

# Storage Technologies: Scale & Limits

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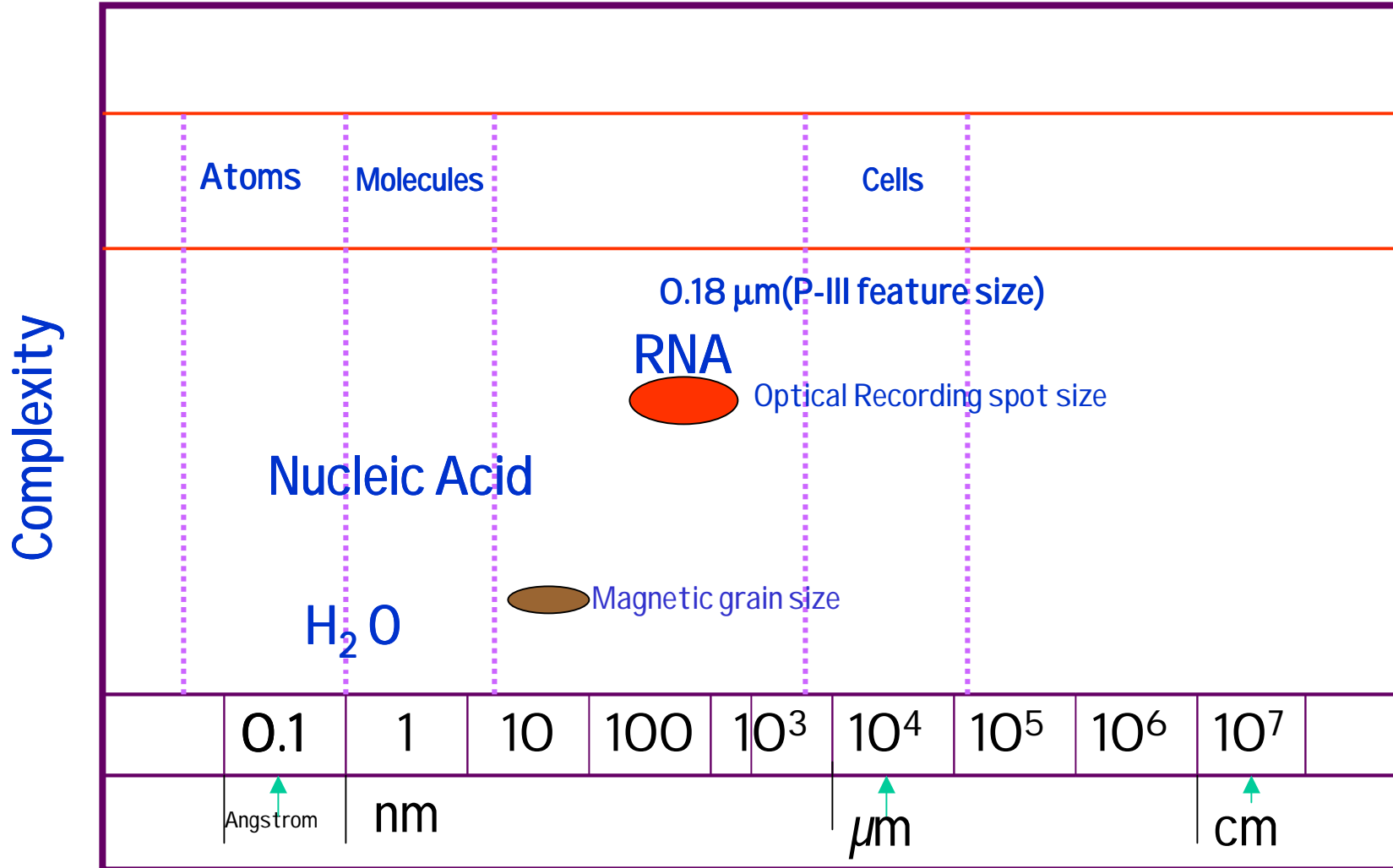
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# Nature's scale



## Size vs Complexity

- Brain size does not necessarily correlate with intelligence
- Complexity of the interconnections is significant
- IC's have been growing progressively smaller and more complex
- Is there a limit of nature to the ultimate size of the feature on an IC?

Optics: Rayleigh's limit  $d = k_1 \lambda / NA$

where  $\lambda$  is the wavelength,  $NA$  is the numerical aperture and  $k_1$  is a process-dependent constant

Depth of Focus:  $DOF = k_2 \lambda / (NA)^2$

## Brain/Body weight ratio for some species

	Brain/Body (%)
Apatosaurus	0.001
Whale	0.003
Elephant	0.2
Dog	0.85
Marmoset	1.4
Man	2.5
Sparrow	4.2
Spider Monkey	4.8

## Human Brain Weight distribution

	Weight (kg)
Heaviest human brain	2.05
Jonathan Swift	2
Ivan Turgenev	2
Average male	1.35
Average female	1.21
Anatole France	1.02

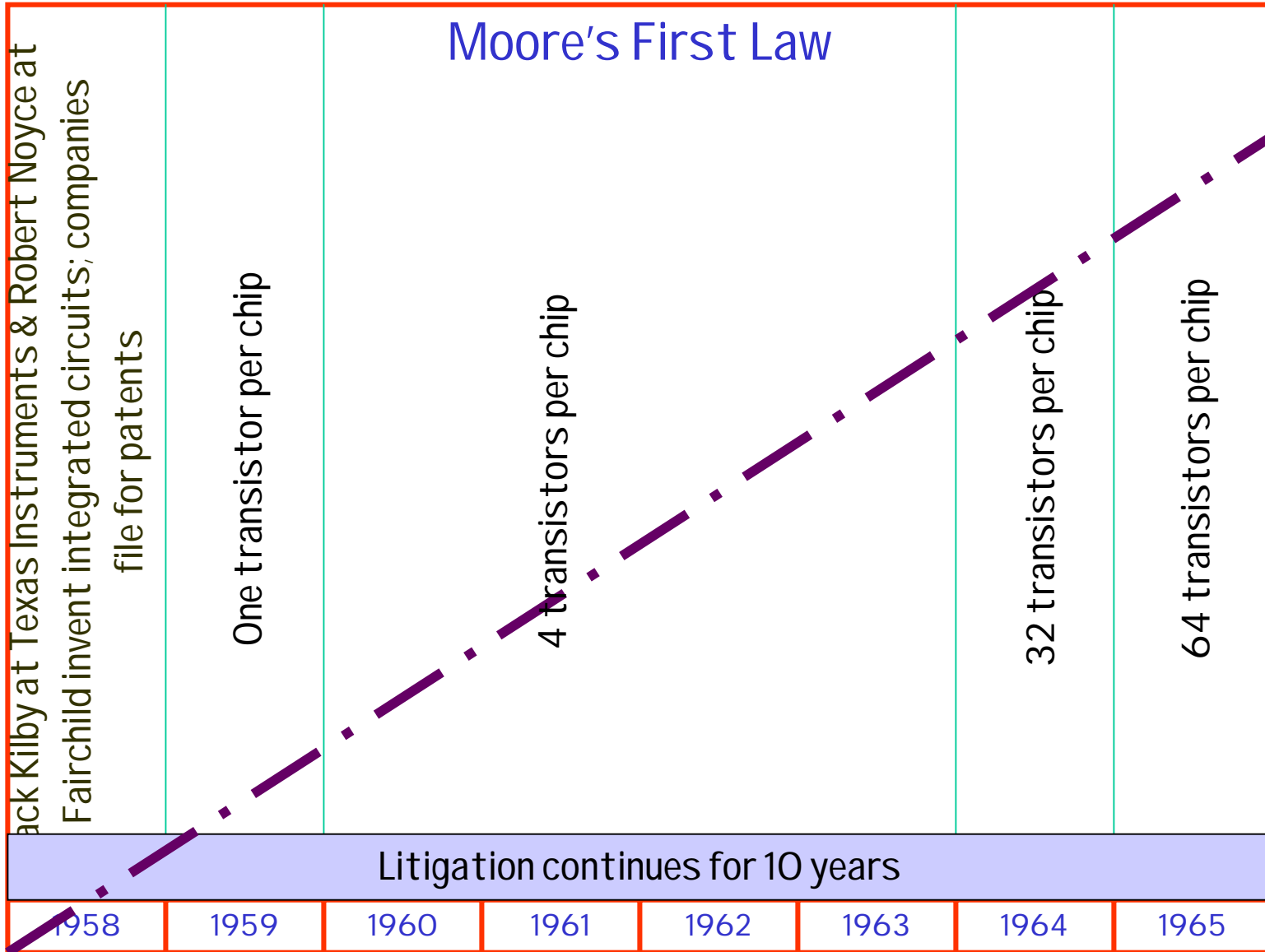
## Moore's Laws

First Law: Number of components in a chip (IC) will double roughly every 18 months (1965, in *Electronics*). This has held true more or less since then.

Second Law: Facility costs increase on a semilog scale (terminology due to Eugene Meieran, Intel Fellow). Fab costs double approximately every four years.

For a general discussion, see:

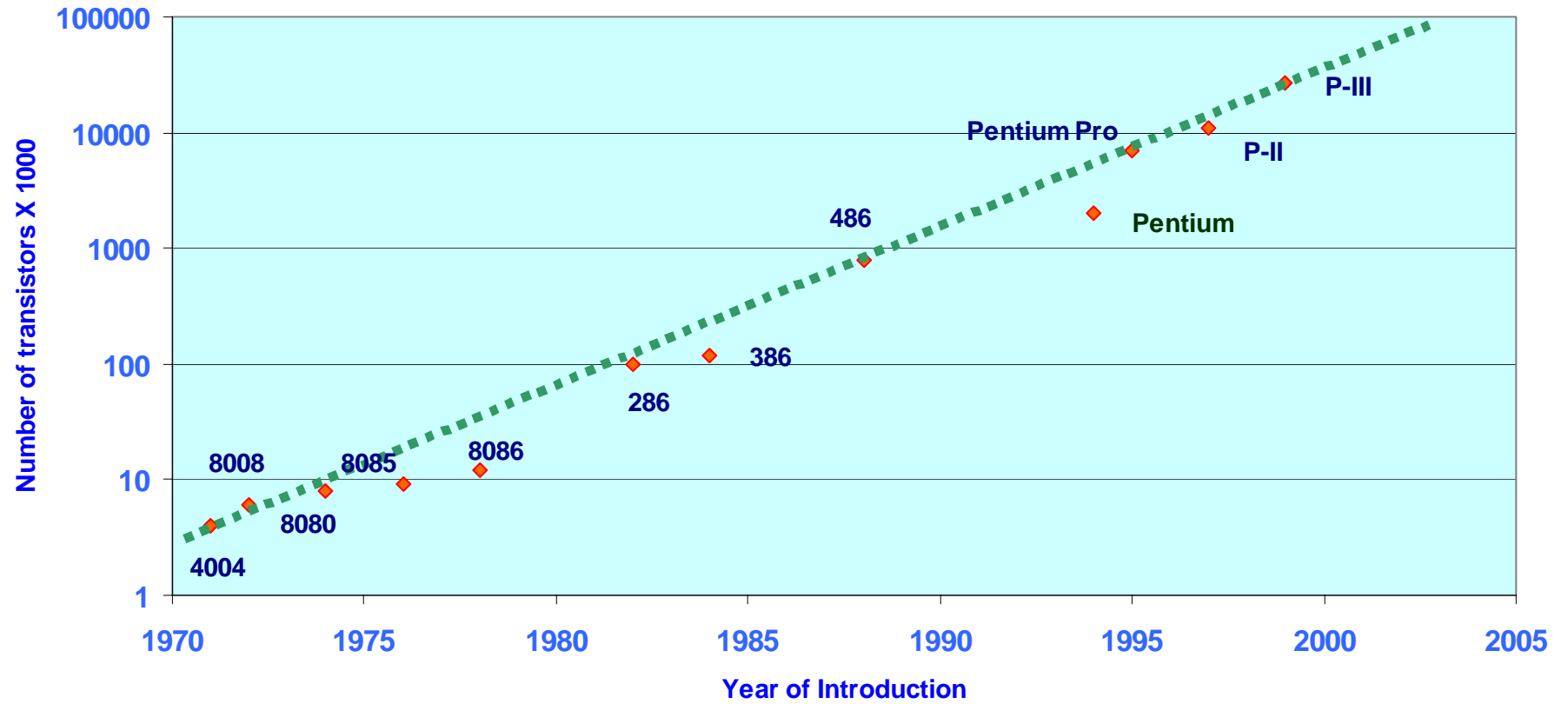
G D Hutcheson and J D Hutcheson, *Technology and Economics in the Semiconductor Industry*, *Scientific American*, October 1997.



Jack Kilby will share one half of the 2000 Physics Nobel Prize with the other half going to Zhores I Alferov (St Petersburg, Russia) and Herbert Kroemer (UC Santa Barbara)

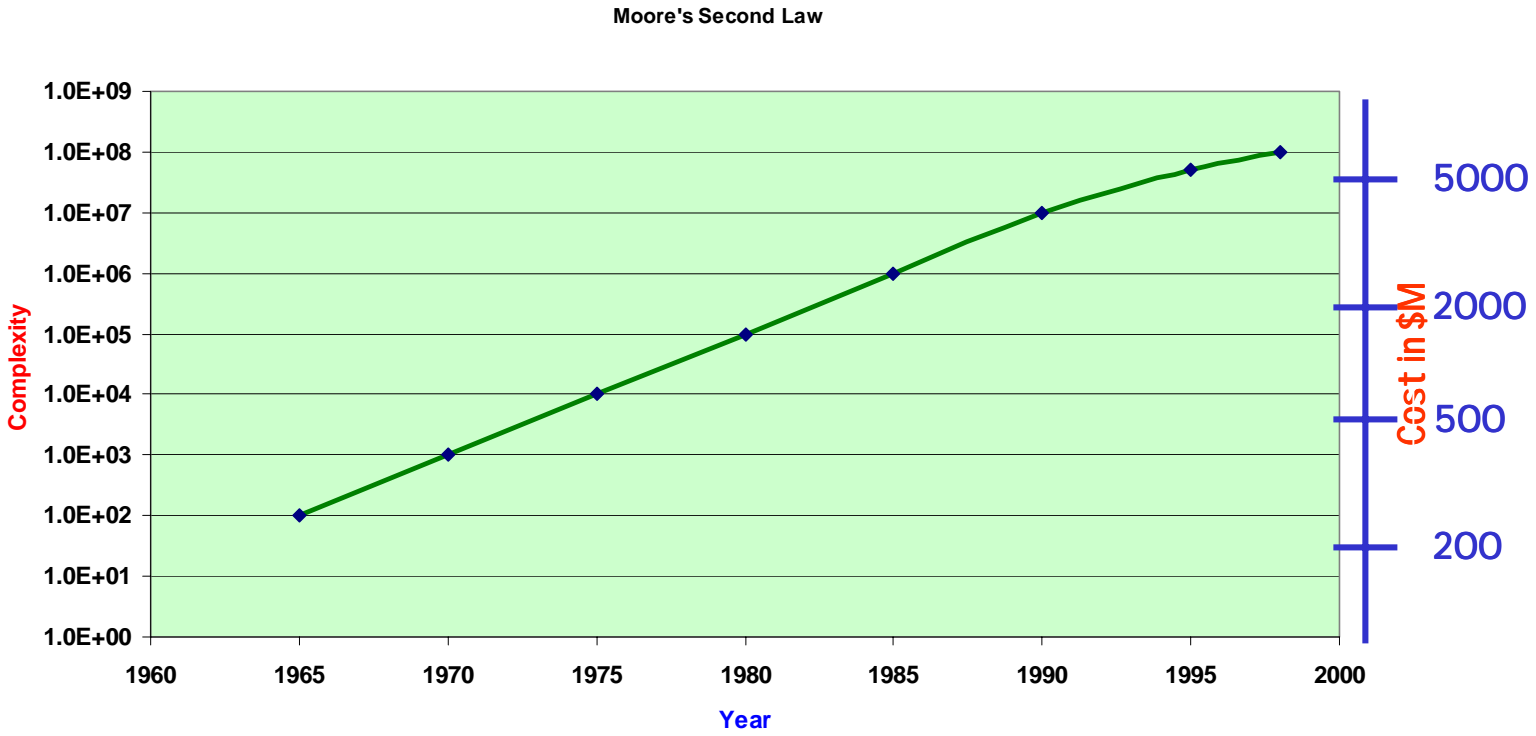
The researchers' work has laid the foundations of modern information technology, IT, particularly through their invention of rapid transistors, laser diodes, and integrated circuits (chips) (Royal Swedish Academy of Sciences Announcement)

## Moore's law for Intel Processors



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# Moore's Second Law



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## Some Corollaries

What Moore/Grove giveth, Gates taketh away. Software is getting slower and fatter quicker than processors are getting faster.

"The whole point of integrated circuits is to absorb the functions of what previously were discrete electronic components, to incorporate them in a single new chip, and then to give them back for free, or at least for a lot less money than what they cost as individual parts. Thus, semiconductor technology eats everything, and people who oppose it get trampled."

**Source:** Gordon Moore (Intel Chairman) quoted in Brent Schlender, "Why Andy Grove Can't Stop," *Fortune*, July 10, 1995, p. 91

"The Law of the Microcosm ordains that one-chip systems will be better, not worse, than intersecting boards strewn with devices linked by wires and buses. As Will Corrigan, chief of LSI Logic, observes, "From calculators to cellular phones, every time a system has moved onto a single chip, it has wreaked havoc with the existing industry."

**Source:** George Gilder, "Goliath at Bay," *Forbes ASAP*, February 26, 1996, p. 114

## A Comparison

In 1997, counting ICs, over  $10^{17}$  transistors were manufactured.

According to E O Wilson, the Harvard biologist, there are about that number of ants on earth. Thus, that year saw the manufacture of one transistor for every ant. It has since been growing at the compound rate of about 20% every year. The ants are not doing quite so well. They now have the burden of carrying more than one transistor per colony member worldwide!

The calculation above is due to Dr Gordon Moore himself.

If we are shipping an exabyte of storage a year, then the poor ant has also been inheriting a byte of data to go with that transistor!

"Our achievements speak for themselves. What we have to keep track of are our failures, discouragements, and doubts. We tend to forget the past difficulties, the many false starts, and the painful groping."

Eric Hoffer (1902-1983) Longshoreman and Philosopher