International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 12 Issue 3, March-2023, Impact Factor: 7.957

Analysis of Moore's Law and its Applicability in the Future

Akaash Sai Sagi

Research Scholars Program, Harvard Student Agencies, In collaboration with Learn with Leaders

INTRODUCTION

Moore's Law is not a law in the legitimate sense nor a proven theory in the scientific sense (e.g., E=MC^2). Rather, it was an observation made by Gordon Moore (Intel co-founder and former CEO) in his 1965 article "Cramming More Components on Integrated Circuits." The law is a statement made by observing empirical data over a period of time. According to Moore's Law, the number of transistors on a microchip doubles every two years. The law stipulates that he should expect his computer to improve in speed and capabilities every two years, but he is paid less overall for it. Another principle of Moore's Law states that this growth is exponential in nature. Chips and transistors are microscopic structures containing perfectly aligned carbon and silicon molecules that move electricity faster along circuits. The faster the microchip can process electrical signals, the more efficient the computer. The cost of more powerful computers is falling each year due to lower labor costs and lower semiconductor prices. Doubling the complexity of a chip doubles the computational power without significantly increasing the cost. The number of transistors per chip has grown from a few in the 1960s to billions in the 2010s. We have benefited greatly from this. In fact, almost every aspect of our high-tech society benefits from Moore's Law. Mobile devices such as smartphones and computer tablets cannot function without small processors. The same is true for video games, spreadsheets, accurate weather forecasts, and global positioning systems (GPS) etc. Other examples of industries that have evolved as a result of the increasing power of computer chips include transportation, healthcare, education, and energy generation.

1. HISTORY AND ANALYSIS OF MOORE'S LAW IN THE PAST

Mathematical modeling and log graphical analysis of Moore's law

Moore first published what became known as Moore's Law in an article in Electronics magazine in 1965 while working at Fairchild Semiconductor the term "Moore's Law" was coined around 1975 by Carver Mead, a professor at the California Institute of Technology (Caltech) in Pasadena, California**.** His early work paved the way for advanced semiconductor design that benefited from Moore's law. Moore's law can be mathematically expressed as $pn = po \times 2^n$ where:

Pn = computer processing power in future years
Po = the computer processing power at the start of the year
n = number of years to develop a new microprocessor divided by 2 (i.e., every two years)

For example, in 1988, the Intel 386 SX microprocessor had 275,000 transistors. How many transistors did the 1997 Pentium II Intel microprocessor have?

Resolution:

With Intel doubling the number of transistors every two years
Pn = 275,000 x 2n (n = 9/2 = 4.5)
= 275,000 × 22.63
= 66,223,250 transistors

In 1997, the Pentium II had 7.5 million transistors. In other words, from 1988 to 1997 (nine years), Intel doubled the number of transistors in its microprocessors in less than two years. Thus, we can see that Intel had doubled the number of transistors per chip count in less than two years and Moore's Law in action.

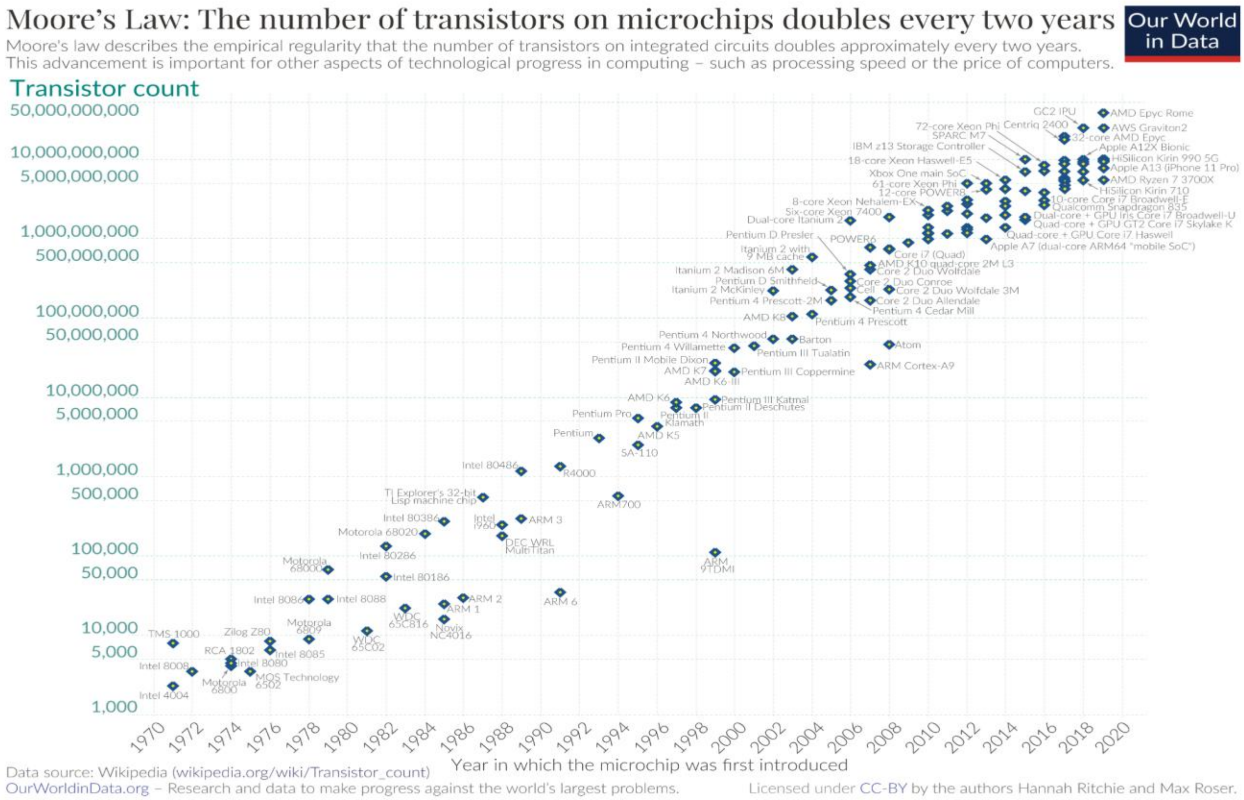

Figure 1: A semi-log-plot of transistor counts for microprocessors against dates of introduction shows nearly doubling every two years[1]
Source: Roser & Ritchie

Gordon Moore posited a log-linear relationship between device complexity (higher circuit density at reduced cost), here we observe the log relationship, as the above image composites the log relationship of transistor count in the Y-axis over time in the X-axis as see in log graph data values are over to billions scale from mere few thousands as we can the words acted as a self-fulfilling prophecy and consistently advanced the scaling of transistor available in microchips to new heights. we see Moore's law in a linear form even though its exponential by since it's convenient to show Moore's Law to its logarithm, which shows a linear dependence to -y making it easier to depict the increase (since on a logarithmic scale this will be a straight line) it's possible to calculate using logarithmic function

$$\log_{10} ni = \log_{10} n_0 + \frac{y_i - y_0}{T2} \log_{10} 2$$

where n_0 is random reference year, y_0, and T2=2 is the number of years taken in this instance two double this number. In the code below we can see how we can create a log plot to show Moore's Law from the given time period upto 2012.

```
import pylab

# The data - lists of years:
year = [1972, 1974, 1978, 1982, 1985, 1989, 1993, 1997, 1999, 2000, 2003,
2004, 2007, 2008, 2012]
# and number of transistors (ntrans) on CPUs in millions:
ntrans = [0.0025, 0.005, 0.029, 0.12, 0.275, 1.18, 3.1, 7.5, 24.0, 42.0,
220.0, 592.0, 1720.0, 2046.0, 3100.0]
# turn the ntrans list into a pylab array and multiply by 1 million
```

[1] By Max Roser, Hannah Ritchie https://ourworldindata.org/uploads/2020/11/Transistor-Count-over-time.png

```
ntrans = pylab.array(ntrans) * 1.e6

y0, n0 = year[0], ntrans[0]
# A linear array of years spanning the data's years
y = pylab.linspace(y0, year[-1], year[-1] - y0 + 1)
# Time taken in years for the number of transistors to double
T2 = 2.
moore = pylab.log10(n0) + (y - y0) / T2 * pylab.log10(2)

pylab.plot(year, pylab.log10(ntrans), '*', markersize=12, color='r',
        markeredgecolor='r', label='observed')
pylab.plot(y, moore, linewidth=2, color='k', linestyle='--', label='predicted')
pylab.legend(fontsize=16, loc='upper left')
pylab.xlabel('Year', fontsize=16)
pylab.ylabel('log(ntrans)', fontsize=16)
pylab.title("Moore's Law")
pylab.show()
```

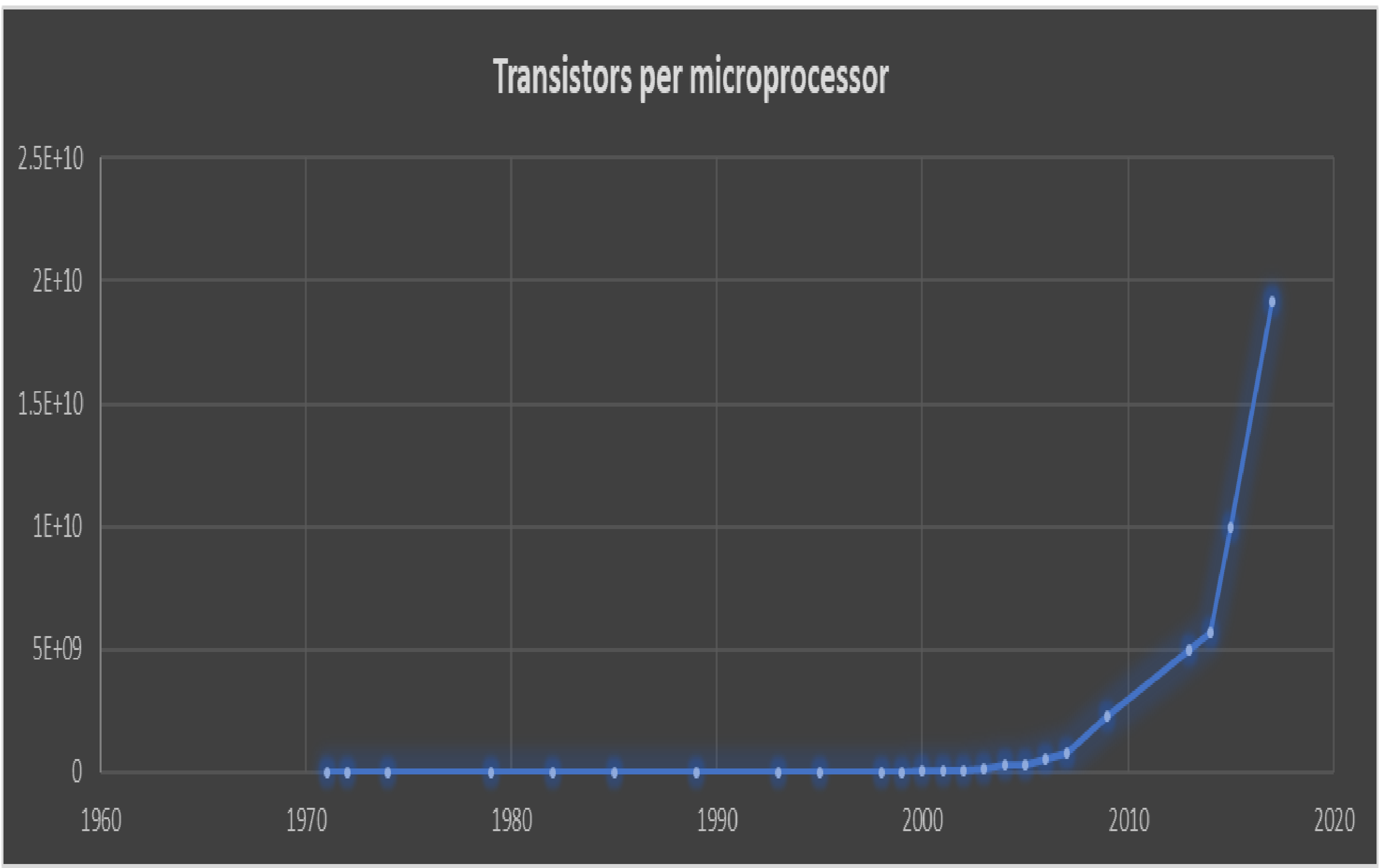

Figure 2: Linear graphical representation of Moore's Law

A linear-plot of transistor counts for microprocessors against dates of introduction shows nearly doubling every two years[2]

[2] Rupp, Karl. "40 Years of Microprocessor Trend Data | Karl Rupp." *Karlrupp.net*, 25 June 2015, www.karlrupp.net/2015/06/40-years-of-microprocessor-trend-data/.

The above graph depicts the linear graphical version of the compounding number transistors present in chip worldwide and it is in this graph we truly see the true exponential nature of Moore's Law in in the drastic up scaling reaching 1.92E+10 in 2017 showing the great number of transistor count present in the current and its growth from the past. Such we can see how Moore's Law played a guiding role in playing as a roadmap for the semiconductor industry and benefiting many others as well and skyrocketing our computational abilities.

2. MOORE'S LAW IN THE PRESENT ANALYZING CURRENT LIMITS

Current limits of Moore's Law

Experts agree that computers should hit the physical limits of Moore's Law sometime in the 2020s. Ultimately, the high temperatures due to high density of transistors make it impossible to create smaller circuits, leading to higher energy requirements to cool the transistor than it already has. Eventually the transistors will become so small that quantum mechanics can hamper their function as electrons reach the quantum level, they start jumping from to another or "tunnel through". Processors rely on logic gates, components that allow or block the movement of electrons, to function. If electrons simply bypass the logic gates due to its quantum nature the processor will stop functioning, but before we calculate the quantum limit, Moore's Law can be mathematically expressed as

$$n_2 = n_1 \times 2^{[(y1-y2)/2]} \rightarrow 1$$

This equation predicts the number n2 of transistors or equivalent computing power in any given year y2 from the number n1 of transistors in any other earlier year y1 present. From the definition of Moore's Law, we know that the characteristic dimension or length L of a transistor is inversely proportional to the number of transistors n on the IC. If the n measurement is in "counts per meter" (m-1), the L measurement from the dimensional analysis is in meters (m). Or equivalently, 1/L is the number per meter hence we can rewrite the formula as

$$\frac{1}{l2} = (\frac{1}{l1}) \times 2^{(y1-\frac{y2}{2})}$$

for l(1) we can take a 2008 study as the current nm as that seems to what top companies like intel and Ryzen seems to offering for h we can take the Compton wavelength

$$\lambda_c = h/m_e c = 2.4263 \times 10^{-12}\text{m} \rightarrow 2$$

based on measurement from the dimensional analysis is in meters (m). Or equivalently, 1/L is the number per meter hence we can be based on Planck's constant as 'h', the mass of the electron a as m_e ,finally the speed of light as "c" electron as $'m_e'$, and finally the speed of light 'c'.

The Compton wavelength of an electron is a fundamental limit for measuring its position based on the length scale of quantum mechanics and special relativity, or relativistic quantum field theor**y.** Hence the Compton wavelength fundamental in determining the spin or location of the electron satisfying Stephen Hawking prediction that this limit **is** based on the speed of light and the atomic propertie**s** of matter**,** since c depends on c, m_e, and h. Now (2) can be rewritten using the current year, Compton wavelength and the current transistor feature size

$$(2.4263 \times 10^{-12})^{-1} = (0.045 \times 10^{-6} m)^{-1} \times 2^{[(y2-20)/2]}$$

Next, solving for the exponent Δy= $(y2 - 2022)$ by using natural log function

$$ln(0.045 \times 10^{-6}/2.426 \times 10^{12}) = (\Delta y/2) \times (ln2)$$

Therefore, resulting in:

$y2 = \Delta y + y1 = 2(9.827)/0.693$ we get $y1 = 28.36y + 2008 = 2036$

If the electron were implemented as the smallest quantum computing transistor **e**lement, the year 2036 would be the quantum limit year predicted by Moore's Law.

The Moore's Law problem is an inherent and growing complexity in semiconductor process technology. Because transistors are now three-dimensional and the feature sizes of today's advanced process technologies are small**,** multiple exposures were required to reproduce these features on a silicon wafer**.** This greatly complicated the design process and **"**slowed down" Moore's Law**.** As the ability to scale a single chip dwindles, the industry is finding other innovative ways to sustain exponential growth, but the costs of doing so are slowing the pace of migration. Semiconductor Technological Perspectiv**e** Among other things, Intel no longer publishes the transistor count of its processors. Also, some processors were introduced much later than originally planned, and the Tik Tok model (**Tick–tock** was a production model adopted in 2007 by chip manufacturer intel. Under this model, every micro architecture change (tock) was followed by a die shrink of the process technology) was changed to include updates and even in a 2005 interview, Moore himself admitted that "...the fact that materials are made of atoms is the fundamental limitation and we may not be able to go further" with transistors reaching the size of atoms physical limitations were being reached as each microchip contains billion of transistors, the economic aspect as well subdues growth of Moore's law due to many intrinsic factors such as demand and competition

3. APPLICABILITY OF MOORE'S LAW IN THE FUTURE

Breakthrough in other Fields to Improve Moore's Law

Since we cannot currently break the barrier of quantum mechanics, due to implied limit at quantum level due to, quantum interference on the electron, our analyzation will at the atomic level or the nano-technology level, meaning no more simply doubling in 18 months as Moore's Law does; another form of transistor doubling can occur in new directions and with different slopes. We are particularly interested in the field of nano-enhancement:

3-D Vertical integration (3D) increases the junction transistor density of devices and helps maintain the Moore's Law correction curve, including the 3rd dimension, while the progress in this helps dimension shrinkage in the plane (2D) slows down and allows us to maintain the law. As devices continue to shrink into the 20–30 nm range, it becomes increasingly important to consider the thermal properties and transport of such nanoscale devices. Hence, we can utilize the breakthrough in other fields such as Carbon Computing. Instead of traditional transistors, these layers of graphene and their varying degrees of manufacturability help increase the speed of computing and information processing applications. Optoelectronic computers, like photonics, use light instead of electricity to send signals from one transistor to another. In most integrated circuits, electricity travels at about 5% the speed of light, whereas photons, by their nature, travel at the speed of light, helping provide us an opportunity to significantly increase our computing power. Optical signals can also vary in intensity, which offers another advantage over electrical signals, where the signal is either on or off. These advancements touch the heart of Moore's Law which is to increase the computational power by increasing the speed of communication to new heights and increasing the overall speed of the device.

CONCLUSION

Moore's Law, with its strictest definition of doubling the number of transistors every two years, no longer applies even, Moore himself once had edited from 1 year to every 2 years. It still delivers exponential improvements, but results come more slowly: Moore's Law is slowing down, but the pace of innovation isn't. Rather, the proliferation of new application areas (big data, Artificial Intelligence, IoT and quantum computing etc.) is increasing the pace of innovation and increasing the need for "exponential" improvements in the technology offered. Ultimately, transistor count isn't the only relevant factor driving better processors. The average consumer cares about cost and performance, not how many transistors a device has. If transistors can no longer be packed into small spaces, other technologies will have to be developed to get around this hurdle and produce more powerful processors. That is the nature of science and research.

BIBLIOGRAPHY

[1]. Moore, Gordon E. *Cramming More Components onto Integrated Circuits*.

[2]. Rupp, K., and S. Selberherr. "The Economic Limit to Moore's Law [Point of View." *Proceedings of the IEEE*, vol. 98, no. 3, Mar. 2010, pp. 351–53,

[3]. Powell, James R. "The Quantum Limit to Moore's Law." *Proceedings of the IEEE*, vol. 96, no. 8, Aug. 2008, pp. 1247–48,

[4]. Wu, Jerry, et al. "A NANO Enhancement to Moore's Law." *SPIE Proceedings*, edited by Harold Szu and Liyi Dai, May 2012,

[5]. figure 1 (semi log plot), By Max Roser, Hannah Ritchie url: https://ourworldindata.org/uploads/2020/11/Transistor-Count-over

[6]. Rupp, Karl. "42 Years of Microprocessor Trend Data | Karl Rupp." *Karlrupp.net*, 15 Feb. 2018,

[7]. Schaller, R. R. "Moore's Law: Past, Present and Future." *IEEE Spectrum*, vol. 34, no. 6, June 1997, pp. 52–59,

[8]. Baxter, Michael. "Photonic Computers Give Moore's Law a New Lease on Life." *Techopian - the Conversation and Voice for Ethical Technology*, Techopian - The conversation and voice for ethical technology, 5 Nov. 2021,

[9]. "Moore's Law." *Scipython.com*, 2012, URL:scipython.com/book/chapter-3-simple-plotting-with-pylab/examples/moore's-law/#:~:text=Since%20the%20data%20cover%2040,T2log102.

[10]. Wu, Jerry, et al. "A Nanotechnology Enhancement to Moore's Law." *Applied Computational Intelligence and Soft Computing*, vol. 2013, 2013, pp. 1–13,