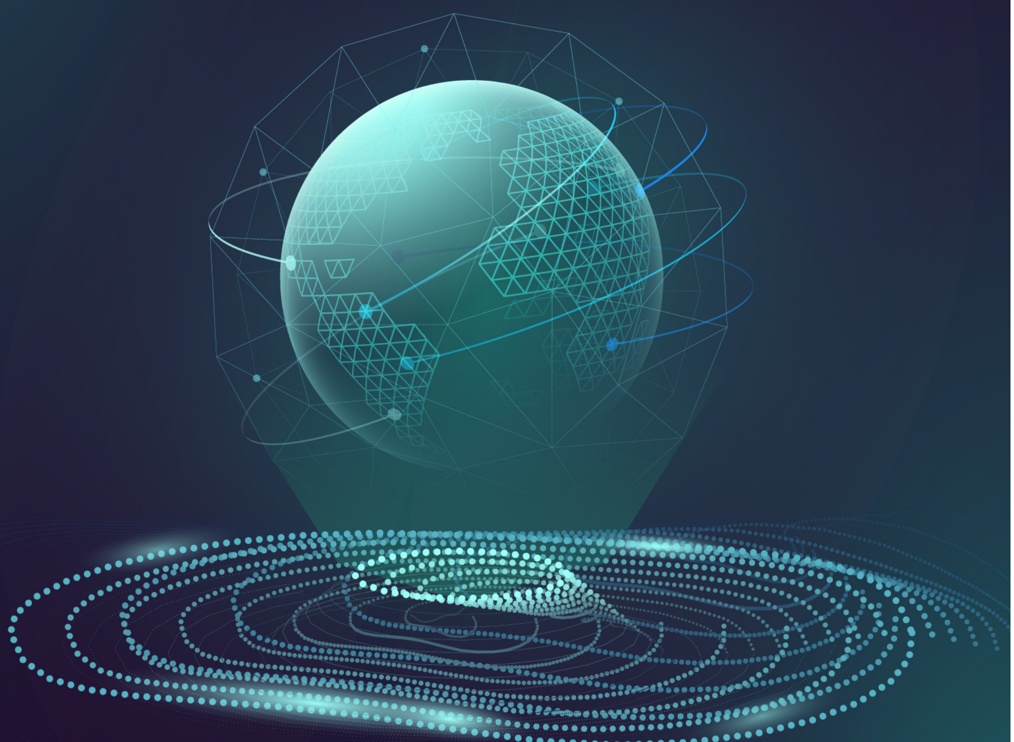

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Summary of “Moore’s Law” by Arnold Thackray, David Brock, and Rachel Jones

Written by Lea Schullery

Learn about Gordon Moore, the brain behind Moore’s Law, and how he revolutionized the electronics and computing industry.

Introduction

What is Moore's Law? Moore's Law is partly a technical observation about the development of digital electronics; however, it is also an astonishing story of imagination, zeal, and world revolution. Beginning with the silicon transistor, which was created to serve the Cold War market, not only did it cost a lot of money to produce, but it was also massive in size, used a lot of power, and was incredibly unreliable. In 1959, Moore and his team made a breakthrough in the manufacturing of these transistors, setting the stage for the microchip that we know today. By the early 1960s, Moore and his team at Fairchild had revolutionized the industry, but Moore wasn't done. He predicted that new methods would create microchips that would become smaller, more reliable, use less power, and even be cheaper. In 1965, Moore introduced a numerical prediction. In the years since 1959, the number of transistors on a chip had doubled each year, so microchips in 1965 incorporated more than 50 transistors each. Therefore, Moore predicted this dynamic would only continue in the coming decade, doubling transistor counts each year while simultaneously shrinking costs. In 1975, microchips no longer had 50 transistors but had 65,000. Moore predicted again that the mechanisms would no longer double each year, but every 18 months. By 1985, microchips had 16 million transistors. And the trend only continued, "transistors now produced in a single year likely exceed the proverbial grains of the sand upon all the seashores of the world. The price of computing has fallen well over a millionfold, while the cost of electronic components has shrunk more than a billionfold."

The silicon transistor within the microchip has had a revolutionary impact on society on par with the steam railroad, the automobile, and the airplane. The impact of Moore's Law has become commonplace as we have experienced telephones, televisions, and video games become better for less, and at a steady rate. Of course, all good things must come to an end. Today, the end of Moore's Law has become a hot topic of debate in the electronic and computing communities. I mean, how small can technology realistically become?

Gordon’s Early Life

Growing up in the 1930s, Gordon Moore lived a life of simplicity in Pescadero in the county of San Mateo, California. The men in his family worked outside and provided for the family, while the women stayed home and took care of the home and raised the children. In the Moore family, little value was placed on education as they pursued practical jobs like becoming the senior sheriff in town, or how to run a ranch or general store, all of which did not require formal education.

As a child, Gordon had fit in quite nicely. He was quiet, explored the outdoors, shot at birds, and fished in the creek. At the end of first grade, however, he brought home a report card stating that he should be held back. The school was concerned about his social development, stating that detachment, inarticulacy, and overall introversion were the issues. Eventually, Gordon was allowed into second grade, he was incredibly smart, just incredibly quiet as well.

In 1939, at just nine-years-old, the Moore family relocated to Redwood city after his father’s promotion, which meant both a higher salary and a better climate. Just a short time later, Gordon Moore turned eleven and discovered his first true love, this love would change the trajectory of his life. While Gordon didn’t interact with many people at school, he would hang out with his next-door neighbor, Donald Blum. One year into Christmas, Donald was given a chemistry set. And back in the day, these sets came with really nice chemicals, like potassium chlorate. Gordan, however, was most interested in explosions.

Experimenting with creating colorful flames, fuel for toy rockets, and small explosions, Gordon quickly became hooked. Soon, he built a small laboratory in the corner of the family’s shed and embraced the experimentation and hands-on experience of creating something new. His parents even encouraged his new hobby, simply telling him to “be careful,” knowing full-well that Gordon was making things explode in their backyard. Gordon even states that once a friend blew a couple of fingers off - not in his laboratory, fortunately. Although, he's not sure if his mother knew about it.

By the time Gordon took his first chemistry lesson at Sequoia High, he had been playing with chemicals for years, and not surprisingly, was well ahead of the other students. He even had quite the reputation of being "the quiet guy with bombs," as he experimented with nitroglycerine and created rockets, dynamite, and many other bombs. Eventually, he graduated high school with good grades and in the fall of 1946, Gordon became a freshman at San Jose State College, today's San Jose State University.

Gordon’s Undergraduate Education

Now a college student, Gordon immersed himself in chemistry, mathematics, and physics. He kept himself busy with homework and a job, and soon, he met his wife and lifelong partner, Betty Irene Whitaker. As the two were attending college and dating, they soon developed a connection and by early 1948, they knew they were in it for the long haul. Later that year, Gordon was only in his sophomore year, but he felt like he needed something bigger. He applied to UC Berkely, and later that year, he packed his bags, bid his home farewell, and moved across the Bay to Berkely to start his junior year.

At the time, California’s economy was booming and Berkely was the place to be for someone like Gordon, a young chemist. The area was rapidly changing, and by the late 1940s, two of Gordon Moore’s chemistry professors, William Giaugue and Glenn Seaborg, would receive Nobel Prizes within three years of Gordon’s arrival. Seaborg had been a key player in the Manhatten Project and became the principal or co-discoverer of 10 elements, including plutonium, einsteinium, and element 106, eventually named “seaborgium.”

In 1946, an assistant professor named George Jura joined the Berkeley physical chemistry program. Together, he and Don Gwinn introduced novel experiments that would become significant in Gordon’s growth as a student of chemistry. Jura encouraged his students to disprove contemporary scientific literature; this method introduced Gordon to the power of independent thinking rather than the ability to simply follow directions. Jura forced Gordon to think and apply trial and error to his experiments. Jura also introduced Gordon to another skill: glassblowing. In later years, his skill in glassblowing would prove useful in building innovative equipment for semiconductor research.

At the time, science enrollments began expanding and university departments were growing, naturally, the next step for Gordon was a Ph.D.

degree, so he made the California Institute of Technology, or Caltech, his first choice. After his acceptance, Gordon was faced with a major life decision. Would he ask Betty Whitaker to come with him? In 1950, an invitation like this was similar to a marriage proposal. He took the leap, however, and the two married in September just a few days before Gordon would start his Ph.D. program at Caltech.

Gordon's Graduate Education at Caltech

When Gordon arrived at Caltech just days after his marriage to Betty, he was subjected to a round of rigorous exams for all incoming graduate students. They tested their skills in organic, inorganic, and physical chemistry, placing you in remedial courses if you weren't up to standards in a particular area. Gordon was the only one from another school who didn't have to take one of the remedial courses. However, the exams did more than just test their skills, they also served as a matchmaking service between faculty and new students. Professors were looking for dedicated, talented students to help them in their faculty research plans and they looked at test scores to find "the perfect match."

Jack Kirkwood, a physical chemist and theorist, looked at Gordon's test scores in physical chemistry and invited him to work with him. Gordon, however, denied his offer. He had his sights set on Richard McLean Badger, a veteran professor at Caltech who specialized in the study of molecules and infrared spectrophotometers. In other words, Gordon decided that "Badger was doing things that looked fun," and he wanted in on it. Not only that, but Badger and Gordon had similar personalities and got along well with one another.

Just over a year after beginning at Caltech, Gordon published his first scientific paper in December 1951. It was titled "The Infrared Spectrum and the Structure of Gaseous Nitrous Acid," and it appeared in the *Journal of Chemical Physics*. Just a few years and more publications later, Gordon felt he had completed enough work to earn his Ph.D., Badger agreed, and Gordon began writing up his results. Having accomplished a Caltech Chemistry Ph.D. in fewer than three years was certainly a tremendous achievement that showed Gordon's ambition and dedication.

He enjoyed teaching during his program and initially aimed to become a professor; however, there weren't many positions available. His mentor, Badger, then convinced him that he should look into working in the field.

Since there were many growing advancements, Gordon’s skills were in high demand. Gordon looked around, he wanted to find a place that would allow him the freedom to continue independent experiments. After an arduous search for jobs, Gordon simply couldn’t find a place that ticked off the boxes he needed, and his lack of social skills hindered him during interviews. Soon, however, Badger would use his connections to bring Gordon into contact with the Applied Physics Laboratory, a research center operated by the US Navy at John Hopkins University. The problem? It was located in Silver Spring, Maryland, just outside Washington, DC. Gordon and Betty were ready to move on from their lives, so they packed their bags and headed east.

A New Opportunity

After settling into life at APL and Maryland, Betty eventually became pregnant and gave birth to a healthy baby boy, Kenneth Moore. As their home lives become hectic with a new, colicky baby, Gordon's life at work was beginning to become just as chaotic. Two recent developments, the digital computer and the transistor, were beginning to change the world as we knew it. Created at Bell Labs in New Jersey in December 1947, the transistor - similar to vacuum tubes - could amplify and switch signals on and off. Unlike vacuum tubes, transistors were made up of a solid material making them much smaller and required less power.

While many commented on the transistor as being an "interesting little device," those in the know knew the significant breakthrough this invention would have in telephone technology. Gordon didn't have his first encounter with a transistor until the end of 1954 when he was twenty-five-years-old. One evening, he traveled with some of his colleagues to the prestigious Cosmos Club to listen to a lecture titled, "Transistor Physics." The lecturer was the world's expert on the topic, William Shockley. At the end of the talk, Shockley tossed handfuls of transistors, the size of peanuts, into the audience and Gordon thought to himself, "what an exciting guy to work for."

Life for the next few years was busy, and Gordon's job at the APL took a turn for the worse as conflicts arose and he began to doubt the worth of his work. Furthermore, he and Betty desperately wanted to get back to the west coast, so Gordon began to actively search for new jobs. While many opportunities presented themselves and then closed, it wasn't until February of 1956 that Gordon received a telephone call from the transistor expert himself, William Shockley. By now, Shockley had left Bell Labs in New Jersey to start his own venture in California under Arnold Beckman. Shockley explained that he was looking to hire "the best and brightest young PhDs" to join him in Mountain View, a small town south of Palo Alto on the San Francisco Peninsula.

In the world of transistor making, manufacturing, and researching, Palo Alto was “nowhere land.” However, Shockley was intent on setting up on the west coast to try and produce a new kind of transistor that used silicon as a semiconductor. All he needed was someone like Gordon to take over, and without hesitation, Gordon agreed. They quickly booked their flights to the west coast to begin again in the place they considered home.

The Conception of Fairchild Semiconductor

As Gordon worked with Shockley and his team of chemists, they began to make significant strides toward creating the silicon transistor. However, after just 18 months, the team was still far from its goal. Tensions began to mount as Shockley would have frequent outbursts over the stress of technical setbacks and business pressures. Things got worse in May of 1957 when Beckman Instrument's presented the team with the news that they needed to produce something profitable, and soon. Gordon and his colleagues understood; however, Shockley didn't take the news so well. He quickly exploded and threatened to leave with all of his researchers and find new backing if Beckman wasn't on board with them.

After the meeting, Gordon and the rest of his team knew they had to do something. Later that evening, Gordon and his team met after working hours to speak with Arnold Beckman. Beckman could sense the tensions between the team and Shockley and agreed to meet with Gordon and the other researchers...without Shockley. Soon, tensions rose as Shockley found out about meetings behind his back. After much stress and conversation, not much changed, so Gordon and his colleagues sought to leave together if they could find a willing investor.

They soon found an investor in Sherman Fairchild, one of IBM's biggest shareholders. Gordon and his team made a deal with Fairchild, signed the papers, and on Wednesday, September 18, they handed in their resignation letters to Hanafin, who quickly informed Shockley that the most important members of his senior staff had just resigned en masse. Shockley never spoke to them again and labeled the group, "The Traitorous Eight."

Gordon and his team now had a new venture, Fairchild Semiconductor, and in that same week, the Soviets launched the world's first satellite, Sputnik. The world was stunned. But Gordon knew this momentous feat would create demand for the exact transistor they were trying to create: a fast-switching transistor. Nothing else had ever been created like it. Texas

Instruments was one of the first on the market in 1954, offering small silicon transistors for military use. While they were able to withstand heat better than others, they still had the problem of being slow-switching. By the end of 1957, however, IBM was in desperate need of a fast-switching silicon transistor. With a contract for the development of a proposed supersonic bomber carrying thermonuclear weapons, the B-70 Valkyrie, the engineers were researching the exact transistor that Fairchild Semiconductor was working on.

Gordon knew his team was small, so they had to be quick to bring the transistor to the market. And in August of 1958, just one year after the company was founded, they created the world's first fast-switching silicon transistor and brought it to the market, calling it the ZN696.

The Beginning of a Microchip Revolution

Soon, the silicon transistor became the standard and Fairchild Semiconductor continued to grow rapidly. Meanwhile, one of Gordon's colleagues, Bob Noyce, was writing a notebook entry that would soon change the world. On January 23, 1959, Noyce wrote about the *microchip:* an integrated circuit in which all the components of a complete circuit were made within a single piece of silicon. He asked himself, "why not leave the transistors together in the wafer? If you could interconnect them there, a set could be detached as a single unit; it could be a reliably connected integrated circuit or 'microchip.'" Noyce understood the drawback of wiring individual components together, and the microchip would soon be the answer.

They decided to get started, so they began Micrologic, a division of Fairchild strictly dedicated to integrated circuits. Fairchild was ahead of the game, they understood where transistors were headed and they aimed to be at the forefront of the electronic revolution. In February 1965, Gordon published an article titled, "The Future of Integrated Electronics," in which he made a numerical prediction. Gordon had noticed that the complexity of the microchip had doubled each year since its development, so he predicted that this trend would continue into the next decade. Simultaneously, the cost of manufacturing would halve each year.

This prediction became known as Moore's Law, and it proved to be correct. In 1965, there were roughly 50 transistors on a microchip. However, Gordon predicted that by 1975, there would be 65,000 transistors on a single microchip. While it seemed near impossible, even to many of Gordon's peers, Gordon and his team set out to change the future of technology.

Together, Noyce and Gordon discovered the demand for greater memory-processing in devices such as computers and calculators. At the time, data was stored on punch cards, which were slow and heavy. So they decided to search for another team member, someone who could pioneer the charge for memory storage. They found Joel Karp, a microchip designer at General Microelectronics in Santa Clara.

Karp eventually created Intel's 1101 memory microchip, it held 256 bits of data and launched Intel into the emerging memory market. While Intel was making a nice profit off Karp's microchip, Gordon would soon meet Berkely electrical engineer, Dov Frohman who would offer up a new kind of microchip. At the time, chips were only able to store data when the power was on; therefore, Frohman proposed a version in which data would be retained even when the power was turned off. Furthermore, Frohman stated that his chips were reprogrammable. This function was far different from the chips of the past that had their data physically printed on them. Gordon knew this microchip was revolutionary and put them immediately on the market. Those chips are now called EPROMs, and between 1972 and 1985, EPROM chip sales were the main source of Intel's income.

The Microprocessor that Changed the World

While Intel’s business was thriving and making revenue of half a billion dollars per year, the competition in the computer memory industry was becoming fierce. Japanese makers began manufacturing chips at a higher rate and a lower cost, causing Intel’s business to become increasingly less profitable. Personally, Gordon didn’t feel comfortable long-term and knew they needed to act quickly to stay ahead and in business. At the time, microprocessors were gaining popularity, and Gordon himself had been intrigued by their possibilities in everything from traffic lights and scoreboards to medical equipment and industrial machines.

So they began their work on microprocessors, enthusiastic about presenting microprocessors as simply tiny computers, or “microcomputers.” Gordon understood that they were no longer in the computer memory business, but the computer-making business and he was nervous about switching to selling a consumer product. Despite his hesitations, he desired to facilitate the growth of Intel’s markets and approved the decision to make circuit boards with a complete microprocessor chip set installed. This would enable customers to buy a pre-assembled product.

Gordon understood the importance of going all-in in this endeavor and invested $100 million into researching and developing Intel’s next product, the 386 microprocessor. With 275,000 transistors, the microprocessor was the most powerful on the market. The product was a success. Then, in 1986, Intel began collaborating with Microsoft to produce their new PC, the Deskpro 386, which combined Microsoft’s software and Intel’s microprocessors. As you know by now, personal computers quickly saw success as well. Soon, computers began to change the world and how we lived, and in 1990, the average U.S. citizen spent 40 percent of his time looking at screens, either watching television, playing video games, or using a computer.

Because of Gordon and his team, Intel was able to secure a top position in the microprocessor market, and between 1981 and 1987, consumers spent billions of dollars on hardware and software for personal computers. Each computer, of course, relied on Intel's microprocessor. Soon, Intel left the memory market and focused solely on microprocessors. Due to the high cost and complexity of the microprocessor, other companies simply couldn't compete with Intel who continued to create better, more efficient microprocessors each year. And by the mid-1990s, Intel had over 80 percent of the market share in PC microprocessors.

In 2001, Gordon decided it was time to retire at the age of 72. At the time, Intel's revenue was $10.5 billion. Gordon, however, turned to philanthropy and began to make significant contributions to educational institutions like Caltech. In 2005, Gordon was even named the year's most charitable person, joining the ranks of philanthropists like Bill Gates and Warren Buffet who donate billions of dollars towards education.

When it comes to Moore's Law, however, all good things must come to an end. The microprocessor is nearing its physical boundaries, now the size of just tens of atoms. Gordon himself believes Moore's Law will soon reach its limits and the topic has become a hot debate in today's electronic and computing companies. Until a new revolutionary idea comes around, technology will begin to grow at a much slower and stagnant rate. So now it's time to ask the question, what do you think the future of technology looks like?

Final Summary

As a child, Gordon Moore didn't have many expectations. His parents didn't place much value on education, and because of his quiet demeanor, he was labeled as socially inept and teachers even recommended holding him back. It wasn't until junior high that Gordon found something that really interested him: chemistry. By mixing chemicals and playing with fire, Gordon became enthralled with making bombs and controlling the elements around him. This passion would soon lead him to research transistors and semiconductors. Alongside some of the greatest innovators in the industry, Gordon would go on to revolutionize technology with the creation of the microprocessor. Today, Intel is still a powerhouse in the computer industry; meanwhile, Gordon has decided to take a step back and focus his efforts on philanthropy, hoping the next revolutionary idea is just moments away in the mind of someone like him.