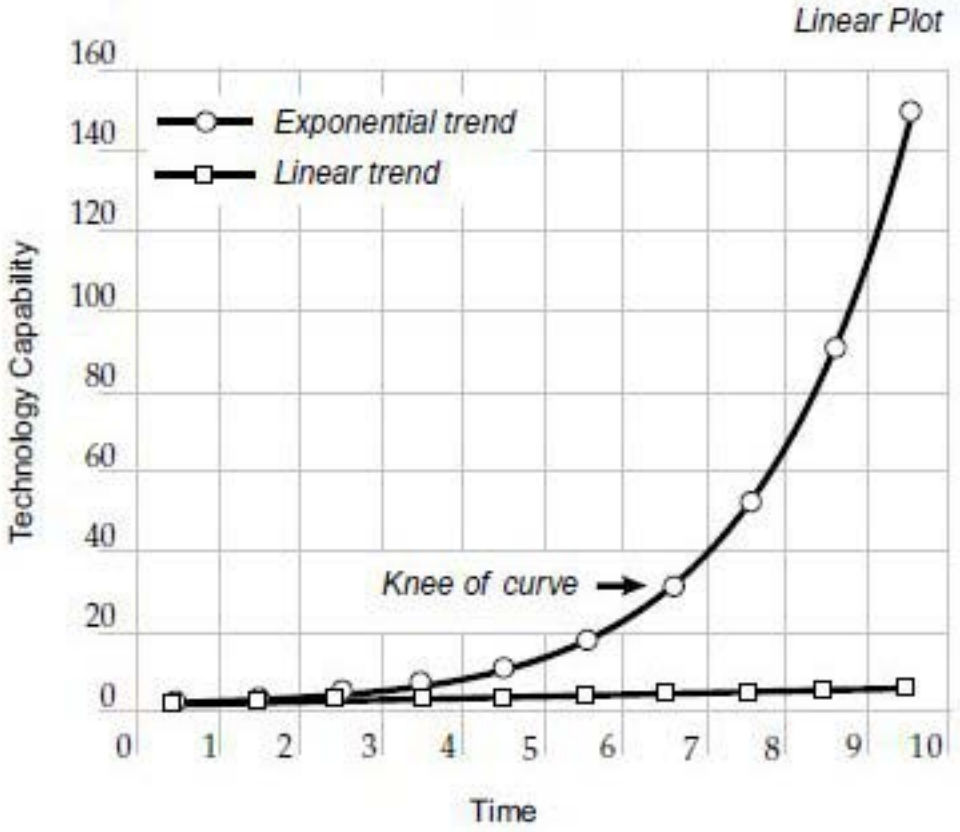
The Singularity Is Near:

When Humans Transcend Biology

By Ray Kurzweil

Linear vs. Exponential Growth

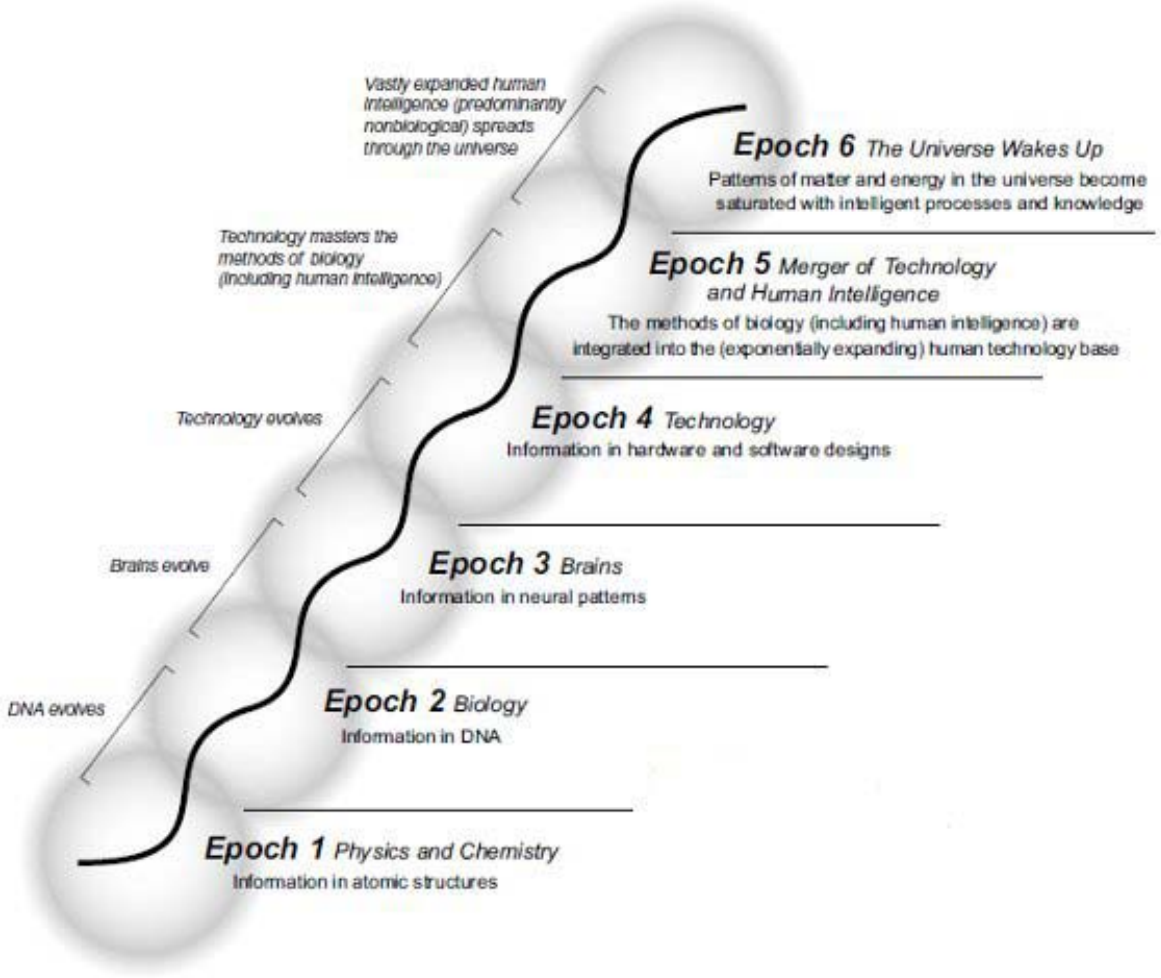
Linear versus exponential: **Linear growth is steady; exponential growth becomes explosive.**



CHAPTER ONE: THE SIX EPOCHS

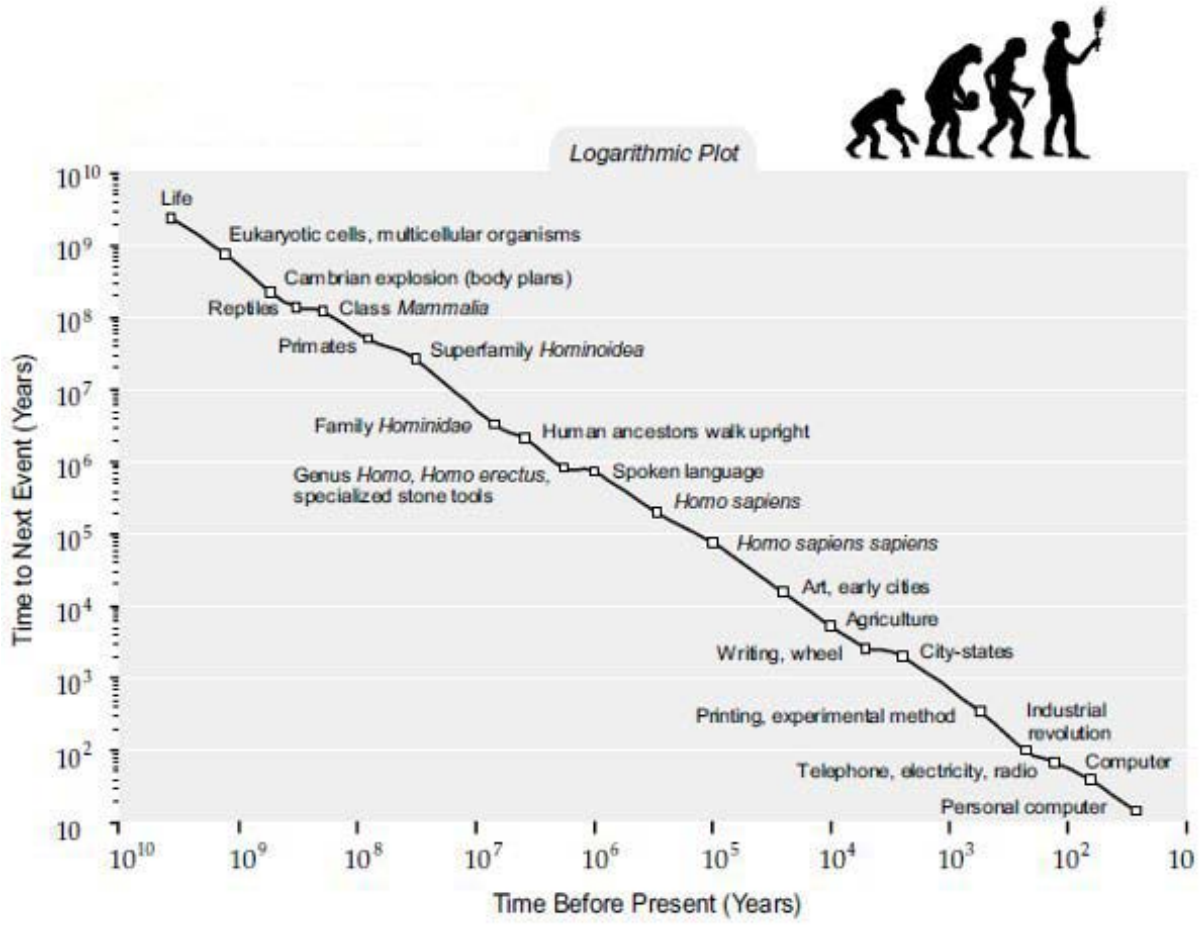
The Six Epochs of Evolution

Evolution works through indirection: it creates a capability and then uses that capability to evolve the next stage.



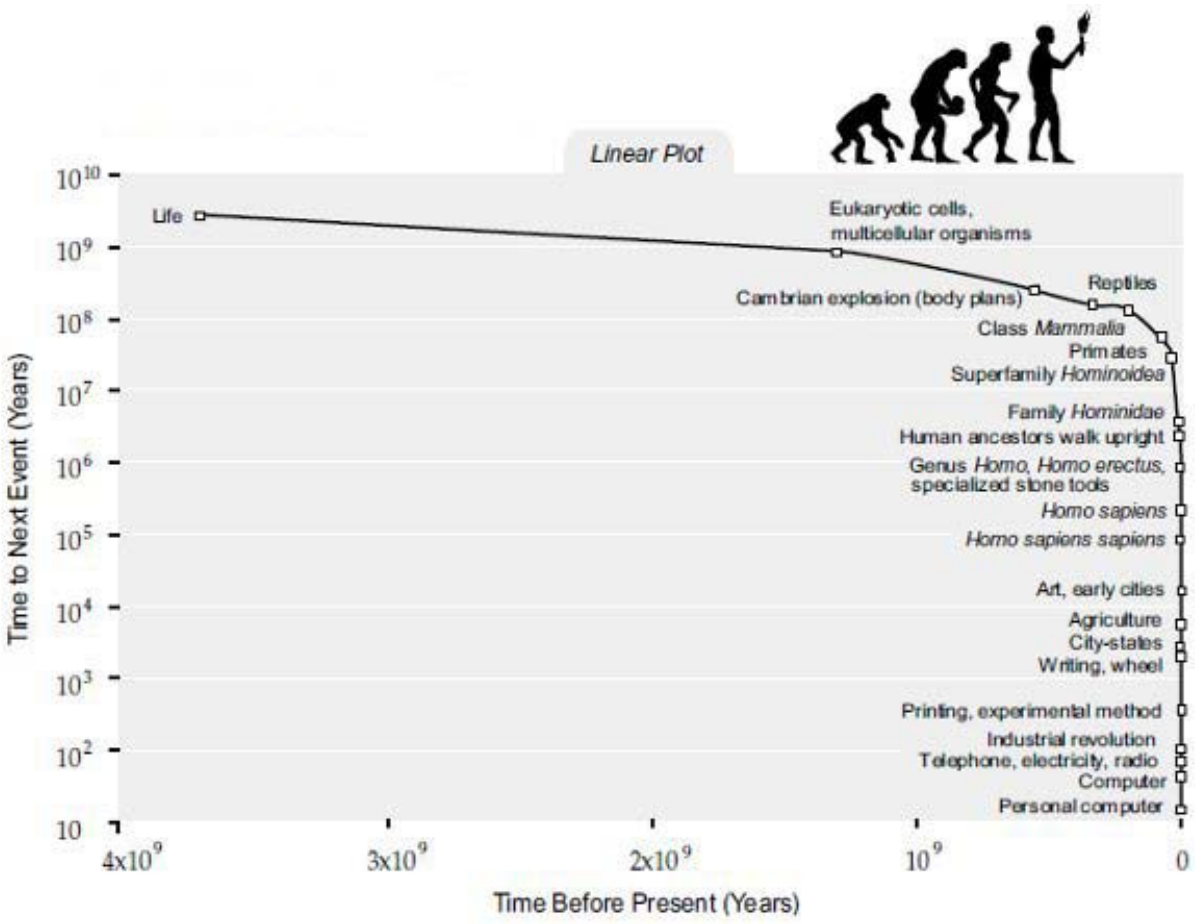
Countdown to Singularity

Countdown to Singularity: **Biological evolution and human technology both show continual acceleration, indicated by the shorter time to the next event (two billion years from the origin of life to cells; fourteen years from the PC to the World Wide Web).**



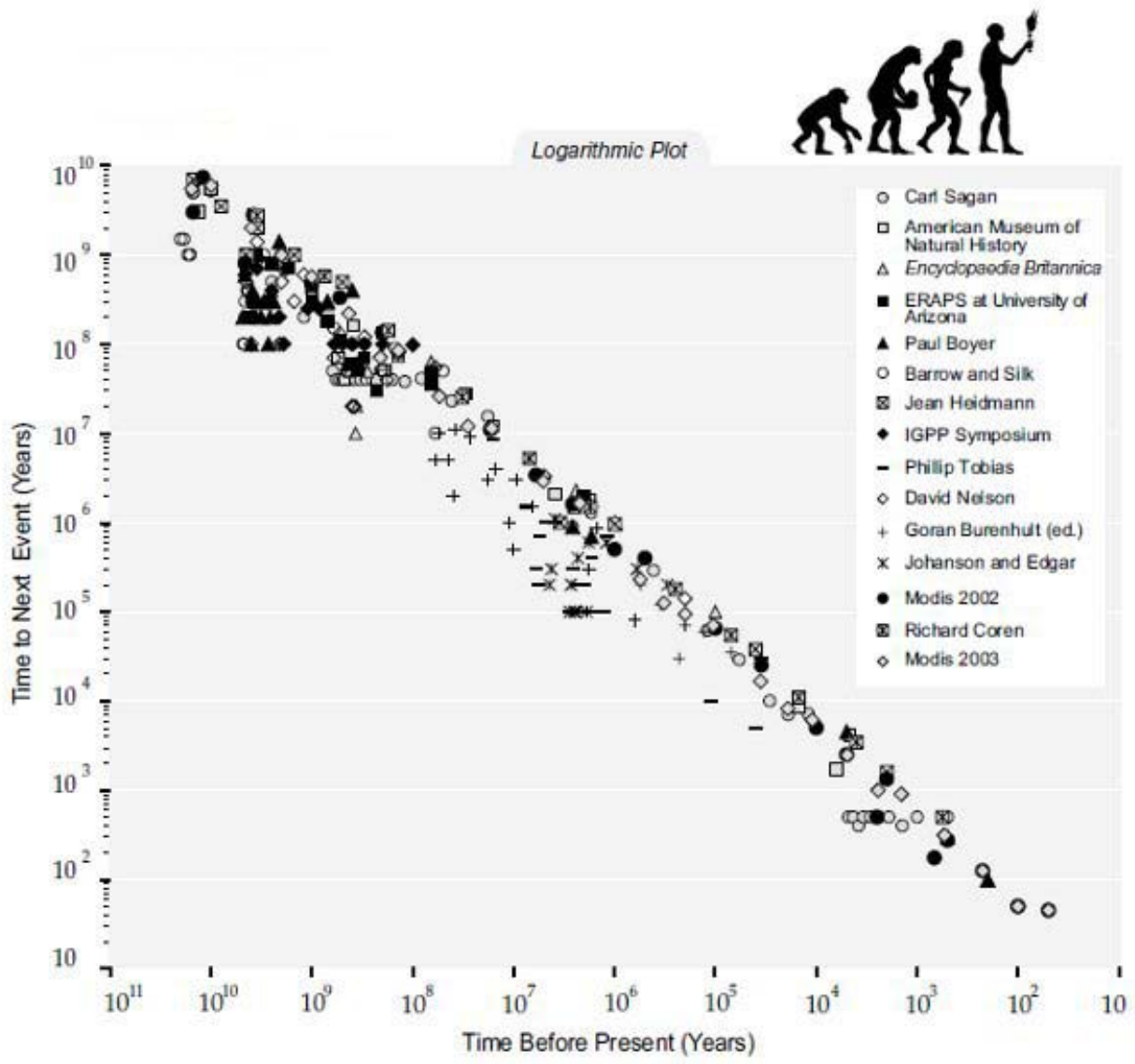
Countdown to Singularity

Linear view of evolution: **This version of the preceding figure uses the same data but with a linear scale for time before present instead of a logarithmic one. This shows the acceleration more dramatically, but details are not visible. From a linear perspective, most key events have just happened "recently."**



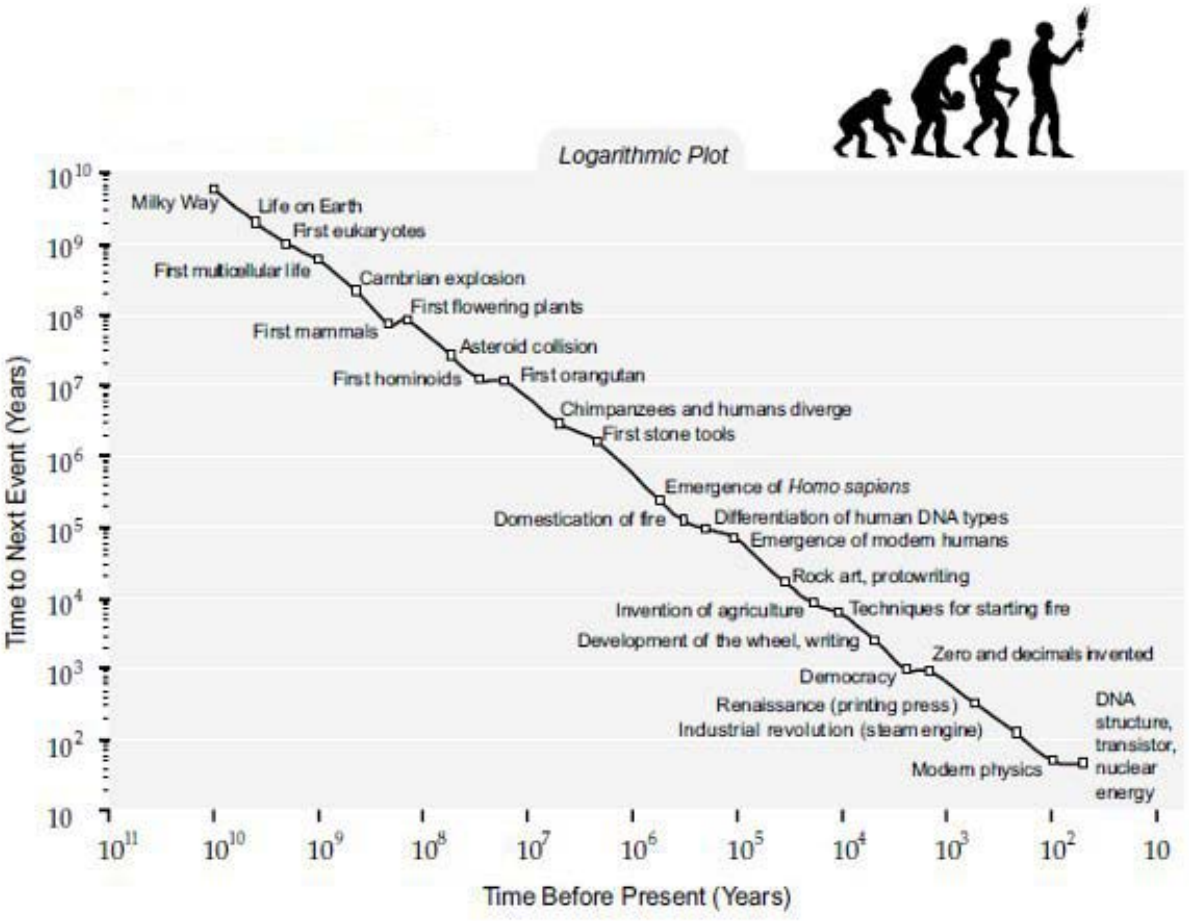
Paradigm Shifts for 15 Lists of Key Events

Fifteen views of evolution: **Major paradigm shifts in the history of the world, as seen by fifteen different lists of key events. There is a clear trend of smooth acceleration through biological and then technological evolution.**



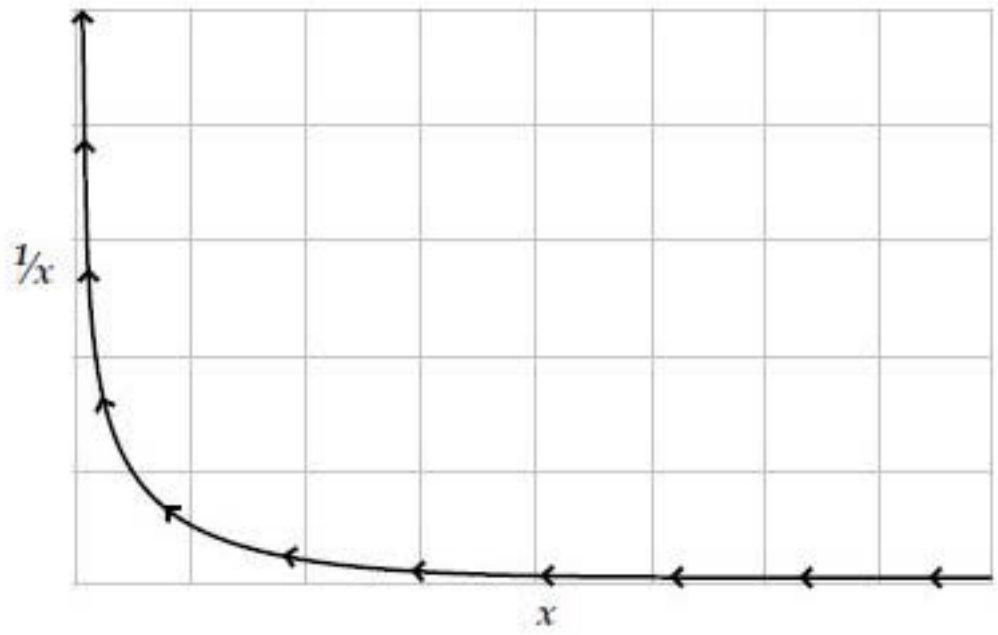
Canonical Milestones

Canonical milestones based on clusters of events from thirteen lists.



A Mathematical Singularity (Linear Plot)

A mathematical singularity: **As *x* approaches zero (from right to left), 1/*x* (or *y*) approaches infinity.**



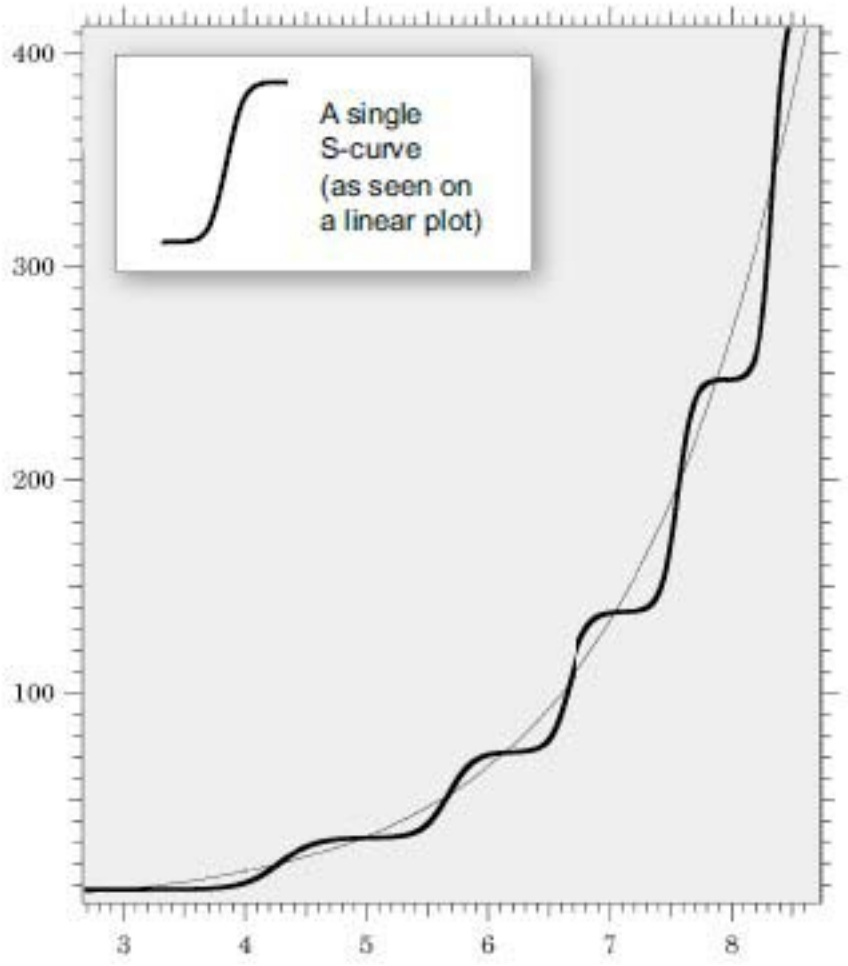
The Life Cycle of a Paradigm

Each paradigm develops in three stages:

1. **Slow growth (the early phase of exponential growth)**
2. **Rapid growth (the late, explosive phase of exponential growth), as seen in the S-curve figure below**
3. **A leveling off as the particular paradigm matures**

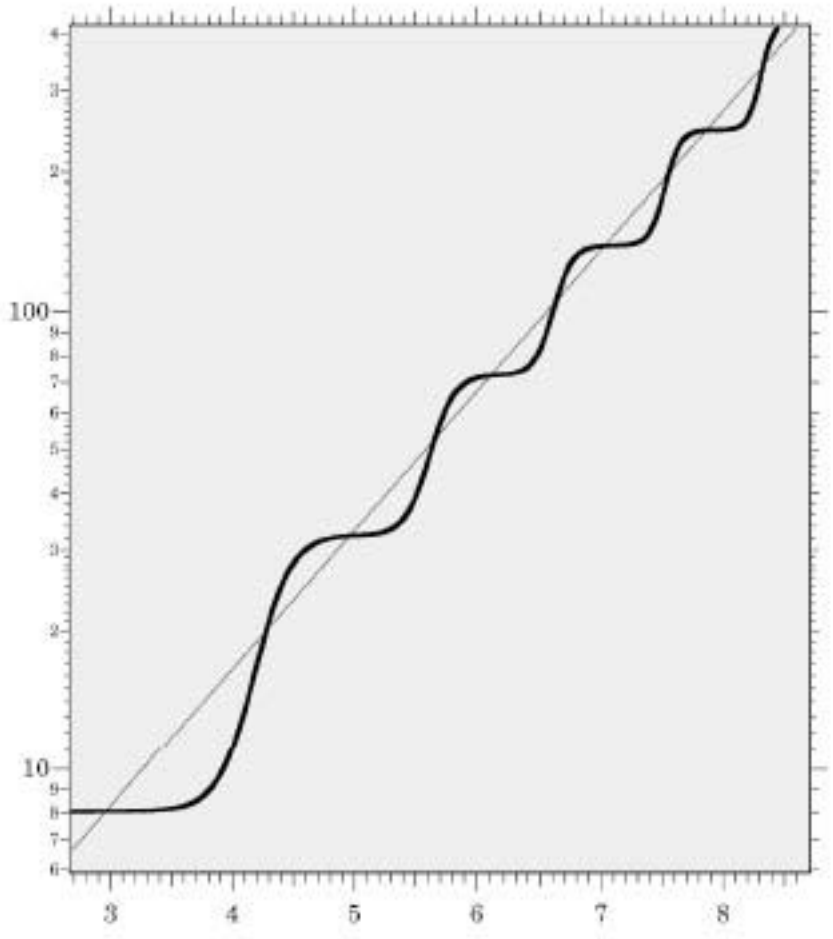
The progression of these three stages looks like the letter S, stretched to the right. The S-curve illustration shows how an ongoing exponential trend can be composed of a cascade of S-curves. Each successive S-curve is faster (takes less time on the time, or *x*, axis) and higher (takes up more room on the performance, or *y*, axis).

The image shows an ongoing exponential sequence made up of a cascade of S-curves (linear plot).

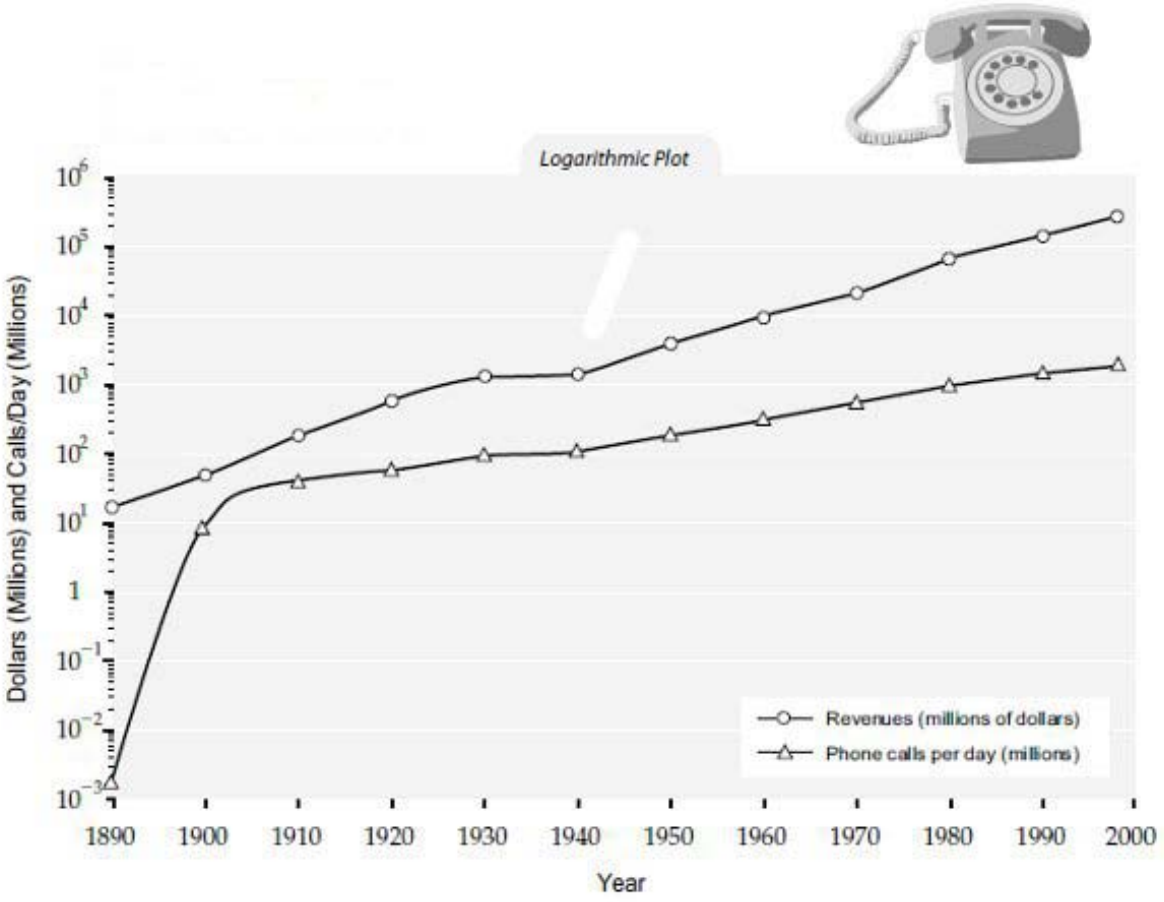


The Life Cycle of a Paradigm, continued

The same exponential sequence of S-curves on a logarithmic plot.

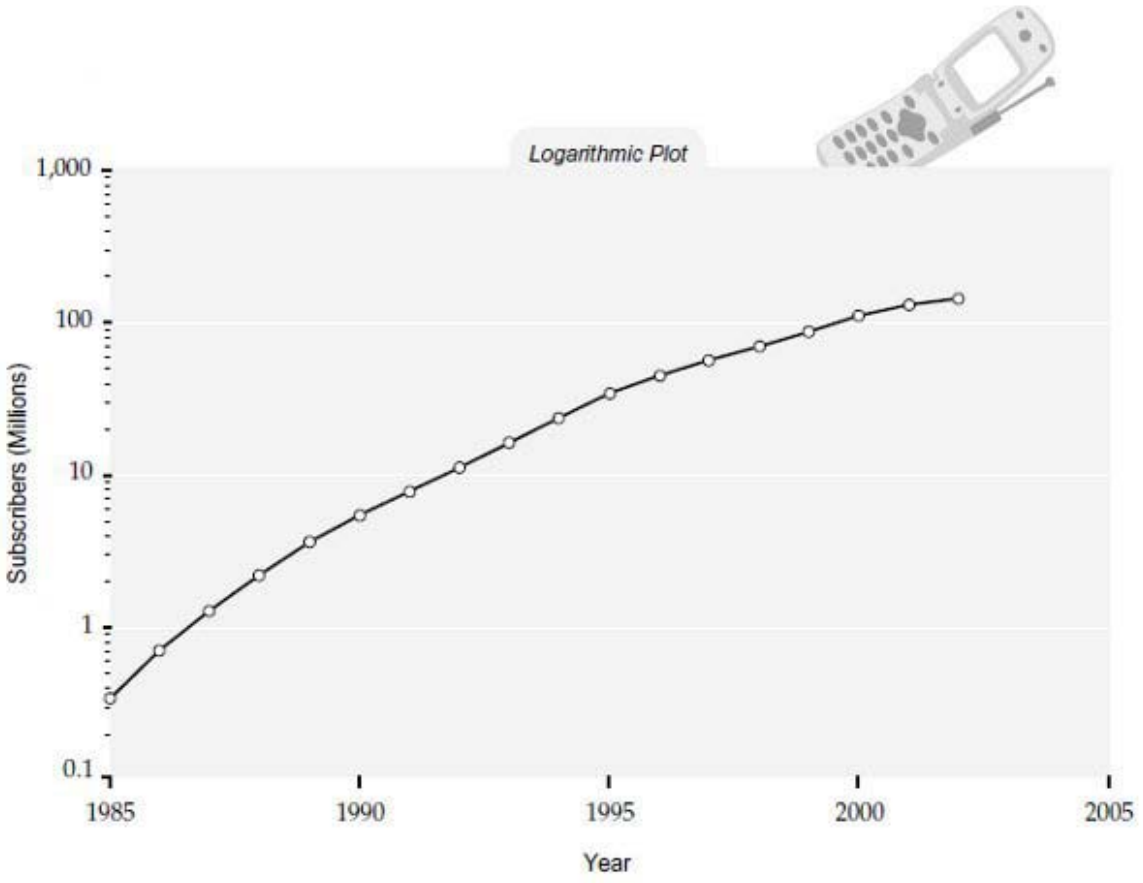


Growth of U.S. Phone Industry



Source: Andrew Odlyzko, "Internet Pricing and the History of Communications," AT&T Labs Research, revised version February 8, 2001.

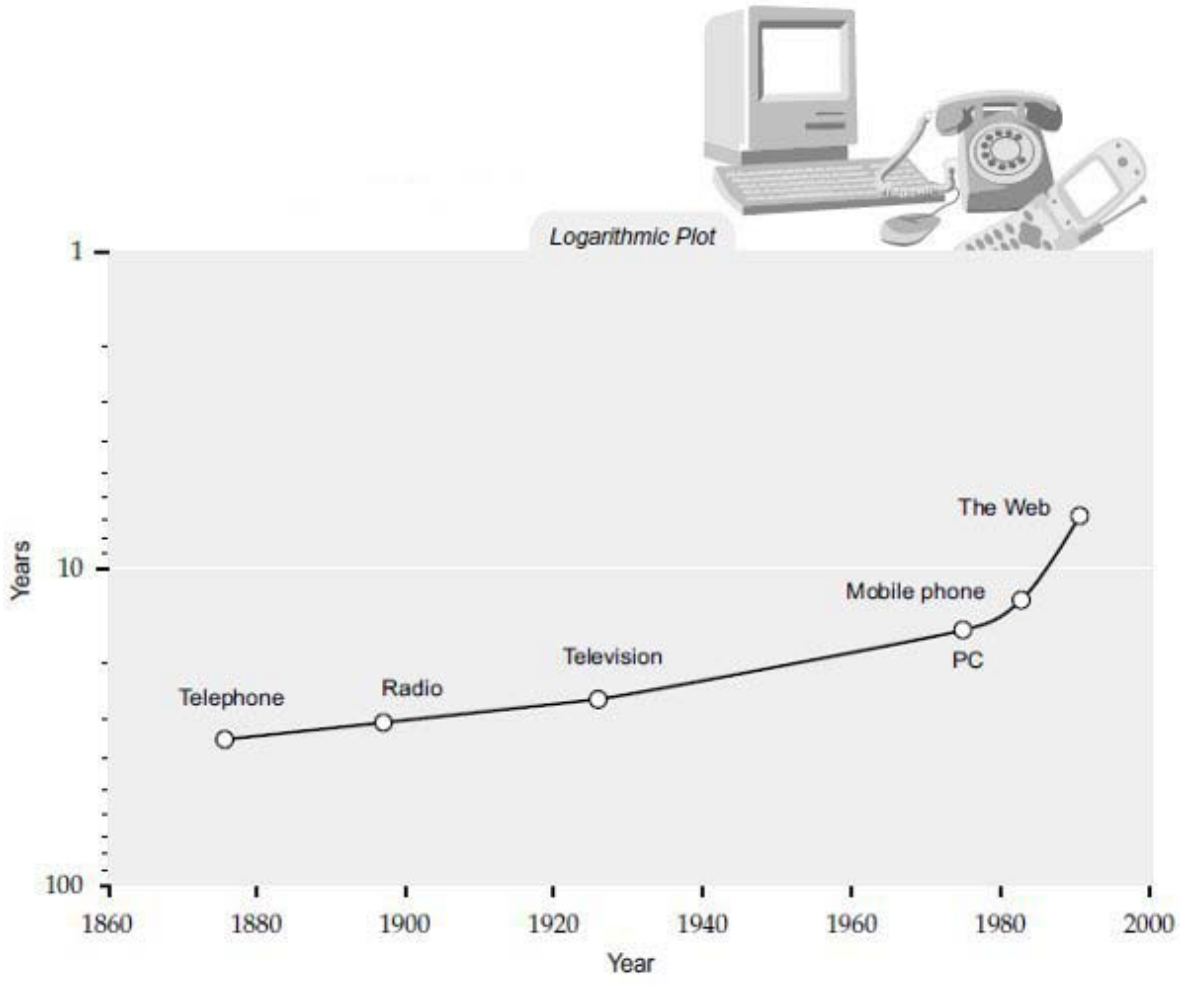
Estimated U.S. Cell Phone Subscribers



Source: Cellular Telecommunications and Internet Association, Semi-Annual Wireless Industry Survey, June 2004.

Mass Use of Inventions

Years Until Use by 1/4 U.S. Population

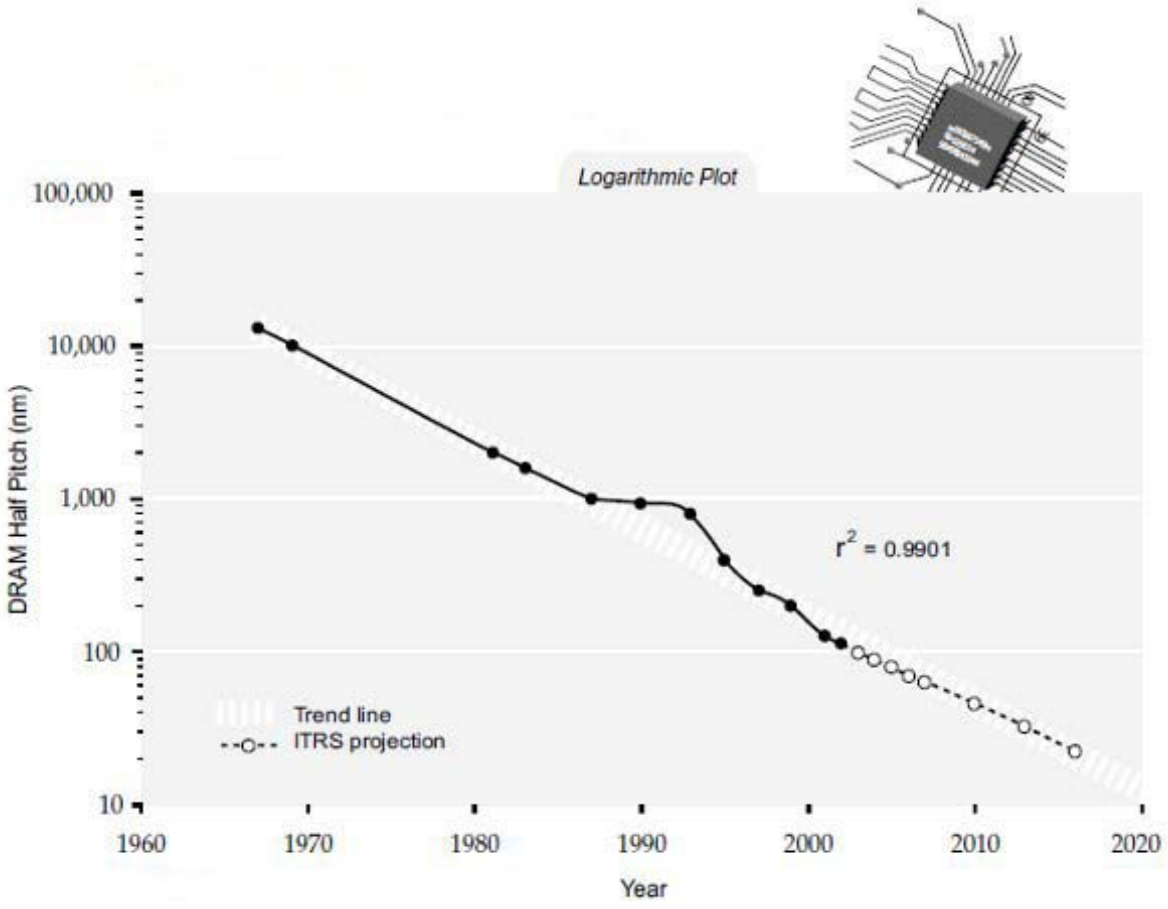


Sources: FCC, U.S. Census Bureau.

Dynamic RAM

Smallest (Called "Half Pitch") Feature Size

Halving time: 5.4 years

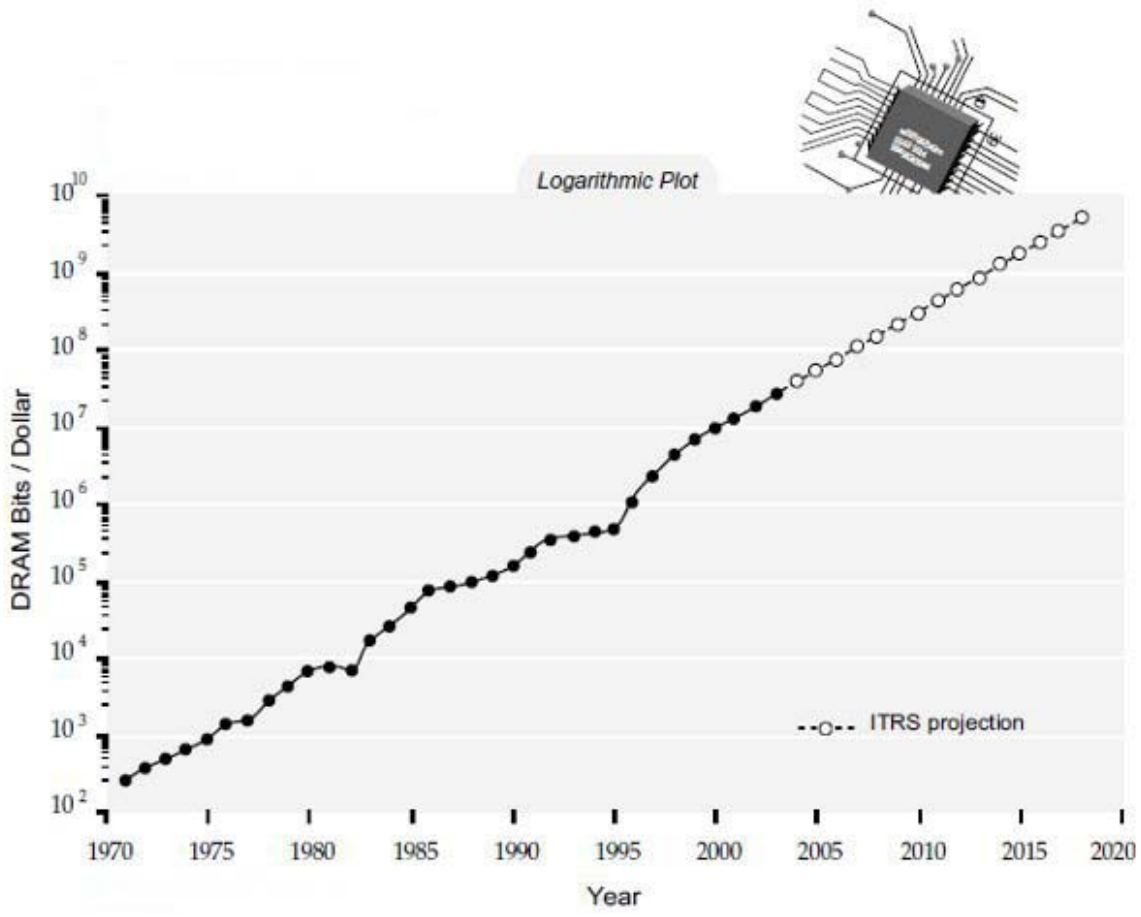


Dynamic RAM Price

Bits per Dollar at Production (Packaged Dollars)

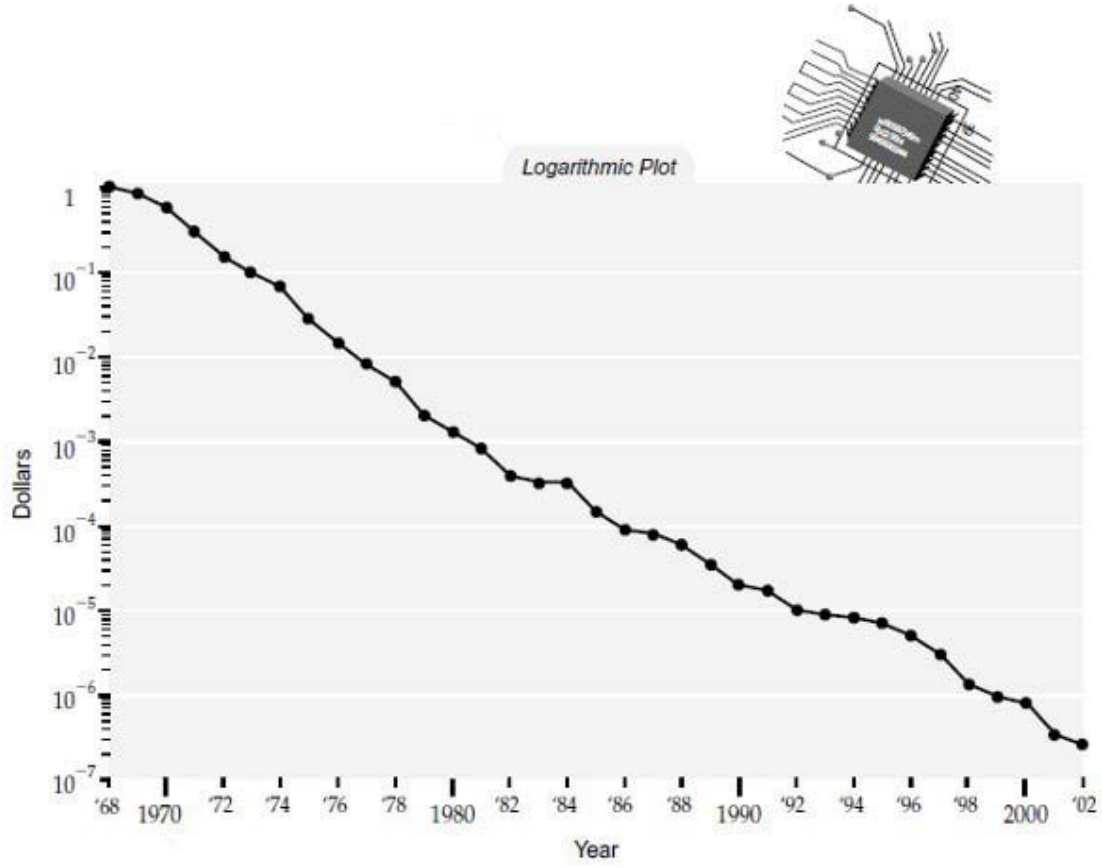
Doubling time: 1.5 years

Note that DRAM speeds have increased during this period.



Average Transistor Price

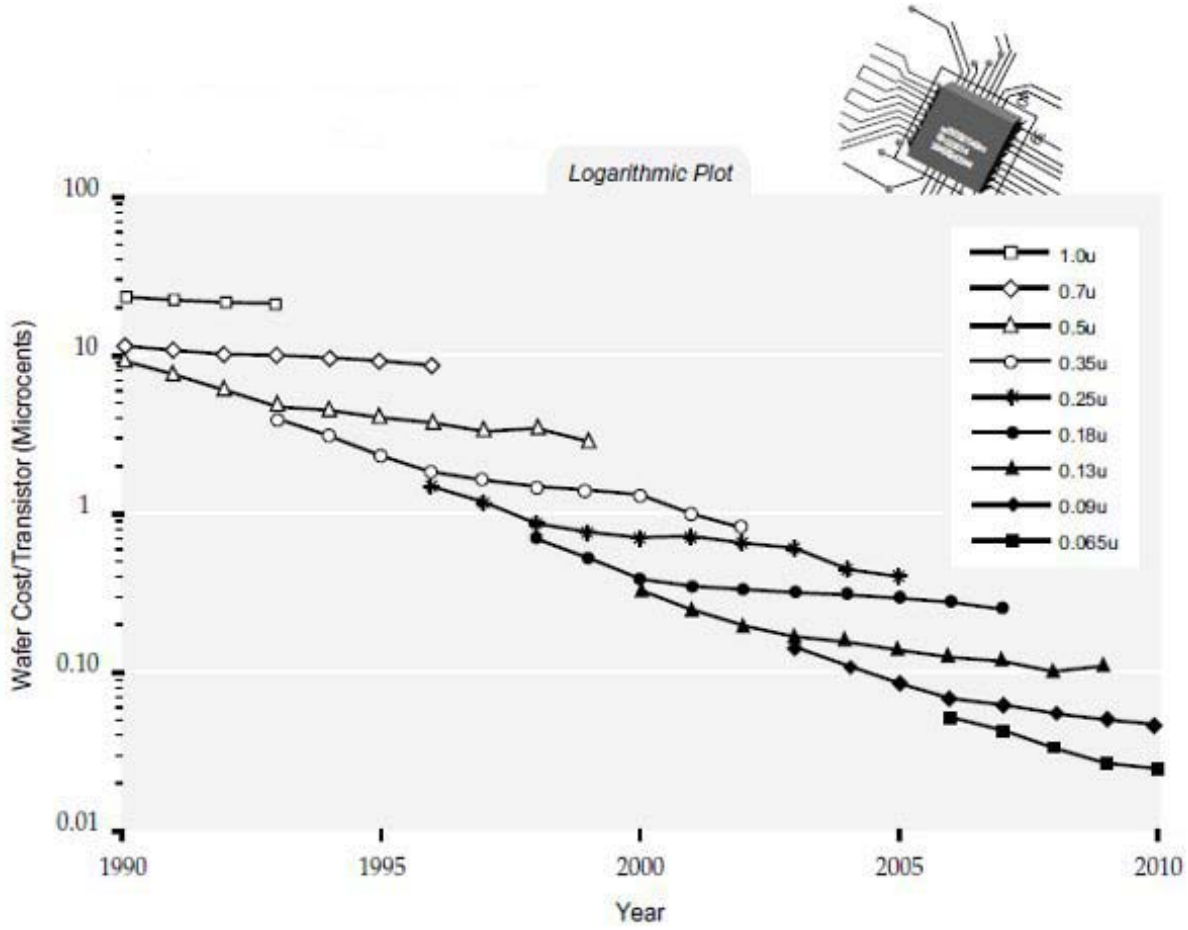
Halving time: 1.6 years



Source: Intel and Dataquest reports (December 2002).

Transistor Manufacturing

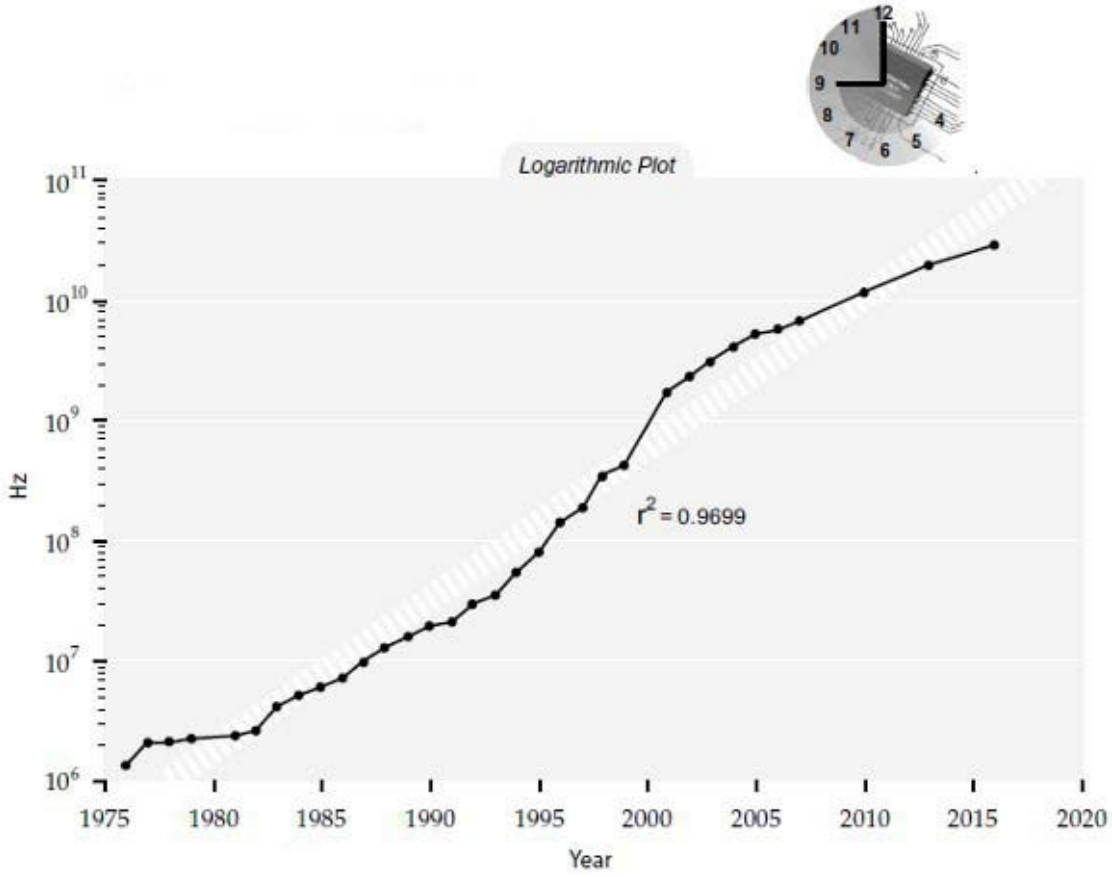
Costs Falling



Source: Randal Goodall, D. Fandel, and H. Huffet, "Long-Term Productivity Mechanisms of the Semiconductor Industry," Ninth International Symposium on Silicon Materials Science and Technology, May 12–17, 2002.

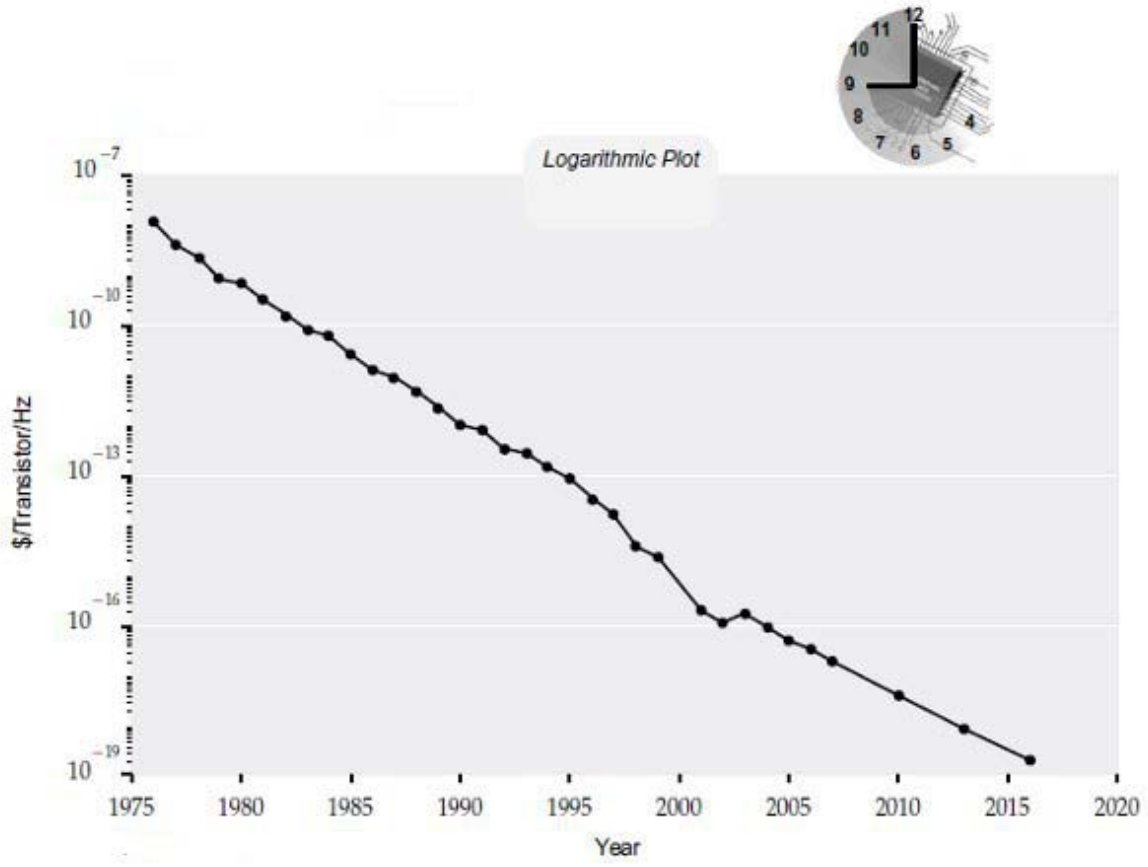
Microprocessor Clock Speed

Doubling time: 3 years



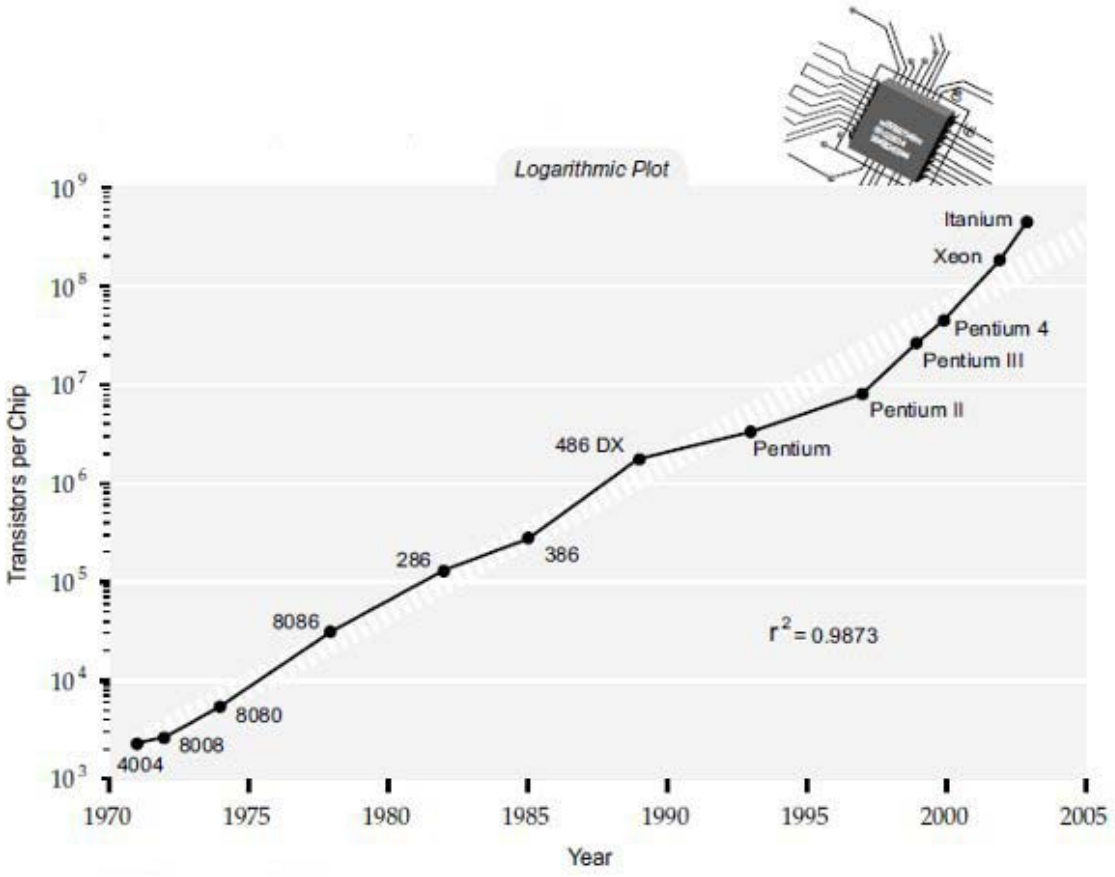
Microprocessor Cost per Transistor Cycle

Halving time: 1.1 years



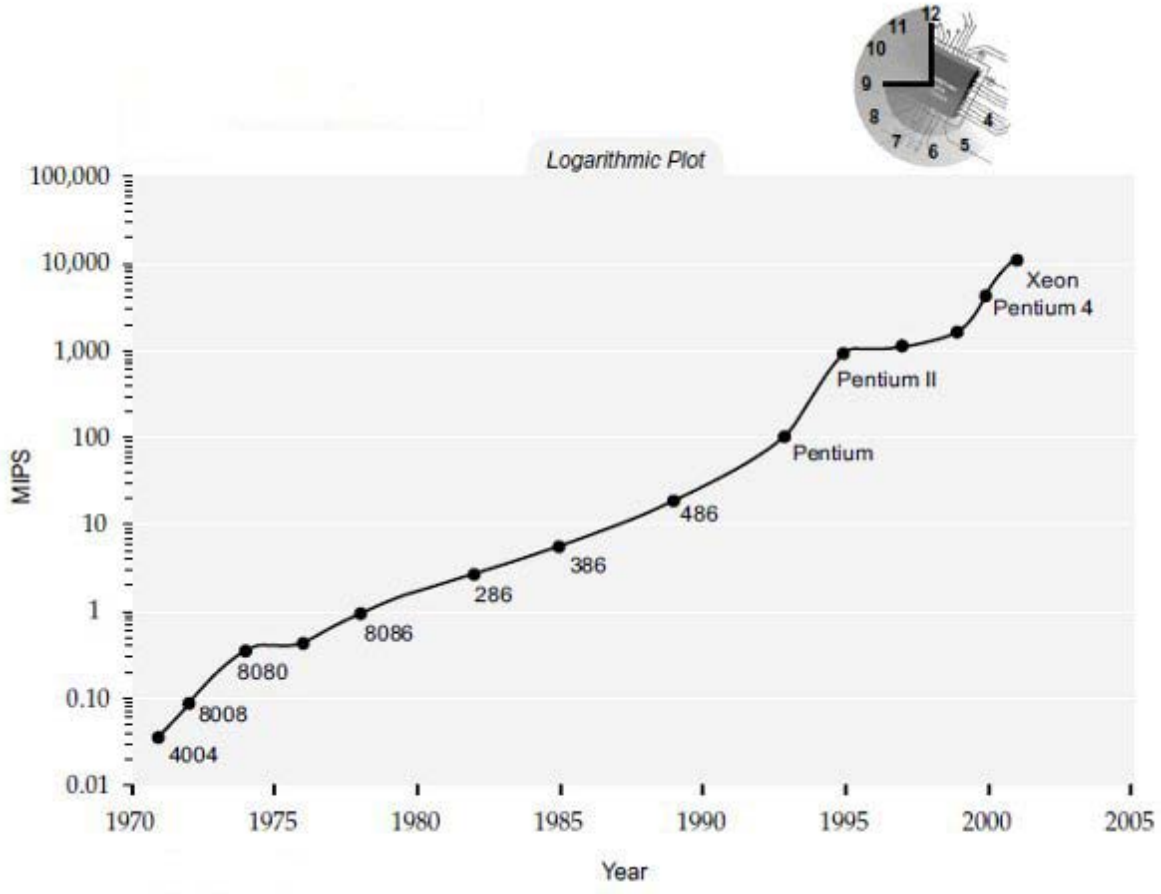
Transistors per Microprocessor

Doubling time: 2 years



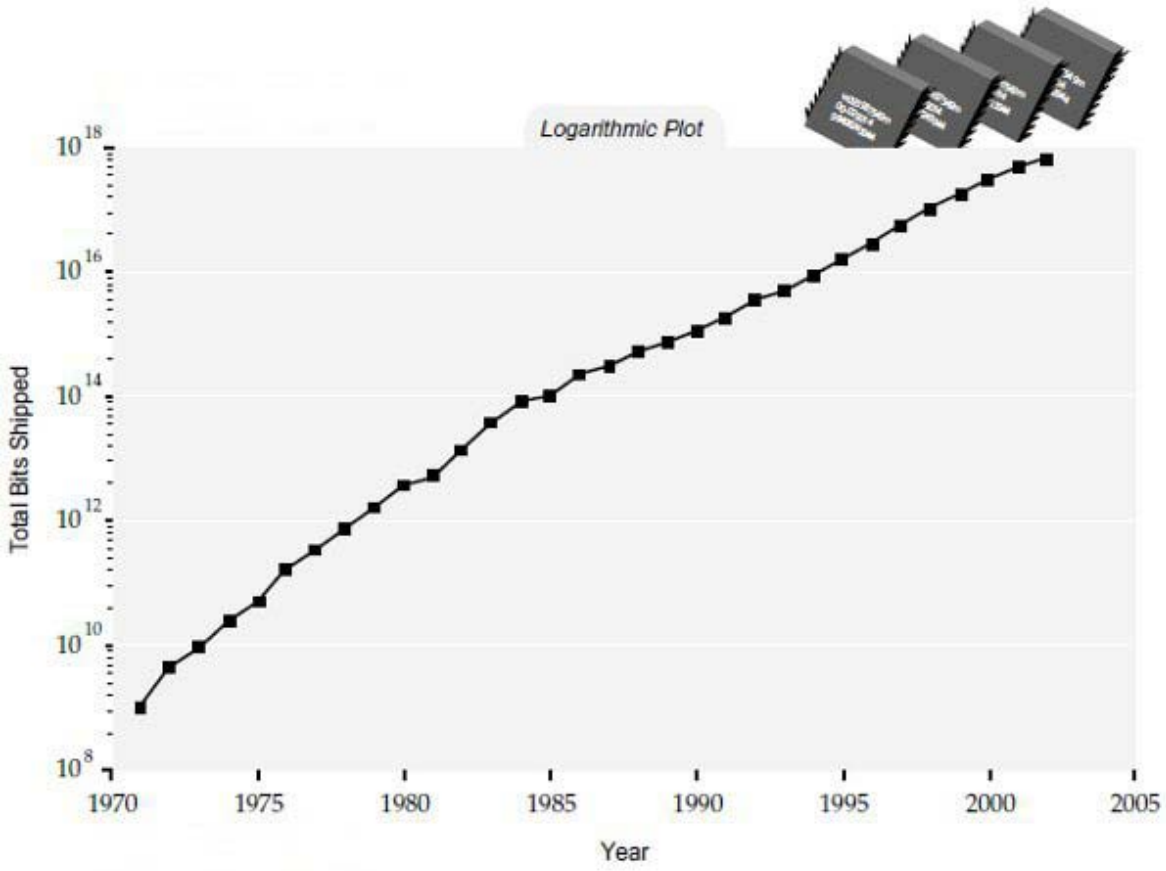
Processor Performance (MIPS)

Doubling time: 1.8 years



Total Bits Shipped

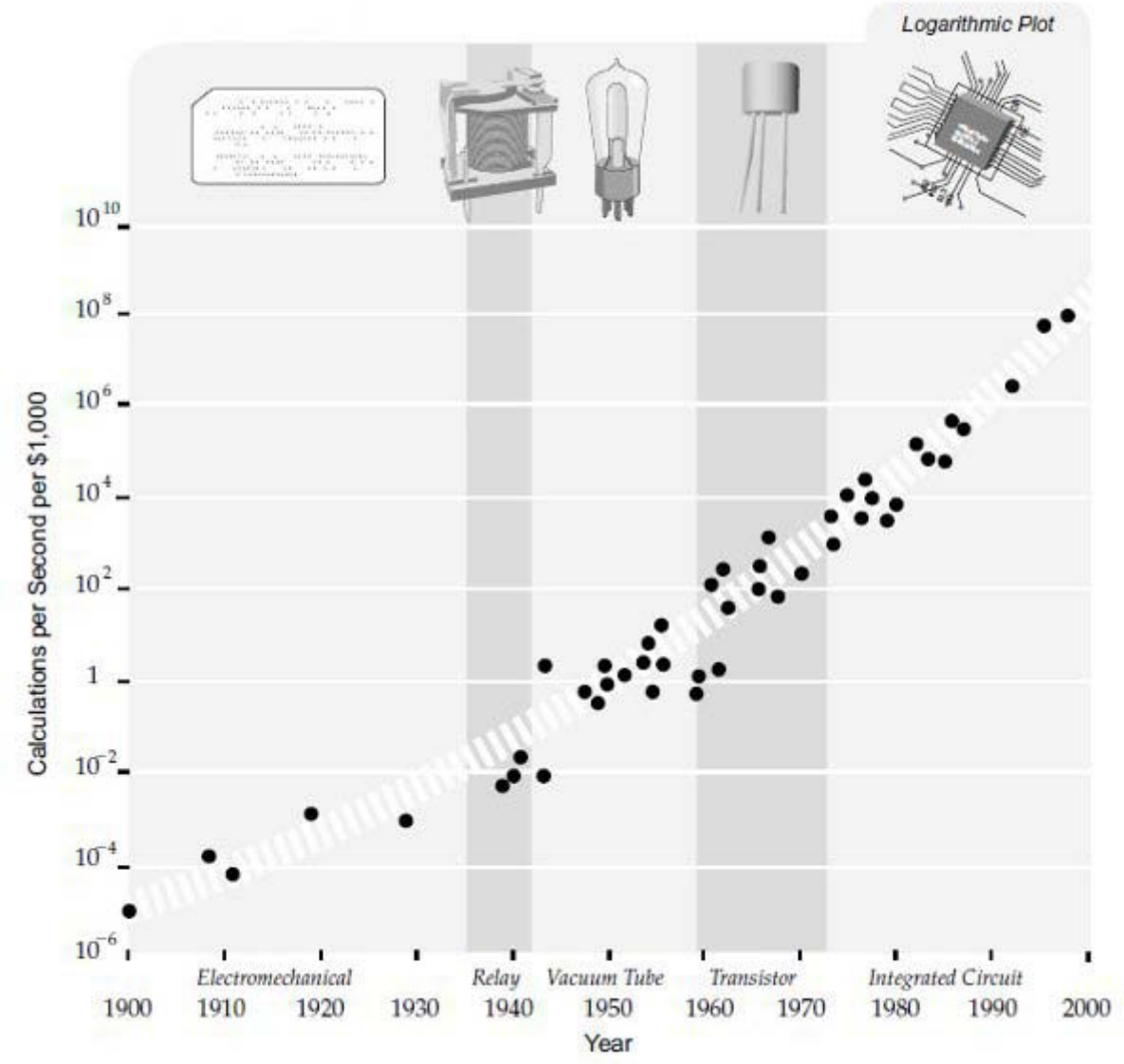
Doubling time: 1.1 years



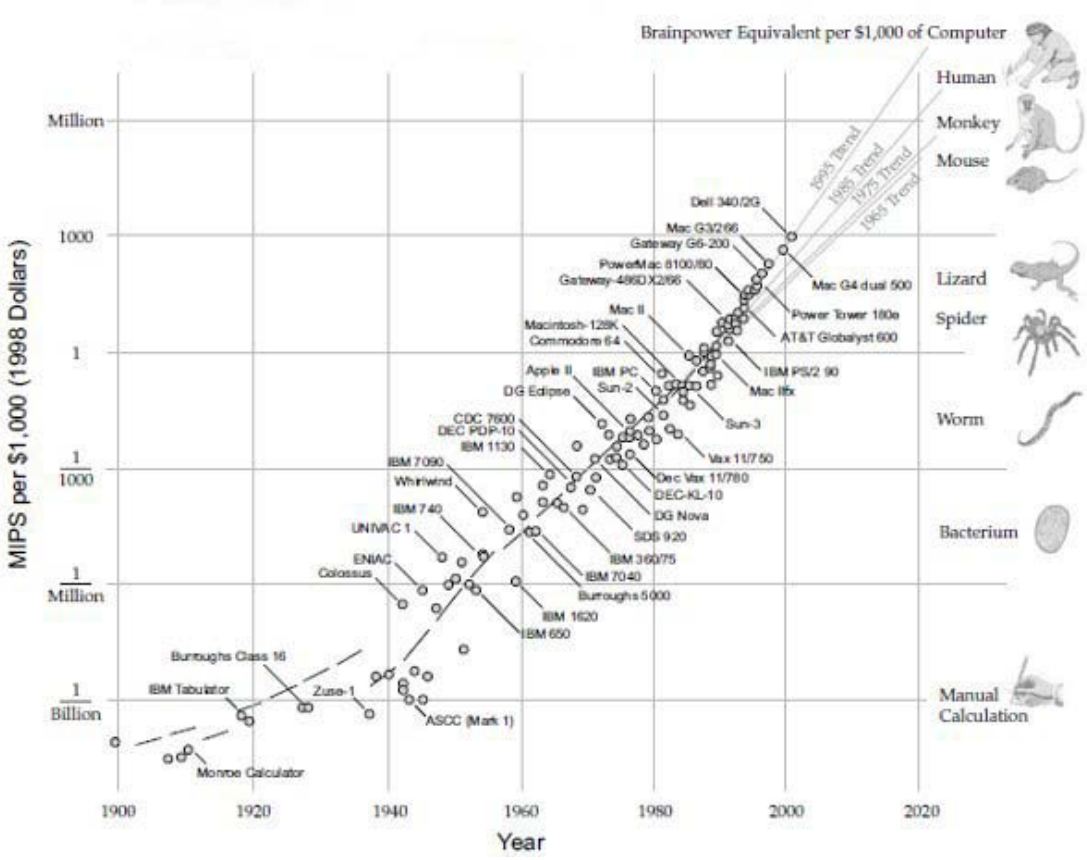
Moore's Law: The Fifth Paradigm

The five paradigms of exponential growth of computing: **Each time one paradigm has run out of steam, another has picked up the pace.**

As the figure demonstrates, there were actually four different paradigms—electromechanical, relays, vacuum tubes, and discrete transistors—that showed exponential growth in the price-performance of computing long before integrated circuits were even invented.



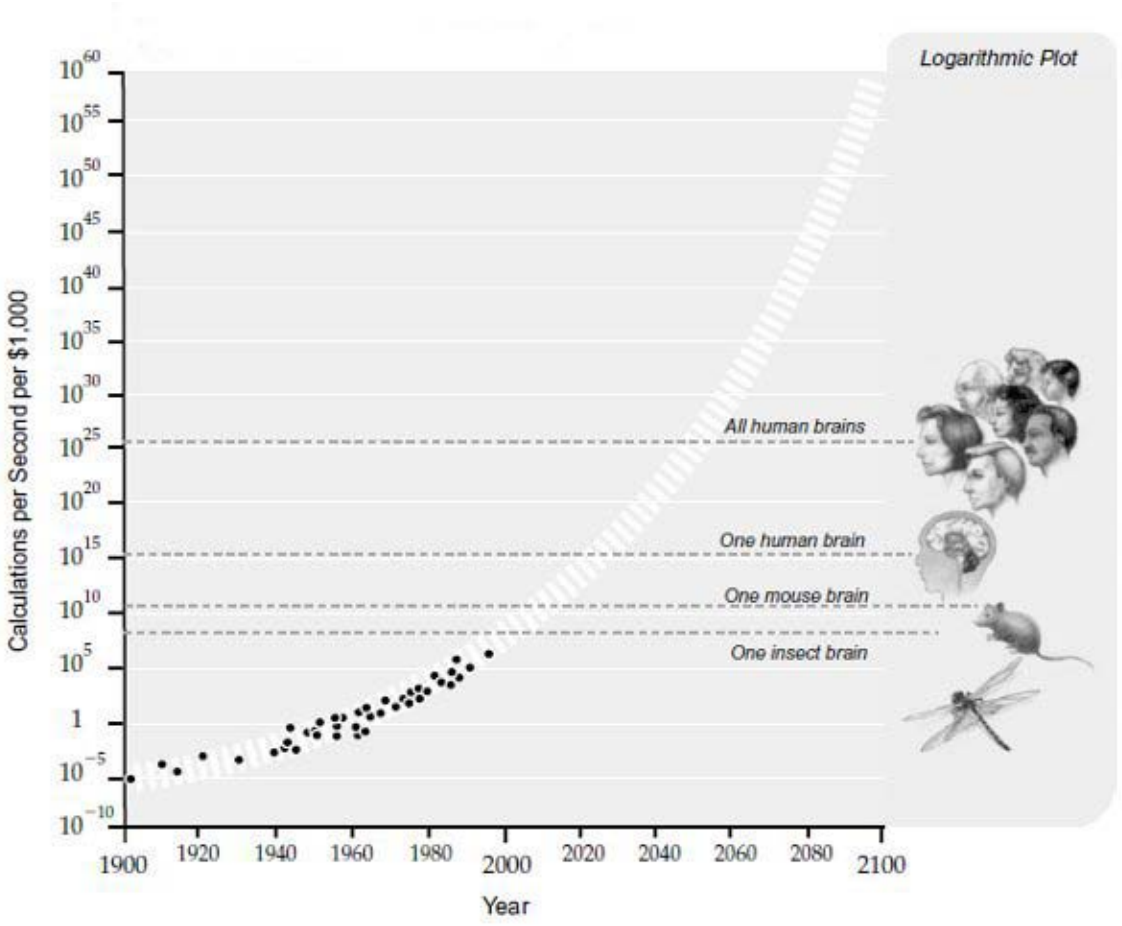
Evolution of Computer Power/Cost



Source: Hans Moravec, "When Will Computer Hardware Match the Human Brain?" *Journal of Evolution and Technology* 1 (1998).

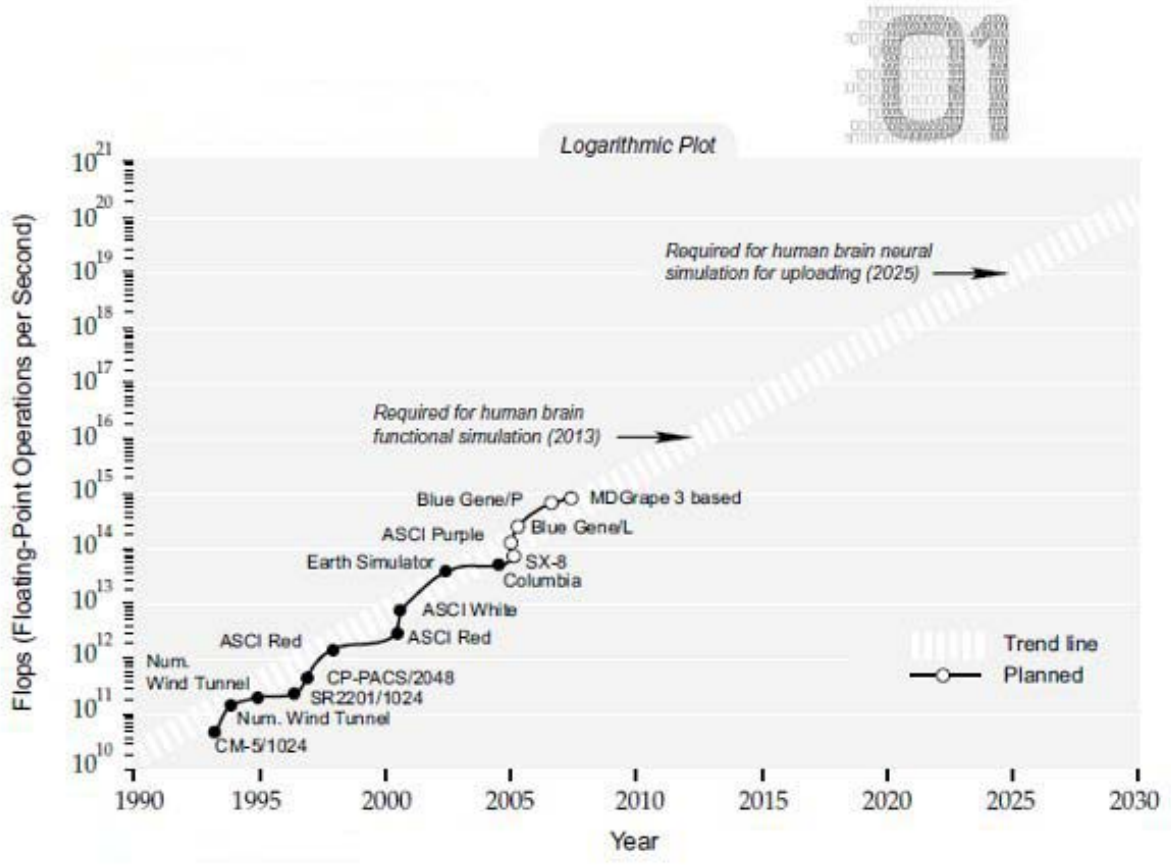
Exponential Growth of Computing

Twentieth Through Twenty-First Century



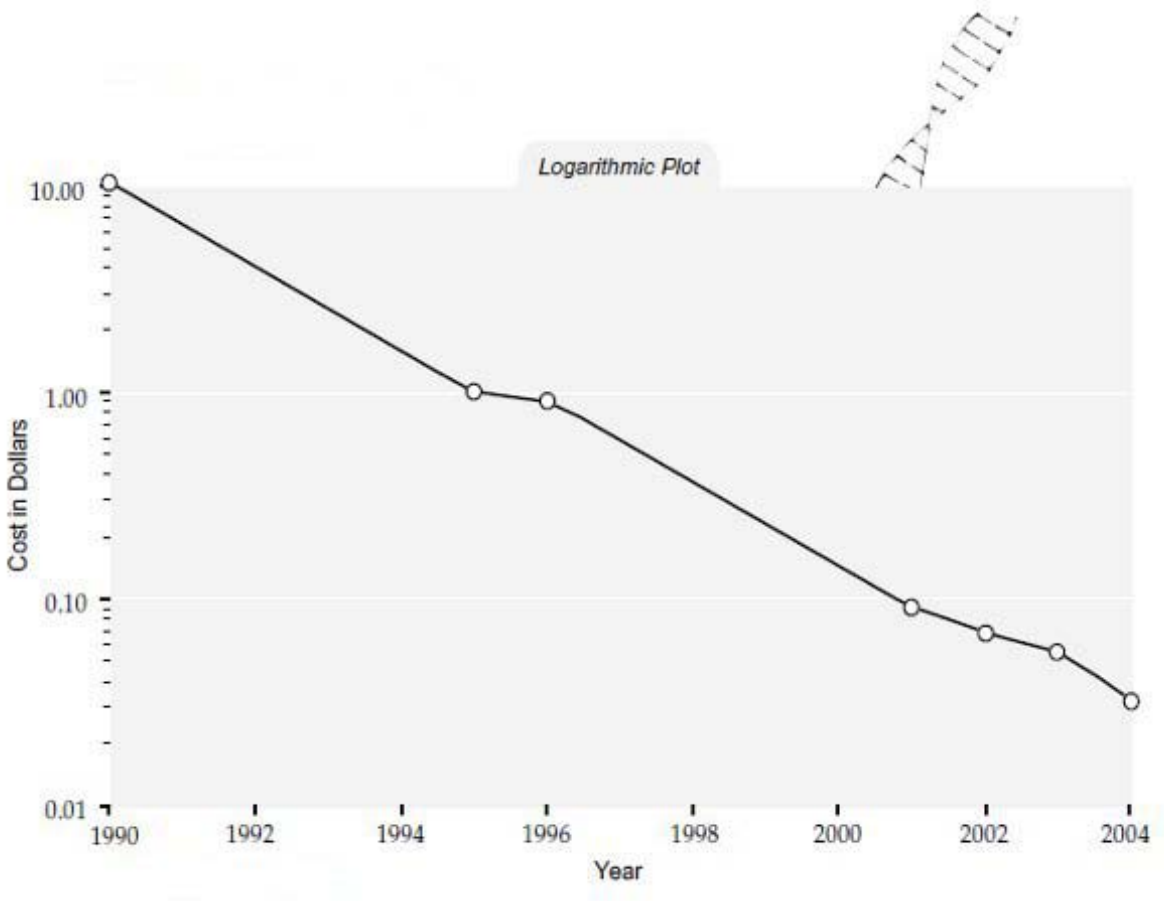
Growth in Supercomputer Power

Doubling time: 1.2 years



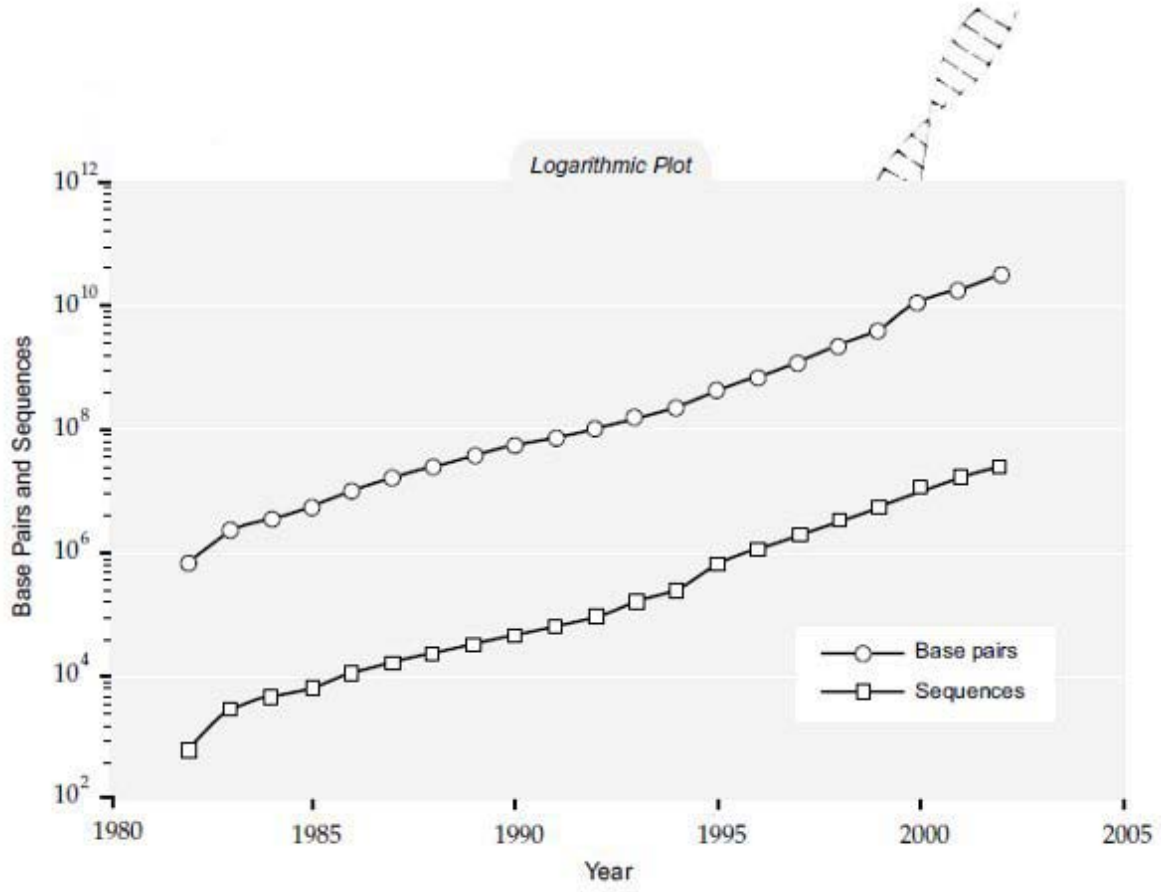
DNA Sequencing Cost (per Finished Base Pair)

Halving time: 1.9 years



Sources: Human Genome Project; Stanford Genome Technology Center; National Human Genome Research Institute; Tabitha Powledge, "How Many Genomes Are Enough?" *Scientist*, November 17, 2003.

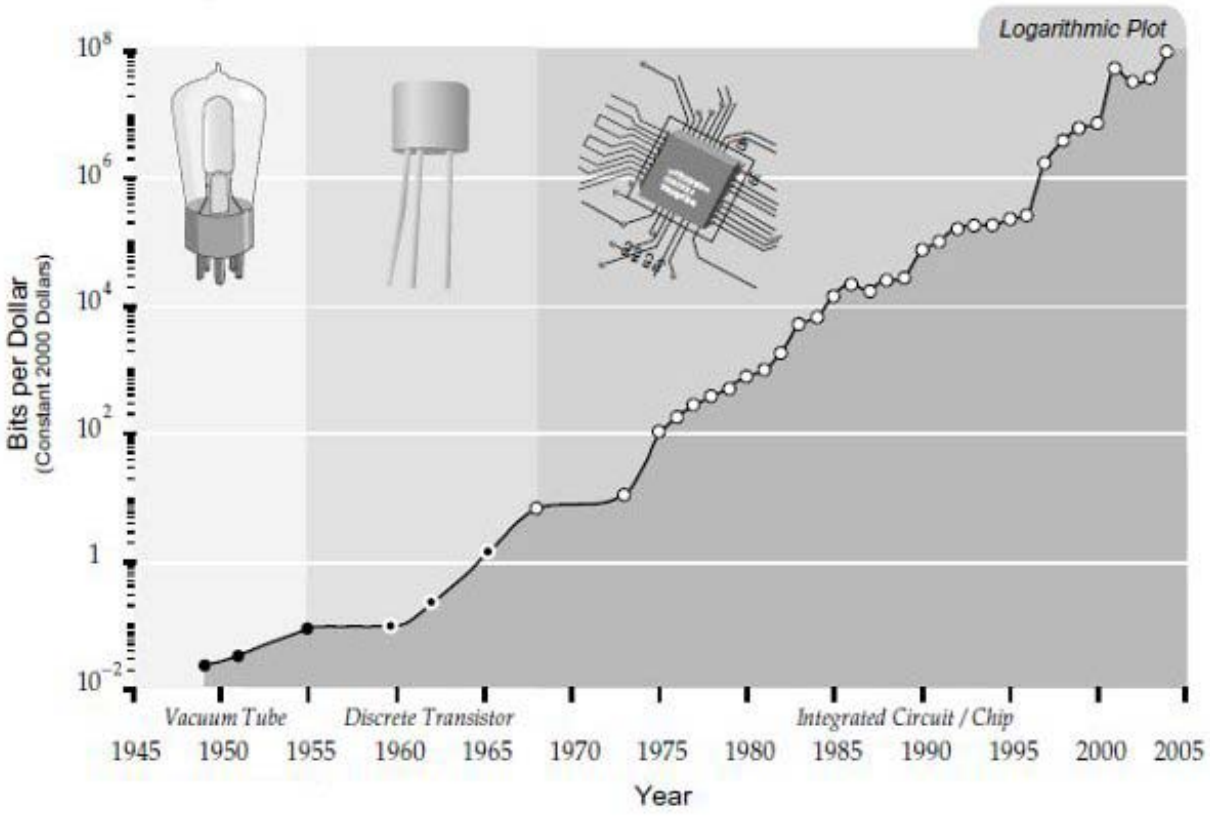
Growth in Genbank: DNA Sequence Data



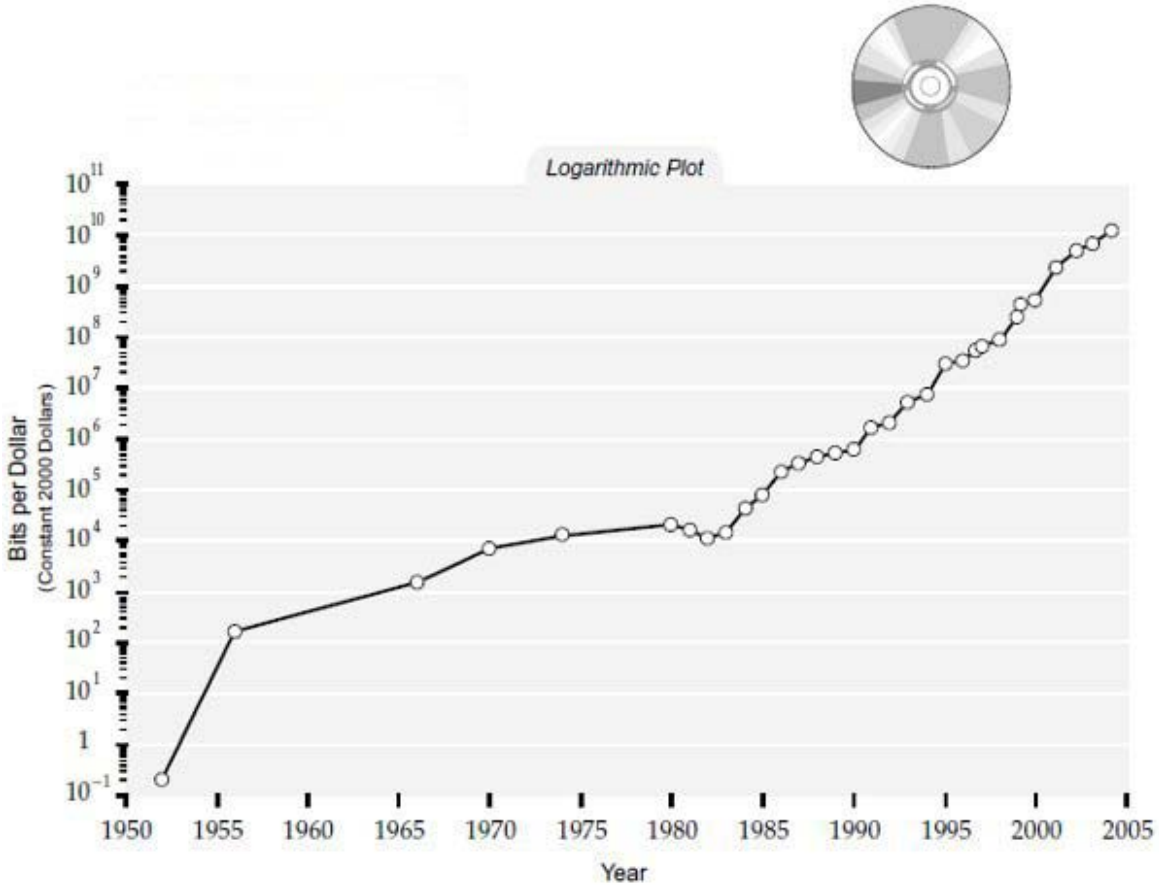
Random Access Memory: Bits per Dollar (1949–2004)

Exponential growth in RAM capacity across paradigm shifts

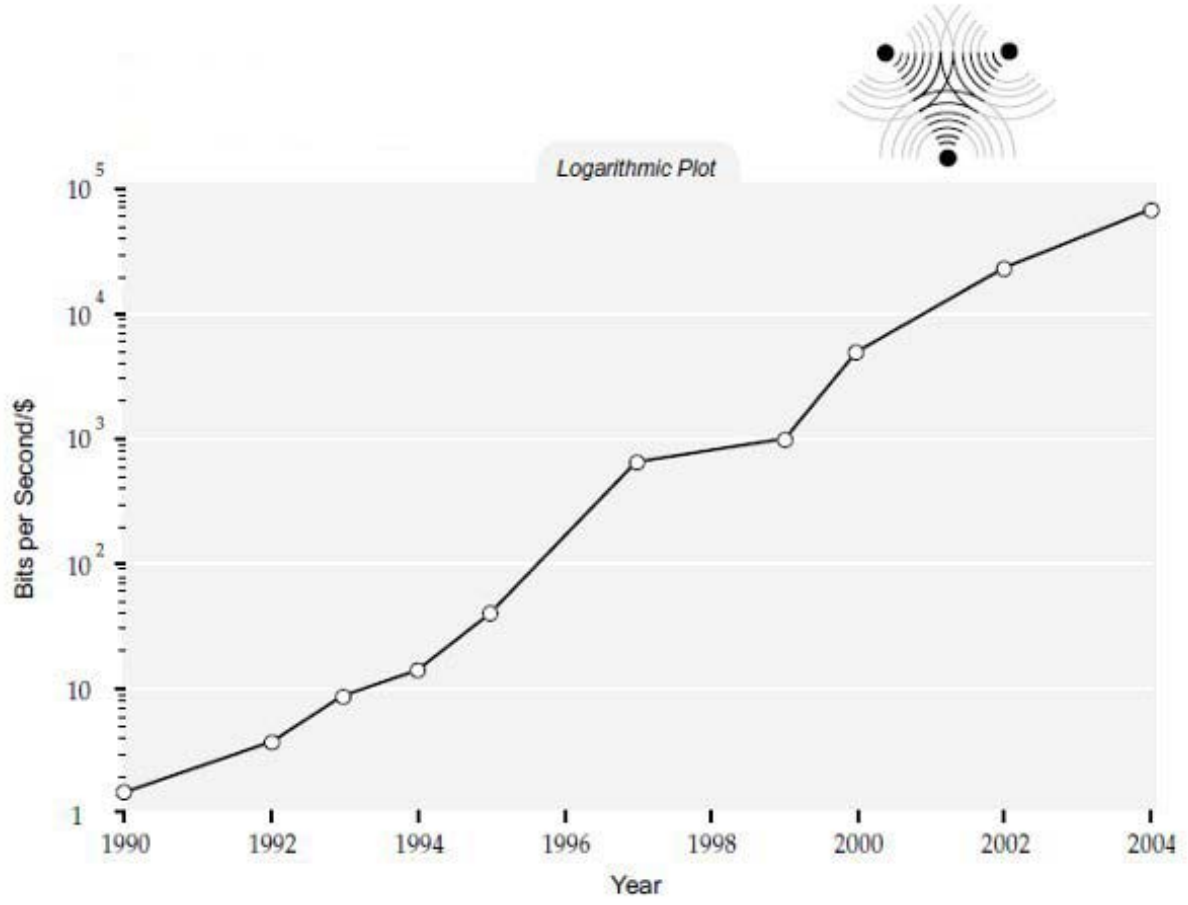
Doubling time: 1.5 years



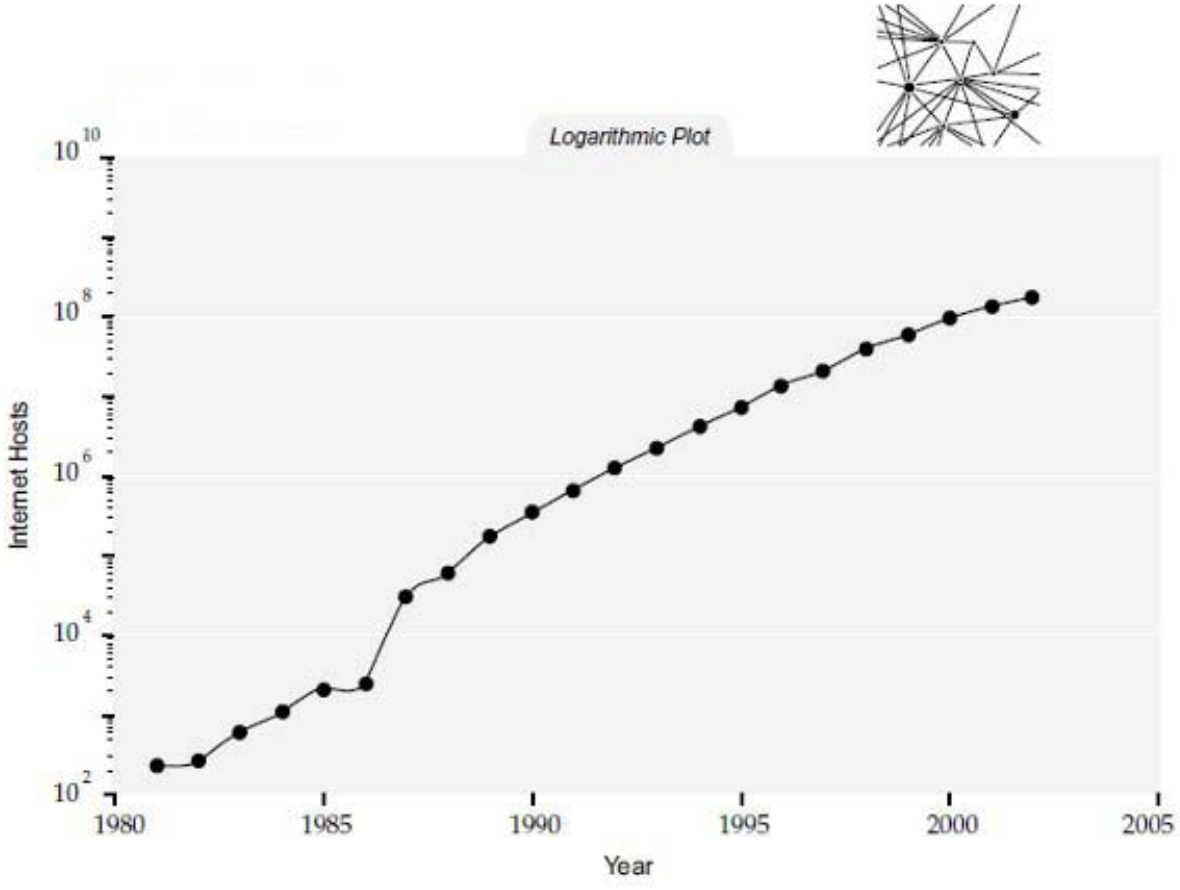
Magnetic Data Storage: Bits per Dollar



Price-Performance (Wireless Data Devices)



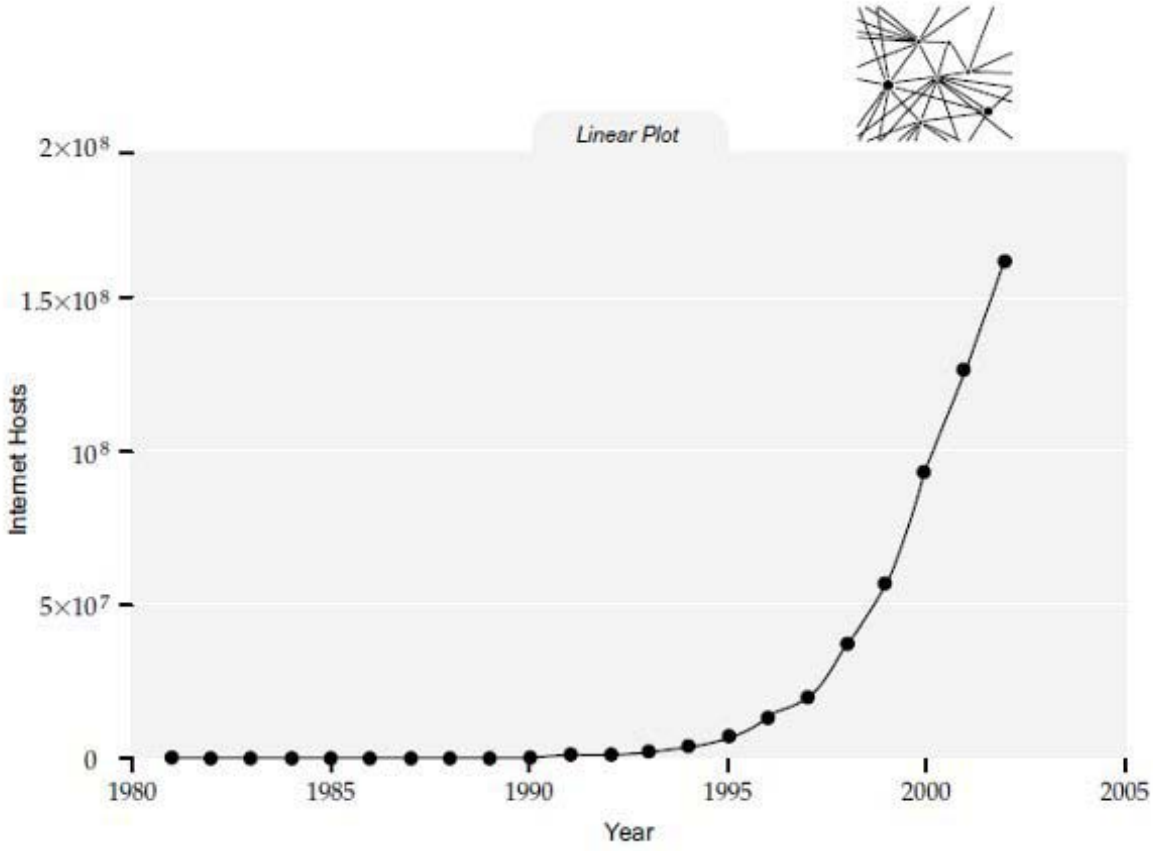
Internet Hosts, Logarithmic Plot



Source: Internet Software Consortium (http://www.isc.org), ISC Domain Survey: Number of Internet Hosts.

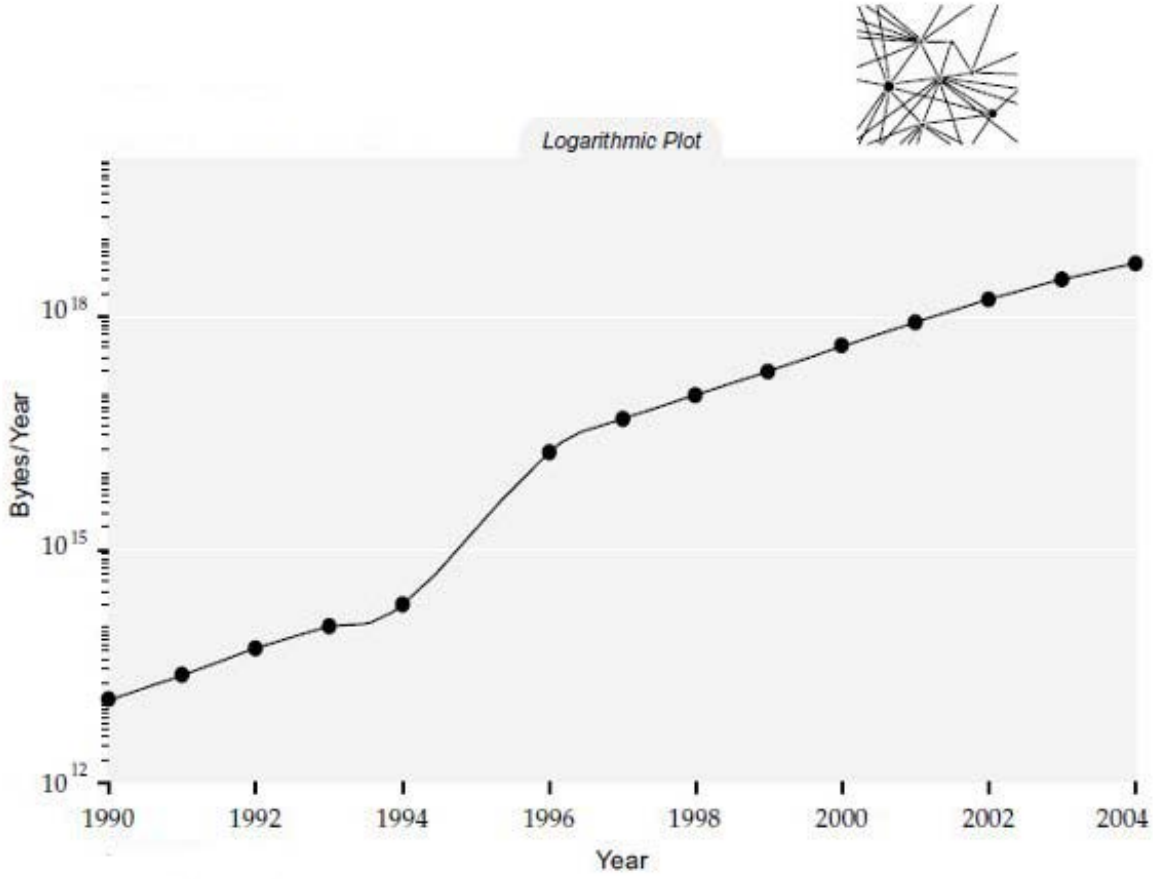
Internet Hosts, Linear Plot

The explosion of the Internet appears to be a surprise from the linear chart but was perfectly predictable from the logarithmic one.

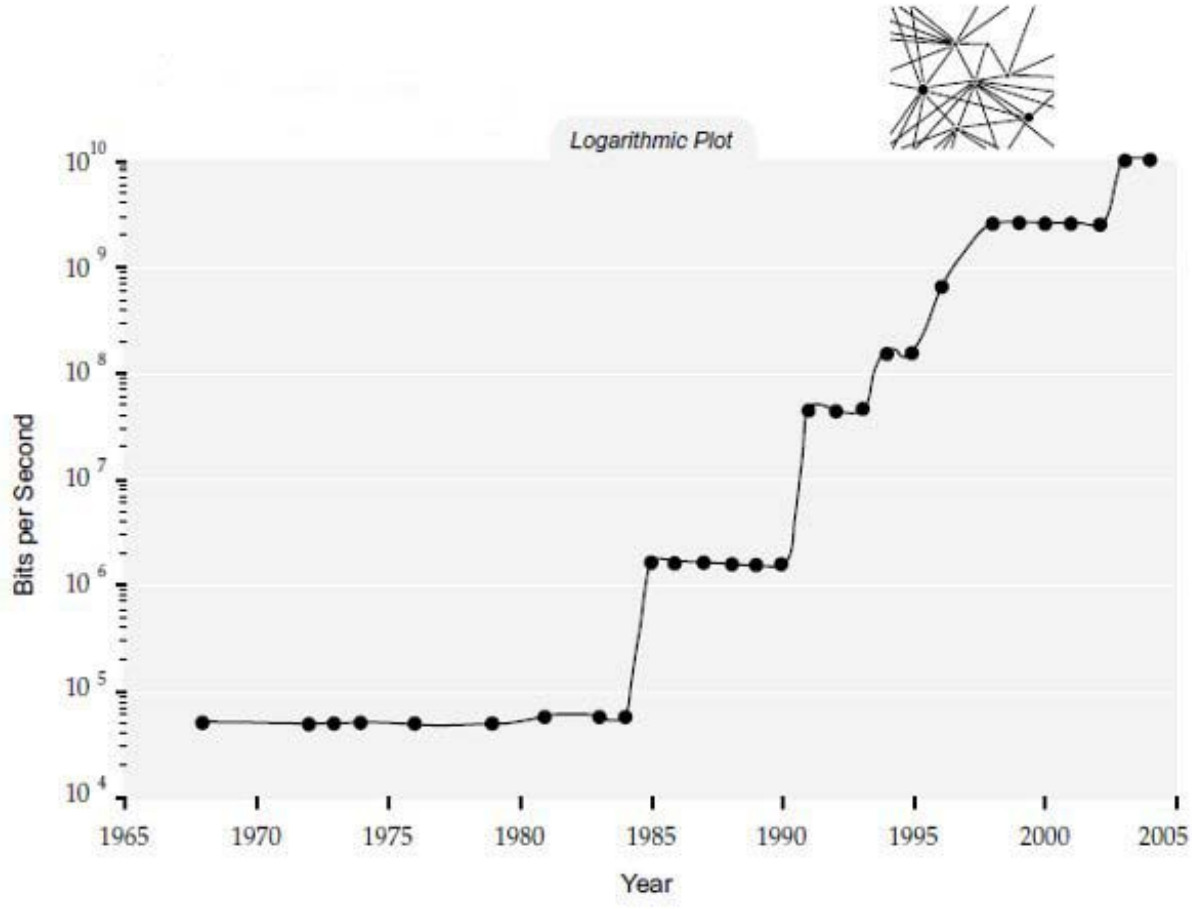


Internet Data Traffic

Doubling time: 1 year

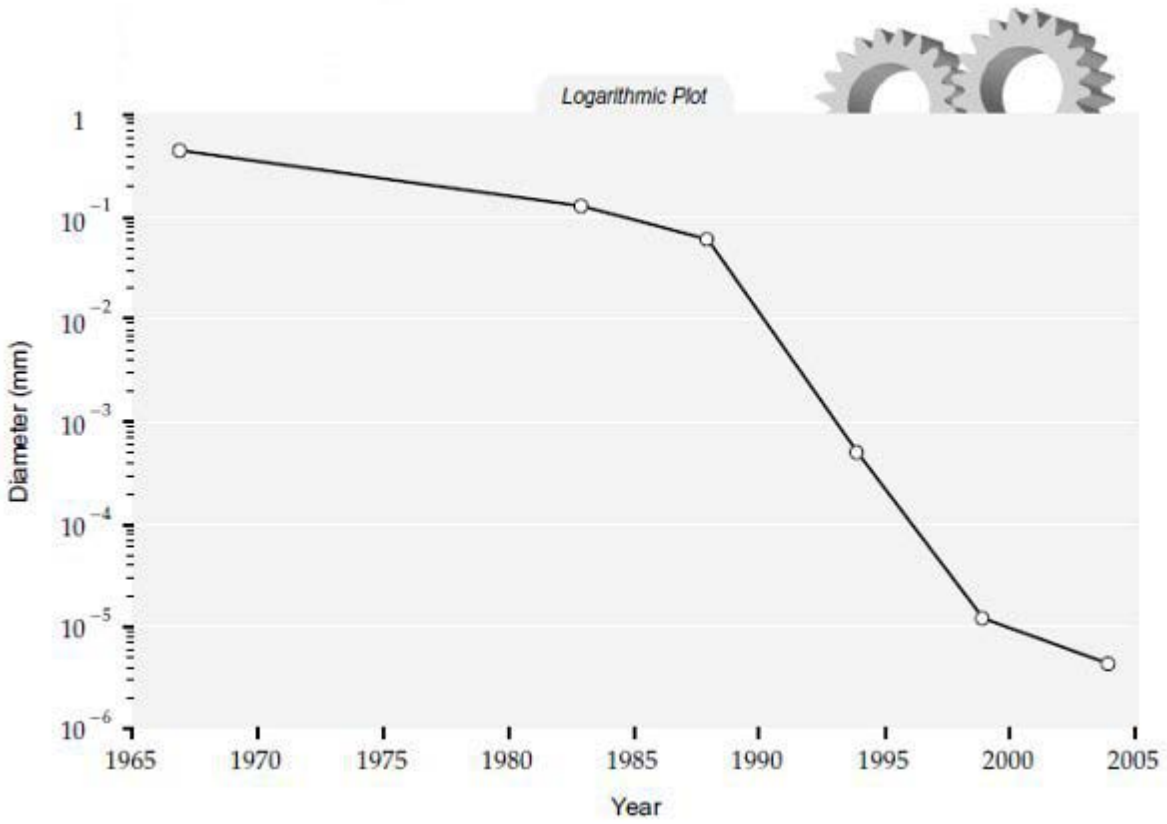


Internet Backbone Bandwidth (Bits per Second)



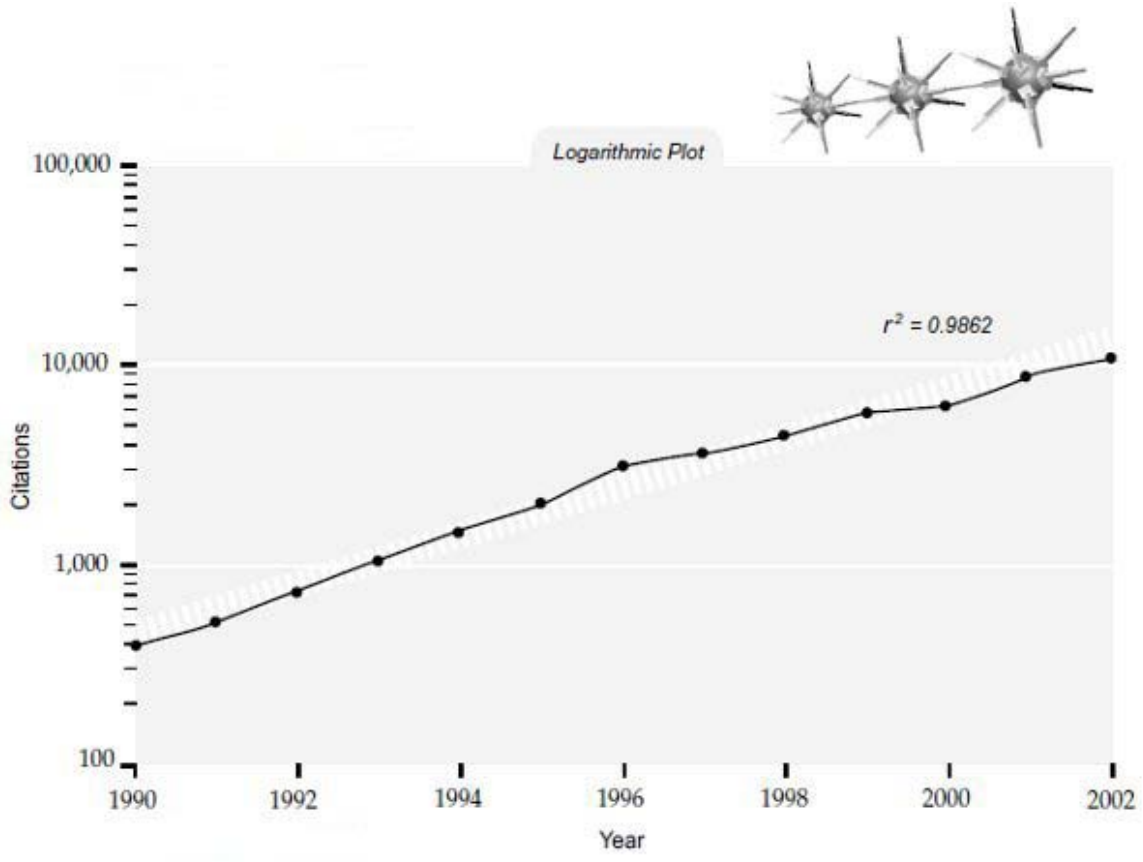
Decrease in Size of Mechanical Devices

(Diameter in millimeters)



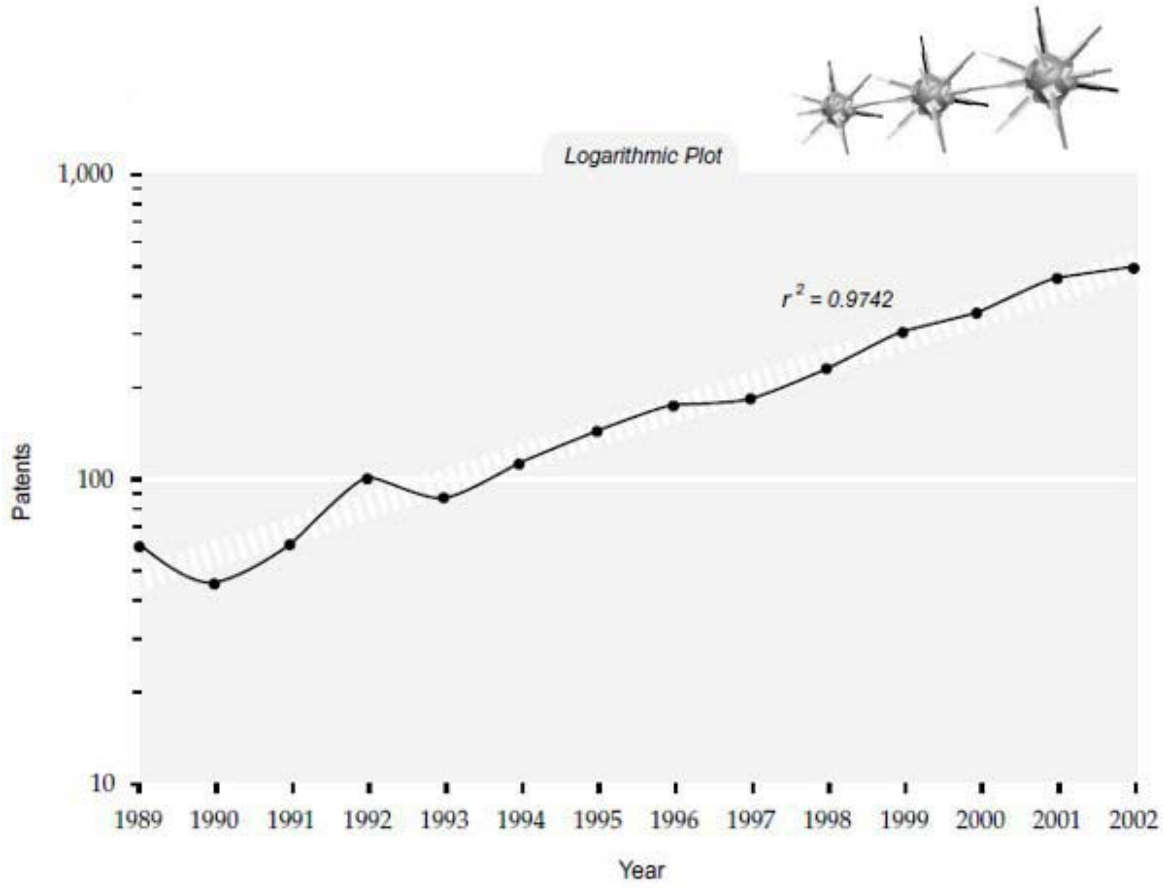
Nanotech Science Citations (1990–2002)

Doubling time: 2.4 years



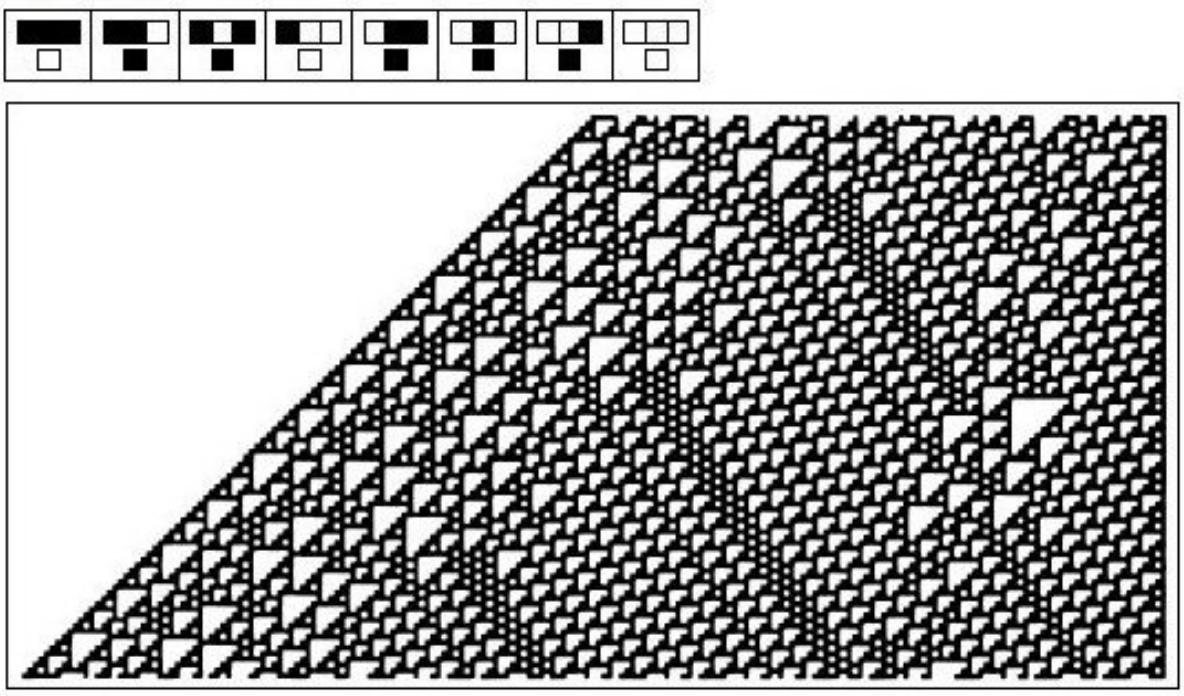
Source: ETC Group, "From Genomes to Atoms: The Big Down."

U.S. Nanorelated Patents

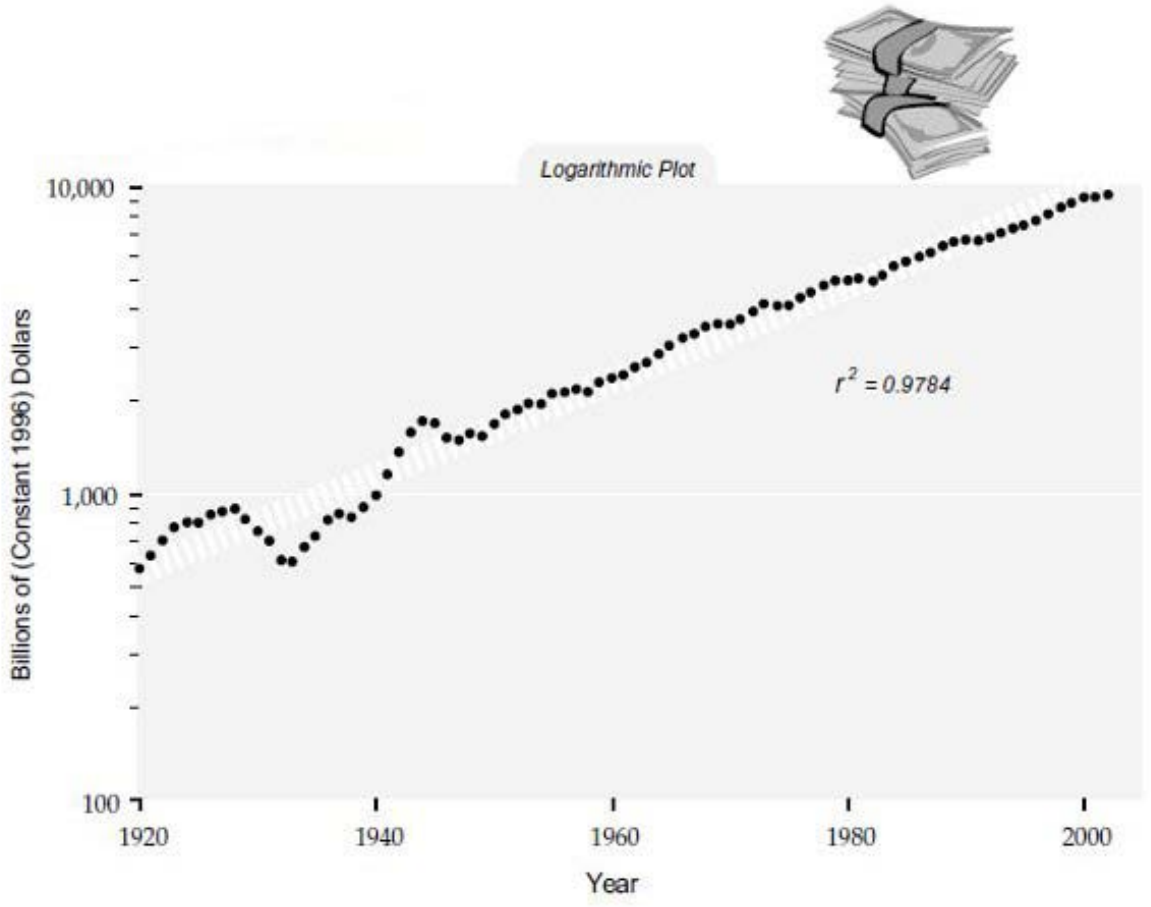


Rule 110

Portion of image generated by rule 110

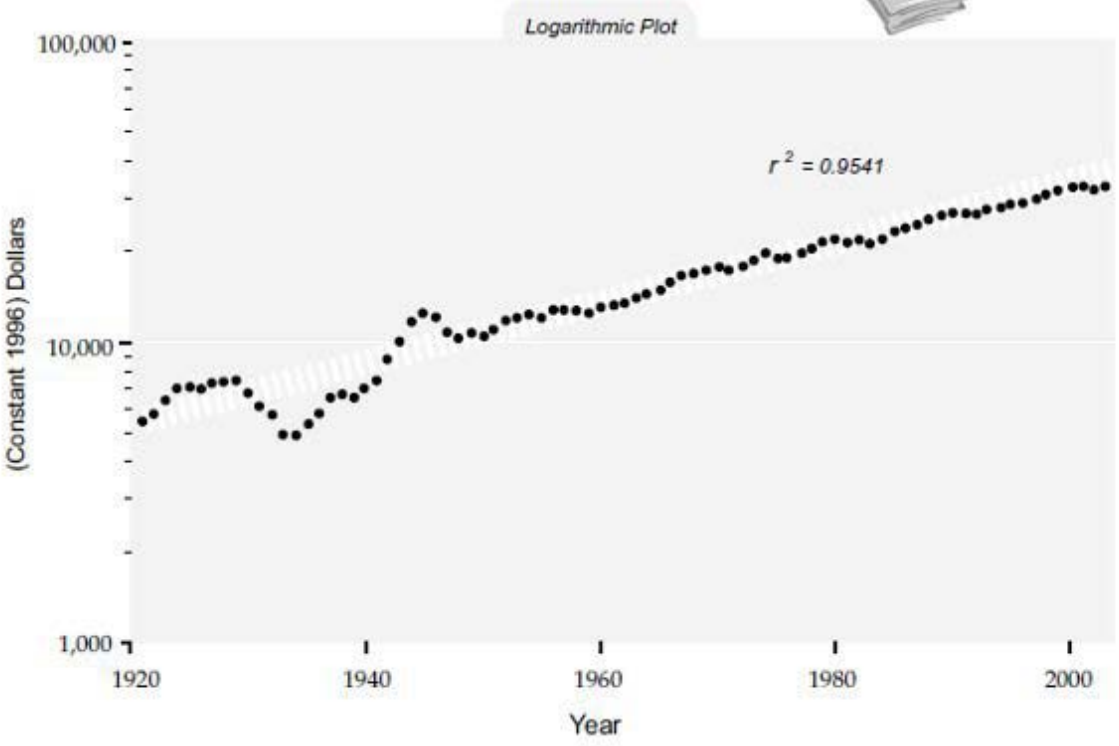


Real Gross Domestic Product



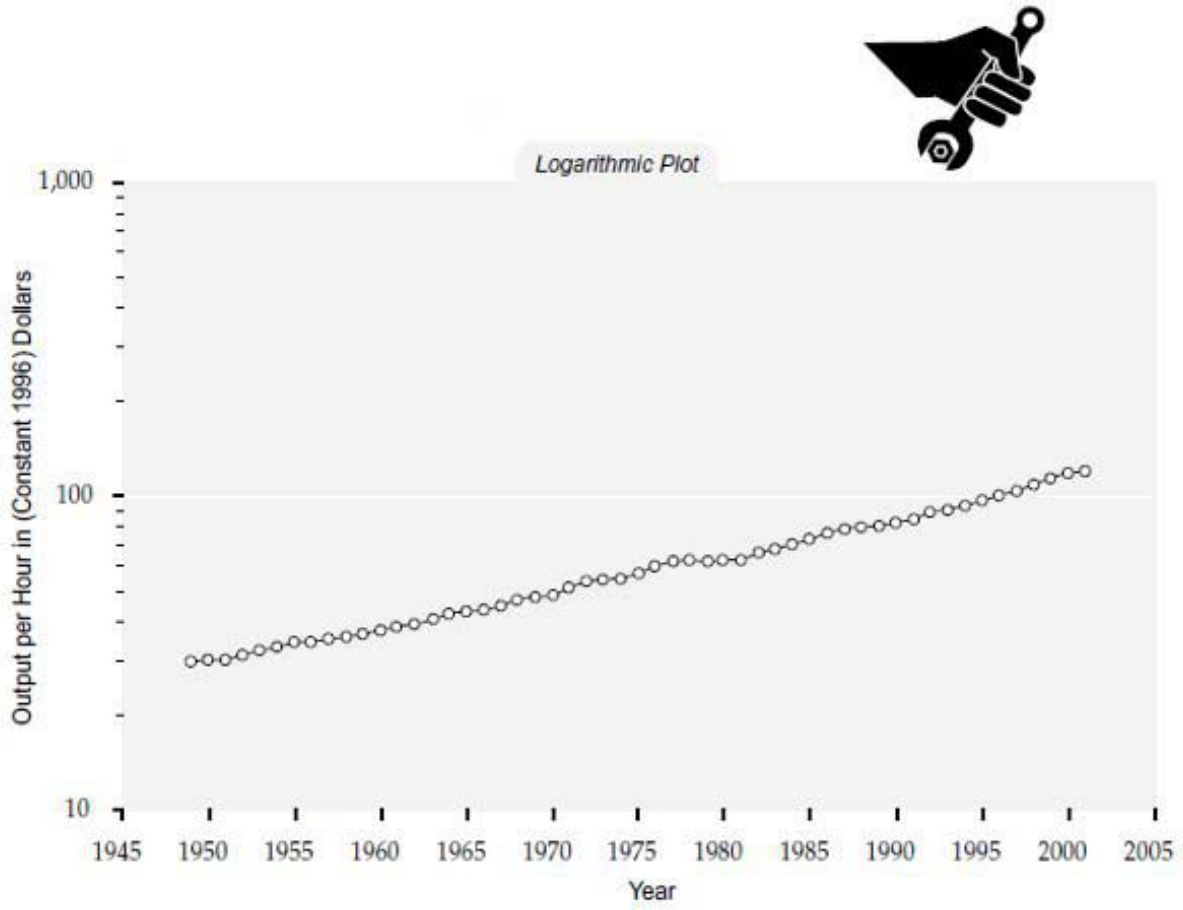
Source: U.S. Department of Commerce, Bureau of Economic Analysis.

Per-Capita GDP



Source: U.S. Department of Commerce, Bureau of Economic Analysis.

Private Manufacturing: Output per Hour



Source: Bureau of Labor Statistics, Major Sector Multifactor Productivity Index, Manufacturing Sector: Output per Hour All Persons.

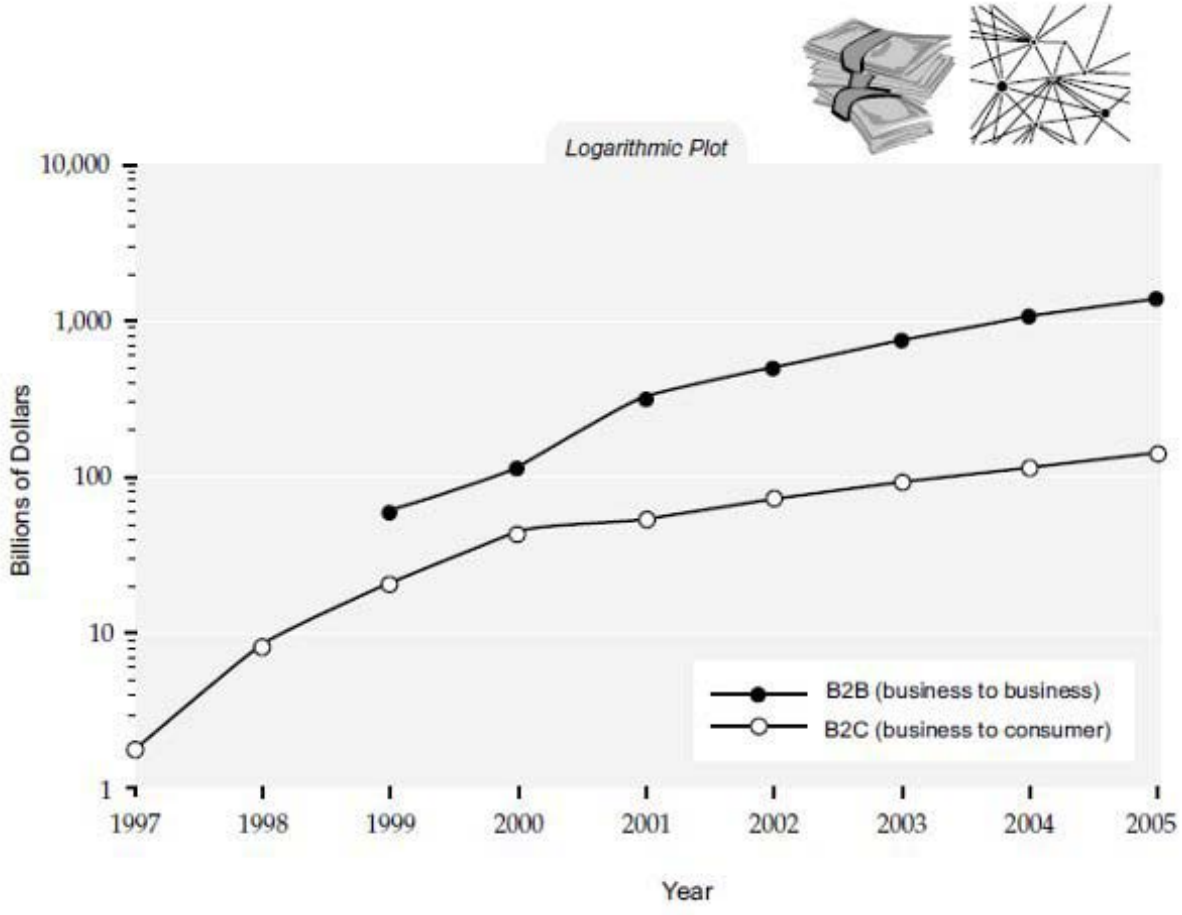
Exponential Software Price-Performance Improvement

Example: Automatic Speech-Recognition Software

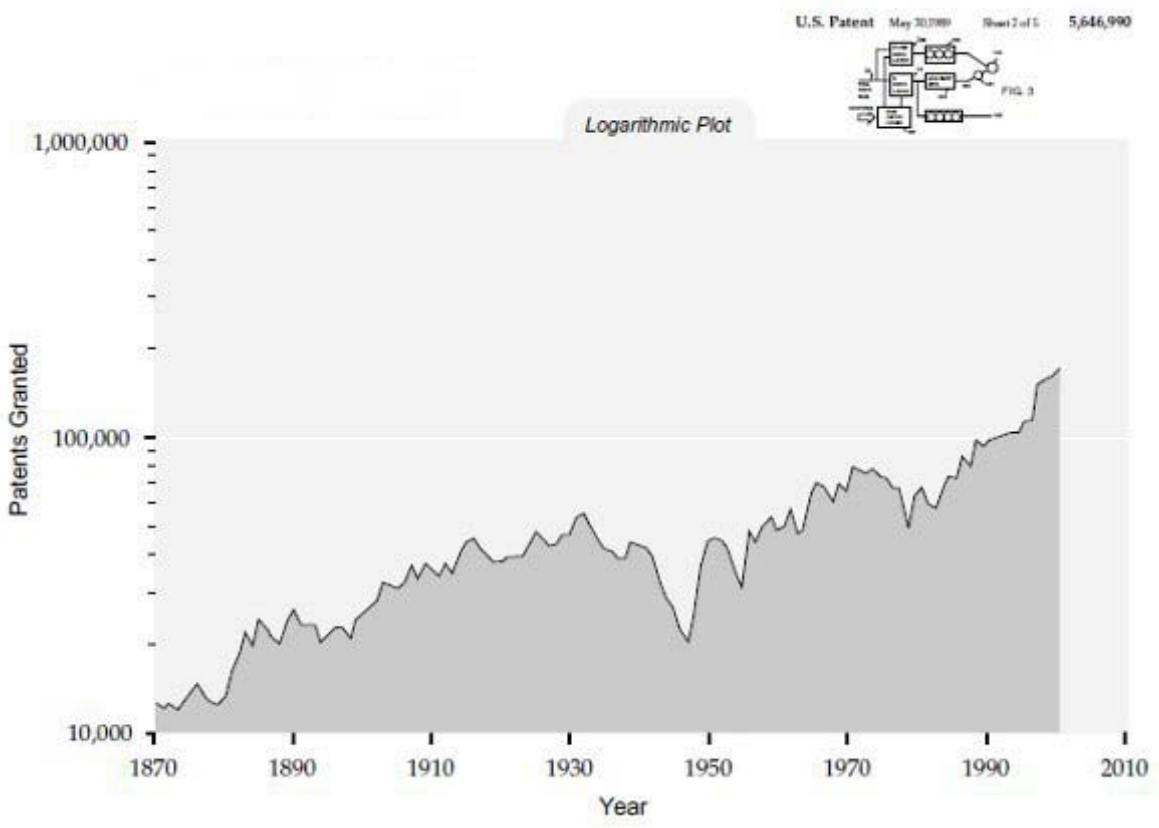
	1985	1995	2000
Price	$5,000	$500	$50
Vocabulary Size (number of words)	1,000	10,000	100,000
Continuous Speech?	No	No	Yes
User Training Required (minutes)	180	60	5
Accuracy	Poor	Fair	Good

Source: Data from Kurzweil Applied Intelligence, now part of ScanSoft (formerly Kurzweil Computer Products).

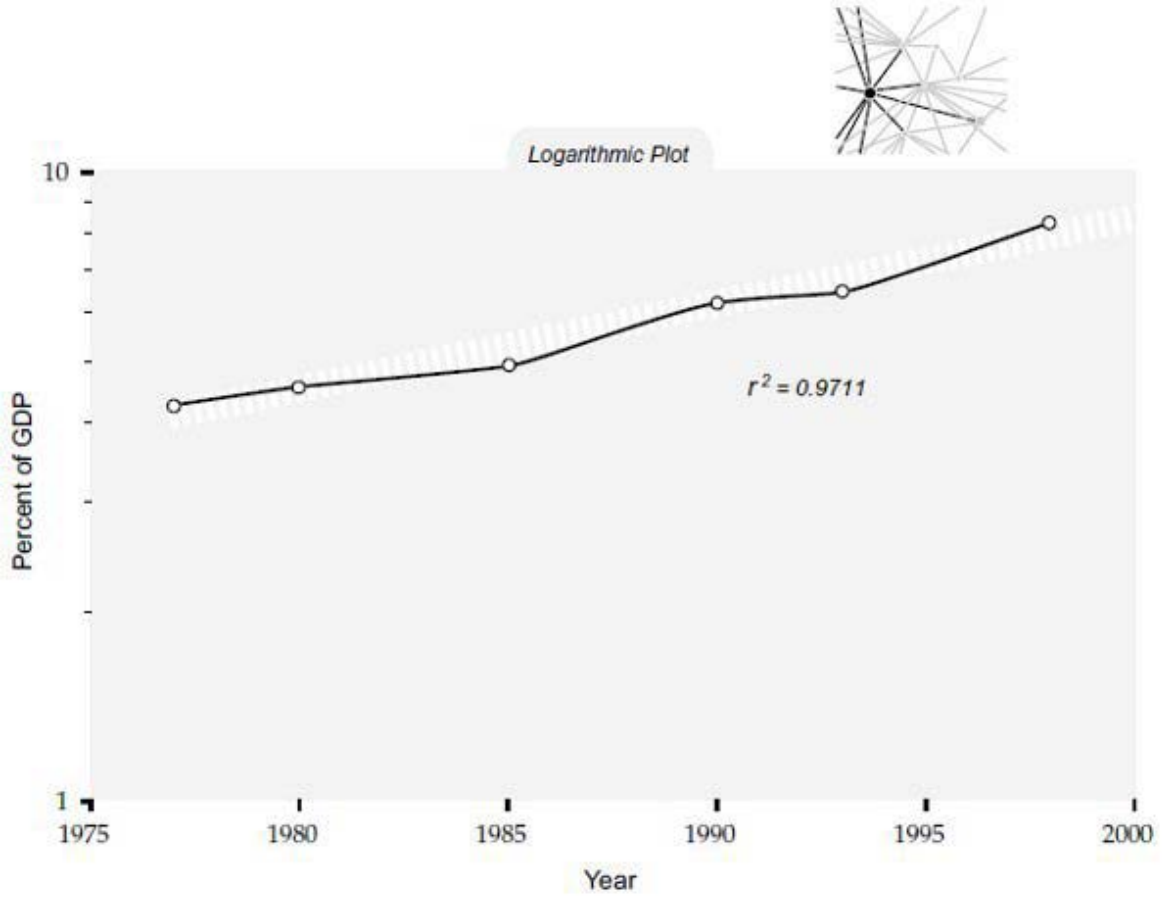
E-commerce Revenues in the United States



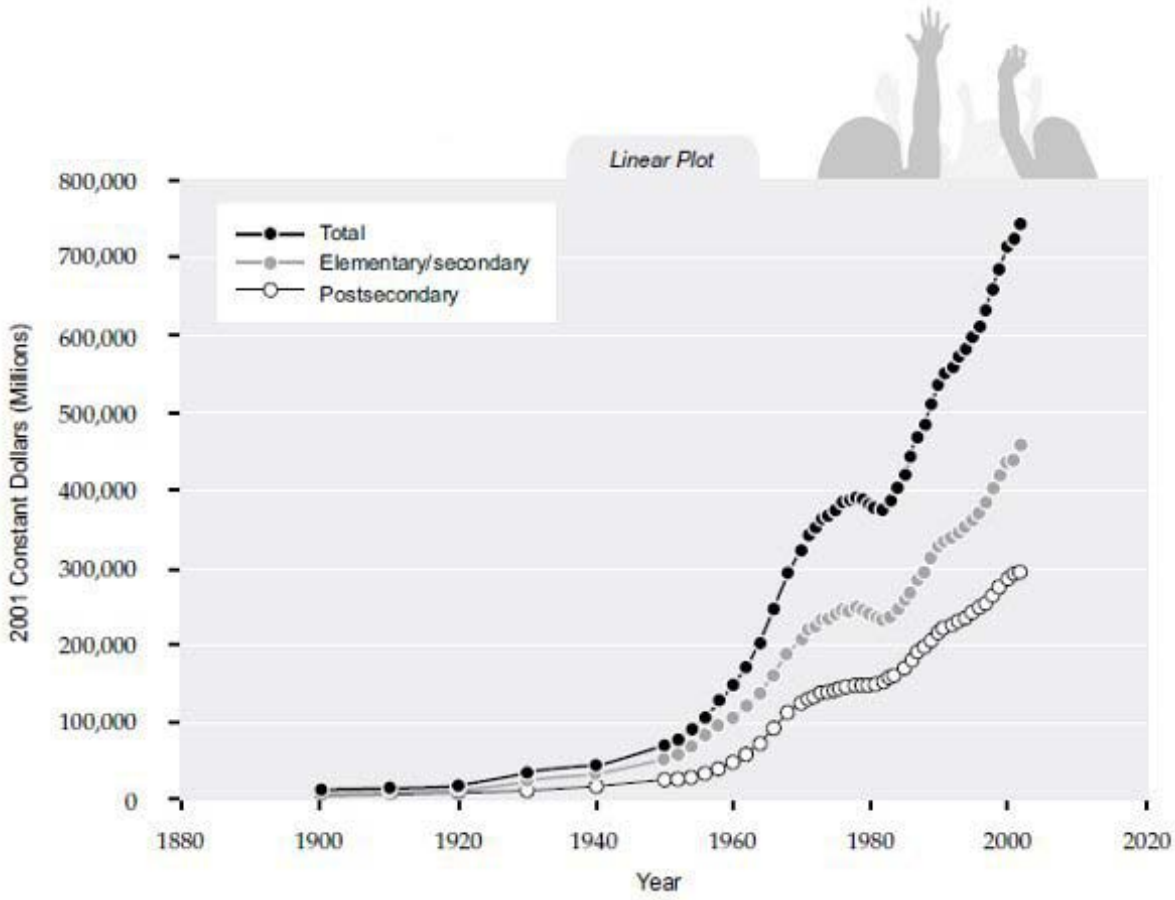
U.S. Patents Granted



IT's Share of the Economy

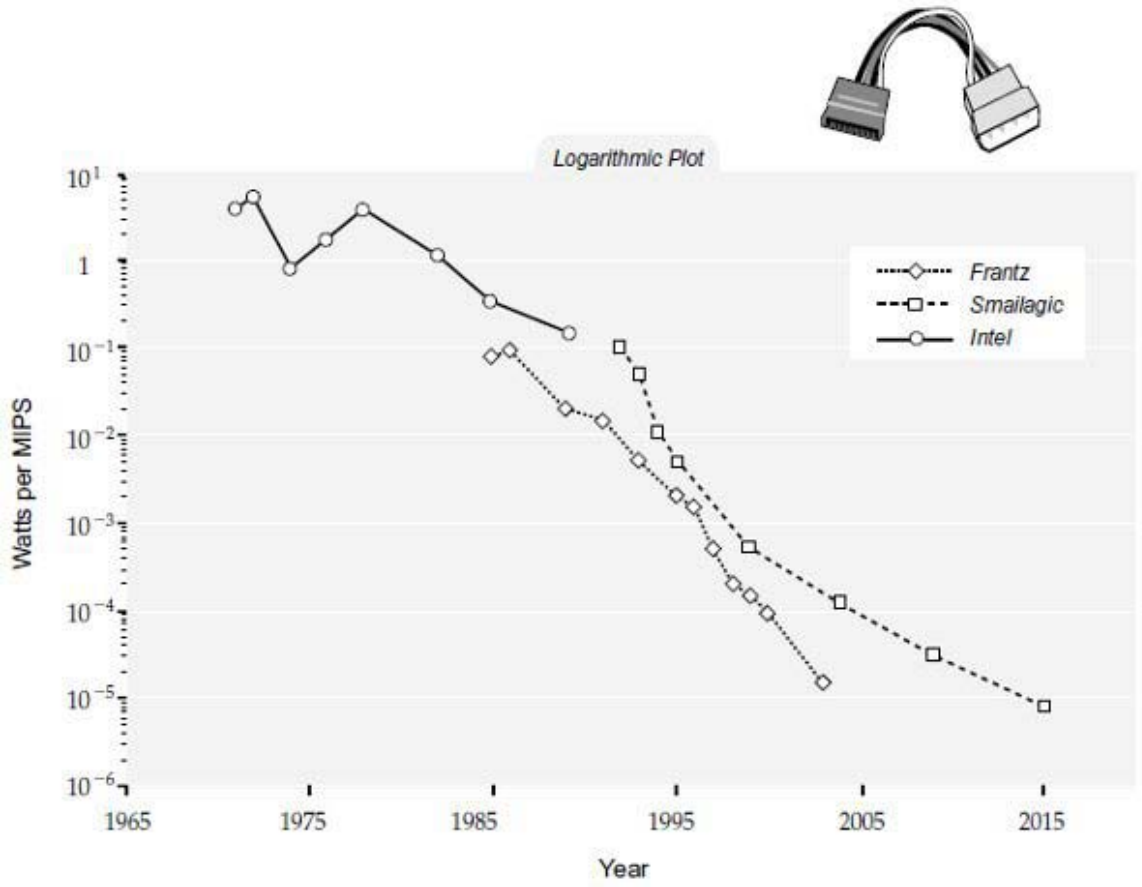


U.S. Education Expenditure



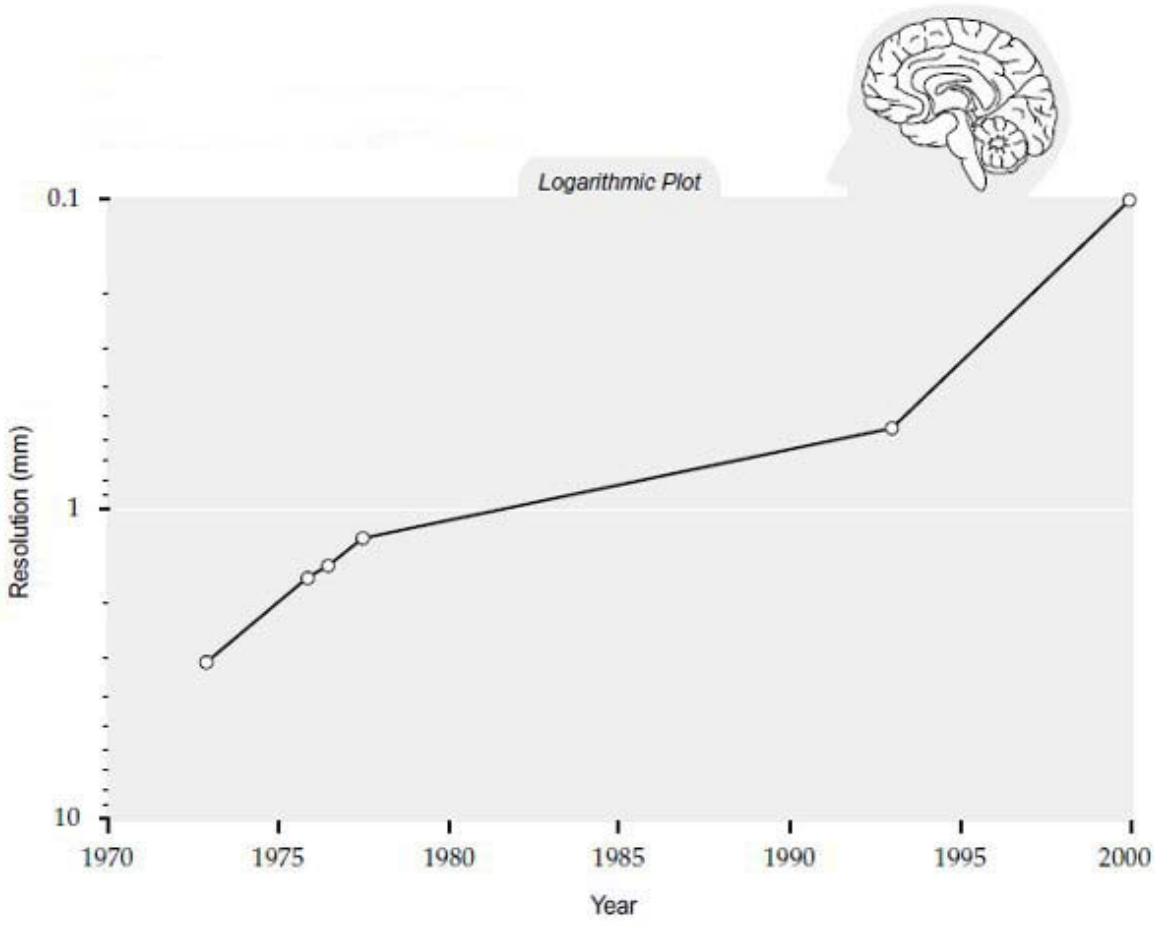
Source: National Center for Education Statistics, Digest of Education Statistics, 2002.

Reduction in Watts per MIPS



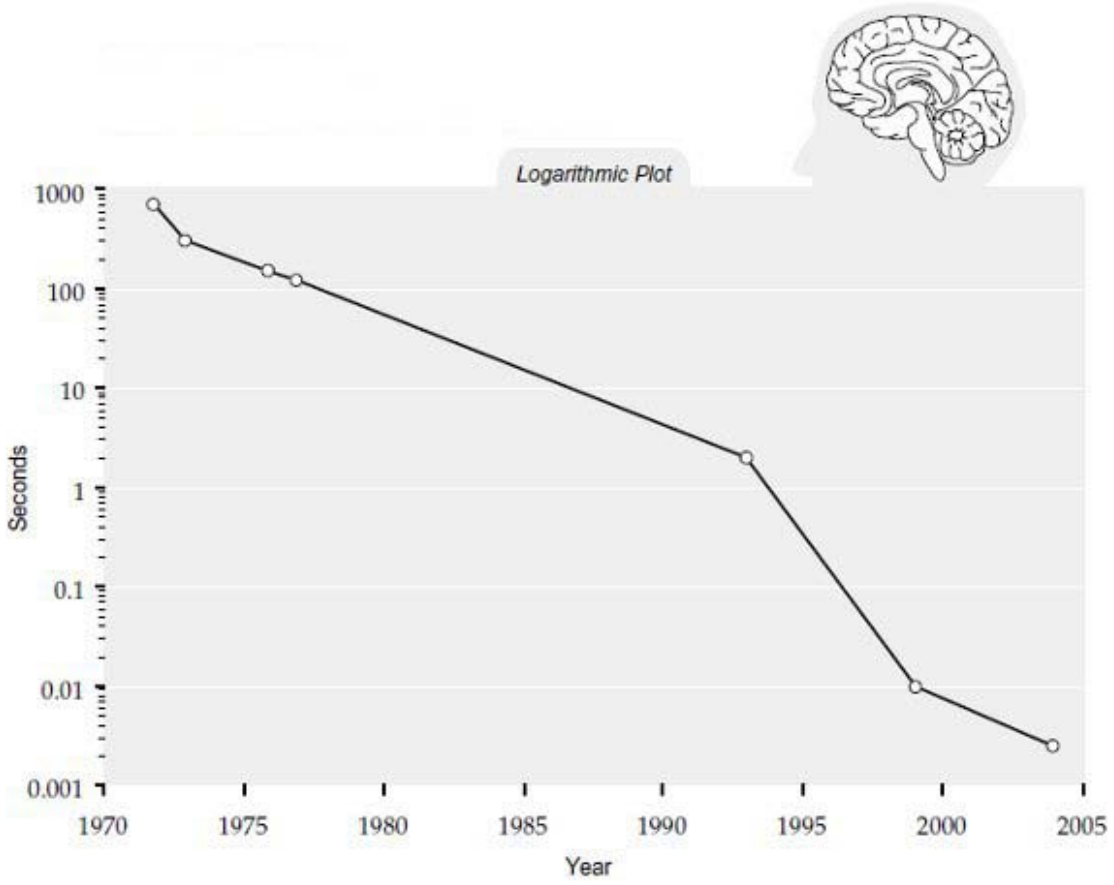
Source: Gene Frantz, "Digital Signal Processing Trends," *IEEE Micro* 20.6 (November/December 2000): 52–59.

Resolution of Noninvasive Brain Scanning

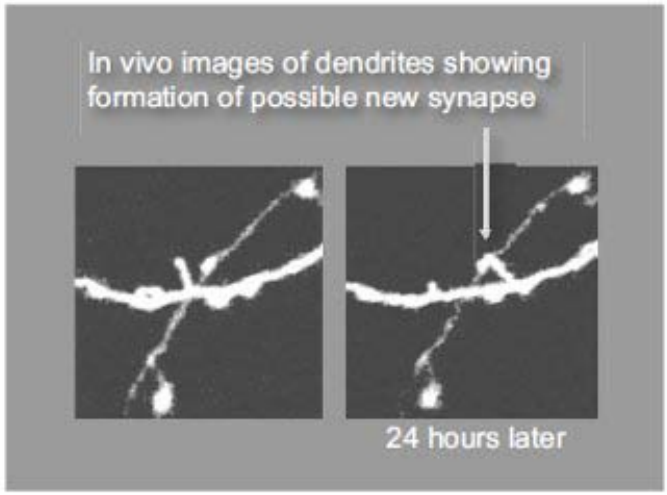


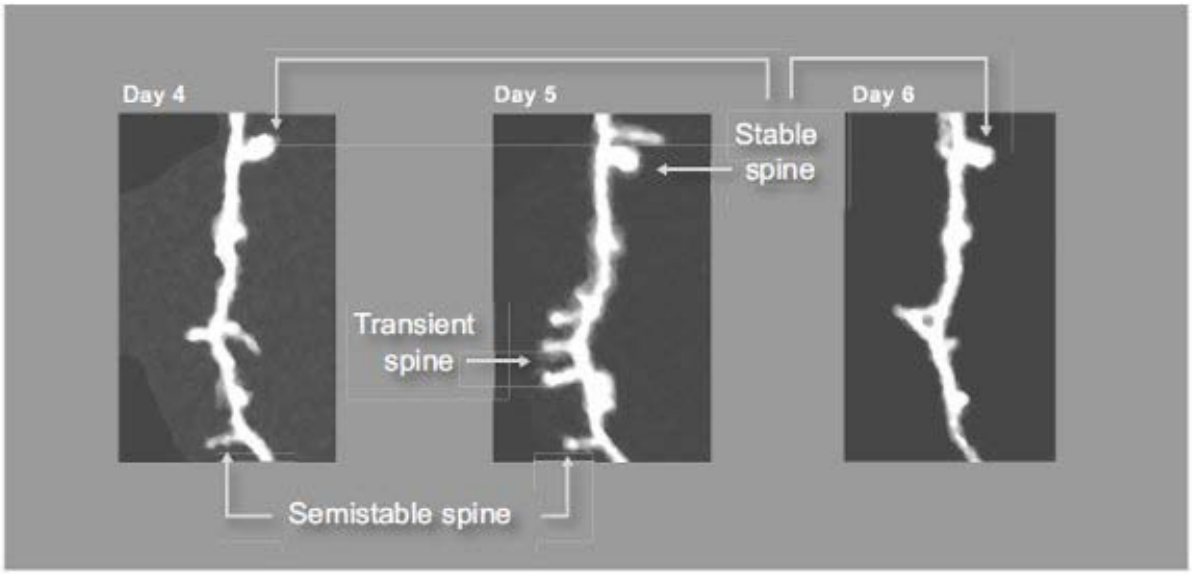
Source: Manuel Trajtenberg, *Economic Analysis of Product Innovation: The Case of CT Scanners*; Michael H. Friebe, Ph.D., president, CEO, NEUROMED GmbH; P-M. L. Robitaille, A. M. Abduljalil, and A. Kangarlu, "Ultra High Resolution Imaging of the Human Head at 8 Tesla: 2K x 2K for Y2K," *Journal of Computer Assisted Tomography* 24.1 (January–February 2000): 2–8.

Brain Scanning Image Reconstruction Time (Seconds)

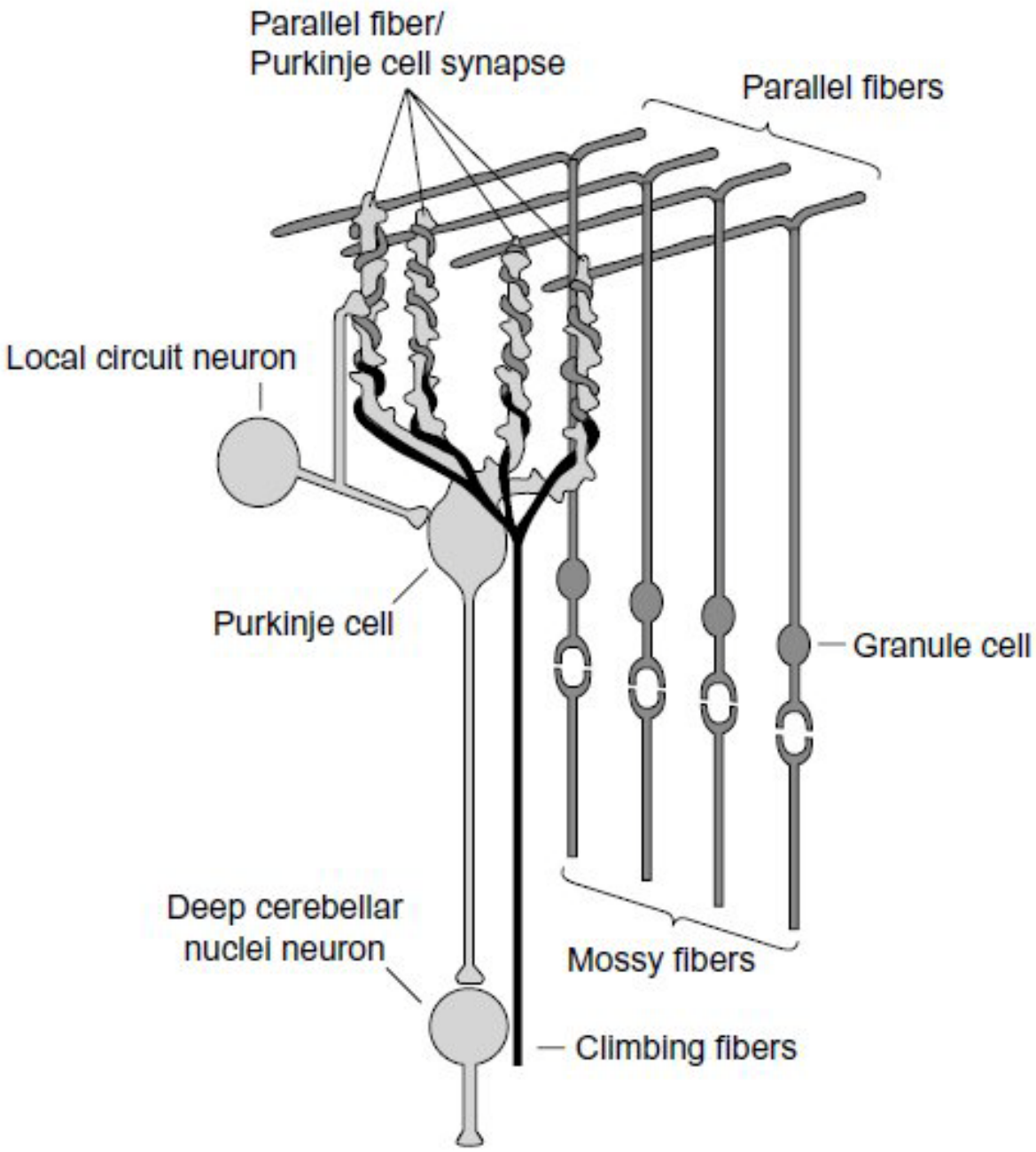


In Vivo Images of Neural Dendrites Showing Spine and Synapse Formation

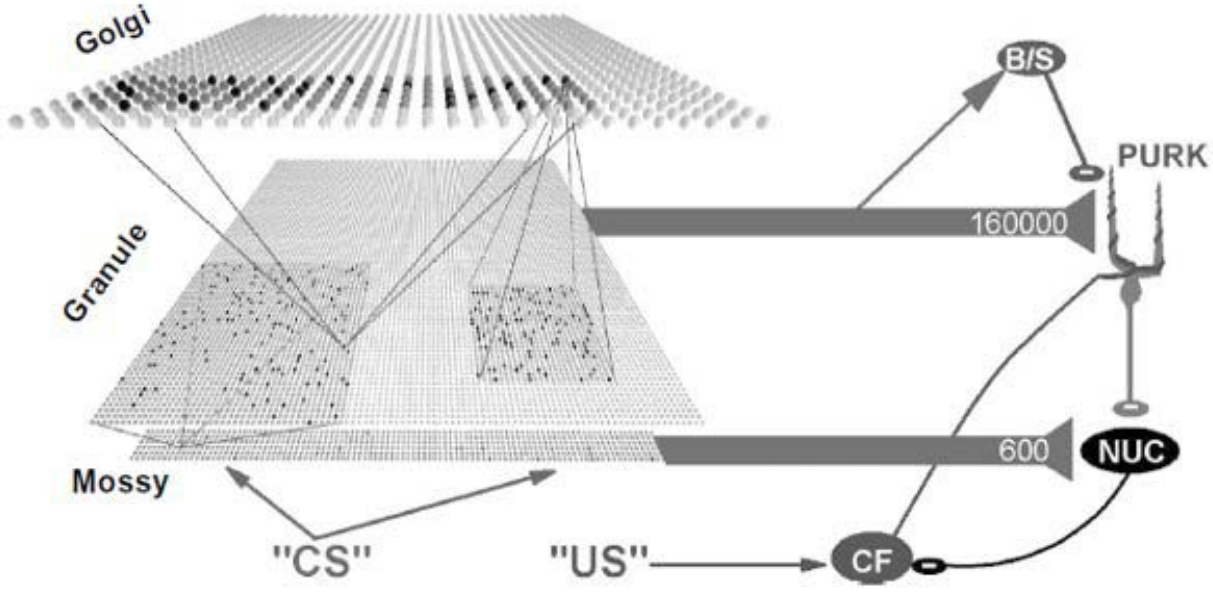




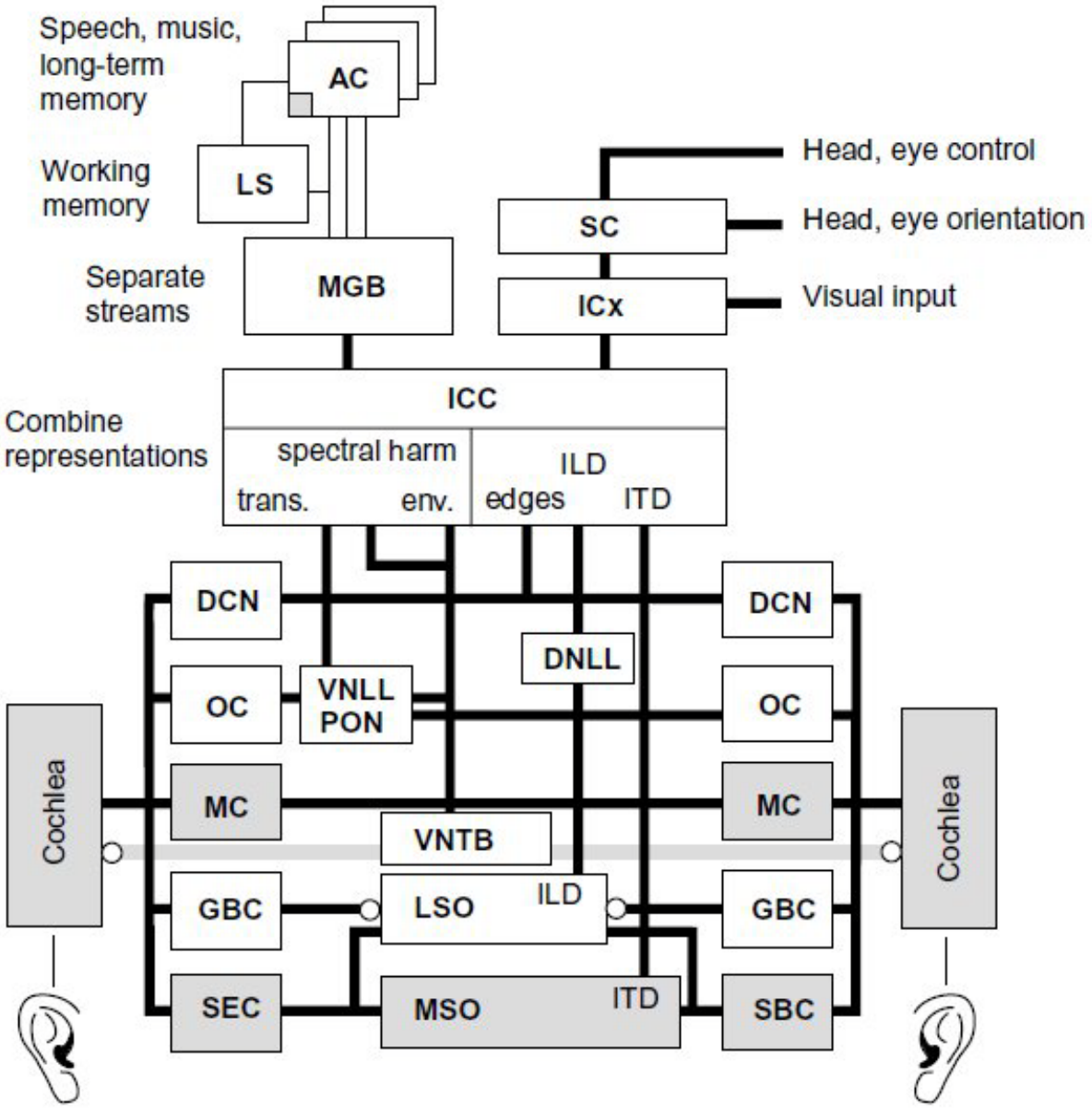
Massively Repeated Cerebellum Wiring Pattern



University of Texas Cerebellum Model and Simulation

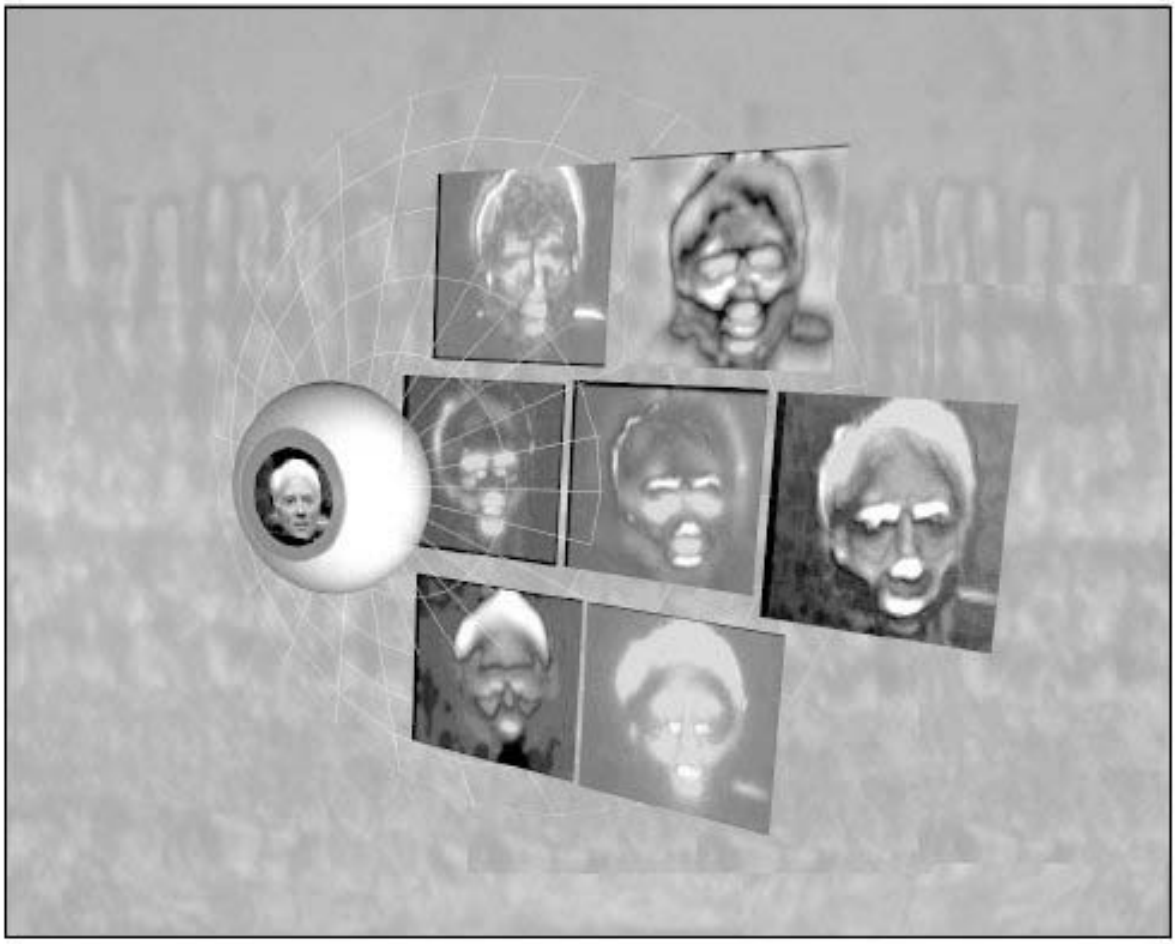


Reverse Engineering the Human Brain: Five Parallel Auditory Pathways

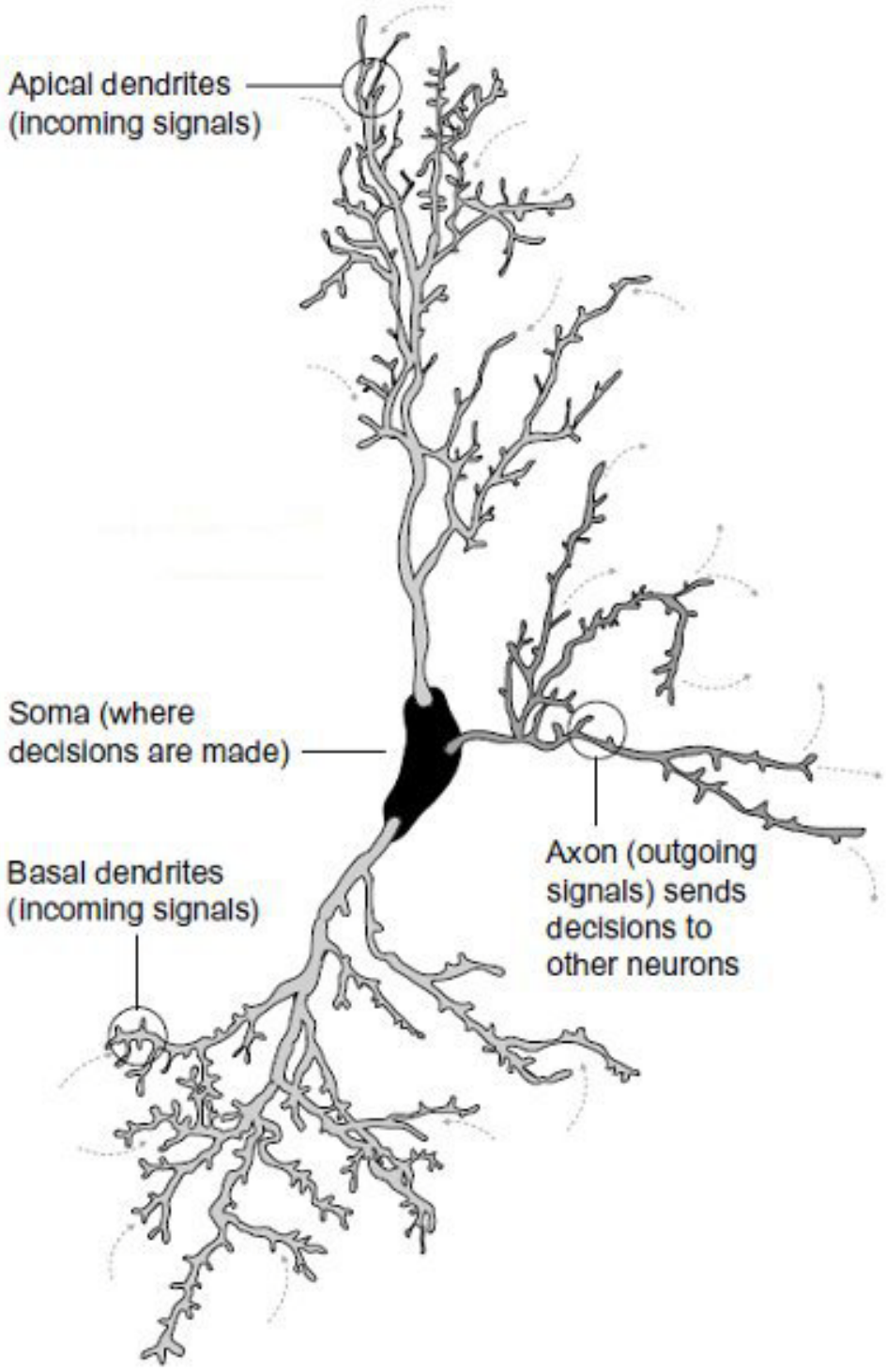


Source: Diagram by Lloyd Watts, adapted from E. Young, "Cochlear Nucleus" in G. Shepherd, ed., *The Synaptic Organization of the Brain*, 4th ed.; D. Oertel in D. Oertel, R. Fay, and A. Popper, eds., *Integrative Functions in the Mammalian Auditory Pathway*; John Casseday, T. Fremouw, and E. Covey, "Inferior Colliculus" in ibid.; J. LeDoux, *The Emotional Brain*; J. Rauschecker and B. Tian, "Mechanisms and Streams for Processing of 'What' and 'Where' in Auditory Cortex," Proceedings of the National Academy of Sciences 97.22: 11800–11806.

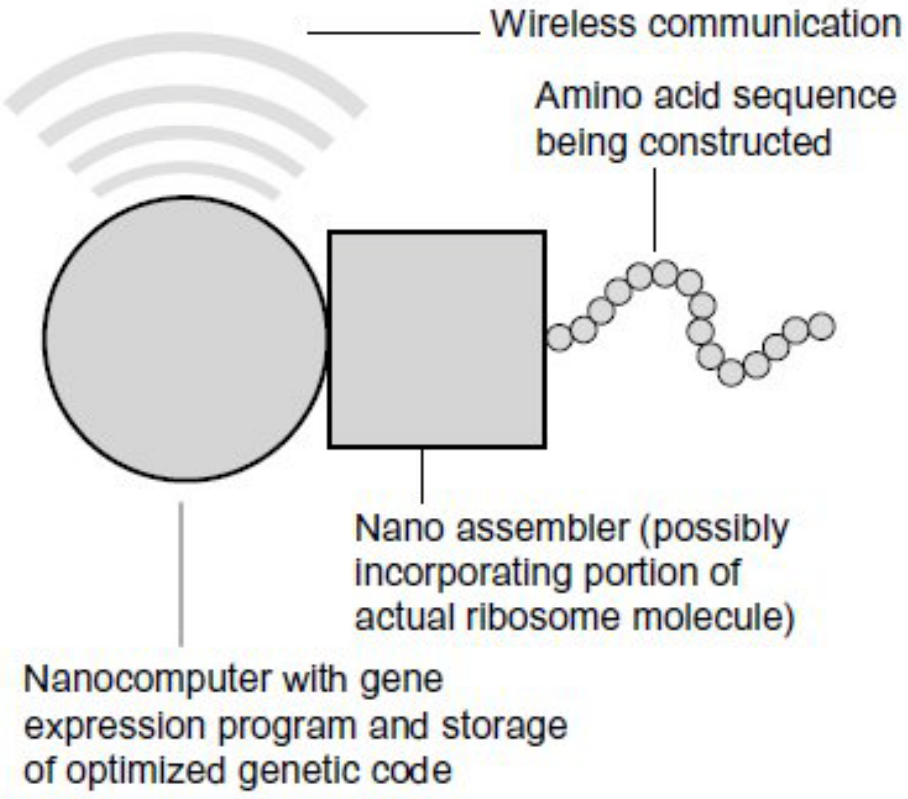
Seven of the dozen separate movies that the eye extracts from a scene and sends to the brain



Spindle Cell

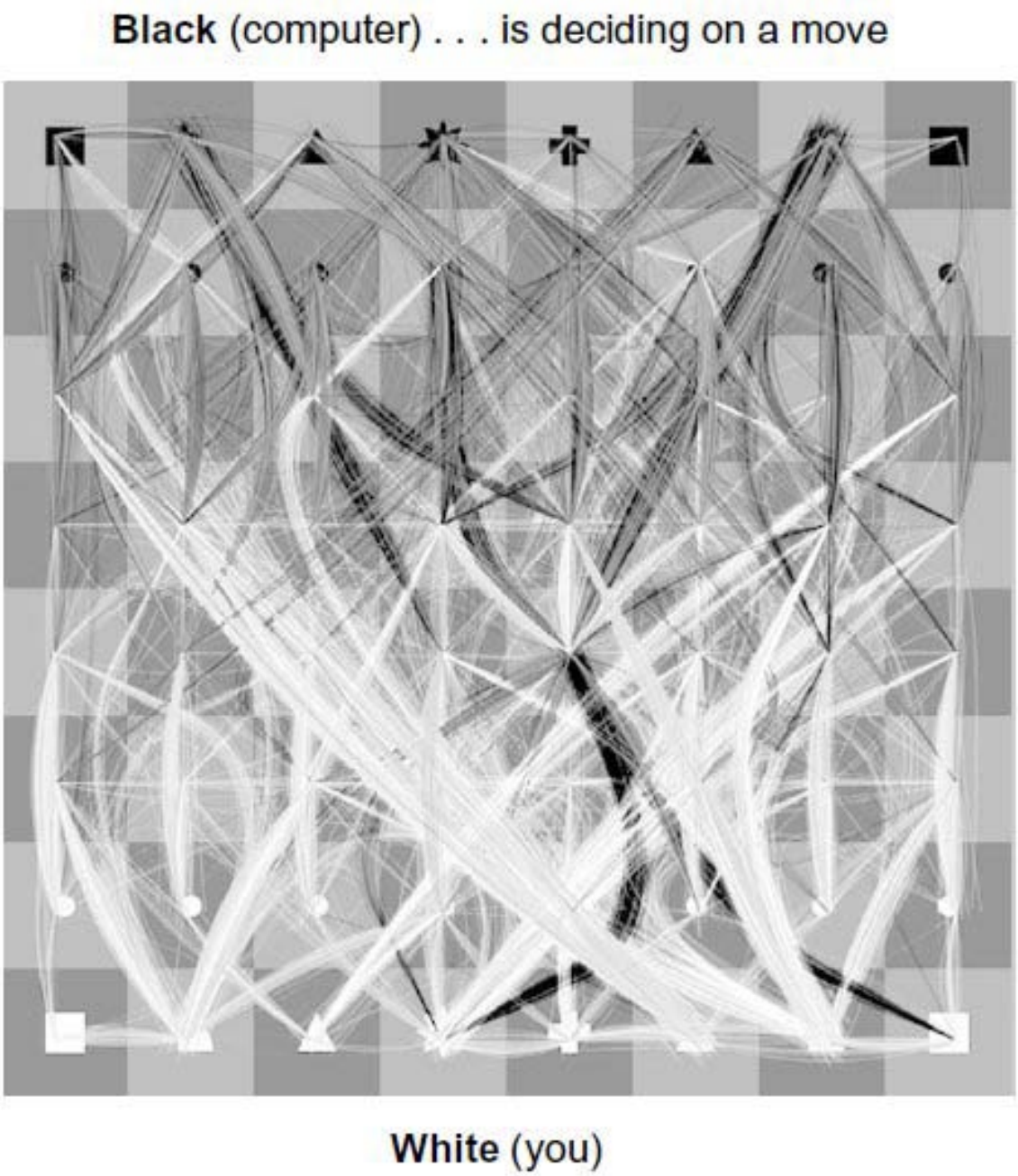


Nanobot-Based Nucleus

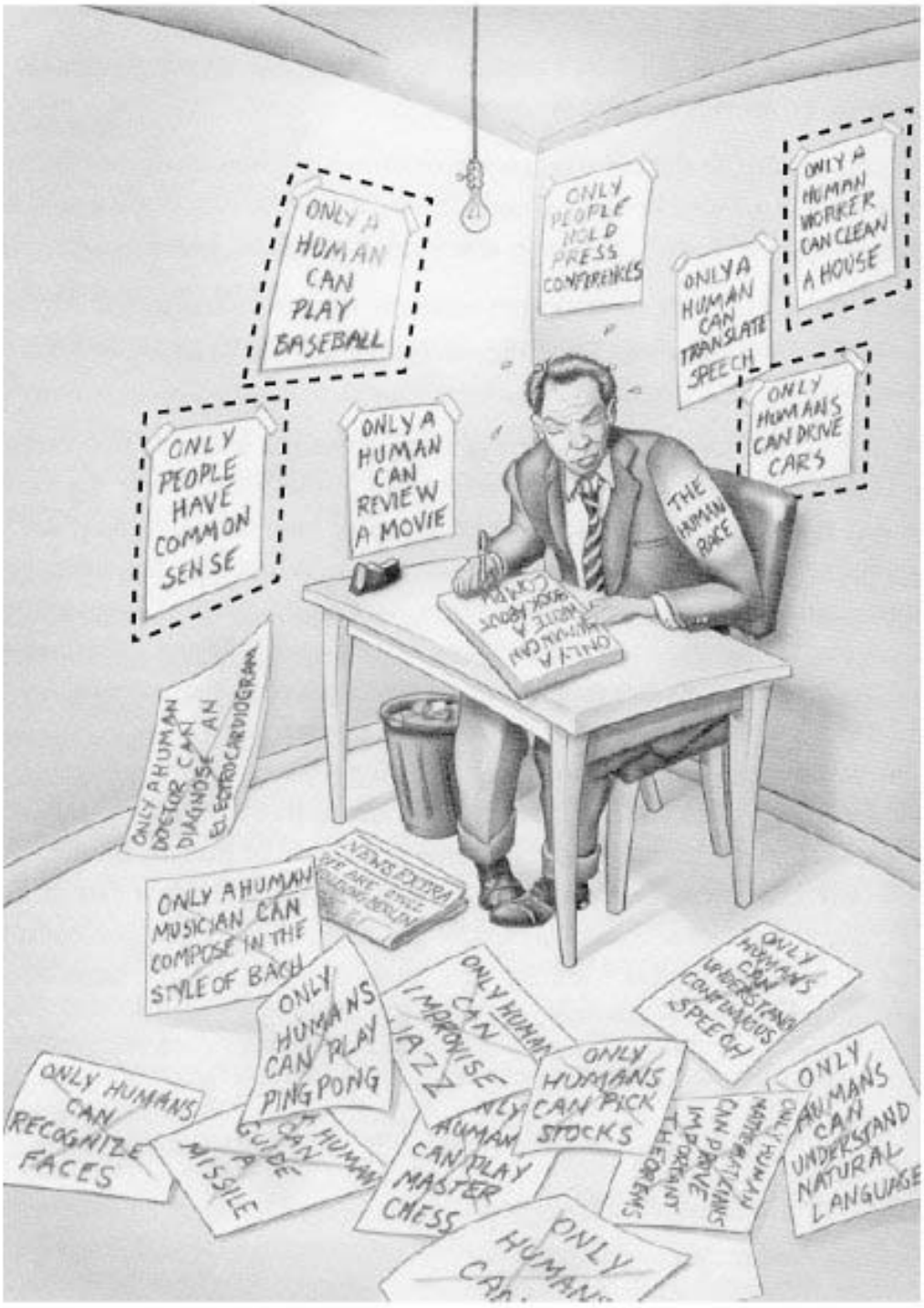


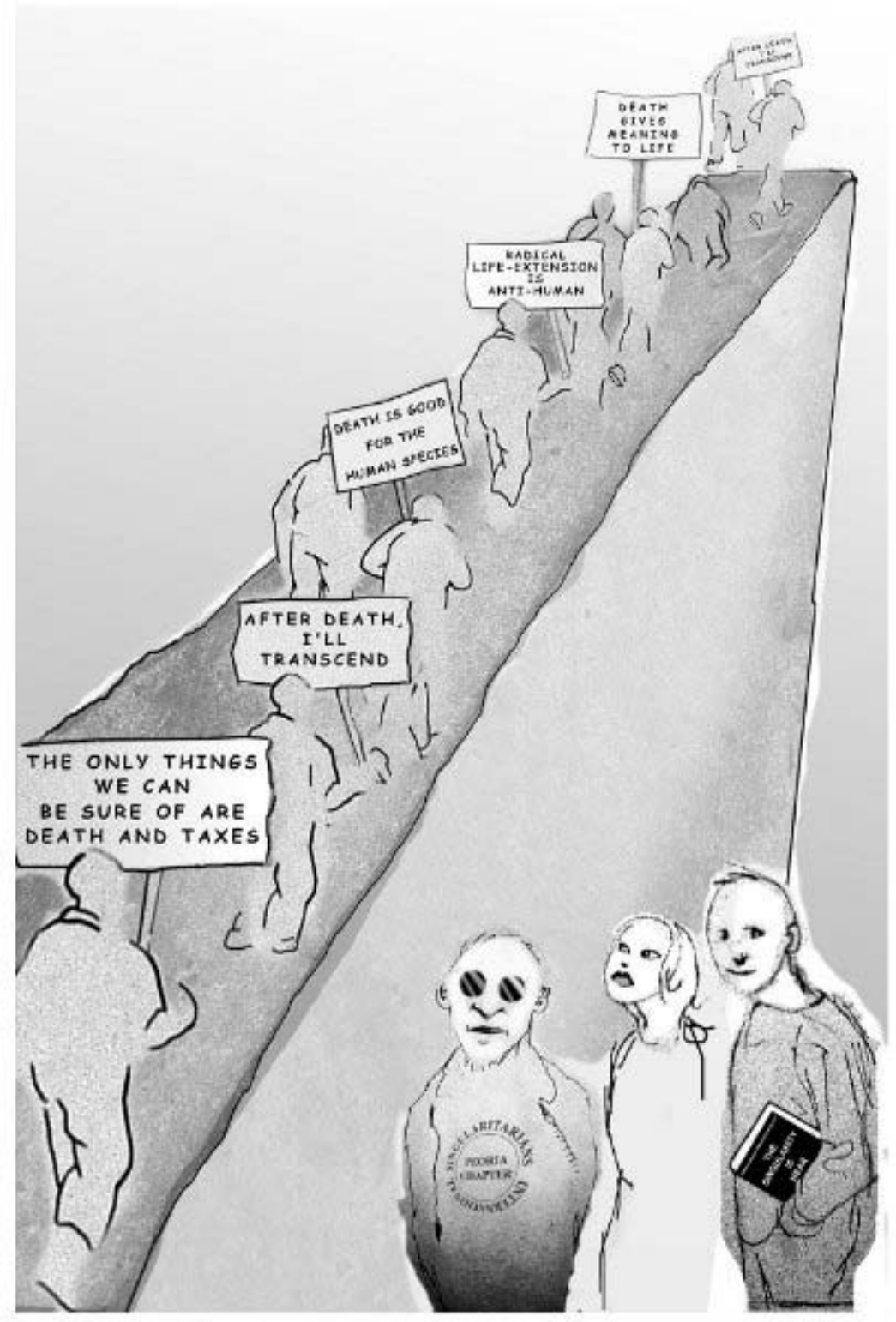
Thinking Machines 2

"Thinking Machines 2" by mathematician Martin Wattenberg with Marek Walczak displays the move-countermove sequences it is evaluating as it considers its next move.

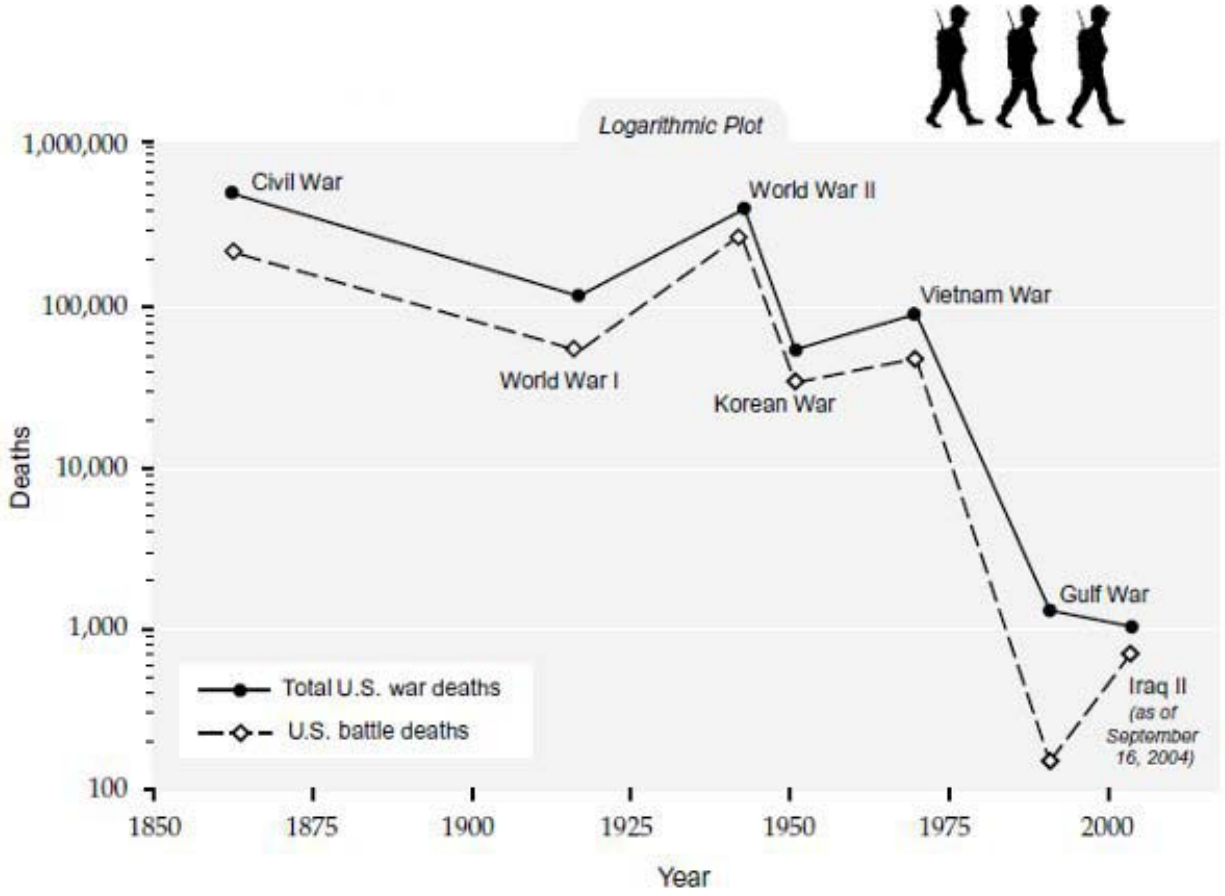


A defensive "human race" is seen writing out signs that state what only people (and not machines) can do. If we were to redesign this cartoon in a few years, some of the signs on the wall behind the man would also be likely to end up on the floor.



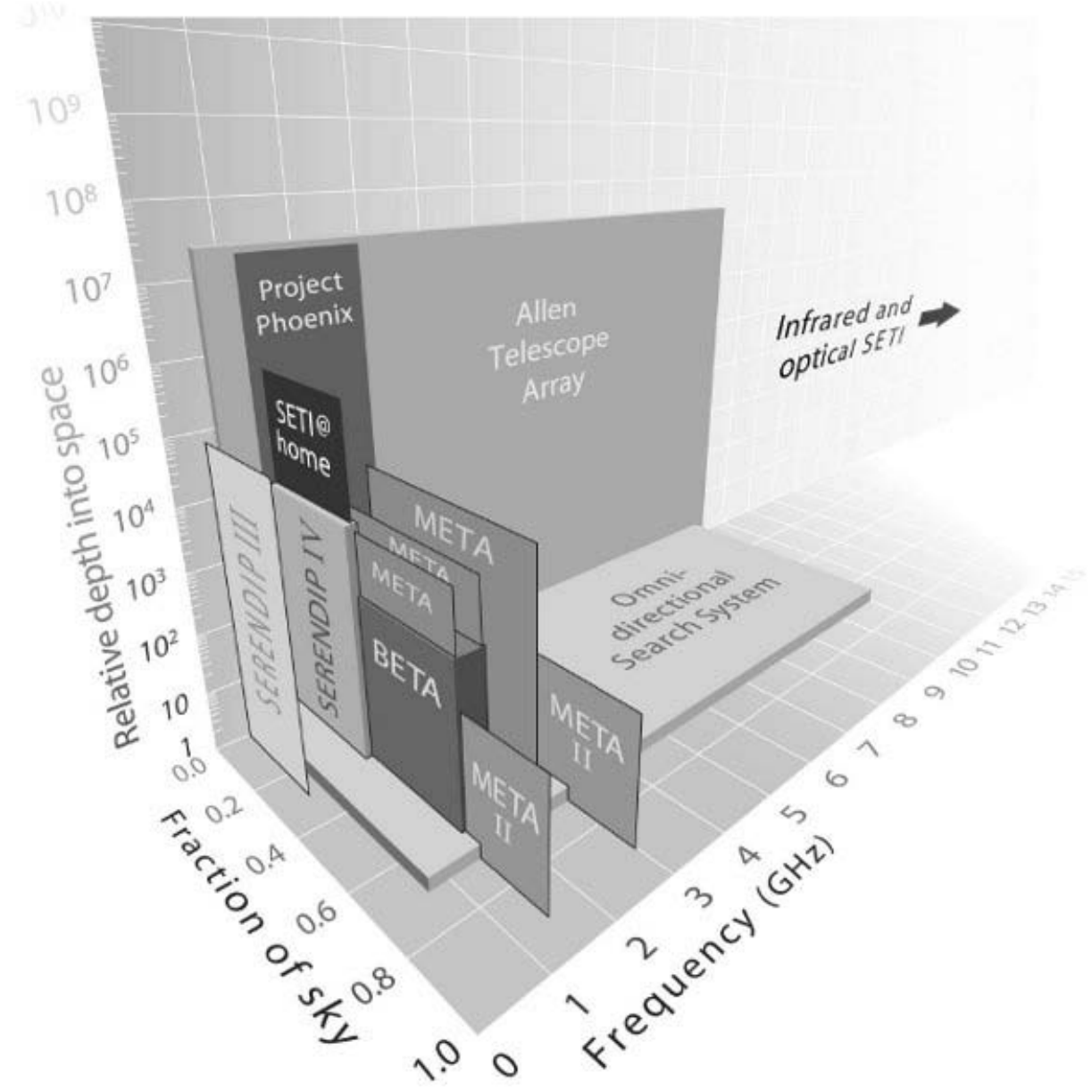

DEATH GIVES MEANING TO LIFE
RADICAL LIFE-EXTENSION IS ANTI-HUMAN
DEATH IS GOOD FOR THE HUMAN SPECIES
AFTER DEATH, I'LL TRANSCEND
THE ONLY THINGS WE CAN BE SURE OF ARE DEATH AND TAXES

U.S. War Deaths



The Allen Telescope Array

SETI's Next Big Step: **The diagram from *Sky & Telescope* plots the capability of the varied scanning efforts for extraterrestrial intelligence against three major parameters: distance from Earth, frequency of transmission, and the fraction of the sky.**



Source: Alan M. MacRobert, "The Allen Telescope Array: SETI's Next Big Step," *Sky & Telescope,* April 2004.

Bostrom's Categorization of Risks

		Intensity of Risk	
		Moderate	**Profound**
	Global	Ozone Thinning	***Existential Risks***
Scope	**Local**	Recession	Genocide
	Personal	Stolen Car	Death
		Endurable	**Terminal**

Source: Nick D. Bostrom, "Existential Risks: Analyzing Human Extinction Scenarios and Related Hazards," May 29, 2001.

Mandelbrot Set