Happy 40th birthday, Moore’s Law

Chip industry’s guiding principle marks milestone of technology

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SANTA CLARA, Calif. - To mark its 35th year, Electronics magazine broke from its usual coverage of vacuum tubes, newfangled lasers and high-tech minutia to ask a handful of experts to look ahead and write about their vision of the future.

Among the contributors was the young research director of a company that made integrated circuits — a relatively recent advance that combined transistors on a chip and seemed a promising but expensive way to make electronics smaller.

“The future of integrated electronics is the future of electronics itself,” he wrote. “The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas. Integrated circuits will lead to such wonders as home computers …”

The year was 1965, the author Gordon Moore.

In three years, Moore would leave his job at Fairchild Semiconductor to co-found Intel Corp. His article — “Cramming More Components Onto Integrated Circuits,” buried on page 114 of the now-defunct magazine’s April 19 issue — set the pace for the chip industry, which has become a significant driver of the global economy.

‘It’s what made Silicon Valley’

Over time, the observation would be called “Moore’s Law.” It has set a guidepost for technologists around the world for four decades — and counting.

“It’s the human spirit. It’s what made Silicon Valley,” said Carver Mead, a retired California Institute of Technology computer scientist who coined the term “Moore’s Law” in the early 1970s. “It’s the real thing.”

Plotting curves on graph paper, Moore saw that the number of components on an integrated circuit had doubled every year and figured that rate would continue for a decade as transistors were made smaller. He saw that the per-component costs would fall as manufacturing improved.

“The accuracy of the plot was not my principal objective,” Moore said in a recent interview at Intel’s headquarters, where the former chairman and CEO still keeps a cubicle. “I just wanted to get the idea across that integrated circuits were the route to much lower-cost electronics.”
A powerful forecast
Time proved the prediction to be accurate — so much so that the chip industry’s future plans are based on Moore’s forecast, which he has since revised to a doubling every two years. A corollary has been a commensurate improvement in performance.

The observation is even more impressive given that in 1965, there were just 50 to 60 transistors, among other components, on an integrated circuit, but the growth rate has closely followed his predicted curve to the present day.

At the same time, the cost per transistor has fallen as Moore predicted. In 1954, a transistor cost, on average, $5.52. By 2004, its price tag was a billionth of a dollar.

The implications have been huge, not just for computing but for everything touched by computers. All is now faster, better and cheaper — from desktop PCs that have the processing capabilities that once required a room-sized computer to feature-packed cell phones and portable music players the size of a pack of gum.

Not to mention all the silicon on factory floors, in automobiles and advanced weapons.

“The accomplishment which Moore’s Law represents has been the greatest technological success of human history,” said Stan Williams, a senior fellow at Hewlett-Packard Co.’s research lab. “There isn’t anything else out there that’s ever been such a spectacular improvement in technology.”

Launching a little company called Intel
Moore, a chemist by background, had joined Fairchild after leaving a firm set up by William Shockley, one of the transistor’s inventors in 1947. Robert Noyce, a pioneer in integrated circuits, also was part of the “Traitorous Eight” defectors.

After a series of management changes at Fairchild, Noyce and Moore bolted again — this time forming Intel — short for Integrated Electronics — to make advanced circuits and find new uses for them.

“It was a very courageous thing to do — to believe this doubling could continue on for a significant number of generations,” Williams said. “But he understood it and placed some pretty significant bets — and boy did it ever pay off.”

Last year, Intel reported $34.2 billion in sales. Now retired, the 76-year-old Moore still ranks among the world’s wealthiest people with an estimated fortune worth $4.3 billion. He remains an active philanthropist.

Success industrywide
Success, however, was not limited to Intel. The global semiconductor industry reported sales last year of $213 billion. The consumer electronics industry, which
relies largely on semiconductors, pulled in $1 trillion.

On a fundamental level, Moore’s Law gives chip makers, their equipment suppliers and their customers headlights for the future.

But cramming more and more transistors onto a chip is only half the story: Companies are left to figure out how to use them.

Recently, Intel and others have moved toward integrating two processor cores on a single chip, a move that could be planned years in advance thanks to guidance from Moore’s Law, said Fred Weber, chief technology officer at Advanced Micro Devices Inc., an Intel rival.

“The reason we had the confidence five years ago to (announce) our multicore design was because we saw where the number of transistors would move, and we knew what computer architecture would make possible,” he said.

**Moore's Corollary: Nothing lasts forever**
But, as Moore himself is quick to point out, nothing can grow at an exponential rate forever. Within the next 15 years, it’s expected that engineers will reach the point where any further shrinkage would require atoms to be split.

“Any exponential extrapolated far enough predicts a disaster,” Moore said.

Then again, predicting the end of Moore’s Law has become a favorite pastime in the Silicon Valley. Its demise has been a few years away for the last 20 years, though each seemingly insurmountable barrier has been bypassed.

“There’s been every reason given why it shouldn’t work anymore, every reason why it’s dead, every reason why it’s about to die,” said Craig Barrett, Intel’s chief executive.

Despite Moore’s influence, there’s not a whiff of arrogance about him. As he walked outside the other day, he offered to hold the door for a delivery man who was carrying a handheld computer but didn’t recognize the man who 40 years ago had predicted such technology could exist.

For years, Moore was uncomfortable uttering the words “Moore’s Law,” and he said he is surprised at how his prediction has been adapted — and sometimes mangled — by others. “I’m going to be as well known as Murphy one of these days,” he said.

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It's Moore's Law, but Another Had the Idea First

By JOHN MARKOFF

SAN FRANCISCO, April 17 - One of the cornerstones of Silicon Valley will mark an anniversary Tuesday. Forty years ago, Electronics magazine published Gordon E. Moore's celebrated article predicting that the number of transistors that could be placed on a silicon chip would continue to double at regular intervals for the foreseeable future.

Named Moore's Law several years later by the physicist Carver Mead, that simple observation has proven to be the bulwark of the world's most remarkable industry.

Yet Mr. Moore was not the only one - or even the first - to observe the so-called scaling effect that has led to the exponential acceleration of computing power that is now expected to continue at least for the next decade.

Before Mr. Moore's magazine article precisely plotted the increase in the number of transistors on a chip, beginning with 1, the computer scientist Douglas C. Engelbart had made a similar observation at the very dawn of the integrated-circuit era. Mr. Moore had heard Mr. Engelbart lecture on the subject, possibly in 1960.

Mr. Engelbart would later be hailed as the inventor of the computer mouse as well as the leading developer of many technologies that underlie both the personal computer industry and the Internet.

In a 2001 interview, Mr. Engelbart said that it was his thinking about the scaling down of circuits that gave him the confidence to move ahead with the design of an interactive computing system.

"I was relieved because it wasn't as crazy as everyone thought," he said.

Significantly, the two pioneers represent twin Silicon Valley cultures that have combined to create the digital economy.

Mr. Moore, who co-founded Intel, is an icon of the precise and perhaps narrower chip engineering discipline that today continues to progress by layering sheets of individual molecules, one on top of the other, and by making wires that are finer in diameter than a wavelength of light.

"Gordon was the classic engineer," said Craig Barrett, Intel's chief executive, who had just begun to teach engineering at Stanford University when Mr. Moore made his famous prediction. The chart that accompanied his article was a plot that showed just five data points over seven years and extrapolated out into the future as far as 1975, when a single chip would be able to hold as many as 65,000 transistors. Forty years later, memory chip capacity has gone far beyond one billion of the tiny switches.
Mr. Engelbart, in contrast, was the architect of a passionately held view that computing could extend or "augment" the power of the human mind. His ideas were set out most clearly in 1968, in a famous demonstration in San Francisco of his Pentagon-financed Augment computing system. Many things were shown to the world for the first time, including the mouse, videoconferencing, interactive text editing, hypertext and networking - basically the outlines of modern Internet-style computing.

Mr. Engelbart had an epiphany in 1950, in which he imagined what would decades later become today's Internet-connected PC. He set about building it. At the time he had no idea of how he would build such a machine, but it soon became clear that it would require a computer that did not yet exist.

Later he was offered a job at Hewlett-Packard, but when he learned that the company had no plans to enter the computer business, he went to work instead at Stanford Research Institute, now SRI International.

There he worked with a group of military-funded researchers who were attempting to build magnetic-based computing circuits. The military was interested in the technology because of its potential performance in outer space.

With the invention of the integrated circuit in 1959, however, the group realized that its work would soon fall by the wayside.

Thinking about the idea of miniaturized circuitry, Mr. Engelbart realized that it would scale down to vastly smaller sizes than the current electronic comments. He had that insight because earlier he had worked as an electronics technician in the wind tunnel at the Ames Research Center, a NASA laboratory in Mountain View, Calif. There, aerodynamicists made models and scaled them up into complete airplanes.

It was an easy conceptual leap to realize that integrated circuits would scale in the opposite direction. In 1959 he put his ideas into a paper, titled "Microelectronics and the Art of Similitude." In February 1960, he traveled to the International Circuit Conference in Philadelphia. There he explained to his audience that as chips scaled down, the new microelectronic engineers would have to worry about changing constraints, just as aerodynamicists had to worry about the macroworld.

One person who has a clear memory of Mr. Engelbart's description is Mr. Moore, although he does not remember whether he heard him speak in Philadelphia or elsewhere.

"The thing that I remember from it is his question if we would notice anything different if everything in the room was suddenly 10 times as large," he wrote in an e-mail message. "He answered it by suggesting that the chandelier might fall."

Several historians pointed out that Mr. Engelbart's previous observation did nothing to detract from the significance of Mr. Moore's careful plotting of the trend.

"It still should be called Moore's Law rather than Engelbart's Law," said Michael Riordan, a historian of physics at the University of California, Santa Cruz. "Science is still based on theory and experiment."

As for Mr. Engelbart, the 1959 paper convinced him that the Augmentation machine he envisioned would be possible, because computing would be plentiful in the future.

He was one of the first to grasp the implications of the new technology. Years later he recalled in an
interview that he told his Philadelphia audience, "Boy, are there going to be surprises over there."