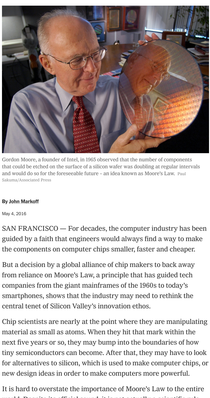
Moore's Law Running Out of Room, Tech Looks for a Successor



Gordon Moore, a founder of Intel, in 1965 observed that the number of components that could be etched on the surface of a silicon wafer was doubling at regular intervals and would do so for the foreseeable future – an idea known as Moore's Law. *Paul Sakuma/Associated Press*

By John Markoff

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SAN FRANCISCO — For decades, the computer industry has been guided by a faith that engineers would always find a way to make the components on computer chips smaller, faster and cheaper.

But a decision by a global alliance of chip makers to back away from reliance on Moore's Law, a principle that has guided tech companies from the giant mainframes of the 1960s to today's smartphones, shows that the industry may need to rethink the central tenet of Silicon Valley's innovation ethos.

Chip scientists are nearly at the point where they are manipulating material as small as atoms. When they hit that mark within the next five years or so, they may bump into the boundaries of how tiny semiconductors can become. After that, they may have to look for alternatives to silicon, which is used to make computer chips, or new design ideas in order to make computers more powerful.

It is hard to overstate the importance of Moore's Law to the entire world. Despite its official sound, it is not actually a scientific rule like Newton's laws of motion. Instead, it describes the pace of change in a manufacturing process that has made computers exponentially more affordable.

In 1965, the Intel co-founder Gordon Moore first observed that the number of components that could be etched onto the surface of a silicon wafer was doubling at regular intervals and would do so for the foreseeable future.

When Dr. Moore made his observation, the densest memory chips stored only about 1,000 bits of information. Today's densest memory chips have roughly 20 billion transistors. To put it another way, the iPad 2, which went on the market in 2011 for $400 and fits in your lap, had more computing power than the world's most powerful supercomputer in the 1980s, a device called the Cray 2 that was about the size of an industrial washing machine and would cost more than $15 million today.

That iPad 2, mind you, is slow compared to newer models.

Without those remarkable improvements, today's computer industry wouldn't exist. The vast cloud-computing data centers run by companies like Google and Amazon would be impossibly expensive to build. There would be no smartphones with apps that allow you to order a ride home or get dinner delivered. And scientific breakthroughs like decoding the human genome or teaching machines to listen would not have happened.

Signaling their belief that the best way to forecast the future of computing needs to be changed, the Semiconductor Industry Associations of the United States, Europe, Japan, South Korea and Taiwan will make one final report based on a chip technology forecasting system called the International Technology Roadmap for Semiconductors.

Nearly every big chip maker, including Intel, IBM and Samsung, belongs to the organization, though Intel says it is not participating in the last report.

To replace what the semiconductor industry has done for nearly 25 years, a professional organization called the Institute of Electrical and Electronics Engineers announced on Wednesday that it will a create a new forecasting system, called the International Roadmap for Devices and Systems, that is intended to track a wider range of computer technologies.

How Moore's Law Helped Drive Innovation

It is hard to overstate the importance of Moore's Law to the tech world. In 1965, the Intel co-founder Gordon Moore observed that the number of transistors that could be etched on a chip would double at regular intervals, leading to astronomical increases in computing power. The premise behind Moore's Law — that computer chips would do more and cost less — helped Silicon Valley bring startling advances to the world, from the personal computer to the smartphone to the vast network of interconnected computers that power the Internet.

1965 Gordon Moore makes his famous observation about component density in an article published in Electronics magazine.

1971 Intel introduces the first microprocessor, the 4004, helping usher in the consumer tech era.

1977 Apple introduces the Apple II personal computer, one of the first successful PCs, with the help of steadily more powerful microprocessors.

1989 Intel introduces the i860 processor, the first microprocessor with more than one million transistors, for use in supercomputing and scientific applications.

1993 Intel announces the creation of the Pentium processor, which contains nearly triple the number of transistors its predecessor had.

2005-07 Microprocessors' clock speeds stop increasing as chips threaten to become as hot as the surface of the sun.

2007 As the number of transistors on a microchip exceeds one billion, Apple ships its first iPhones, transforming the phone into a handheld computer.

2015 Intel delays its shift to microprocessors based on the next-generation 10-nanometer manufacturing process, the biggest hint that Moore's Law has broken down.

One technology could be so-called quantum computing, a cutting-edge reimagining of how computers work that taps quantum physics — a branch of physics that explains how matter and energy interact. Another could be graphene, a form of carbon and an alternative to silicon that could produce smaller and faster transistors that use less power.

"The end of Moore's Law is what led to this," said Thomas M. Conte, a Georgia Institute of Technology computer scientist and co-chairman of the effort to draw up a new set of benchmarks to replace the semiconductor reports. "Just relying on the semiconductor industry is no longer enough. We have to shift and punch through some walls and break through some barriers."

Predicting the end of Moore's Law has for years been a parlor game in Silicon Valley, and not everyone in the industry believes that what it has come to represent is nearly over. Intel, the world's largest chip maker, is a notable contrarian and predicts it has the means and know-how to push further into the atomic level.

In a statement on his company's website last month, Brian Krzanich, Intel's chief executive, played down concerns. "I have witnessed the advertised death of Moore's Law no less than four times," he wrote.

Intel, however, faces its own problems because of a long slump in PC sales and an inability to sell many chips to smartphone makers. Last month, the company announced plans to lay off 12,000 workers — roughly 11 percent of its work force — and take a $1.2 billion charge.

The industry saw signs that Moore's Law was running out of steam as far back as 2005, when researchers began to worry that computer processors were becoming so hot that they would soon match the surface of the sun in heat output.

But the industry managed to fix the problem by worrying less about increasing speed and instead splitting tasks among many processors. In effect, it kept things cool by finding a way to share the load.

By walking away from a task they have managed for so long, the chip makers other than Intel — the Silicon Valley giant says it is no longer formally contributing to the forecasting process — are posing broader questions about their businesses.

"As you look at Intel saying the PC industry is slowing and seeing the first signs of slowing in mobile computing, people are starting to look for new places to put semiconductors," said David Kanter, a semiconductor industry analyst at Real World Technologies in San Francisco.

In addition to the impending physical limits of transistors, other barriers are looming. For example, most of the semiconductor industry now insists that the per-transistor cost of computer chips has stopped falling. That has been one of the factors leading to rapid development of new computer technologies.

Many executives and analysts in the computer industry are skeptical about Intel's ability to keep Moore's Law going. They point out that if the chip maker were able to continue to reduce costs, it would have been able to make larger inroads into the mobile computing world of smartphones. As part of its recent cutbacks, the company killed its Atom microprocessors, which it had been unsuccessfully trying to sell to smartphone makers.

"If your whole business was about Moore's Law, and it was ending, how would you react?" Dr. Conte wrote in an email message.