Moore's Law and Exponential Growth

An Online Continuing Education Course for Engineers

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Moore's Law and Exponential Growth

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Introduction

Advances in technology throughout human history have never been as evident as the advances in computer technology in the latter half of the twentieth century and the early part of the twenty-first century. Technological progress is no longer seemingly liner; it is clearly exponential. The trend in the increase in computational power is predicted by Moore's Law.

Moore's Law is a term used to describe the increase in computing power over time. Moore's Law is the observation that the number of transistors on an integrated circuit (or microprocessor) doubles every two years.

A transistor is a tiny semiconductor device used to switch electronic signals. A transistor is a simple digital switch. When used in a digital circuit the transistor is either on or off.

Logic gates build on the switching power of a transistor to make more complex building blocks. A logic gate is the fundamental building block for a digital integrated circuit, and the fundamental building block for a logic gate is the transistor. Logic gates include AND, OR, NOT, NAND, NOR, XOR. All of these logic gates can be built using only NAND gates. This simplifies and reduces the complexity of integrated circuits by only using one basic type of logic gate. NAND gates can be assembled to form flip flops (like the D flip flop); these flip flops are called registers and form the basis of microprocessor cores. The heart of a computer is a microprocessor, and microprocessors are built from logic gates and the basic building block of a logic gate is a transistor.

Moore's Law

Moore's Law is named for Intel cofounder Gordon E. Moore who described this computing trend in a 1965 paper while he was the director of research and development of Fairchild Semiconductor. Moore's original statement in his 1965 publication "Cramming More Components onto Integrated Circuits", Electronics Magazine, April 19, 1965:

> *The complexity for minimum component costs has increased at a rate of roughly a factor of two per year... Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000.*

He stated that the number of components in integrated circuits had doubled every year from the invention of the integrated circuit in 1958 until 1965 and predicted that the trend would continue for at least ten years. Moore's exact words from his paper were "the complexity for minimum component costs has increased at a rate of roughly a factor of two per year."

He expected this rate to continue in the short term if not increase and that this rate will be uncertain for longer periods, but if the rate was maintained then the number of components per integrated circuit would be 65,000 by 1975.

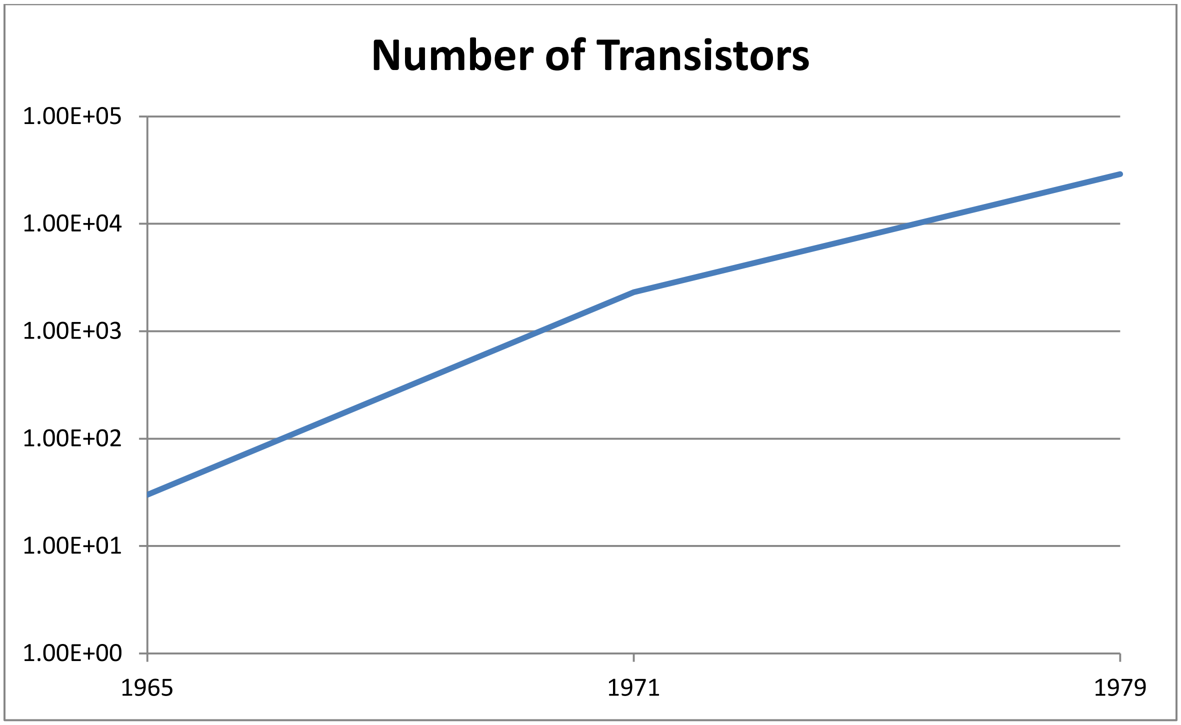


Figure 1 - Graph of 10 year trend from 1965 to 1975

Moore observed that there is a maximum density of transistors at any given point in time that will result in the lowest cost per transistor. As more transistors are put on a chip, the cost to make each transistor decreases, but the chance that the chip will not work due to one or more defects increases. Moore noted that as the technology of photolithography improves, the density of transistors on a single chip will increase.

His prediction has proven to be amazingly accurate for almost five decades.

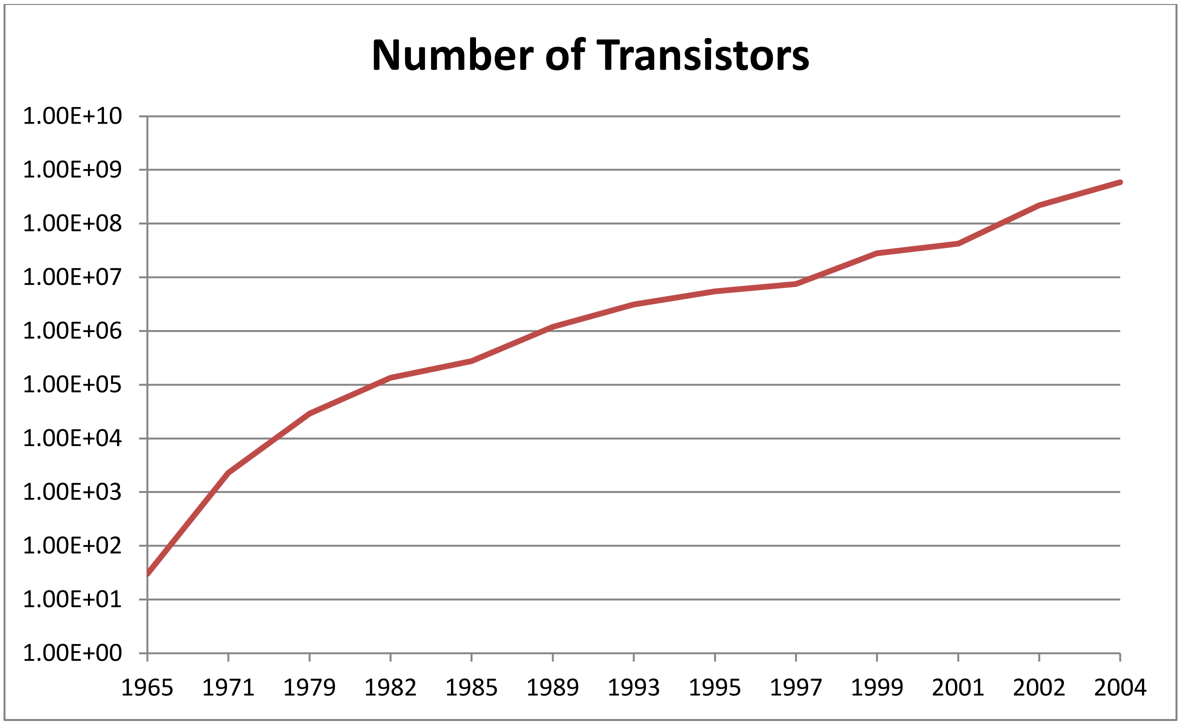


Figure 2 - Graph of 50 year trend from 1965 to 2012

The visionary Moore stated in his paper that "integrated circuits will 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." The semiconductor industry now uses Moore's observation as a guide to long-term planning and to set goals for research and development.

The capability and processing power of digital electronic devices are strongly linked to Moore's Law: processing speed, memory capacity, and the number and size of pixels in digital cameras. Moore stated that "Integrated electronics will make electronic techniques more generally available throughout all of society, performing many functions that presently are done adequately by other techniques or not done at all."

All of these capabilities are increasing exponentially. These improvements to processing power and memory capacity have impacted almost every sector of modern life as well as the world economy.

Examples of this computing trend affecting life:

- personal computers
- communication
- transportation (electronics in cars, airplanes, trucks, trains, etc.)
- the Internet
- medical instrumentation
- social media

- world stock markets (algorithms computing market trends)
- agriculture
- teaching (from preschool to post-graduate college)
- search engines
- navigation devices

Semiconductor Technology
The transistor (or "transfer resistor") was invented in 1947 at AT&T's Bell Labs. John Bardeen, Walter Brattain and William Shockley were experimenting with gold point contacts on a germanium crystal and the effects on signals that pass through it. They found that the output signal had greater power than the input (a condition known as amplification). This amplification effect, the potential for its small size, and the ability to be mass produced using highly automated processes made the vacuum tube almost instantly obsolete. The transistor may be considered one of the greatest inventions of the 20th century. Its greatest potential is its ability to act as a miniature electronic switching device. It is the key building block in an integrated circuit.

The first integrated circuit was invented in the late 1950s by Jack Kilby at Texas Instruments and Robert Noyce at Intel. Kilby described his new device as "a body of semiconductor material... wherein all the components of the electronic circuit are completed integrated." Kilby's chip was made of germanium. Noyce's chip was made of silicon and solved many of the problems of Kilby's germanium chip.

Without the invention of the transistor, the integrated circuit would not be possible. Without the integrated circuit, there would be no microprocessors, no advanced electronics, no cell phones, no Information Age.

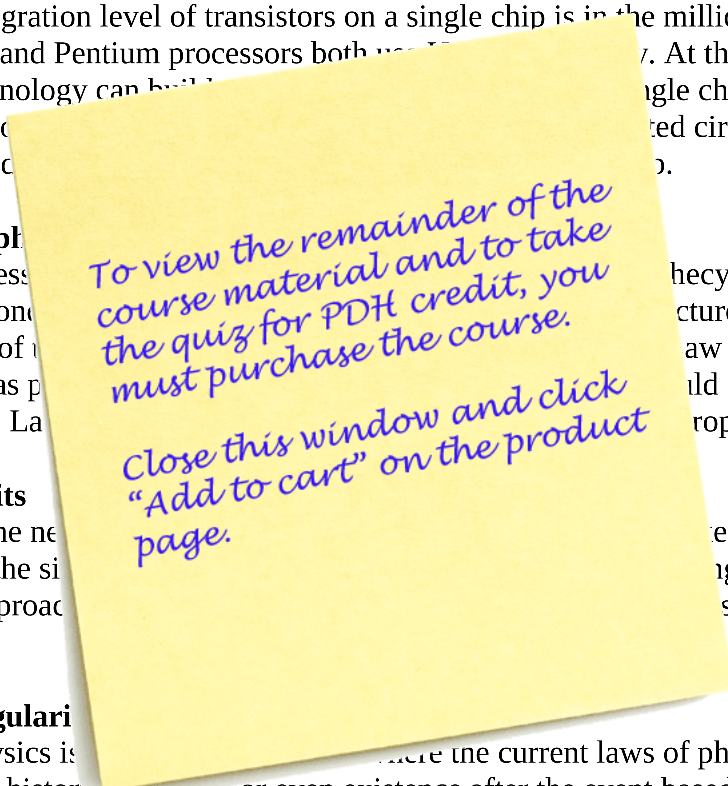
Small-Scale Integration
In the early 1960s the first integrated circuits contained only a few transistors. This level of integration is called small-scale integration (SSI). Digital integrated circuits contained only tens of transistors per chip. This amount of transistors could produce only a few logic gates.
The Minuteman Missile program and the Apollo space program accelerated the SSI state of the art to medium-scale integration for the need for lightweight digital circuits for their inertial guidance systems.

Medium-Scale Integration
The transition from small-scale integration to medium-scale integration (MSI) occurred in the late 1960s. MSI allows for hundreds of transistors on each chip. MSI devices allow for more complex systems to be produced for about the same cost as an SSI device. An MSI device has the capacity of multiple logic gates per integrated circuit.

Large-Scale Integration
In the mid-1970s medium-scale integration took a back seat to large-scale integration (LSI). LSI allows for thousands of transistors per chip. LSI circuits allow for even more complex systems to be produced. The development of LSI produced the first microprocessors and computer memories. The development of LSI and the progression to very large-scale integration (VLSI) is the point at which truly practical computers became a reality.

Very Large-Scale Integration
The development of VLSI occurred in the early 1980s. With this level of integration, it was possible to put tens of thousands to hundreds of thousands of transistors per chip. With the development of VLSI technology, high density memory chips and faster, more complicated microprocessors became a reality.

Ultra-Large-Scale Integration
The development of ultra-large-scale integration (ULSI) technology occurred in the mid-2000s. With ULSI, the integration level of transistors on a single chip is in the millions and even billions. Intel's 486 and Pentium processors both us... . At the time of this writing current technology can bu... ngle chip. ULSI made possible the advent o... ted circuit in which all of the components need... .



Self-Fulfilling Proph...
Some industry profess... hecy. It served as a goal for the entire semicon... cturers to invest enormous amounts of ... aw for processing power because it was p... ld soon attain the same goal. Thus, Moore's La... rophecy

Fundamental Limits
Eventually within the ne... ely be reached as technology pushes the si... ng individual transistors down approac... s a fundamental barrier.

Technological Singulari...
A singularity in physics is ... here the current laws of physics break down. The point in human history ... life or even existence after the event based on technological progress is unpredictable or incomprehensible is known as the technological singularity.
The event is technological in nature. In other words, not something brought on by some sort of natural disaster. The technology relevant for radical change is the semiconductor and computer industries in terms of processing power.

Wikipedia describes the technological singularity as "the theoretical emergence of greater-than-human super intelligence through technological means." Since the capabilities of such an artificial intelligence are beyond our comprehension, this event (assuming that it will occur) is viewed by some as an intellectual event horizon, beyond which events cannot be predicted.
The term "singularity" as it relates to society was introduced by John von Neumann in the mid-1950s in which he spoke of "ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue." This singularity as von Neumann described it would cause an eventual unpredictable outcome in society.