**We’re not prepared for the end of Moore’s Law**

It has fueled prosperity of the last 50 years. But the end is now in sight.

by David Rotman Feb 24, 2020

Gordon Moore’s 1965 forecast that the number of components on an integrated circuit would double every year until it reached an astonishing 65,000 by 1975 is the greatest technological prediction of the last half-century. When it proved correct in 1975, he revised what has become known as Moore’s Law to a doubling of transistors on a chip every two years.

Moore’s argument was an economic one. Integrated circuits, with multiple transistors and other electronic devices interconnected with aluminum metal lines on a tiny square of silicon wafer, had been invented a few years earlier by Robert Noyce at Fairchild Semiconductor. Moore, the company’s R&D director, realized, as he wrote in 1965, that with these new integrated circuits, “the cost per component is nearly inversely proportional to the number of components.” It was a beautiful bargain—in theory, the more transistors you added, the cheaper each one got.

Soon these cheaper, more powerful chips would become what economists like to call a general purpose technology—one so fundamental that it spawns all sorts of other innovations and advances in multiple industries. A few years ago, leading economists credited the information technology made possible by integrated circuits with a third of US productivity growth since 1974. Almost every technology we care about, from smartphones to cheap laptops to GPS, is a direct reflection of Moore’s prediction. It has also fueled today’s breakthroughs in artificial intelligence and genetic medicine, by giving machine-learning techniques the ability to chew through massive amounts of data to find answers.

But how did a simple prediction, based on extrapolating from a graph of the number of transistors by year—a graph that at the time had only a few data points—come to define a half-century of progress? In part, at least, because the semiconductor industry decided it would.

Moore wrote that “cramming more components onto integrated circuits,” the title of his 1965 article, would “lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment.” In other words, stick to his road map of squeezing ever more transistors onto chips and it would lead you to the promised land. And for the following decades, a booming industry, the government, and armies of academic and industrial researchers poured money and time into upholding Moore’s Law, creating a self-fulfilling prophecy that kept progress on track with uncanny accuracy. Though the pace of progress has slipped in recent years, the most advanced chips today have nearly 50 billion transistors.

But what happens when Moore’s Law inevitably ends? Or what if, as some suspect, it has already died, and we are already running on the fumes of the greatest technology engine of our time?

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“It’s over. This year that became really clear,” says Charles Leiserson, a computer scientist at MIT and a pioneer of parallel computing, in which multiple calculations are performed simultaneously. The newest Intel fabrication plant, meant to build chips with minimum feature sizes of 10 nanometers, was much delayed, delivering chips in 2019, five years after the previous generation of chips with 14-nanometer features. Moore’s Law, Leiserson says, was always about the rate of progress, and “we’re no longer on that rate.” Numerous other prominent computer scientists have also declared Moore’s Law dead in recent years.

In truth, it’s been more a gradual decline than a sudden death. Over the decades, some, including Moore himself at times, fretted that they could see the end in sight, as it got harder to make smaller and smaller transistors.

Finding successors to today’s silicon chips will take years of research. If you’re worried about what will replace Moore’s Law, it’s time to panic.

Nonetheless, Intel—one of those three chipmakers—isn’t expecting a funeral for Moore’s Law anytime soon. Jim Keller found ample technical opportunities for advances. He points out that there are probably more than a hundred variables involved in keeping Moore’s Law going, each of which provides different benefits and faces its own limits.

Still, even if Intel and the other remaining chipmakers can squeeze out a few more generations of even more advanced microchips, the days when you could reliably count on faster, cheaper chips every couple of years are clearly over. That doesn’t, however, mean the end of computational progress.

**Time to panic**

One opportunity is in slimming down so-called software bloat to wring the most out of existing chips. When chips could always be counted on to get faster and more powerful, programmers didn’t need to worry much about writing more efficient code. And they often failed to take full advantage of changes in hardware architecture, such as the multiple cores, or processors, seen in chips used today.

Rather than “lifting all boats,” as Moore’s Law has, by offering ever faster and cheaper chips that were universally available, advances in software and specialized architecture will now start to selectively target specific problems and business opportunities, favoring those with sufficient money and resources.

Indeed, the move to chips designed for specific applications, particularly in AI, is well under way.

But the trade-off is that specialized chips are less versatile than traditional CPUs.

At some point, says Erica Fuchs, a professor of engineering and public policy at Carnegie Mellon, those developing AI and other applications will miss the decreases in cost and increases in performance delivered by Moore’s Law. “Maybe in 10 years or 30 years—no one really knows when—you’re going to need a device with that additional computation power,” she says.

The problem, says Fuchs, is that the successors to today’s general purpose chips are unknown and will take years of basic research and development to create. If you’re worried about what will replace Moore’s Law, she suggests, “the moment to panic is now.” There are, she says, “really smart people in AI who aren’t aware of the hardware constraints facing long-term advances in computing.” What’s more, she says, because application--specific chips are proving hugely profitable, there are few incentives to invest in new logic devices and ways of doing computing.

**Wanted: A Marshall Plan for chips**

In 2018, Fuchs and her CMU colleagues Hassan Khan and David Hounshell wrote a paper tracing the history of Moore’s Law and identifying the changes behind today’s lack of the industry and government collaboration that fostered so much progress in earlier decades.

If economists are right, and much of the growth in the 1990s and early 2000s was a result of microchips—and if, as some suggest, the sluggish productivity growth that began in the mid-2000s reflects the slowdown in computational progress—then, says Thompson, “it follows you should invest enormous amounts of money to find the successor technology. We’re not doing it. And it’s a public policy failure.”

We need the research investments now to find out, though. Because one prediction is pretty much certain to come true: we’re always going to want more computing power.