reflections

Moore's Law redux

What is the most fundamental law in electrical engineering? Is it Ohm's law, or is it now Moore's law? My vote goes to Moore. I can't remember the last time I actually had to think about Ohm's law, but not a day goes by that I am not haunted by the specter of Moore's exponential forecast—that semiconductor technology doubles its effectiveness every 18 months.

I often think that there should be more learned discussion about Moore's law—why it is, and what it means. It's easy to say that this "law" is only a projection based on observation, rather than a real physical law. This projection, however, has been accurate for 33 years, so there must be something going on here, something of a fundamental nature that we should understand. I myself waver among three hypotheses involving variously the structure of the universe, self-fulfilling prophecy, or fashion.

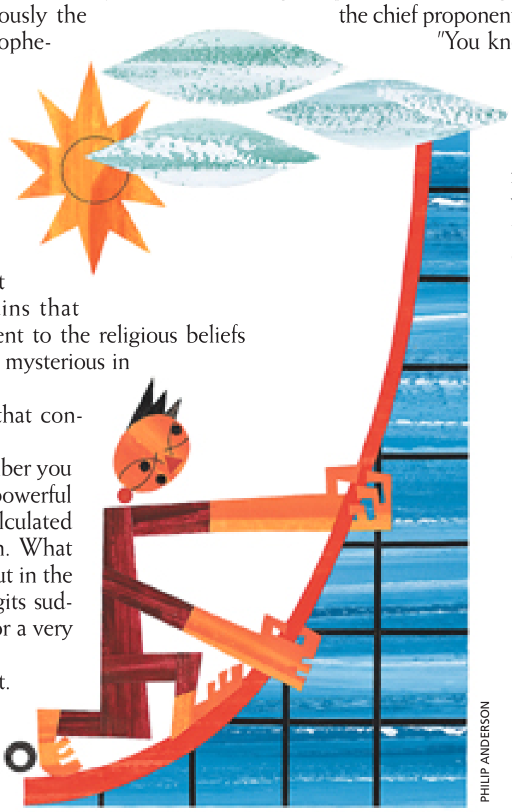
In Carl Sagan's book *Contact*, earth is allowed a brief visit to an advanced alien civilization. In an incident from the book (not included in the movie), the earth's astronaut is allowed the privilege of asking one question of the aliens before departure. After some hesitation, the astronaut asks the aliens about their religious beliefs. An alien explains that although they do not have any equivalent to the religious beliefs held on earth, there is something deeply mysterious in the universe that worries them.

"What is it of religious significance that concerns you?" asks the astronaut.

"Well," says the alien, "You have a number you call Pi. Our computers are much more powerful than yours on earth are, so we have calculated this number to a much greater precision. What concerns us is that when we get far, far out in the decimal expansion of Pi, the decimal digits suddenly turn into binary ones and zeroes for a very long time."

"What does it mean?" asks the astronaut.

"We don't know," muses the alien. "But there is a message encoded into the structure of the universe."



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Imagine the awesome implications should we find a binary message encoded into a fundamental constant like Pi! Yet I wonder if something like that isn't behind Moore's law. Could Moore's law have always been with us, and much more deeply embedded in technology than just semiconductor density? Perhaps it was only noticed in 1965 because we had for the first time a quantitative way of measuring technological progress. Maybe technological progress has always been exponential, as it if were indeed a message encoded into the structure of the universe. Scary thought, isn't it?

We know, for example, that the capacity of optical-fiber communication systems doubles about every 12 months. We know that wireless capacity is currently doubling about every nine months. Exponential progress is everywhere we look and can measure, and in areas that appear to be unrelated to the manufacturing of silicon integrated circuits. Is there, in fact, a larger law at work?

Leaving the structure-of-the-universe hypothesis and moving to the other extreme, it has been suggested that Moore's law is simply a self-fulfilling prophecy. Since everyone knows how fast progress must be, every manufacturer does whatever is necessary to stay on the curve where they expect their competitors to be. Whatever money must be spent, whatever engineering must be accomplished, the stakes get raised exponentially.

Somewhere in the middle between these extremes is my "fashion" theory. This is simply the thought that progress is directly related to the number of people working on something. There has been for a long time a growing army of people working on silicon technology. So, sure, progress happens ever faster.

Recently, for example, I have been trying to understand the economics of packet networks. The world's telecommunications networks are being converted from circuit switching to packet switching because there is a belief that packet switching is a lot cheaper. I was given pause in this evangelism, however, by a comment from one of the chief proponents of packet technology.

"You know, Bob," he said, "we could make circuit switching just as cheap if we all decided to work on that instead. But the fact is that the world is working on packet switching, so its cost is coming down much faster." Whatever is fashionable, wherever the wave gathers, that is the technology to ride, the one that will make exponential progress.

Regardless of the reason behind Moore's law, the implications of exponential progress are profound. All of us tend to understand the world in linear terms. We all learned long ago that everything in engineering plots as a straight line on log paper, yet we think "straight line" and forget "log." Dangerous, but I do it all the time myself.

In a recent talk, the journalist George Gilder drew a compelling analogy for the consequences of Moore's law by recalling the old story of the king, the peasant, and the chessboard. The peasant has done a favor for the king and is asked to name his reward. He says simply a single grain of rice on the first square of a chessboard, and twice as many on each succeeding square. Since this sounds simple, the king agrees.

How much rice does this require? I notice that one university has a physics experiment based on this fable to give students an intuitive understanding of exponentiation. In the beginning, very little rice is needed. The first 18 to 20 squares of the board can be handled easily with the rice in a small wastebasket. The next couple of squares need a large wastebasket. Squares 23–27 take an area of rice about the size of a large lecture table. Squares 28–37 take up about a room. To get to the 64th and last square requires about 2×10^{19} grains—variously estimated as requiring the entire area of earth to produce, weighing 100 billion tons, filling a million large ships, or a billion swimming pools.

That is the way exponentials work. At first they are easy, but later they become overwhelming. Moore's law says there will be exponential progress and that doublings will occur every year and a half. Since the invention of the transistor, there have been about 32 doublings of the technology—the first half of the chessboard. What overwhelming implications await us now as we begin the second half of the board? Think about it.

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