

Thoughts on Moore's Law and Related Topics

From an interview with Gordon Moore conducted by Intel in early 2015 (first seven answers) and an interview by the Chemical Heritage Foundation in 2013 (last two answers)



THE ORIGIN OF MOORE'S LAW

In the early 1960s we were continuing to develop semiconductor technology and make it increasingly practical. It was a difficult technology to implement with the tools we initially had available. I became director of R&D at Fairchild Semiconductor, running the laboratory, looking at what we could do as we improved the technology.

Then, I got asked by Electronics Magazine to submit an article for their 35th annual edition predicting what was going to happen in the semiconductor component industry in the next 10 years.

So I took the opportunity to look at what had happened up to that time. This would have been in 1964, I guess. And I looked at the few chips we had made and noticed we went from a single transistor on a chip to a chip with about eight elements – transistors and resistors – on it.

The new chips coming out had about twice the number of elements, about 16. And in the laboratory, we were creating chips with about 30 elements and we were looking at the possibility of making chips with twice that many, around

60 elements on a chip. Well, I plotted these on a piece of semi-log paper starting with the planar transistor in 1959 and noticed that, essentially, we were doubling every year.

So I took a wild extrapolation and said we're going to continue doubling every year and go from about 60 elements at the time to 60,000 in 10 years.

I was just trying to communicate the point that this was the direction semiconductors were going. And this was going to give a tremendous cost advantage, which wasn't true at the time. The early integrated circuits cost quite a bit more than the pieces to assemble the similar circuits out of individual components.

But one could see the trend was going in the direction that this was going to be the cheaper way eventually. That was my real objective – to communicate that we have a technology that's going to make electronics cheap. But I didn't expect this binary order of magnitude increase, the thousand-fold increase in complexity to be very accurate.

I just thought it was a general trend we were going to have. But in fact, it was far more accurate

than I could have anticipated. And at the end of the 10 years, if we didn't have 10 doublings of the number of elements on a chip, we at least had nine. So one of my colleagues – I believe it was Carver Mead, a professor at Cal Tech – dubbed this “Moore's Law,” a name that has stuck beyond anything that I think could have been anticipated.

THE IMPACT OF MOORE'S LAW ON THE CHIP INDUSTRY

Certainly, the impact the so-called Moore's Law has had has changed over time. In the beginning, it was just a way of chronicling the progress. People were making more complex chips. You could plot, and say, yeah, we're still increasing the complexity. But gradually, it became something that the various industry participants recognized as something they had to stay on or fall behind technologically. In order to stay at the leading edge where most of the advantages of semiconductor technology get exploited, they had to move as fast as Moore's Law predicted. They had to go to the smaller dimensions and the larger chips on the schedule that this suggested was necessary. So it went from a way of measuring what had happened to something that was kind of driving the industry. You had to be at least that fast, or you were falling behind.

THE LONGEVITY OF MOORE'S LAW AND ITS FUTURE

In 1965, and when I updated my observation in 1975, I didn't predict when this trend was going to end. It's a good thing because I'm sure I would have been surprised. The industry has been phenomenally creative in continuing to increase the complexity of chips. It's hard to believe – at least it's hard for me to believe – that now we talk in terms of billions of transistors on a chip rather than 10s, hundreds or thousands.

It's a technology that's been much more open ended than I would have thought in 1965 or

1975. And it's not obvious yet when it will come to the end.

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But gradually, it became something that the various industry participants recognized as the pace of innovation they had to stay on or fall behind technologically. In order to stay at the leading edge where most of the advantages of semiconductor technology get exploited, they had to move as fast as Moore's Law predicted.

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THE MOST SURPRISING INNOVATION MADE POSSIBLE BY MOORE'S LAW

In the 1965 Electronics article I predicted a variety of things from watches to personal computers to phased-array radar. Going back and reading that article, I'm amazed at how accurate my application predictions turned out to be. In terms of an innovation that I didn't foresee, I guess the one that really took me by surprise is the importance of the Internet. We knew computers did useful things. We knew they would improve at some rate once we got started. But I never realized how important they were going to be as a communications medium, driven principally by the Internet. I can't think of another innovation that's comparable.

ADVICE FOR TODAY'S ENTREPRENEURS

I'm not sure I'm the one to give advice. My feeling has been that you identify the products, the areas where you want to do something and then, if it makes sense, start a new concern. So many entrepreneurs today seem to approach things the other way around. They decide they want to start a new company and then start looking for an idea that they could exploit. Some of these

will turn out to be big deals, you know, such as Google. A lot of them will turn out to be kind of a flash in the pan that, for a short period, will be successful but then will be displaced by something else. I guess if I would give current and future entrepreneurs advice it would be look for how you can make a long-term enterprise out of what you're trying to do rather than just a short-term success.

ADVICE TO INTEL EMPLOYEES

When I'm asked what my message is to current Intel employees, I tell them to keep the ball moving forward. There are a lot of obstacles that have to be surmounted to keep the technology moving along the line that has been so important to Intel. So I tell them to keep their eyes on the ball, and keep the ball moving. It's really what will make Intel continue to be successful looking forward. Keep pushing. Extend the art as far as you can. It requires continually pushing the frontier.

THE IMPORTANCE OF EDUCATION FOR TECHNOLOGY

I think that the continual flow of well-educated engineers and scientists is the lifeblood of a company like Intel. And this only happens if we

have the universities turning out people with the skills we need. The good ideas often come from the young engineers and that's going to continue to be the case. They're the ones often willing to make the real leaps that result in qualitatively different products and processes. Those of us who have been around too long think we've seen everything. And we kind of lose our creativity. So I believe that the universities are a very important part of the long-term success of technology. And similarly, companies like Intel are a very important part of the universities' continued success.

HIS BIGGEST ACCOMPLISHMENT

It's hard to pick out any single thing I'm most proud of. Perhaps the founding of Intel was my biggest success.

THE POPULARITY OF MOORE'S LAW

It's amazing how often I run across a reference to Moore's Law. In fact, I Googled 'Moore's Law' and I Googled 'Murphy's Law' and 'Moore' beats 'Murphy' by at least two to one.