

# The Emergence and Impact of Intelligent Machines

**Ray Kurzweil**

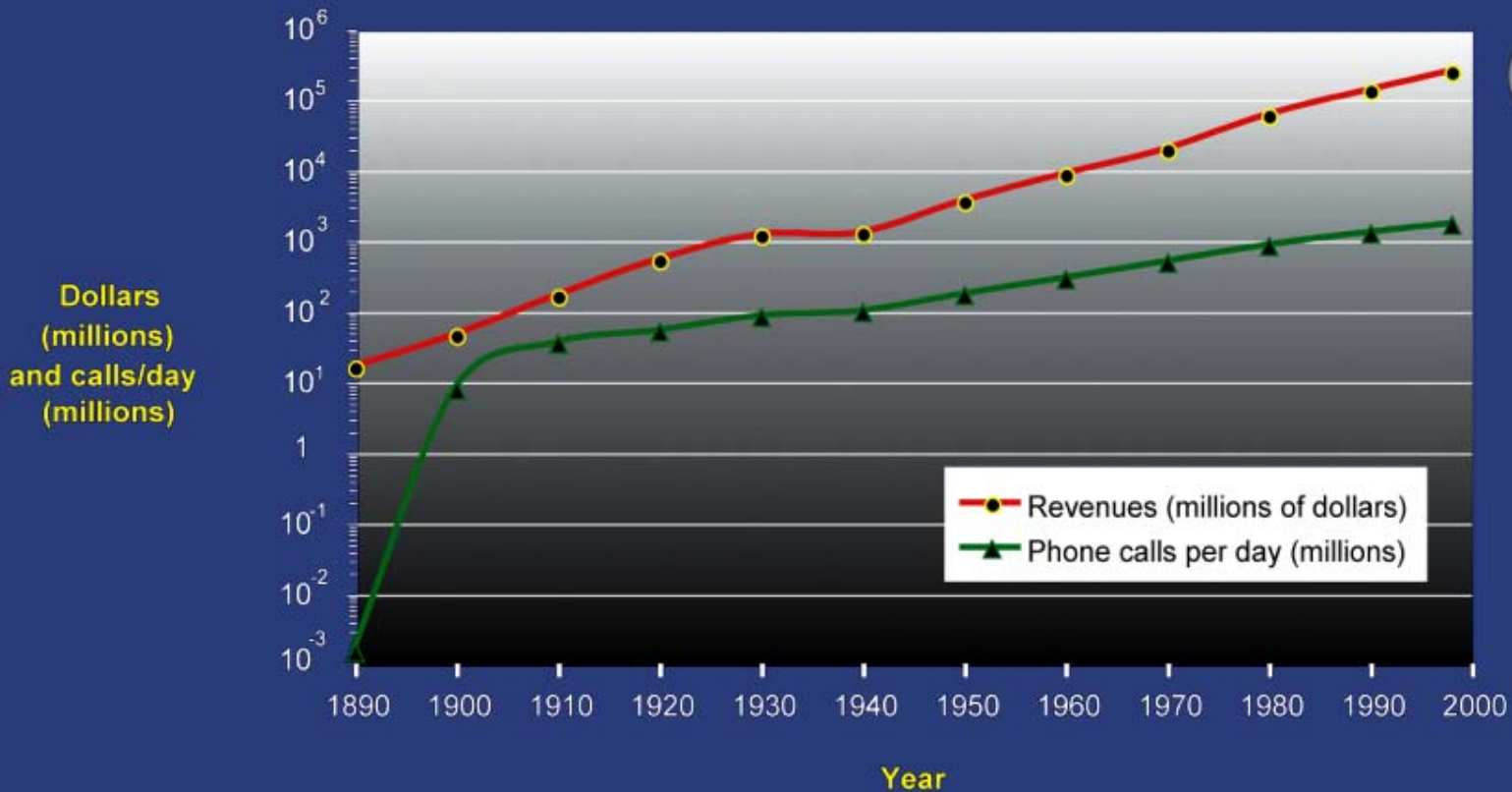
September 23, 2003

Lincoln Lab, MIT

High Performance Embedded Computing Workshop

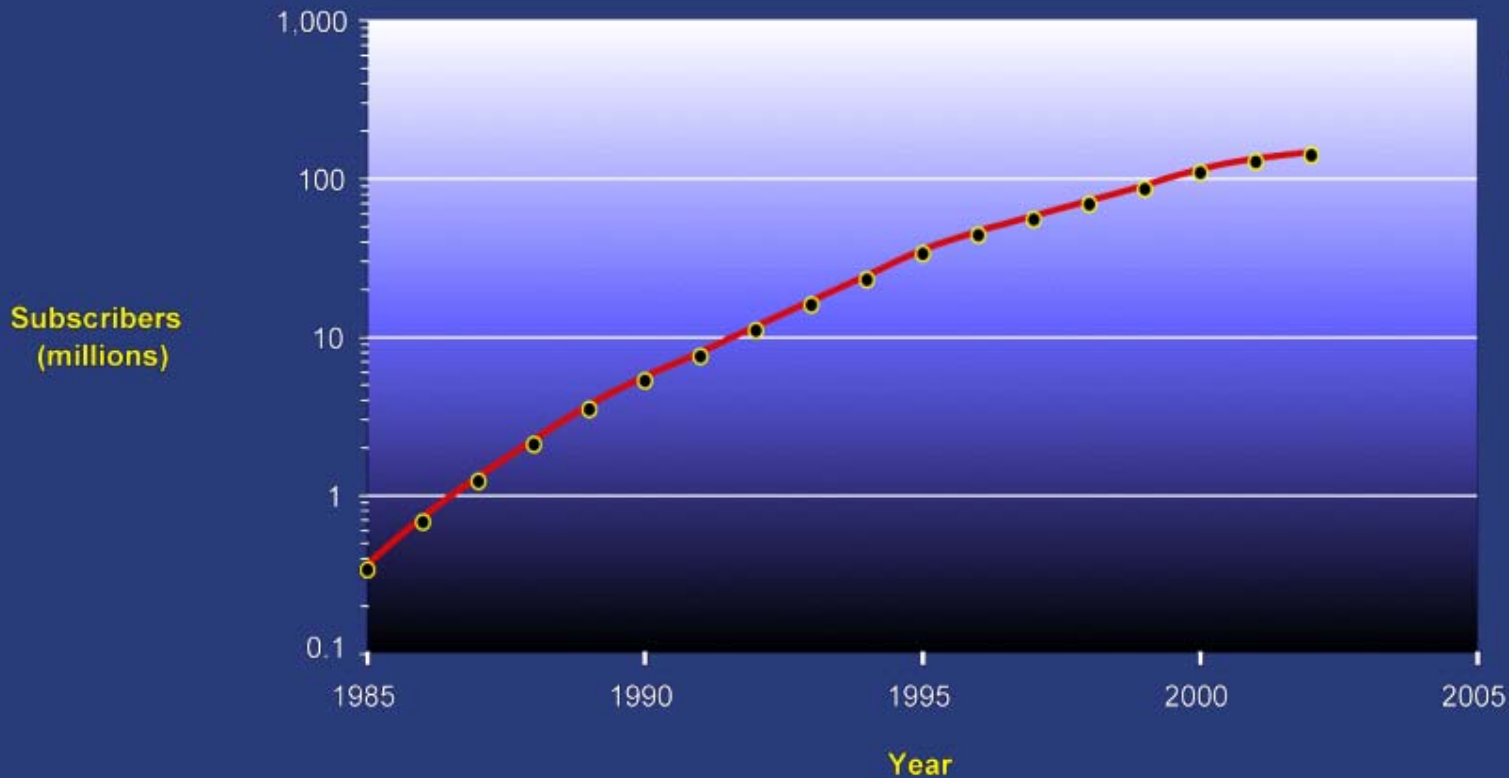
| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                                            | Form Approved<br>OMB No. 0704-0188          |                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------|--------------------------------------------|---------------------------------------------|------------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. |                                    |                                     |                                            |                                             |                                    |
| 1. REPORT DATE<br><b>20 AUG 2004</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    | 2. REPORT TYPE<br><b>N/A</b>        |                                            | 3. DATES COVERED<br><b>-</b>                |                                    |
| 4. TITLE AND SUBTITLE<br><b>The Emergence and Impact of Intelligent Machines</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                    |                                     |                                            | 5a. CONTRACT NUMBER                         |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5b. GRANT NUMBER                            |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5c. PROGRAM ELEMENT NUMBER                  |                                    |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                            | 5d. PROJECT NUMBER                          |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5e. TASK NUMBER                             |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 5f. WORK UNIT NUMBER                        |                                    |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Lincoln Lab, MIT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    |                                     |                                            | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER |                                    |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                            | 10. SPONSOR/MONITOR'S ACRONYM(S)            |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                            | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)   |                                    |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release, distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                            |                                             |                                    |
| 13. SUPPLEMENTARY NOTES<br><b>See also ADM001694, HPEC-6-Vol 1 ESC-TR-2003-081; High Performance Embedded Computing (HPEC) Workshop (7th)., The original document contains color images.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                            |                                             |                                    |
| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                            |                                             |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                            |                                             |                                    |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF<br>ABSTRACT<br><b>UU</b> | 18. NUMBER<br>OF PAGES<br><b>70</b>         | 19a. NAME OF<br>RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                            |                                             |                                    |

## Growth of U.S. Phone Industry



Source: AT&T Labs

## Estimated U.S. Cell Phone Subscribers

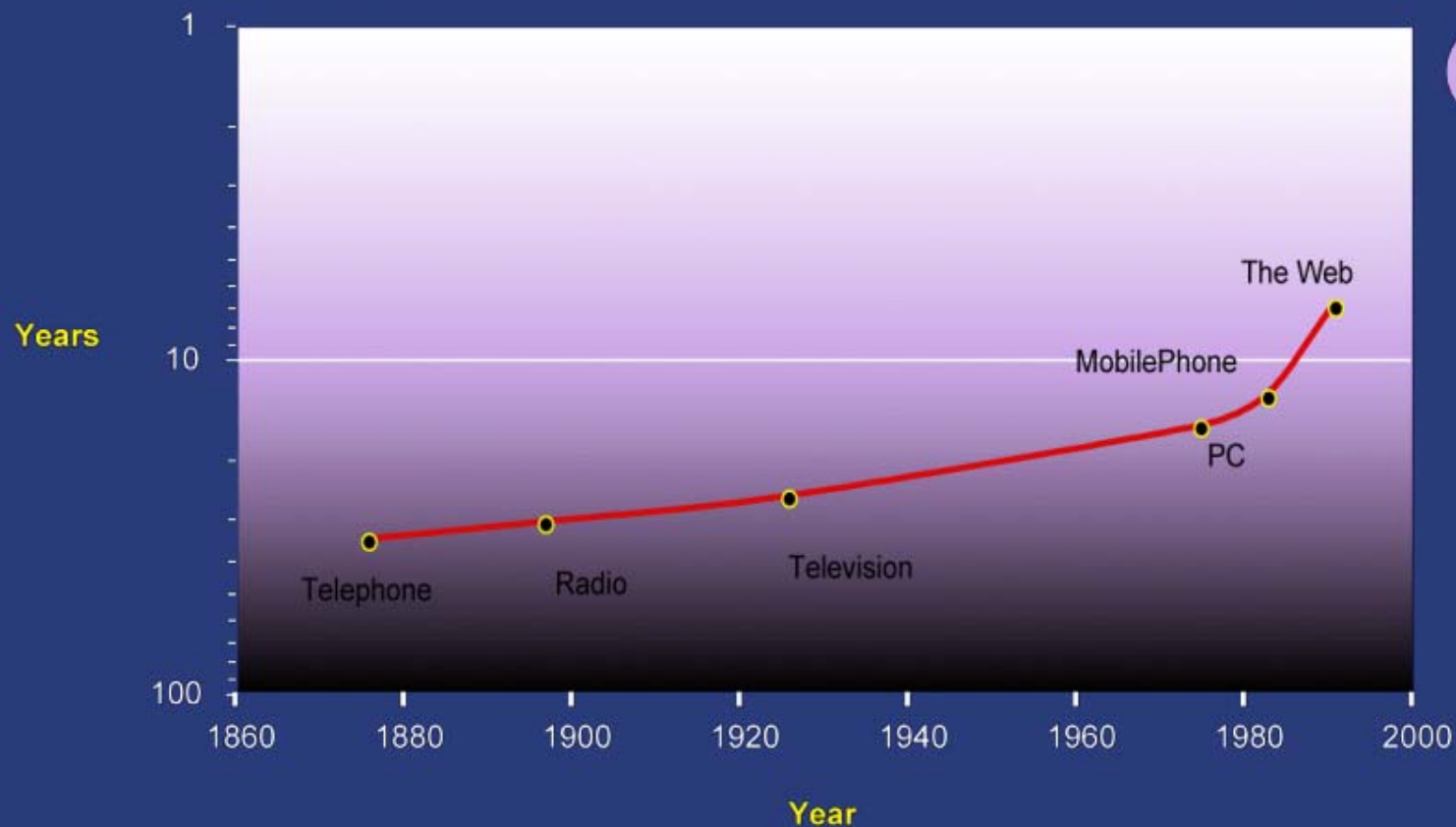


Source: Cellular Telecommunications & Internet Association

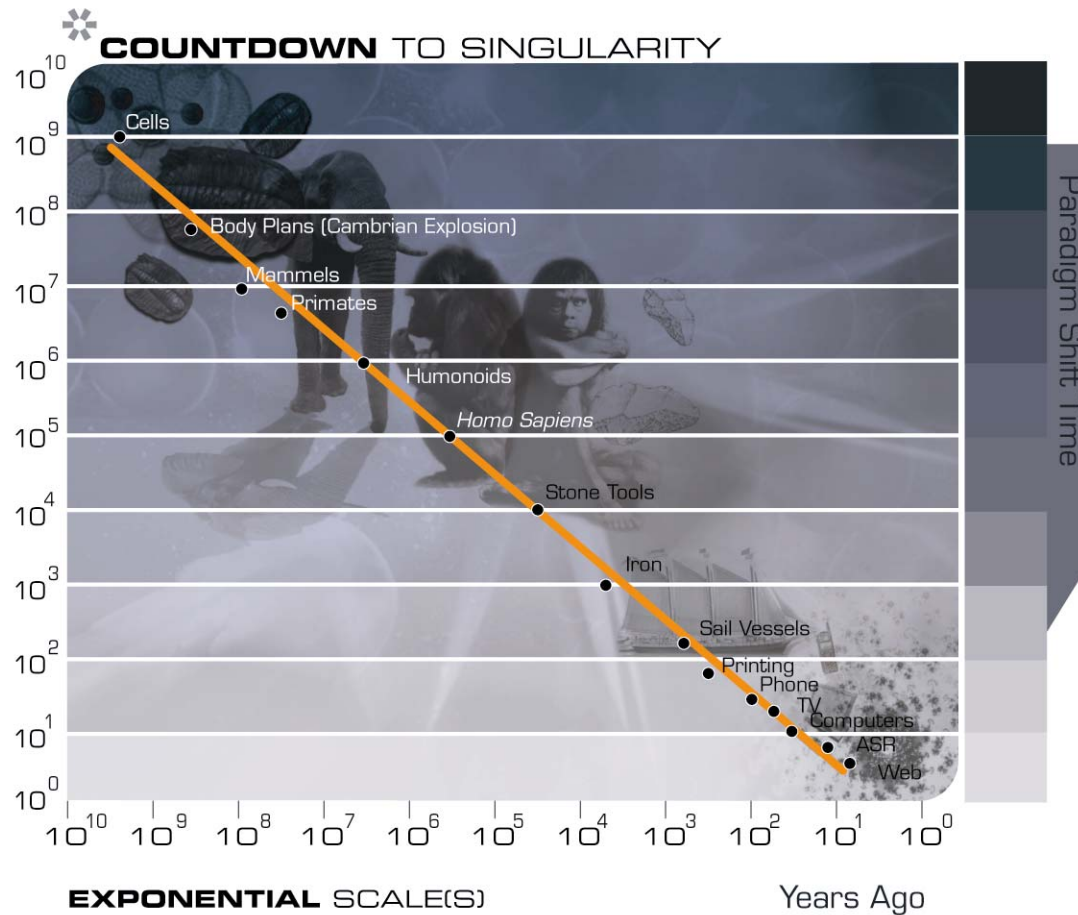


## Mass Use of Inventions

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



Source: The Millennium Notebook, Newsweek

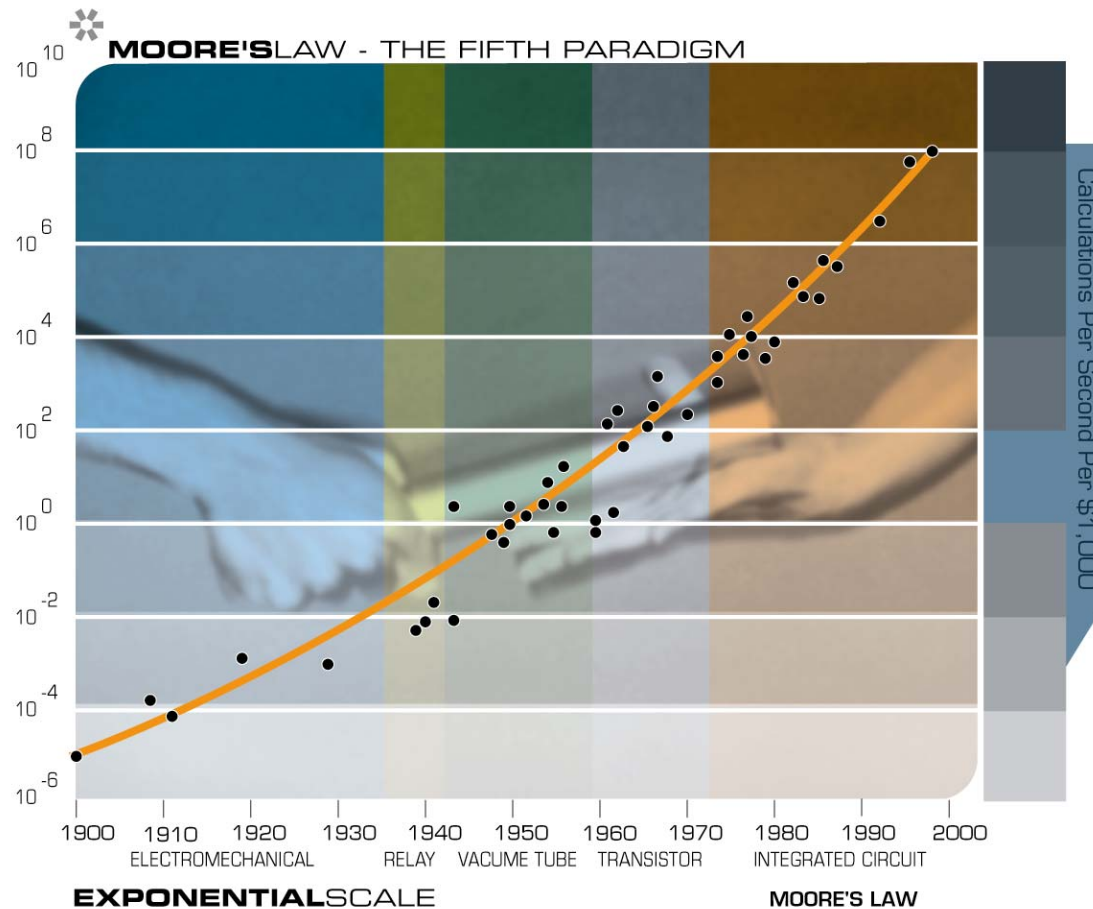


---

| Measure                    | IBM 7094    | Notebook Circa 2003 |
|----------------------------|-------------|---------------------|
| Year                       | 1967        | 2003                |
| Processor Speed (MIPS)     | 0.25        | 1,000               |
| Main Memory (K Bytes)      | 144         | 256,000             |
| Approximate Cost (2003 \$) | \$2,000,000 | \$2,000             |

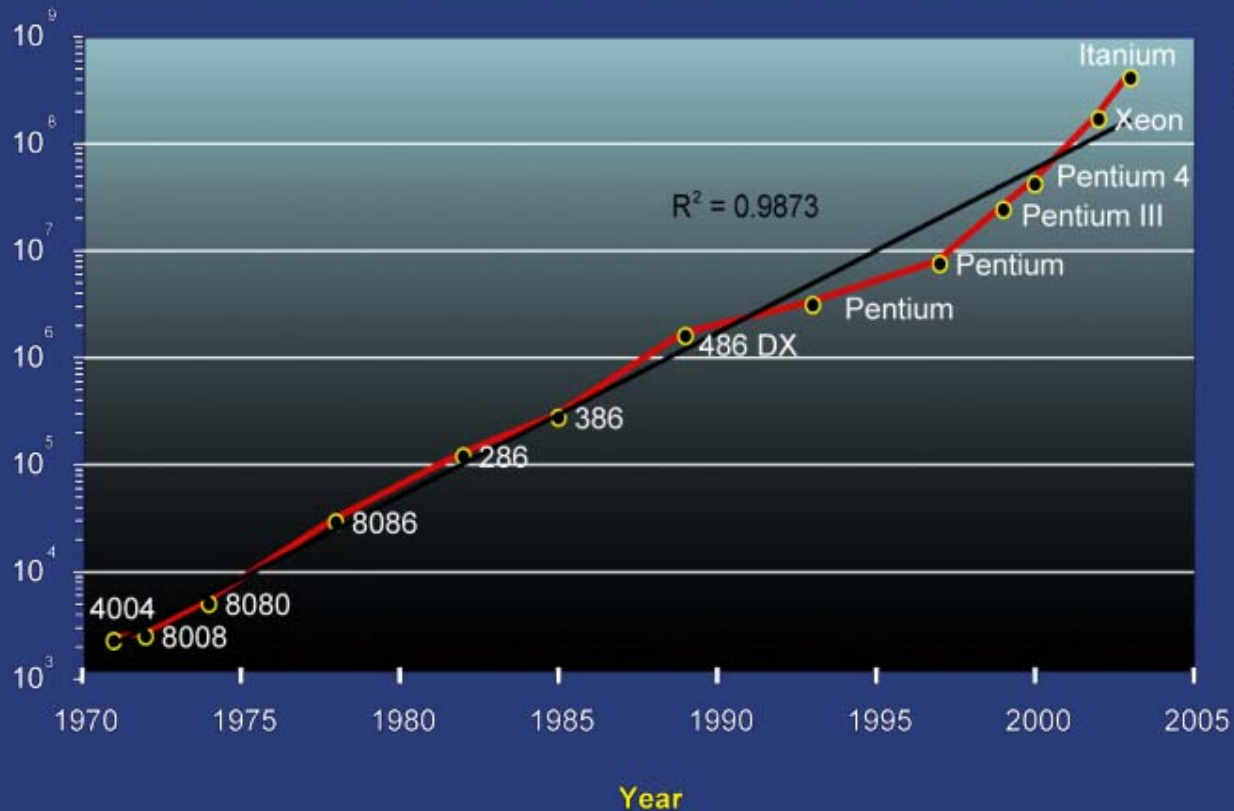
---

22 Doublings of Price-Performance in 36 years, doubling time: 19 months  
not including vastly greater RAM memory, disk storage, instruction set, etc.



## Transistors (Intel processors)

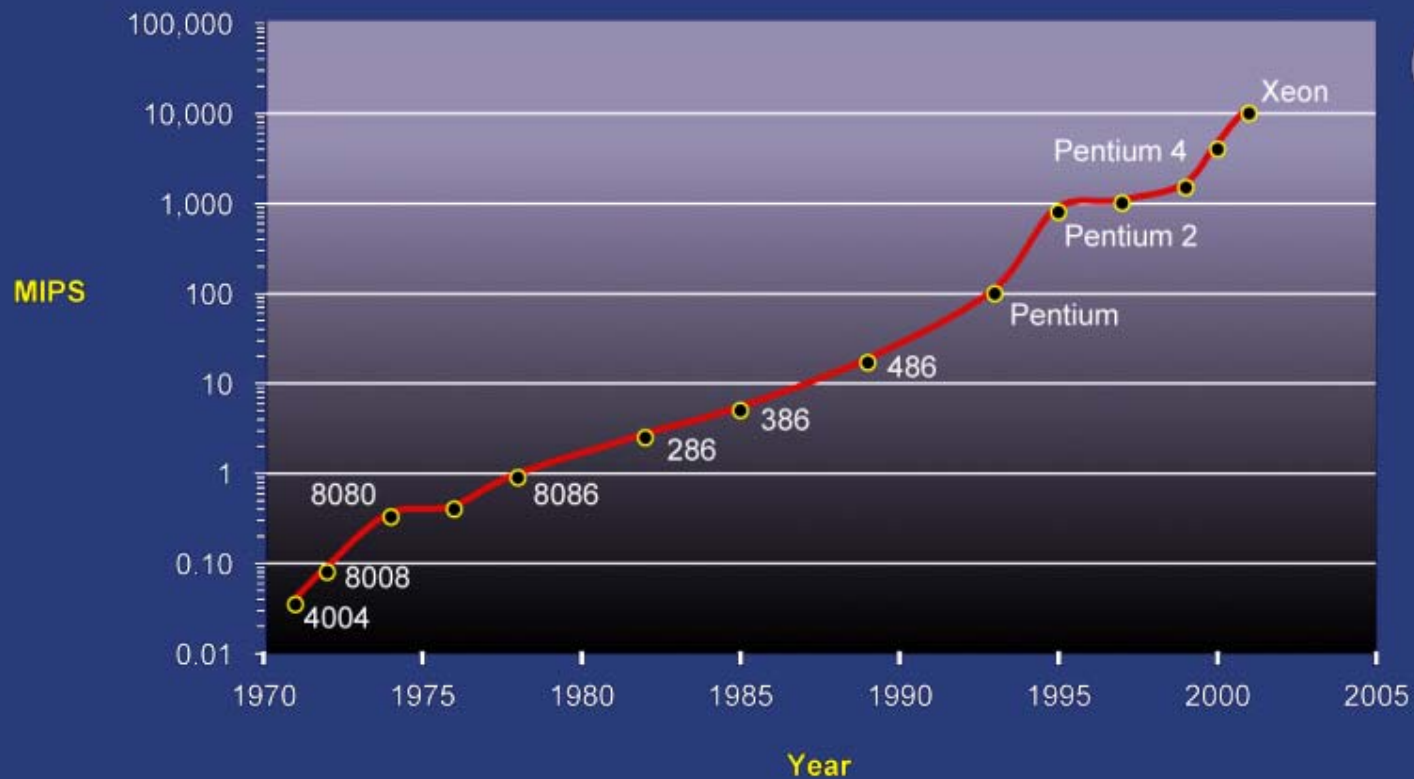
Transistors  
per chip



Source: Intel Research

Doubling time: 2 years

## Processor Performance (MIPS)

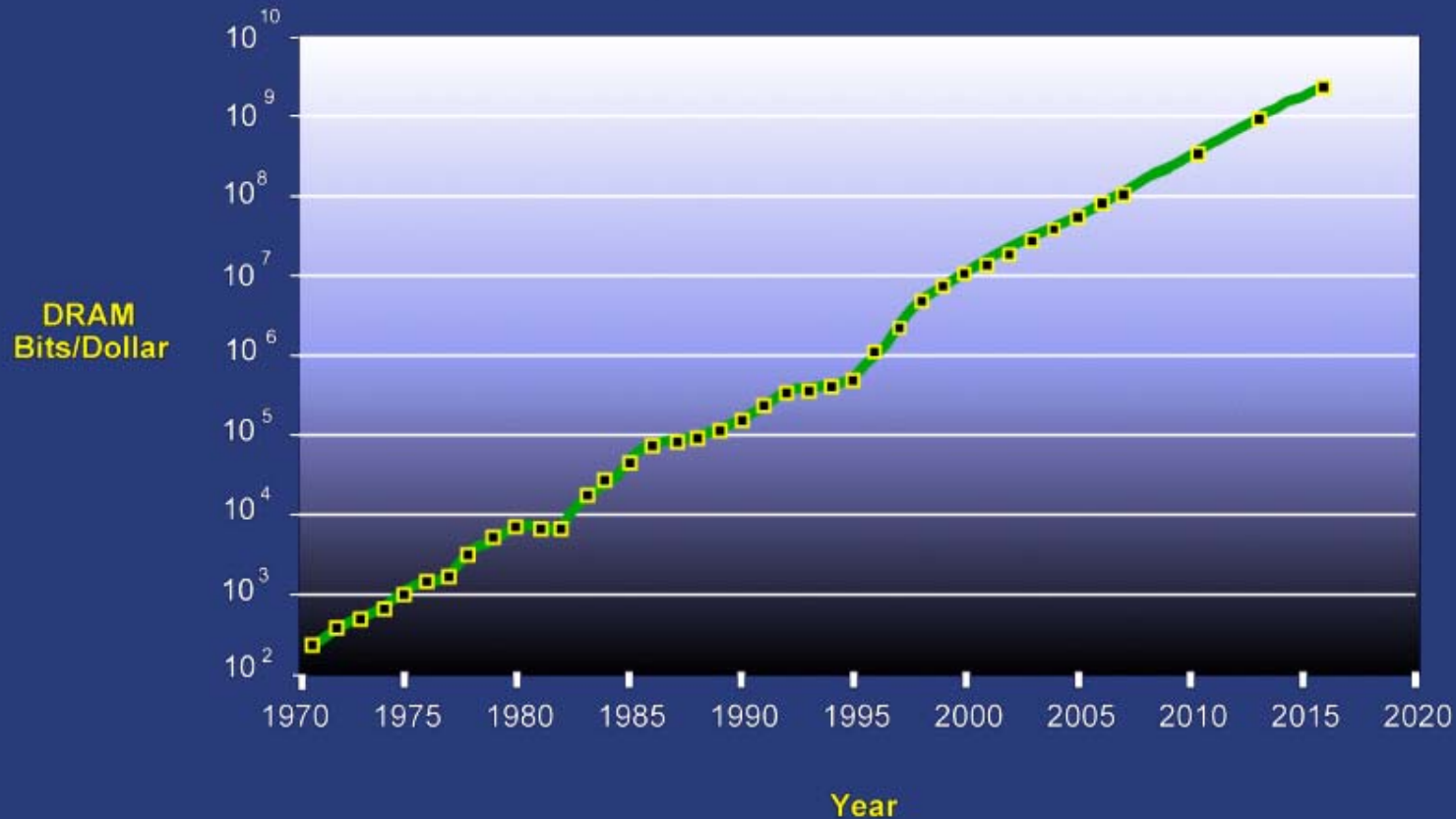


Source: Intel

Doubling time: 1.8 years

## Dynamic RAM Memory

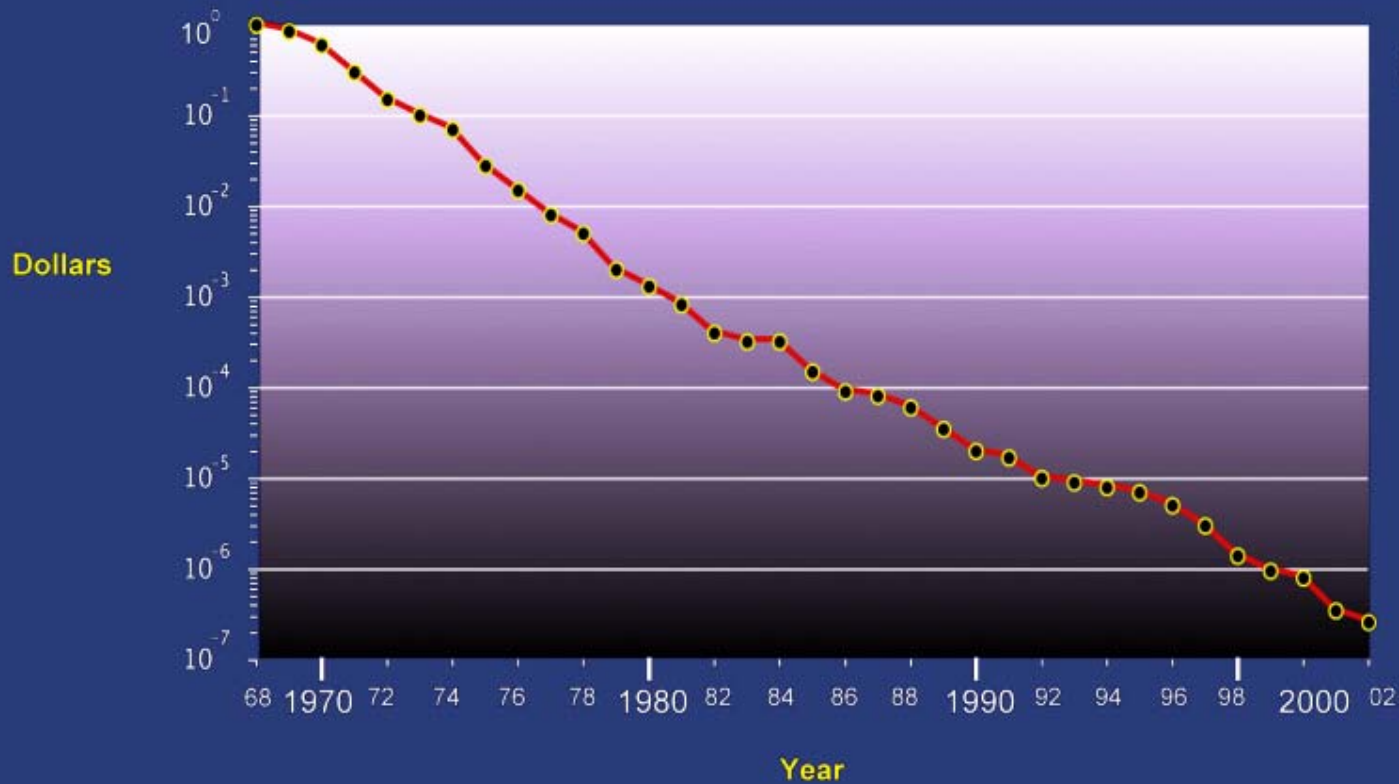
Bits per Dollar at Production



Source: SEMATECH ITRS Roadmap

Doubling time: 1.5 years

## Average Transistor Price

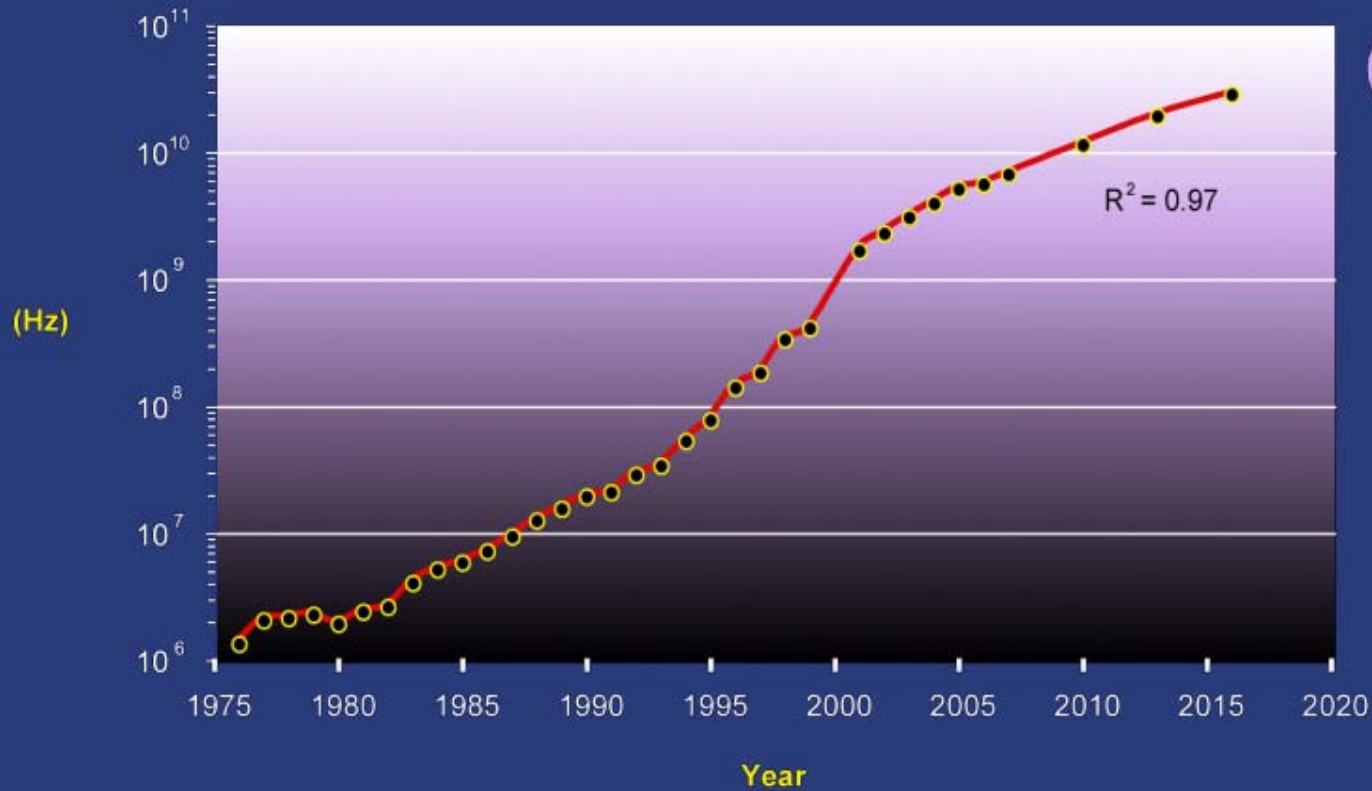


Source: Dataquest/Intel

Halving time: 1.6 years



## Microprocessor Clock Speed



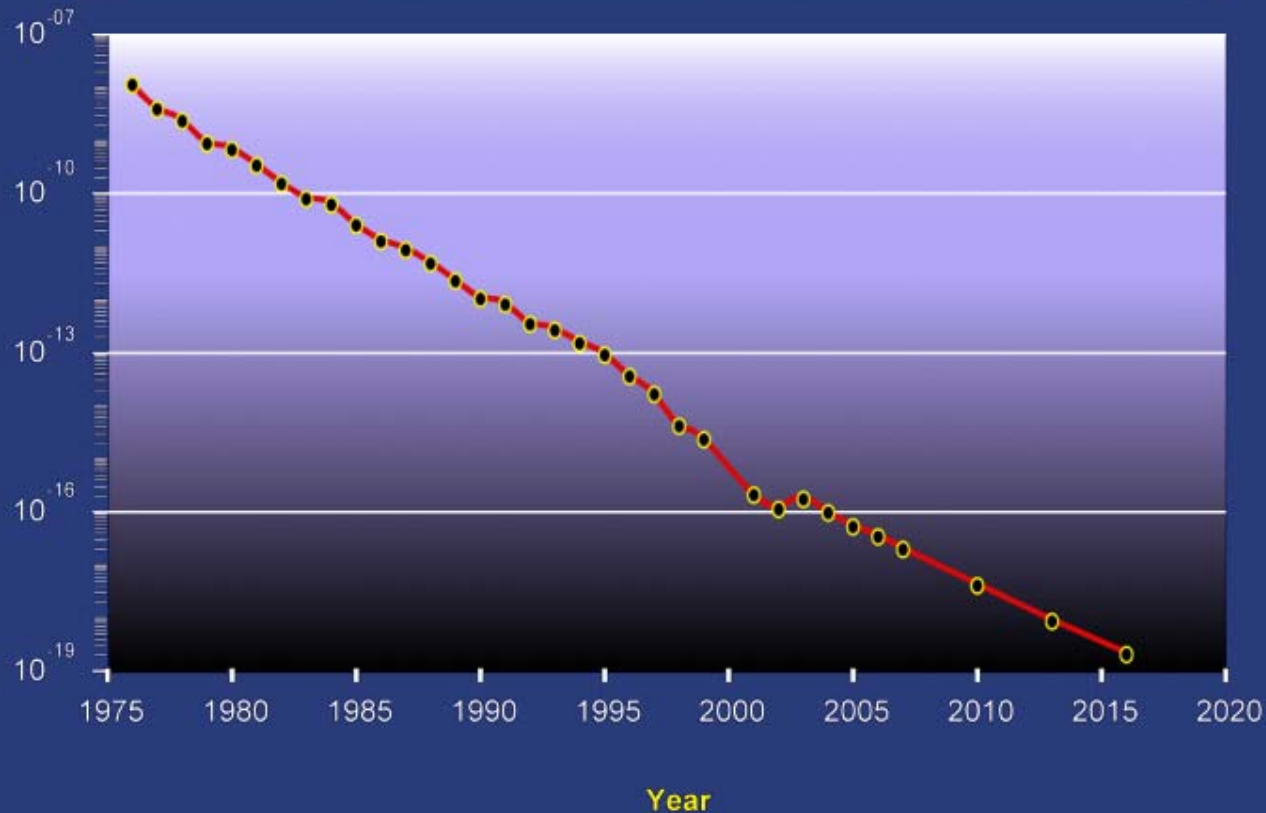
Sources: Berndt et al., ITRS

Doubling time: 2.7 years

## Microprocessor Cost Per Transistor Cycle

*Logarithmic Plot*

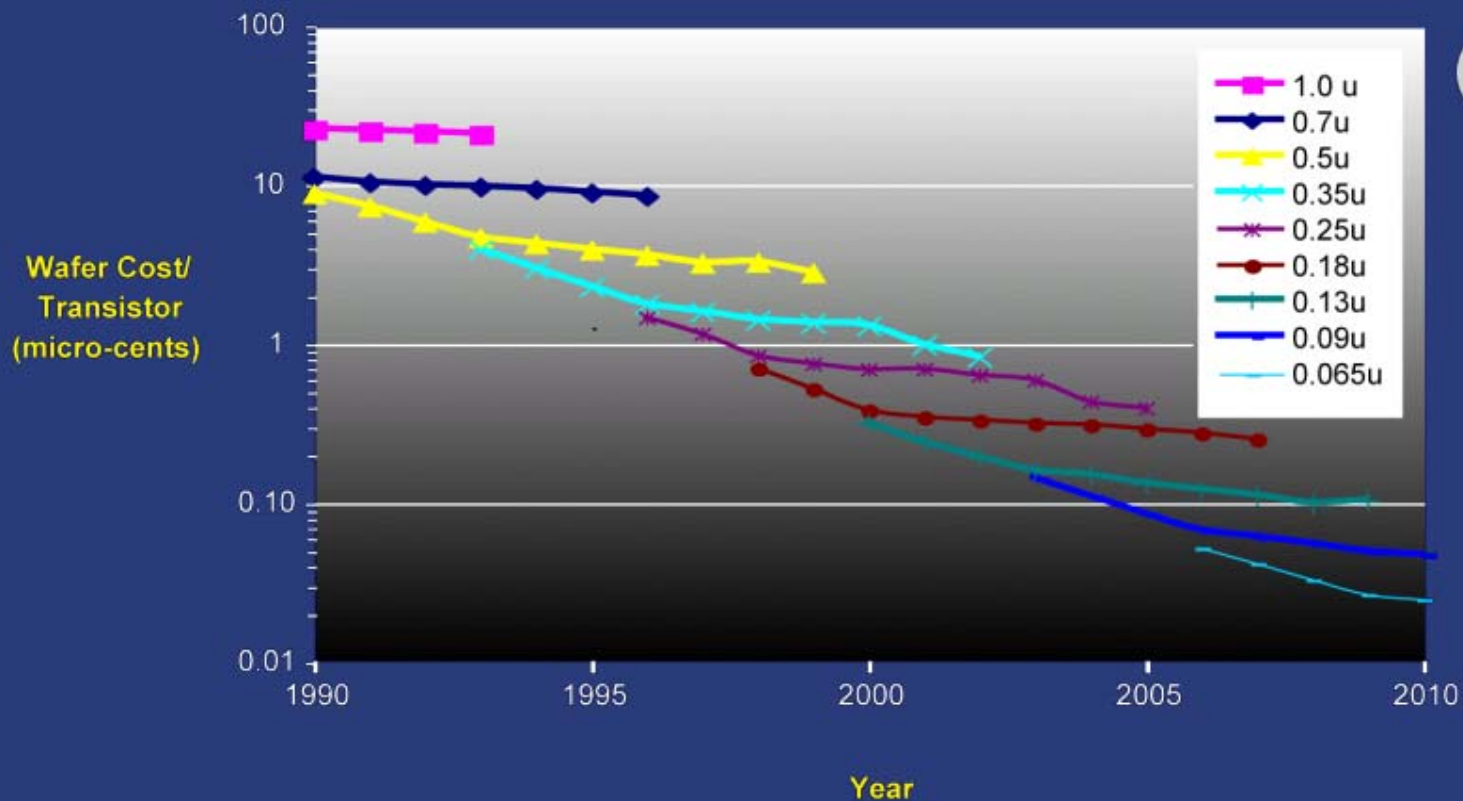
$\$/\text{Transistor}/\text{Hz}$



Sources: Berndt et al., SEMATECH ITRS Roadmap

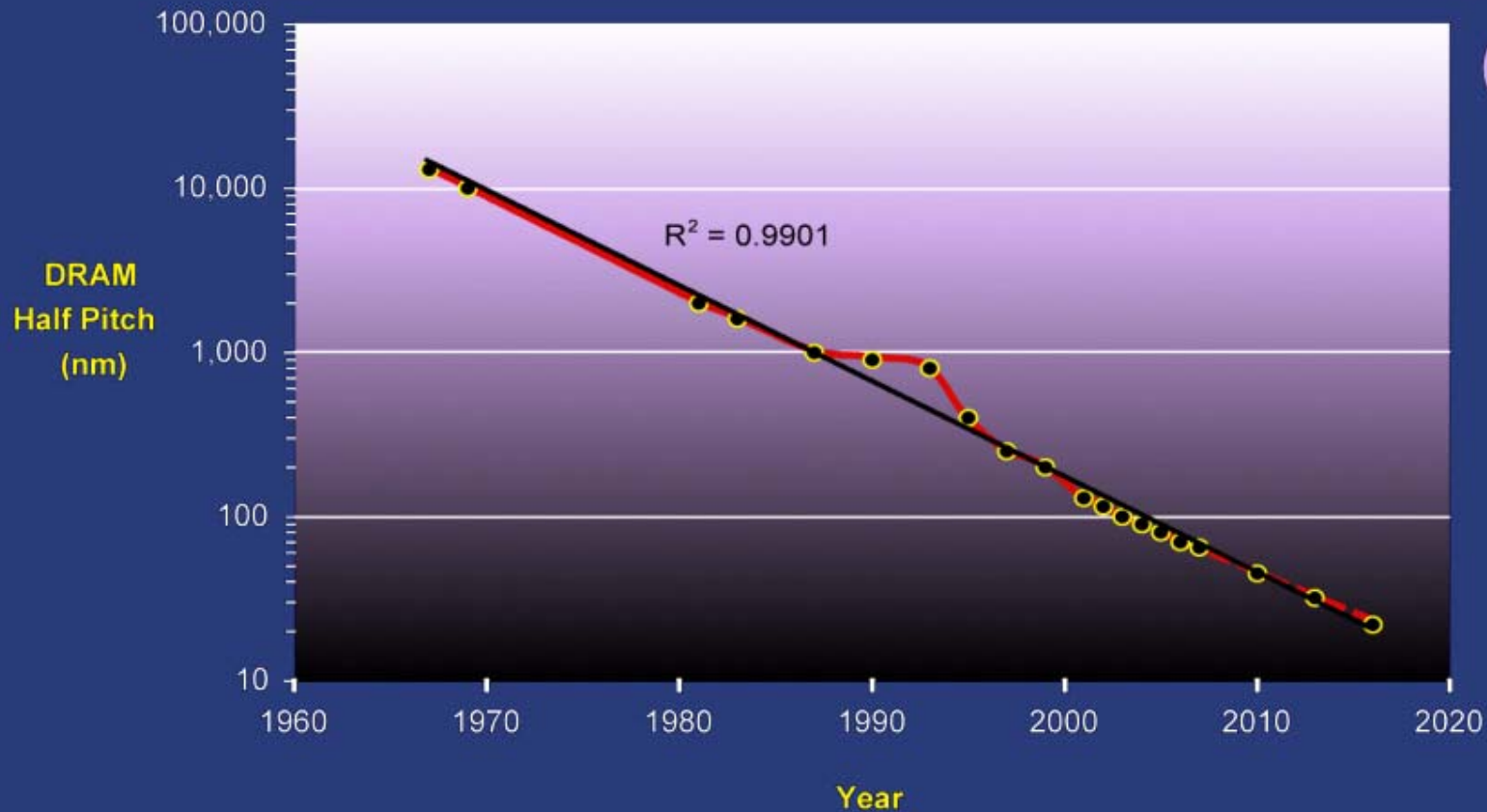
Halving time: 1.1 years

## Transistor Manufacturing Costs Falling



Source: SEMATECH ITRS Roadmap

## Dynamic RAM Memory "Half Pitch" Feature Size



Source: Intel, SEMATECH ITRS Roadmap

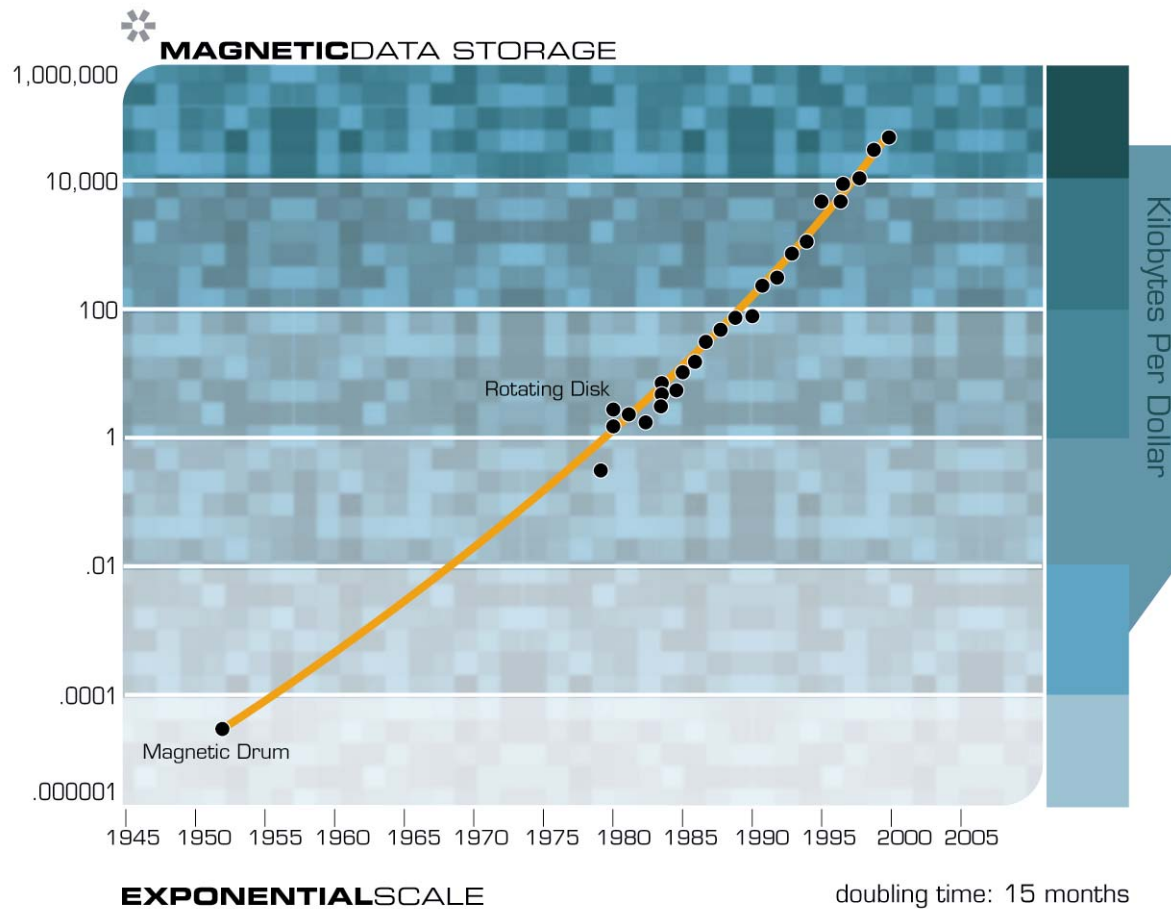
Halving time: 5.4 years

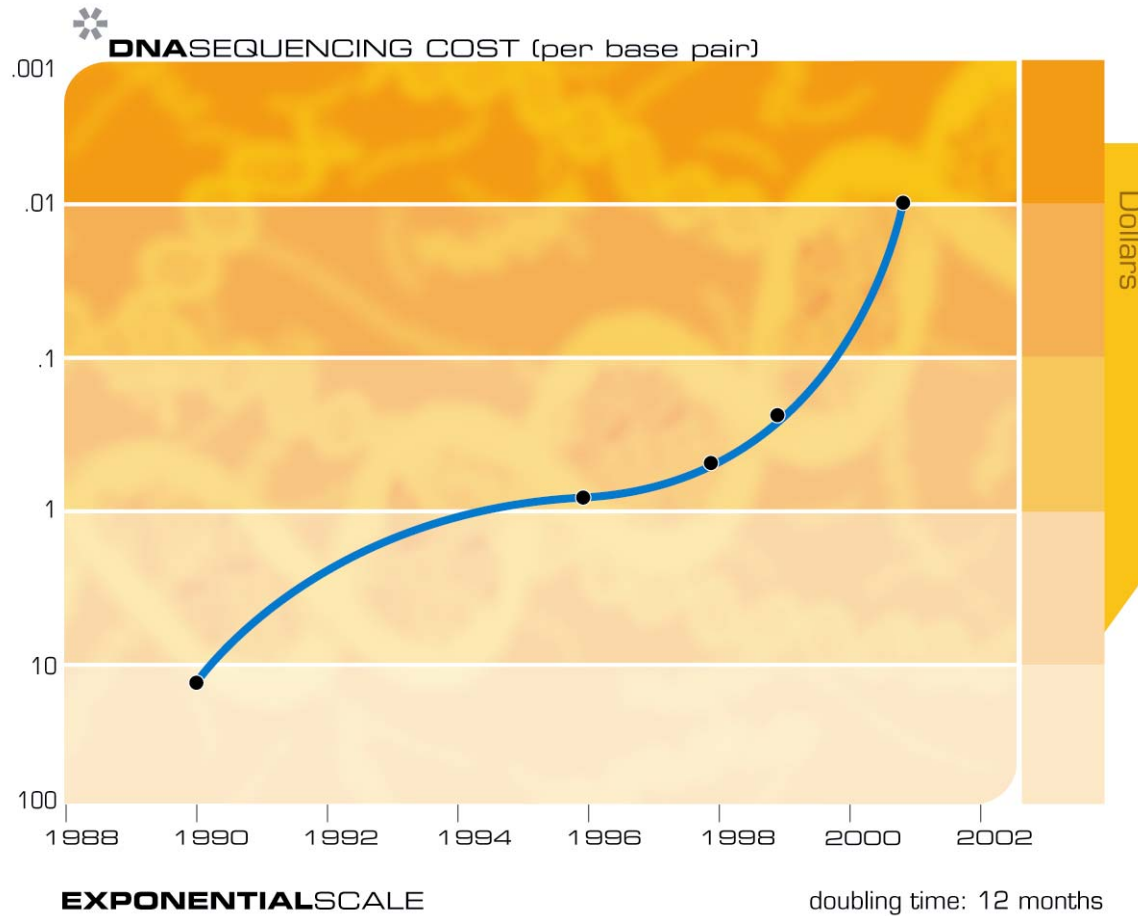
## Total Bits Shipped



Source: In-Stat/MDR

Doubling time: 1.1 years

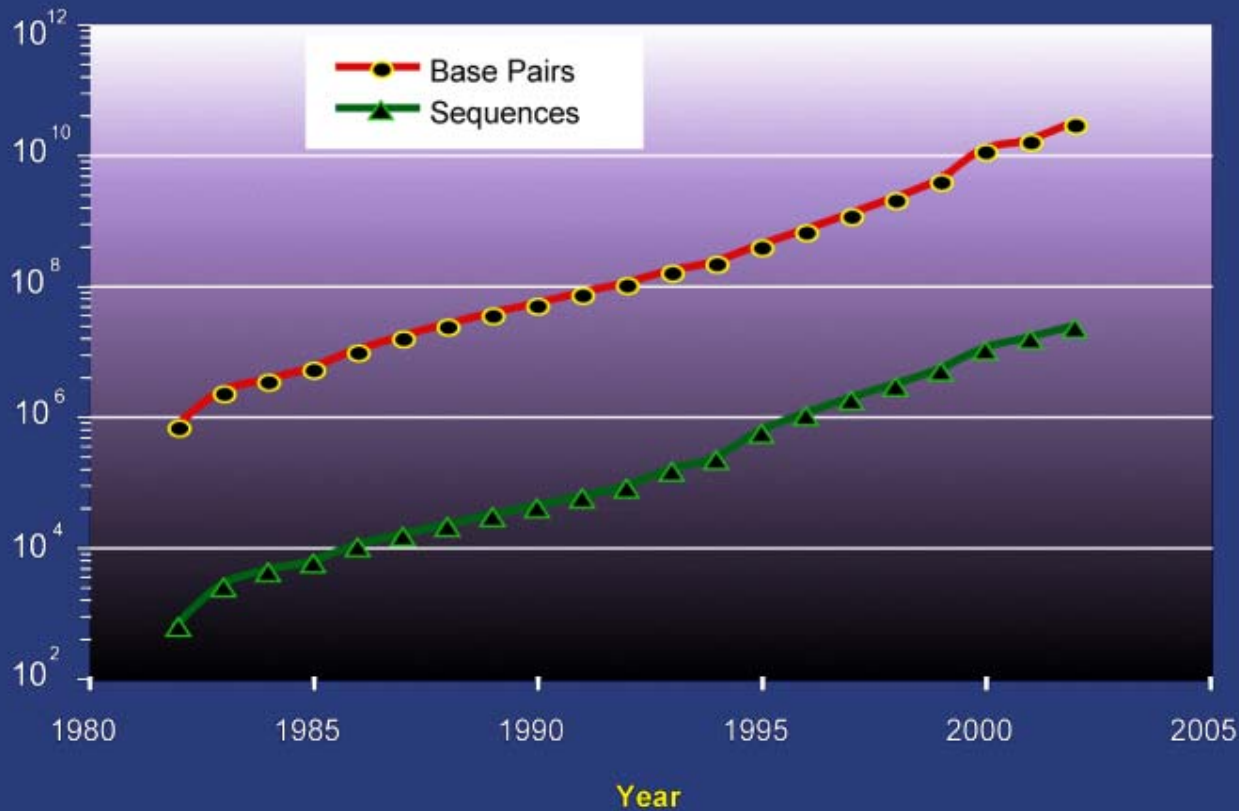






## Growth in Genbank DNA Sequence Data

Base Pairs  
and  
Sequences

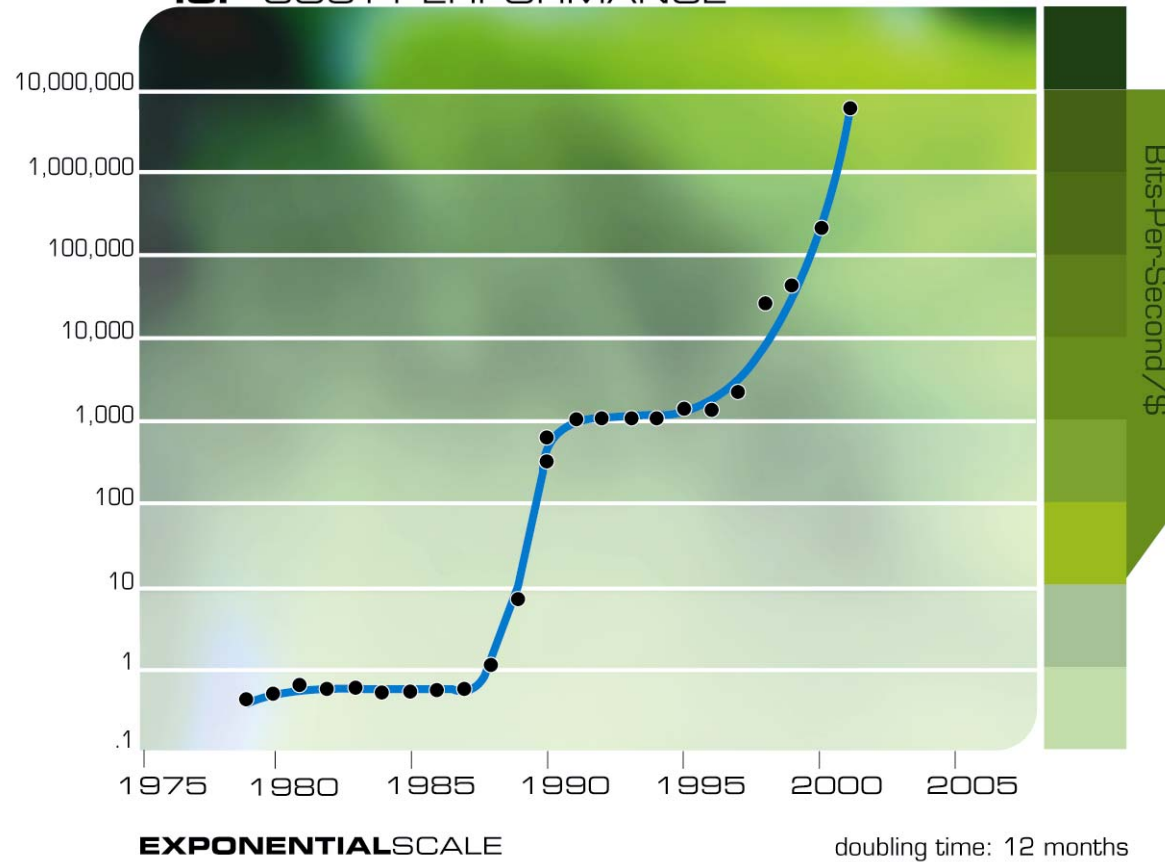


Source: GenBank



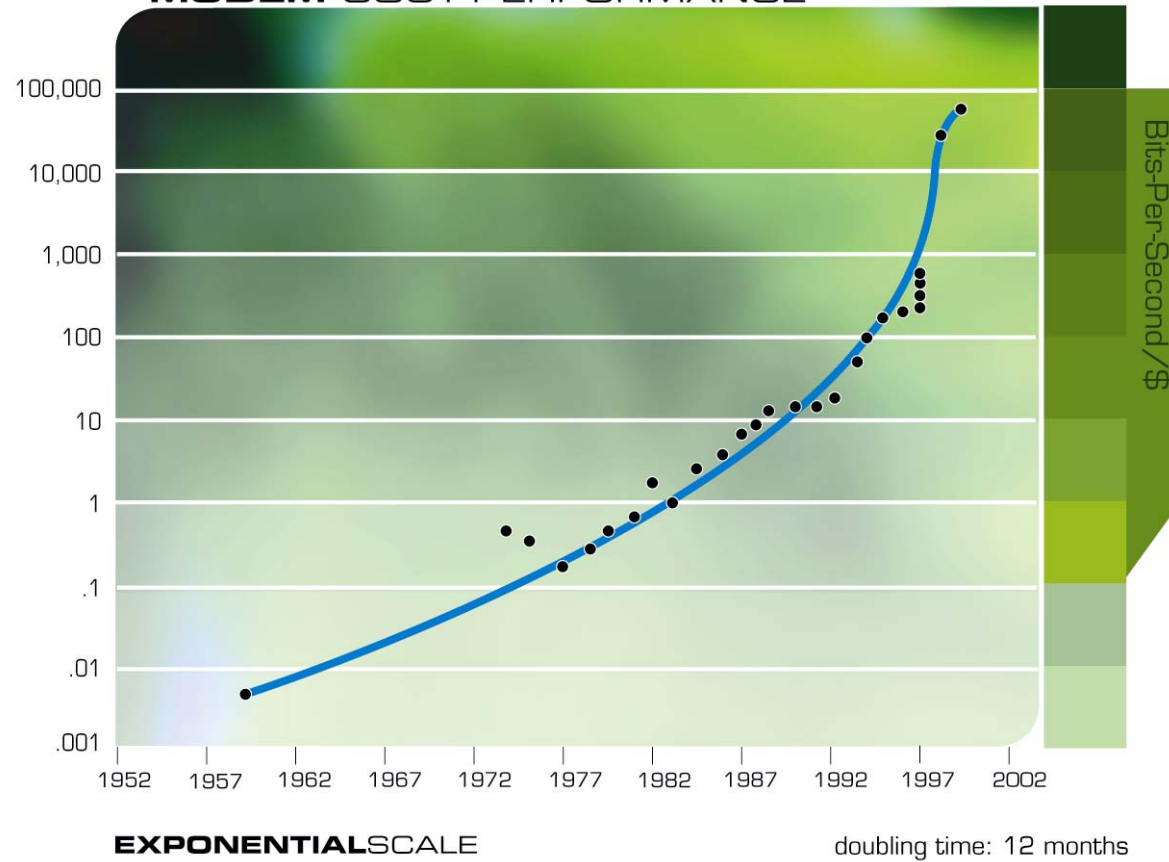


## ISP COST-PERFORMANCE





## MODEM COST-PERFORMANCE



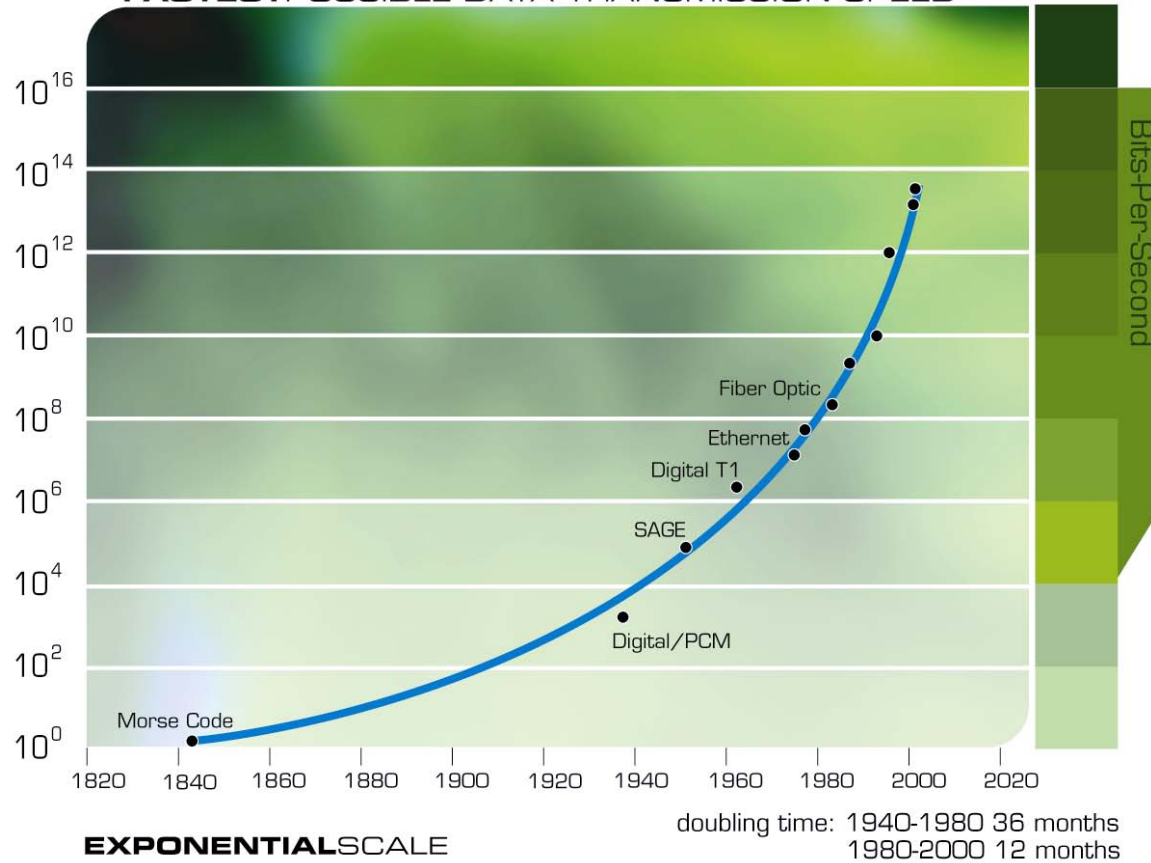
doubling time: 12 months

Bits-Per-Second/\$

EXPONENTIALSCALE



## FASTEST POSSIBLE DATA TRANSMISSION SPEED

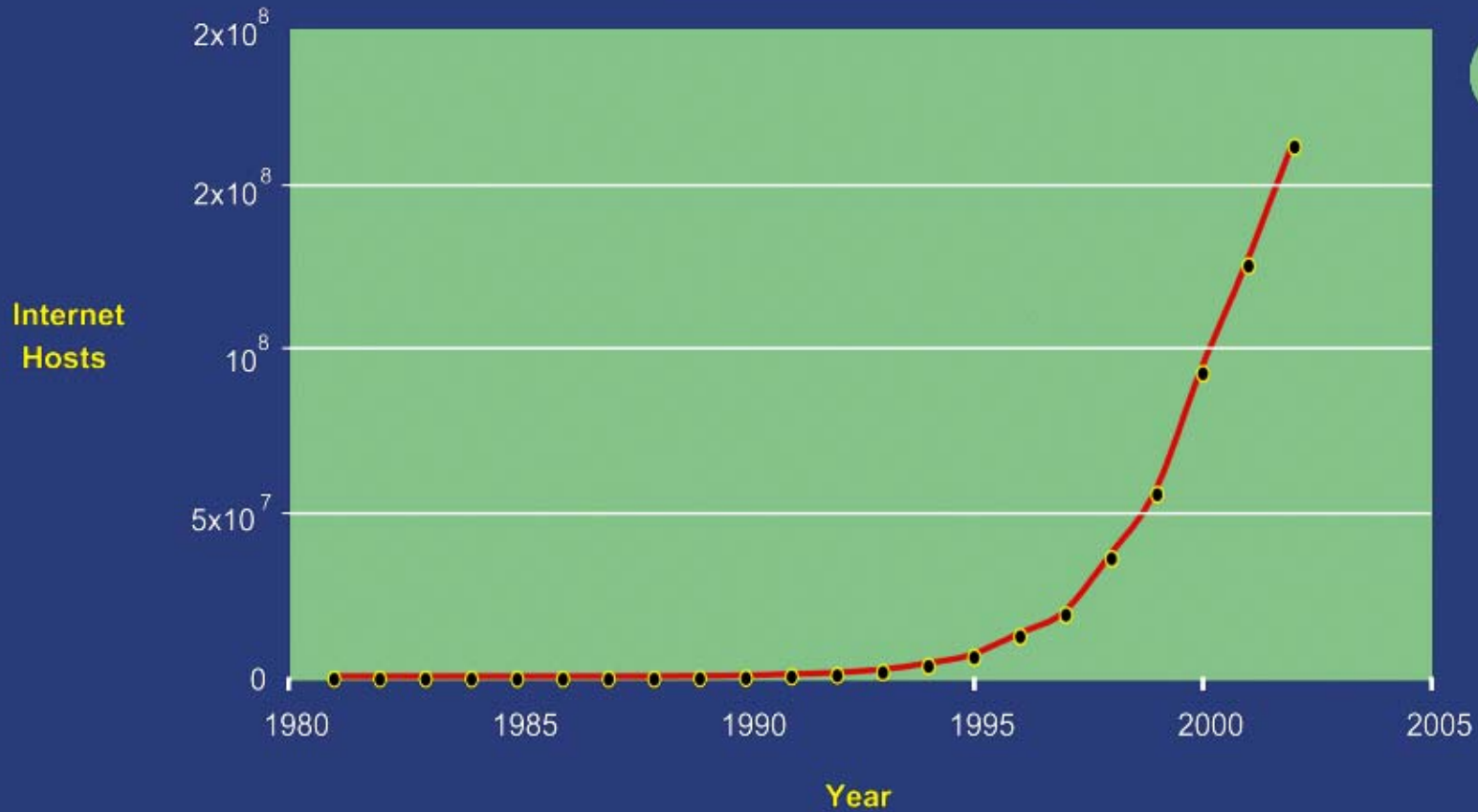


## Internet Hosts

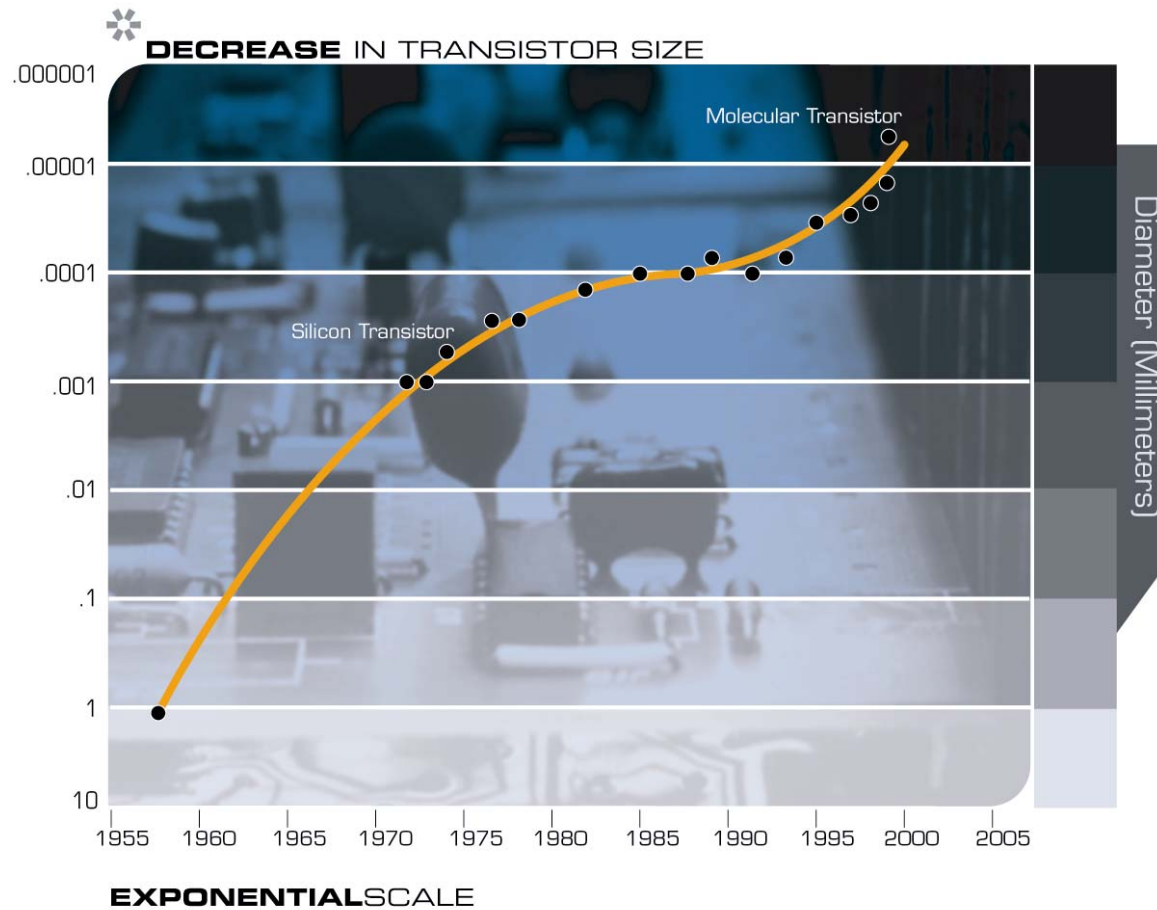


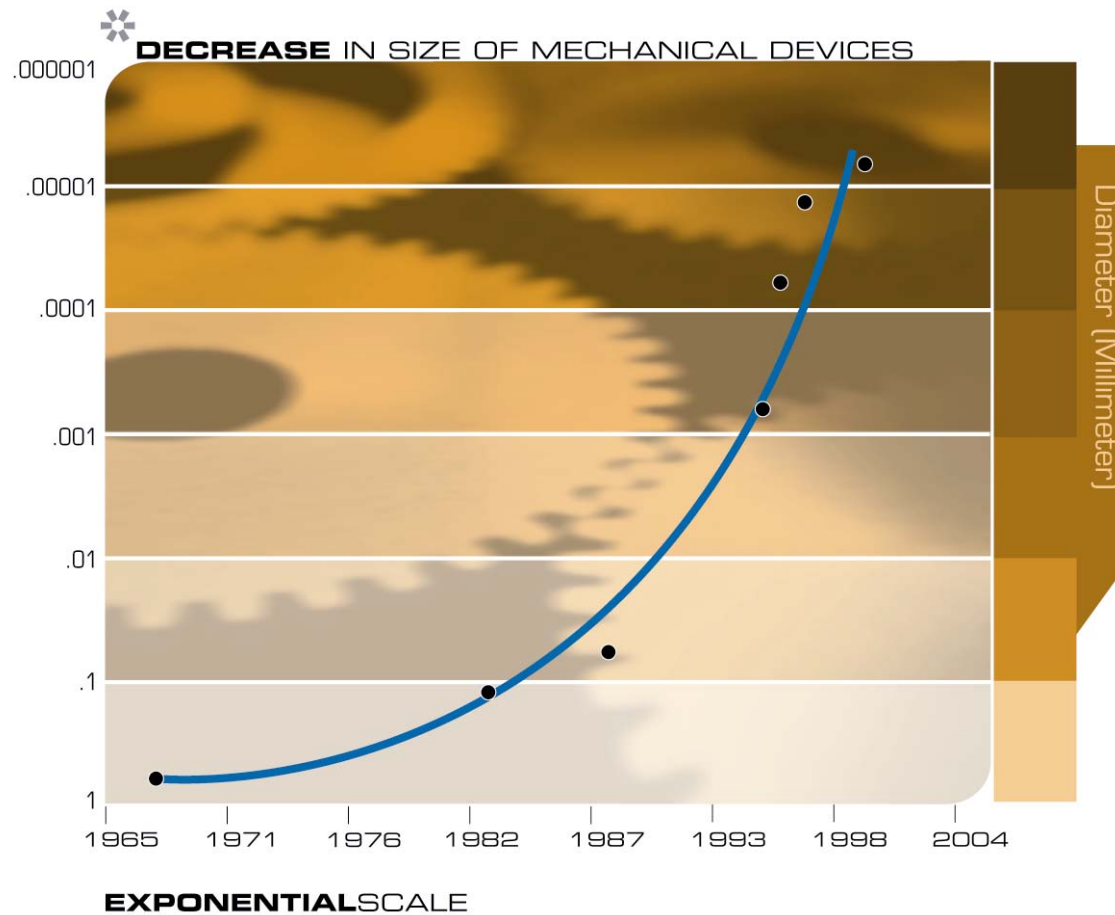
Source: Internet Software Consortium

## Internet Hosts

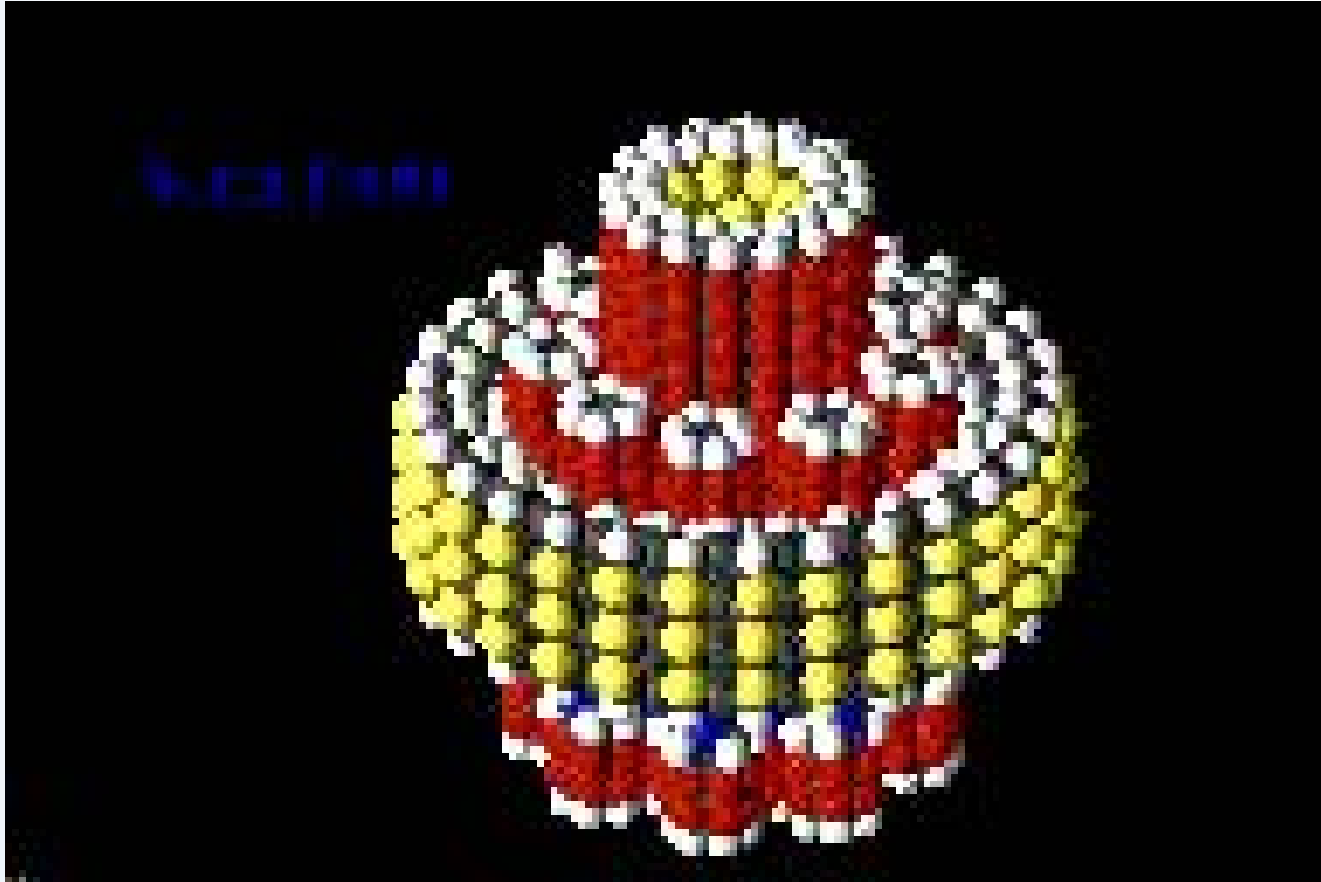


Source: Internet Software Consortium





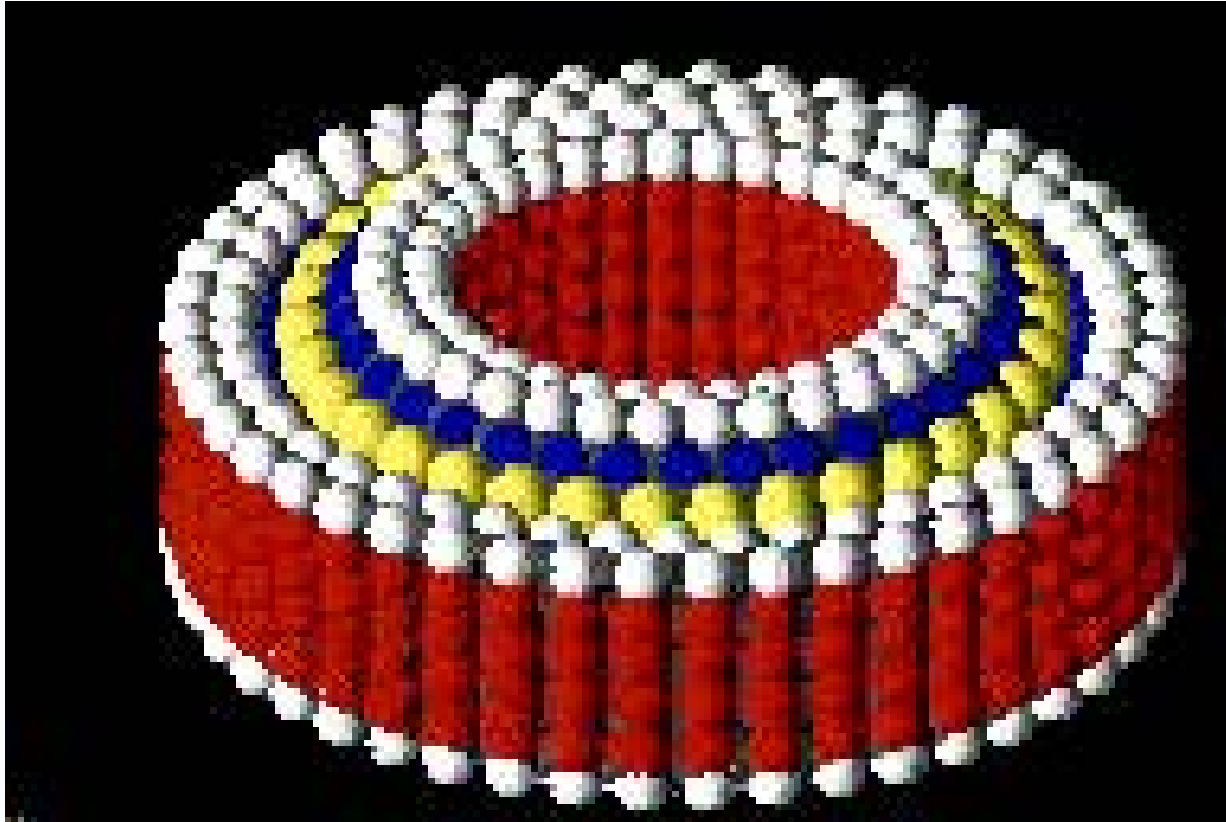
# Planetary Gear



Copyright IMM and Xerox

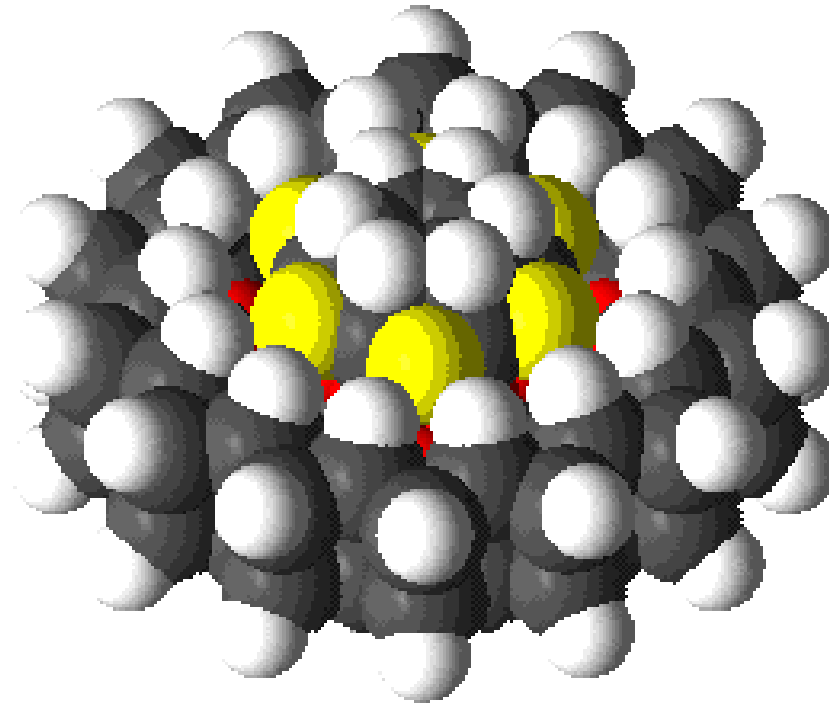


## *Nanosystems bearing*



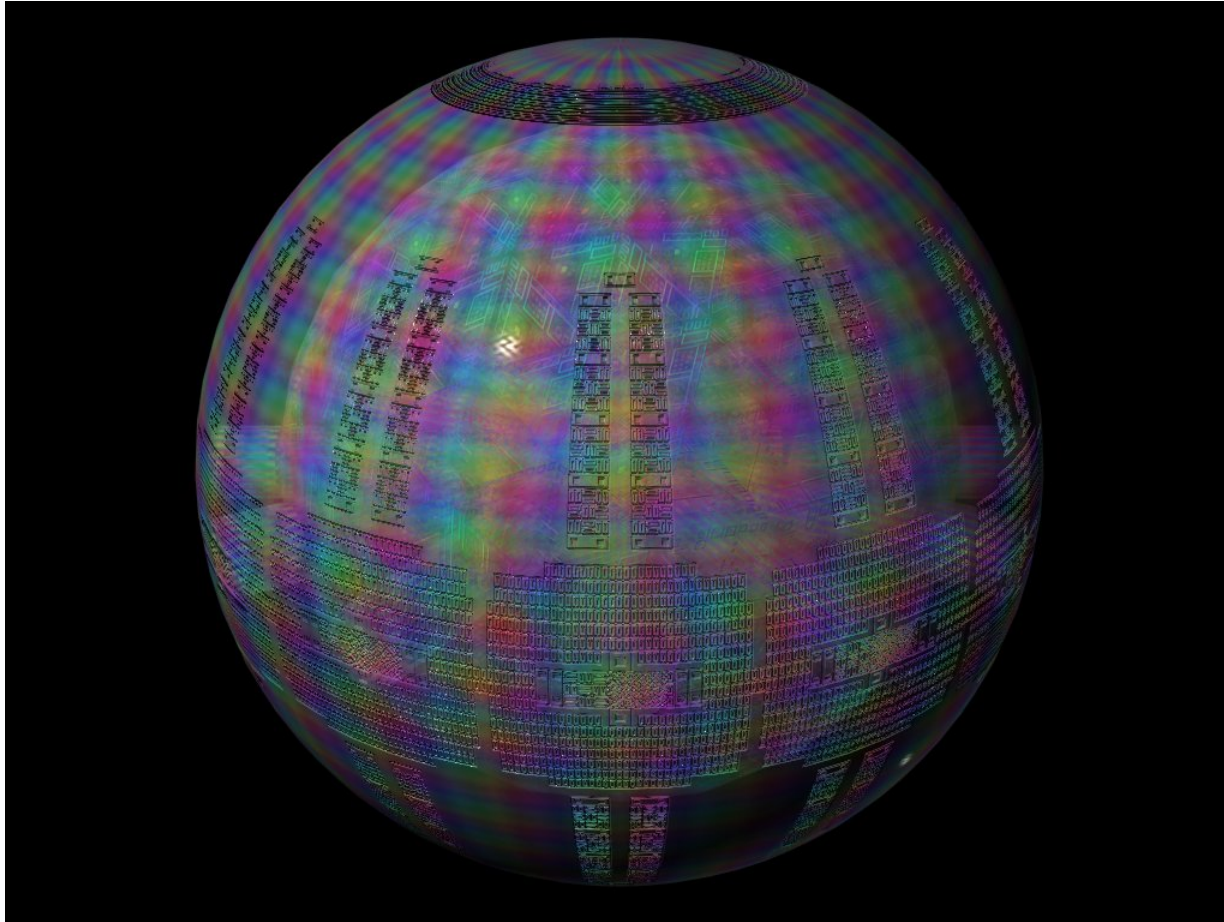
Copyright IMM and Xerox

## *Nanosystems* smaller bearing



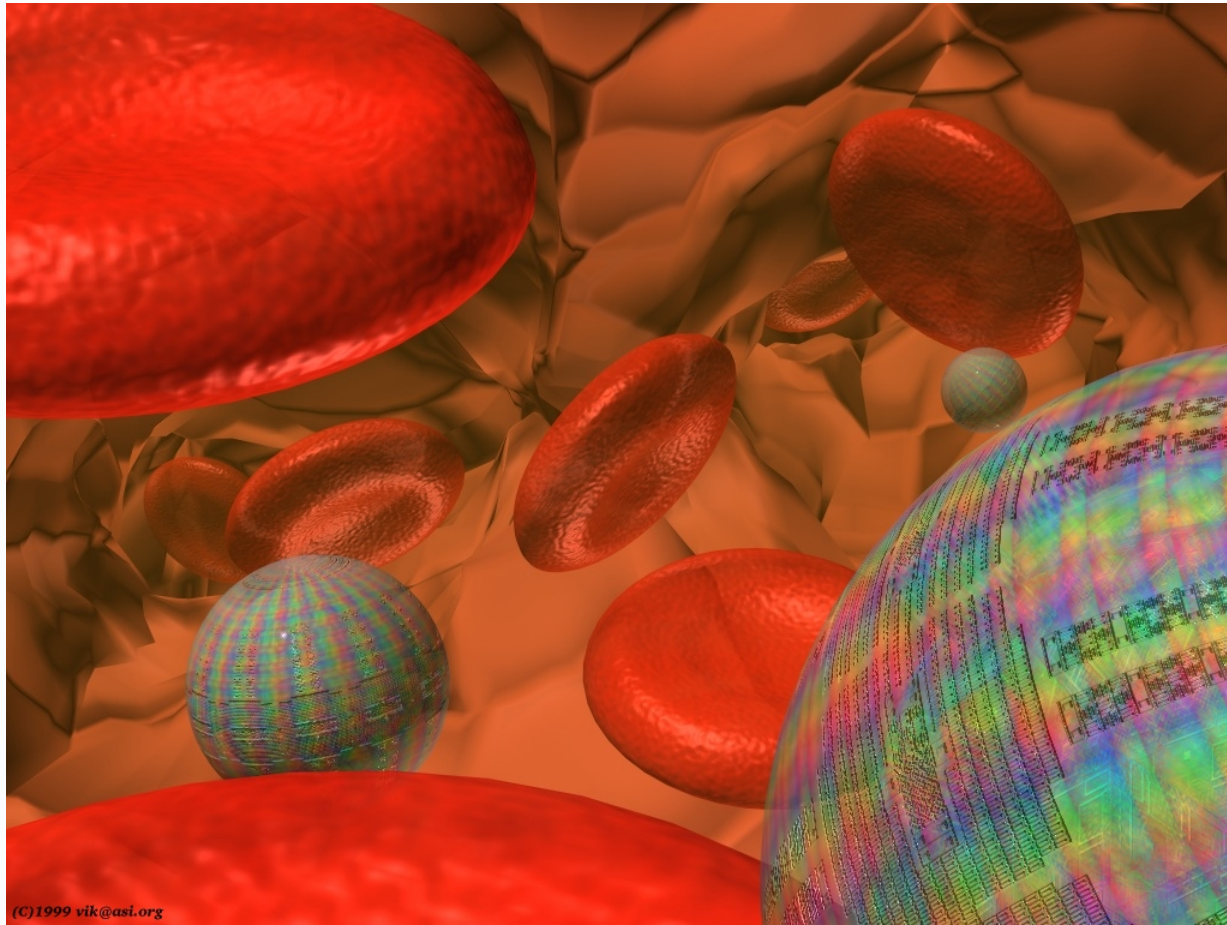
Copyright Zyvex and Robert Freitas, designer

## Respirocyte (an artificial red blood cell)



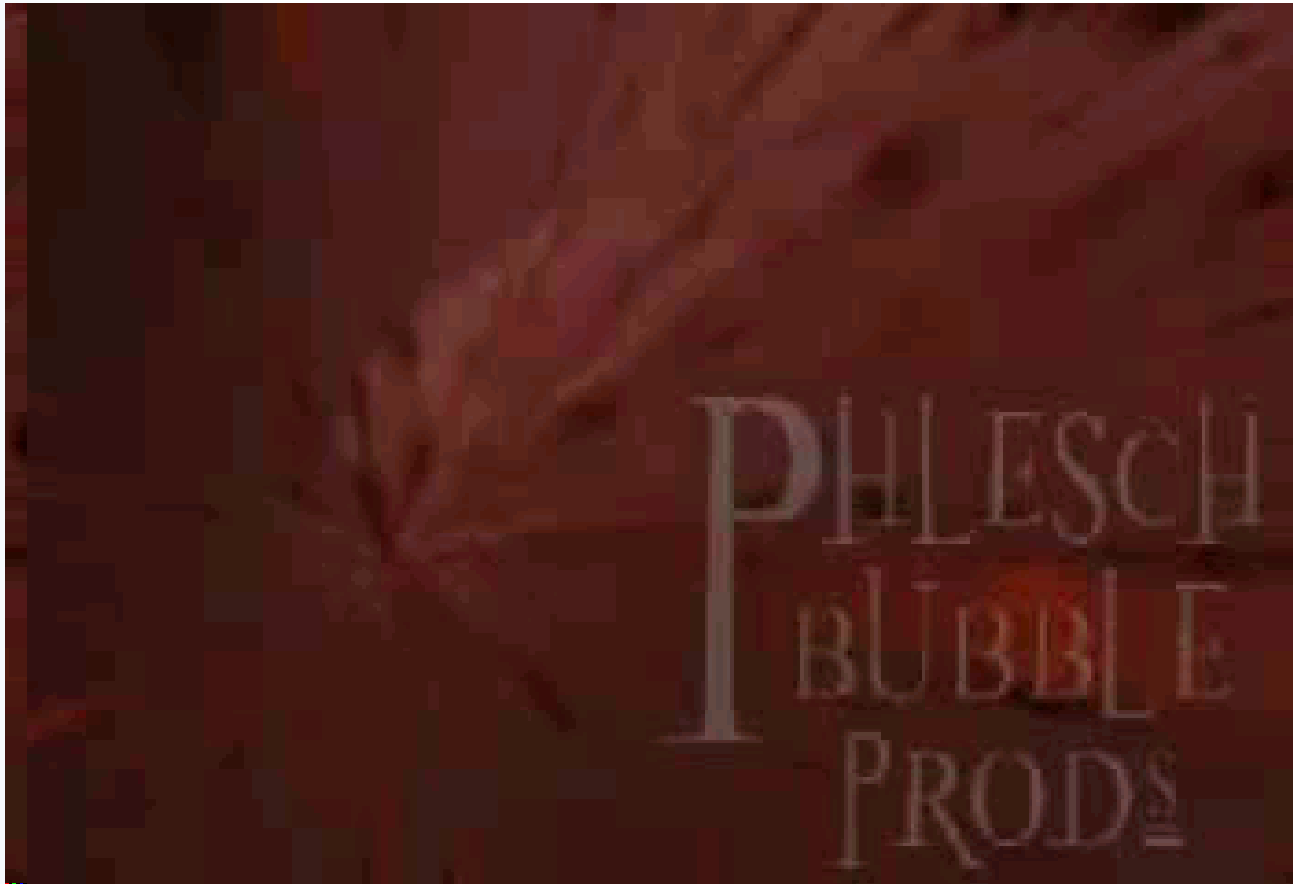
Copyright Vik Olliver, vik@asi.org.

# Respirocytes with Red Cells



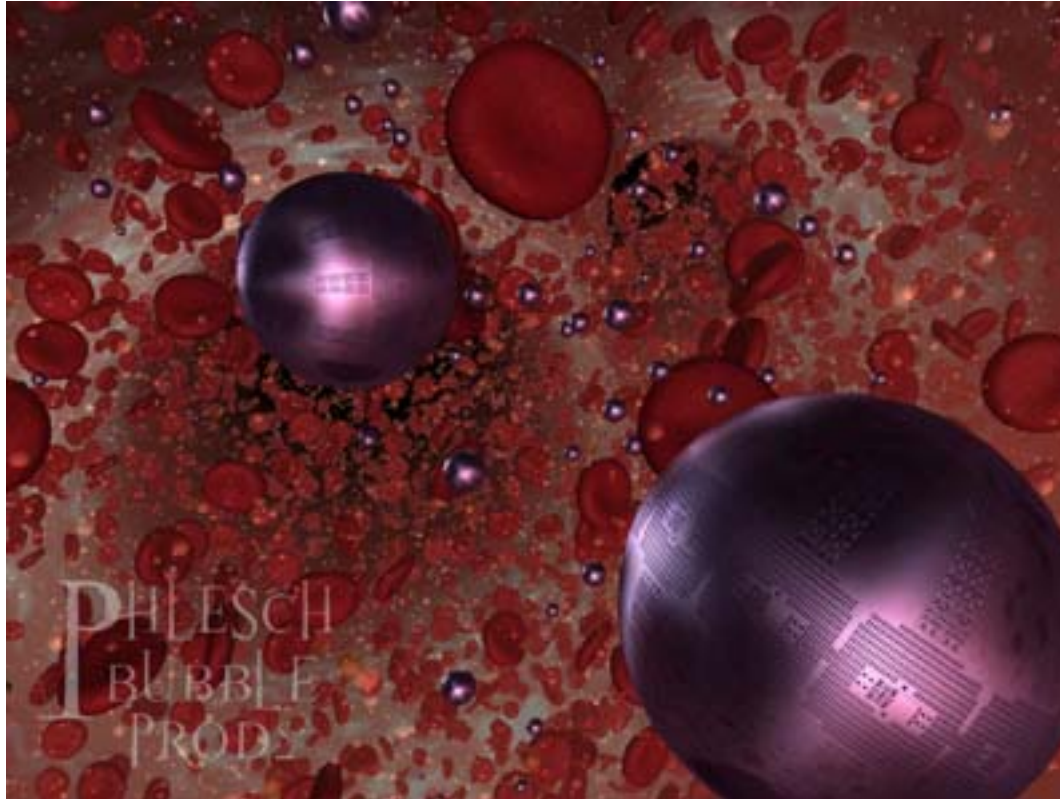
Copyright Vik Olliver, vik@asi.org.

Animation of a respirocyte releasing oxygen in a capillary



Copyright 2001, Lawrence Fields, Jillian Rose, and Phlesch Bubble Productions.

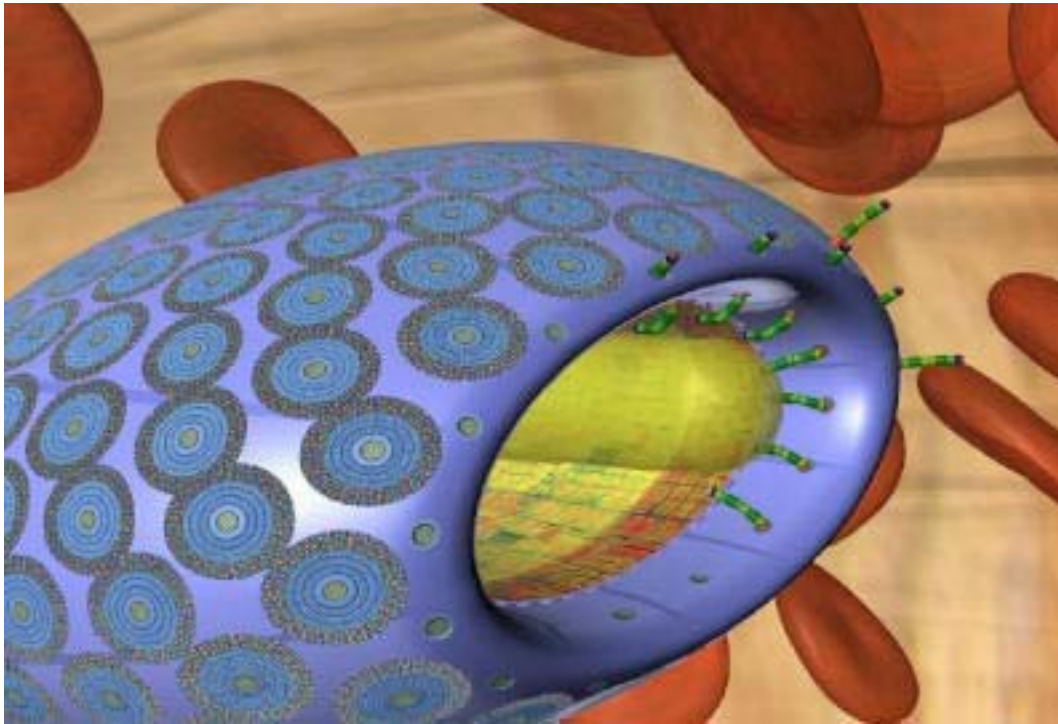
High resolution still from the Animation of a respirocyte



Copyright 2001, Lawrence Fields, Jillian Rose, and Phlesch Bubble Productions.



## Microbivores II



copyright Zyvex (Katherine Green)

## Nanotech Science Citations - 1990-2002

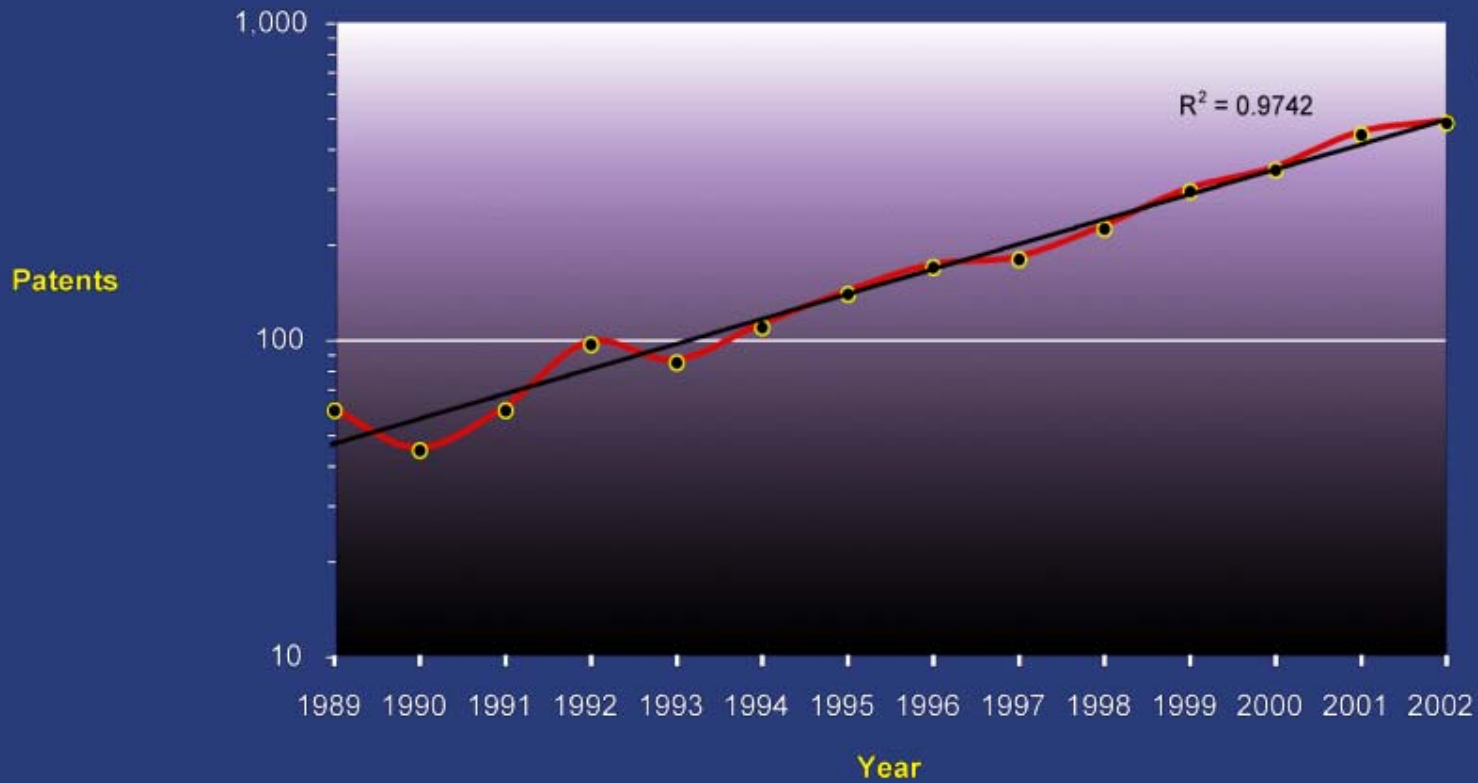


Source: ETC Group

Doubling time: 2.4 years

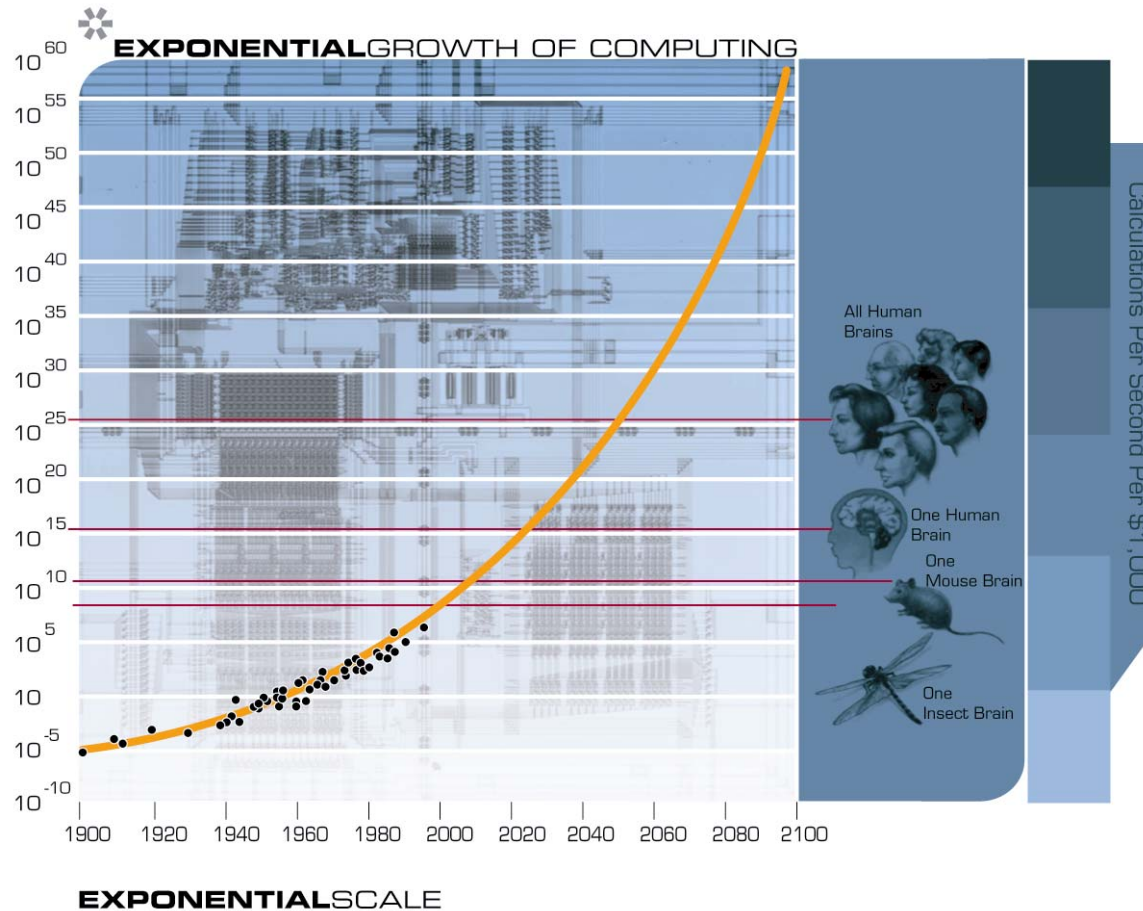


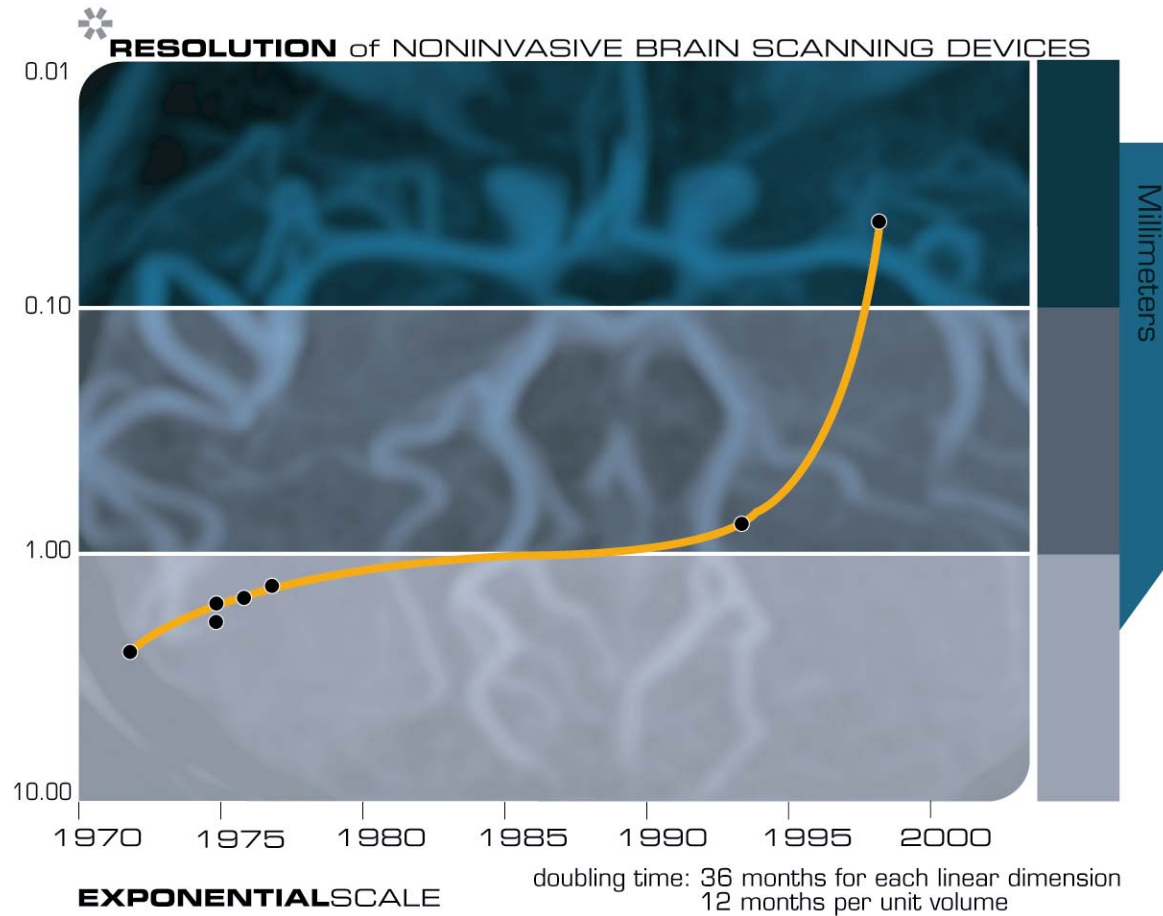
## U.S. Nano-Related Patents

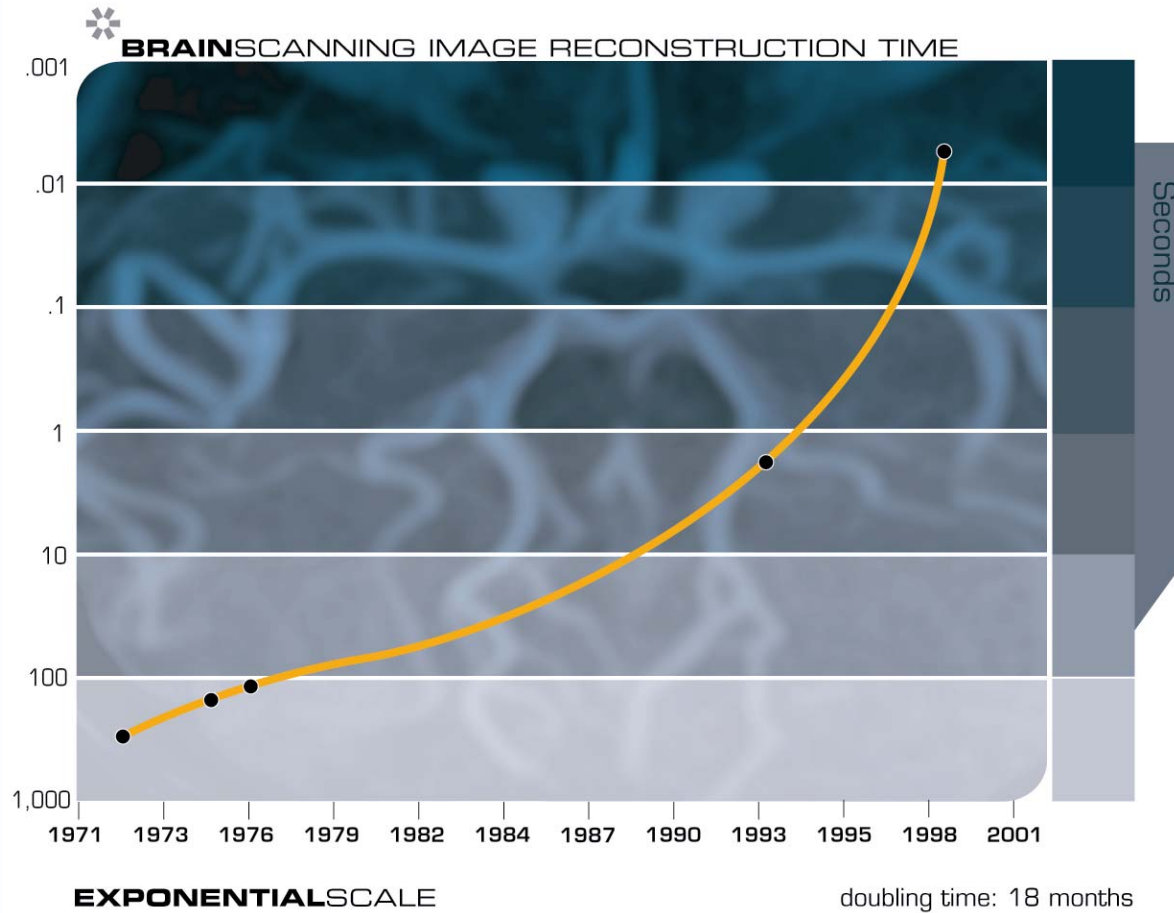


Source: ETC Group

Doubling time: 4 years







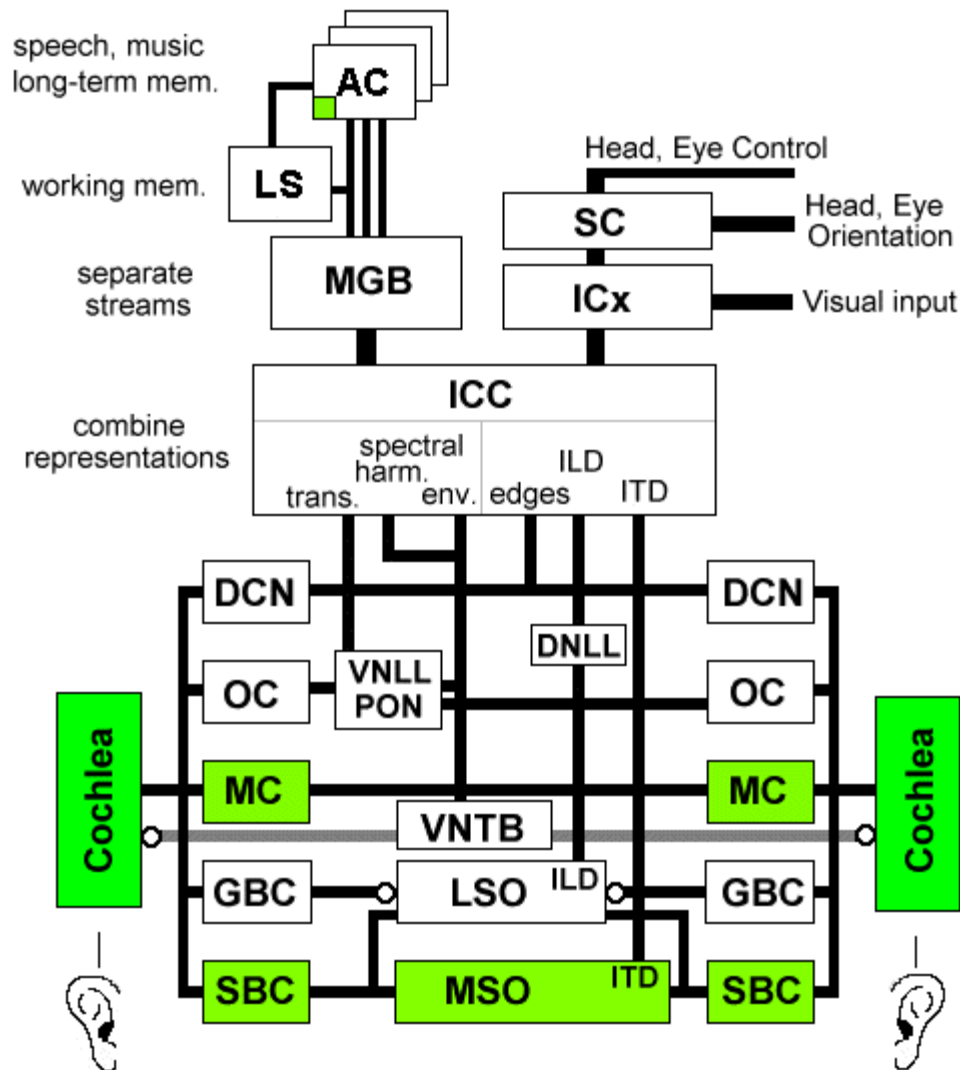
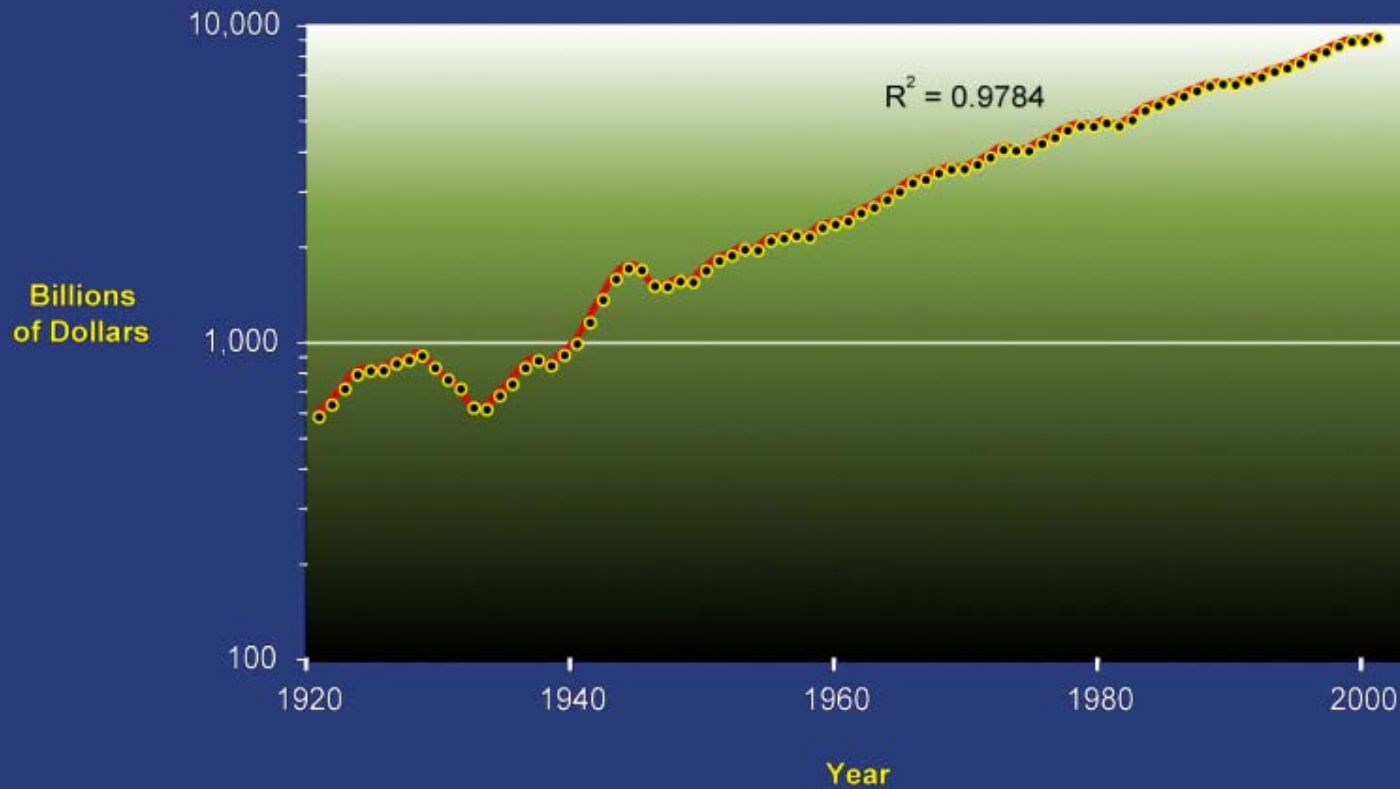


Chart by Lloyd Watts

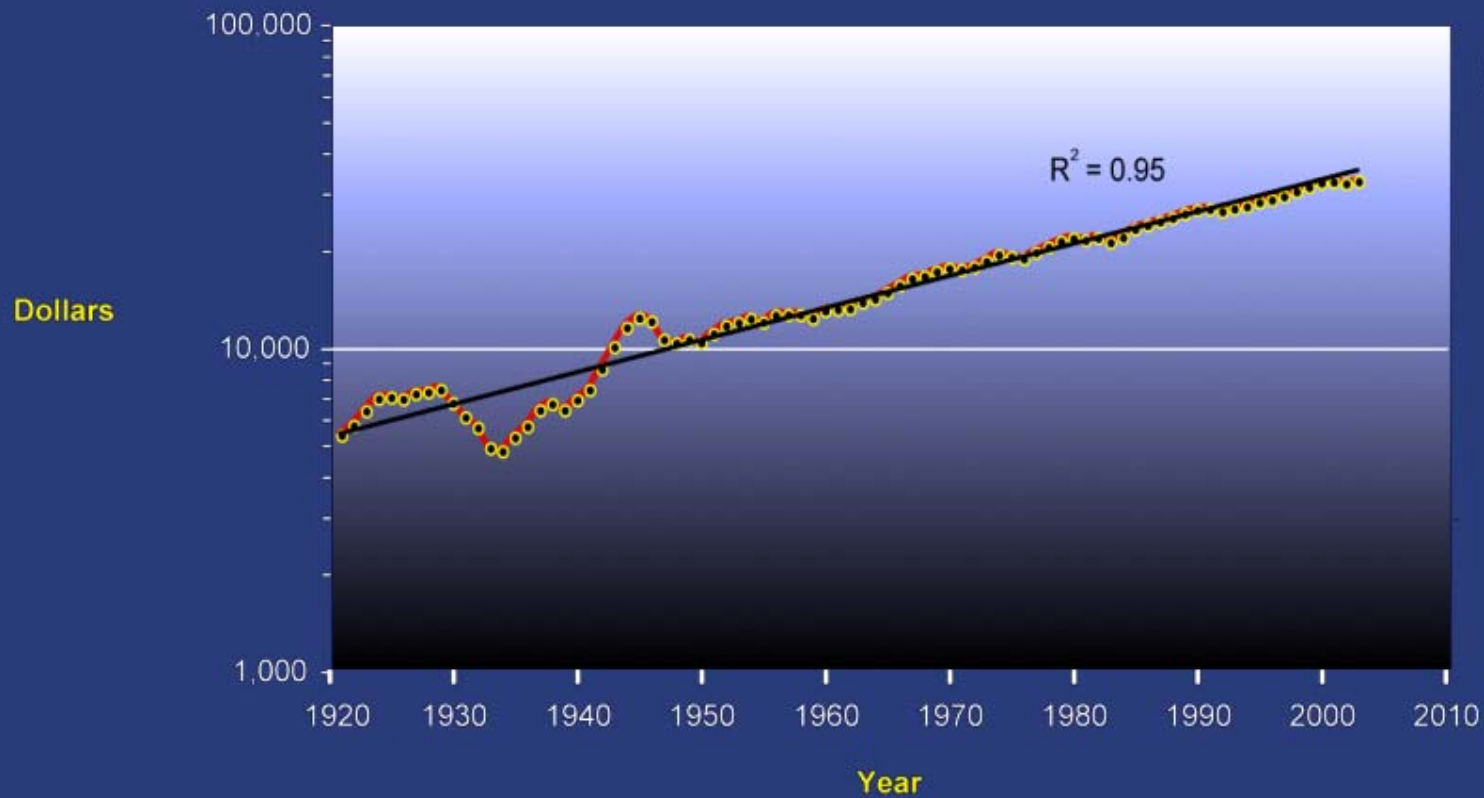
## Real Gross Domestic Product



*Logarithmic Plot*

Source: Bureau of Economic Analysis

## Per Capita GDP



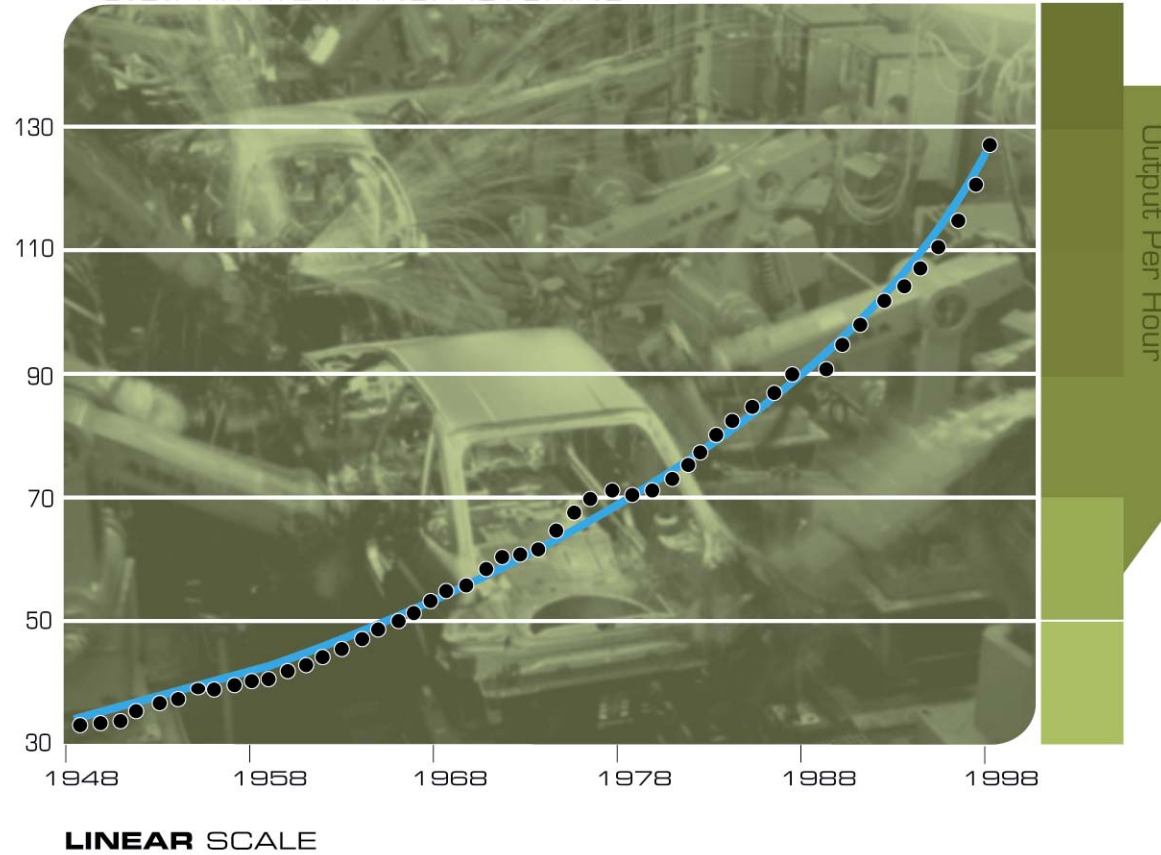
U.S. Census Bureau

Doubling time: 30 years



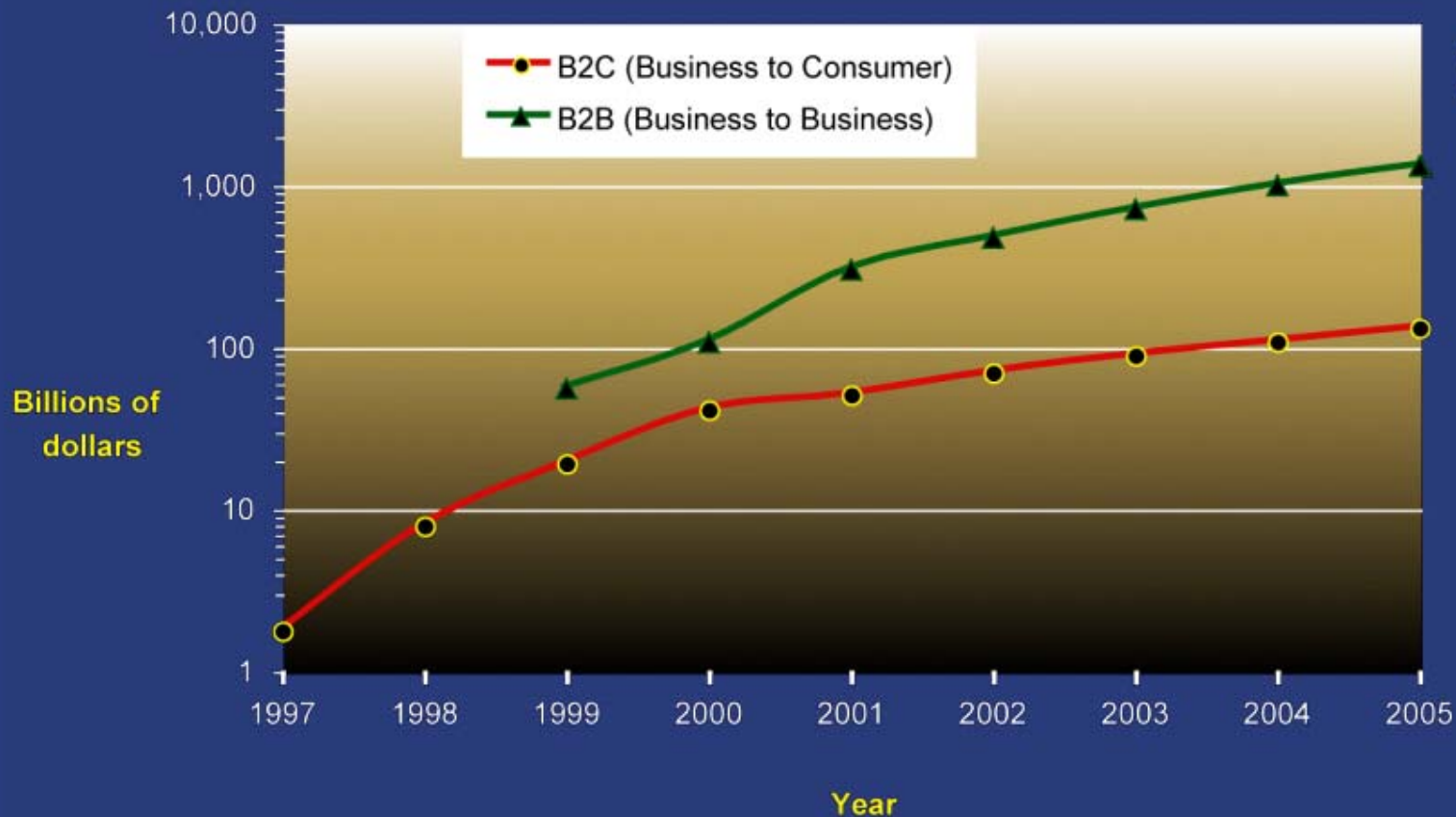


## U.S. PRIVATE MANUFACTURING



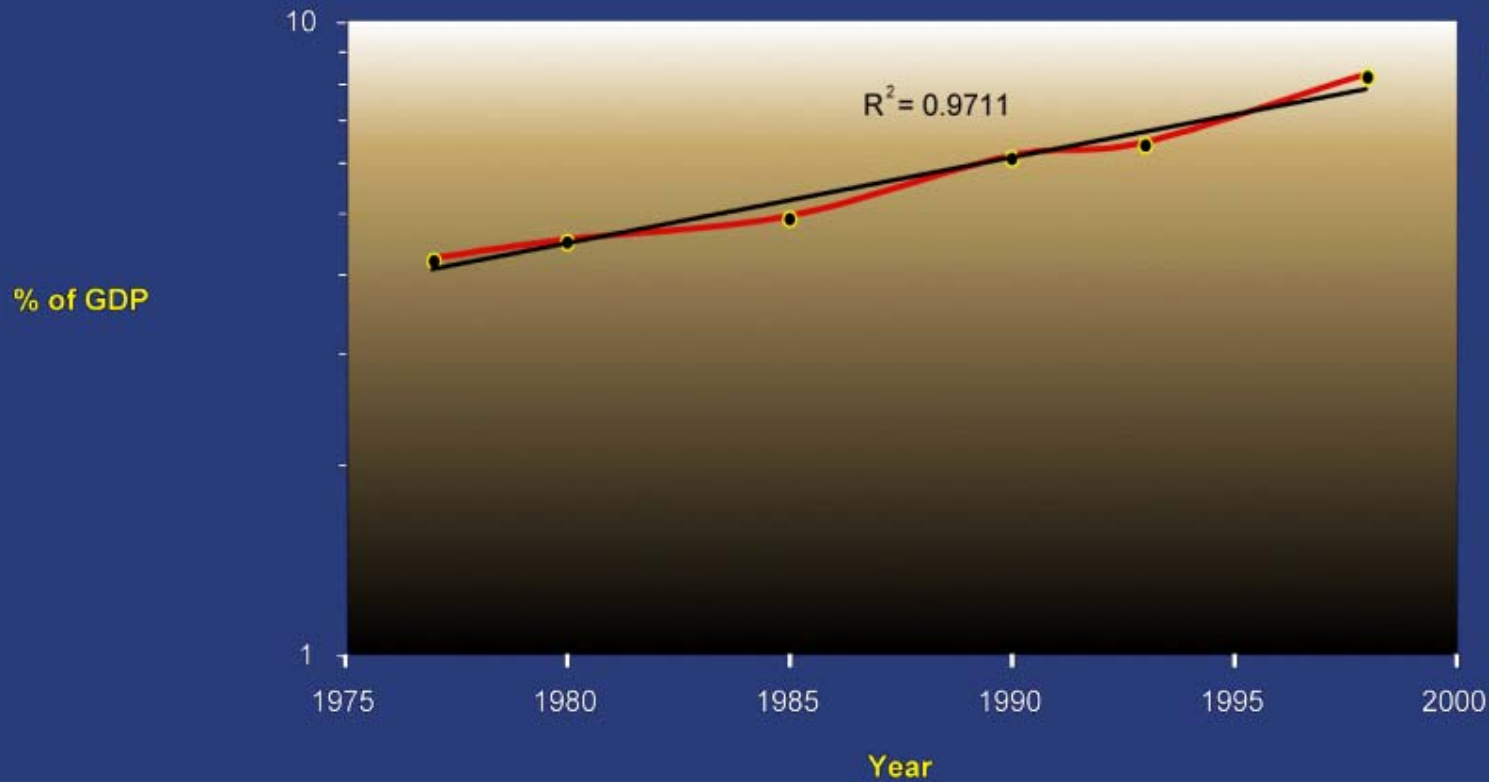
Output Per Hour

## E-Commerce Revenues in U.S.



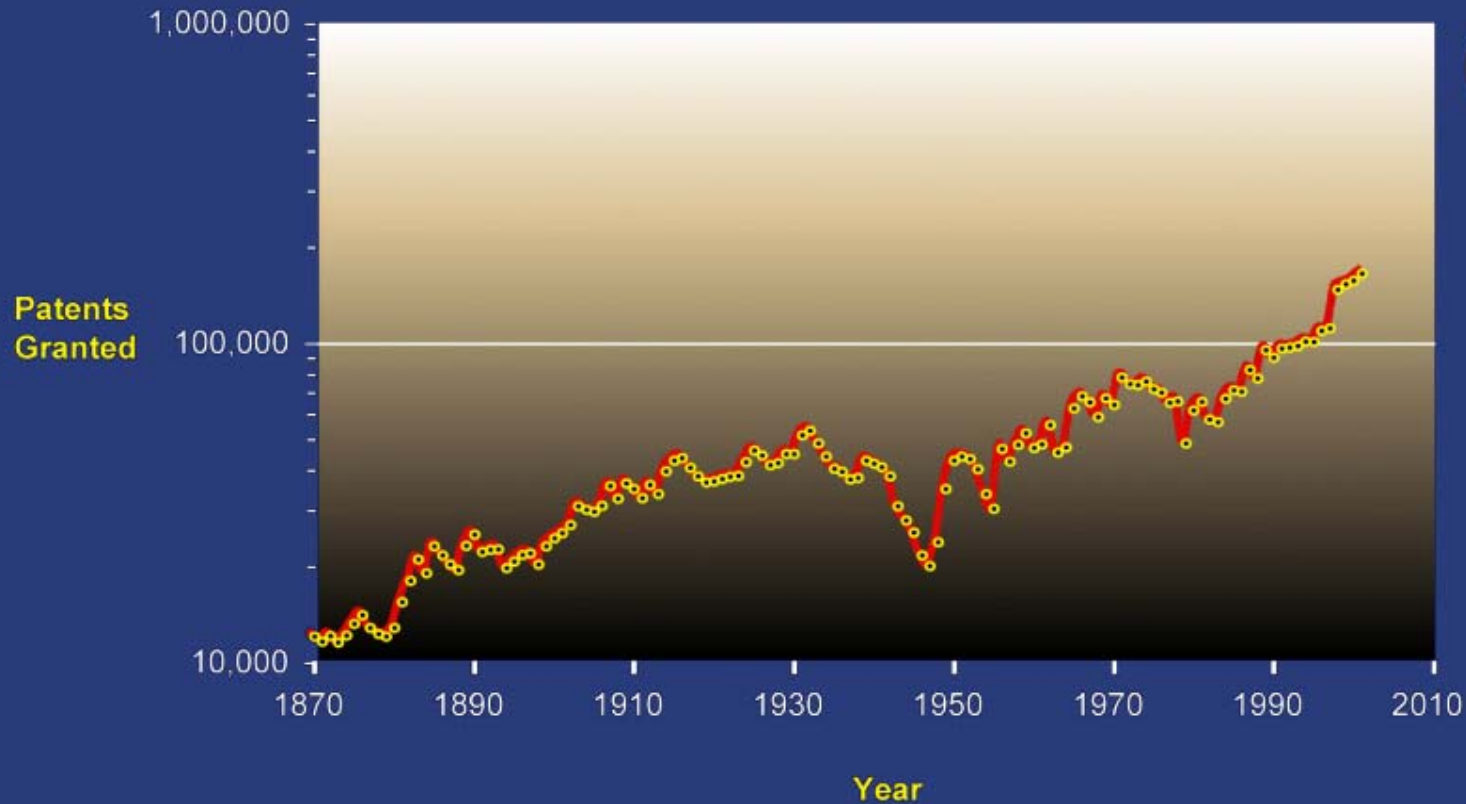
Source: eMarketer

## IT's Share of the Economy



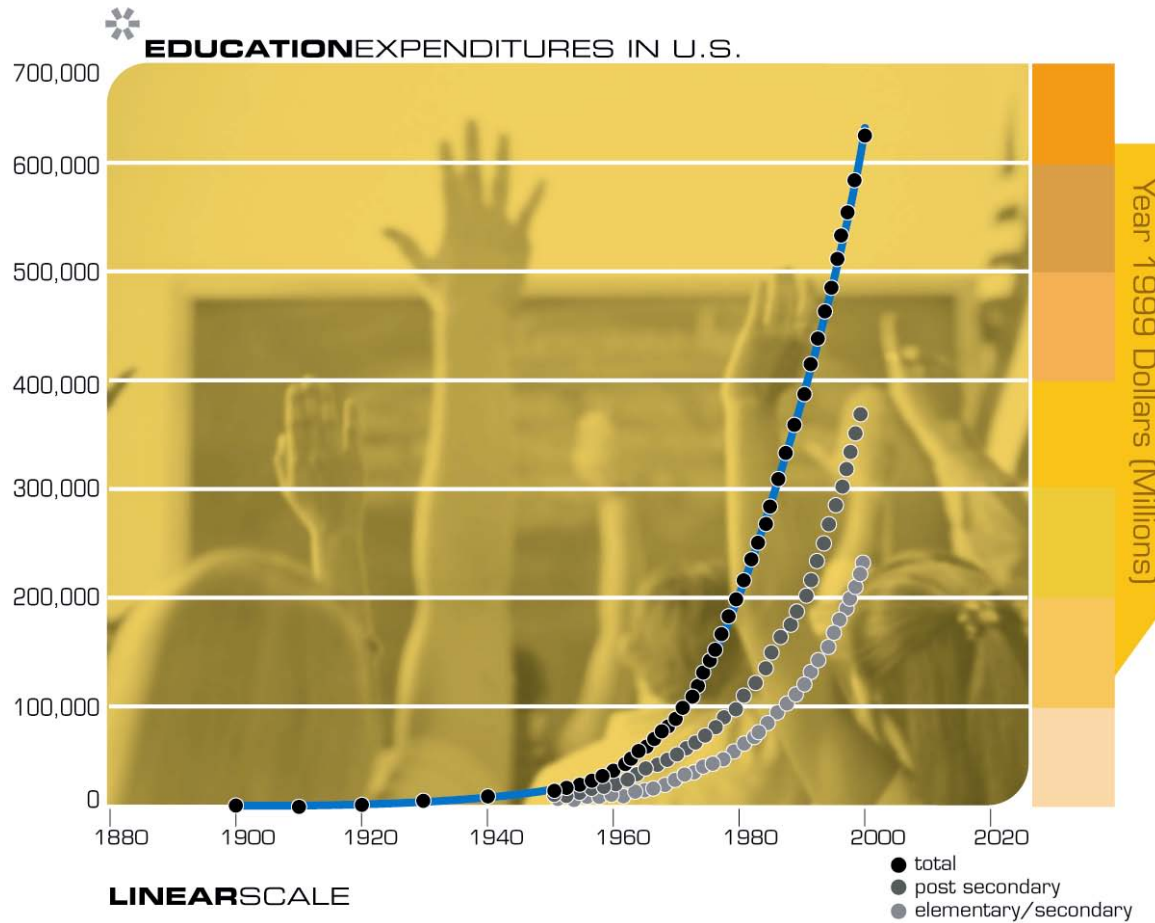
Source: U.S. Department of Commerce

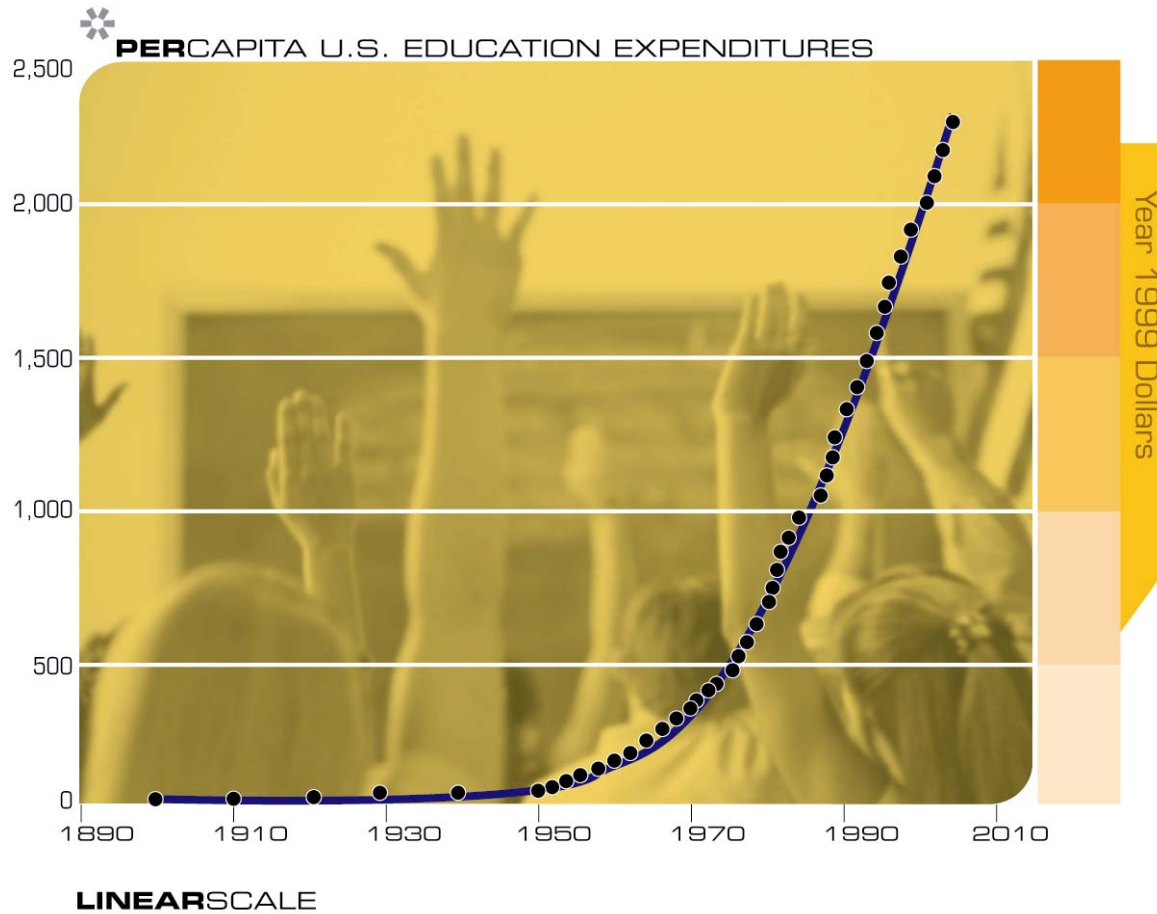
## U.S. Patents Granted



Source: U.S. Patent and Trademark Office

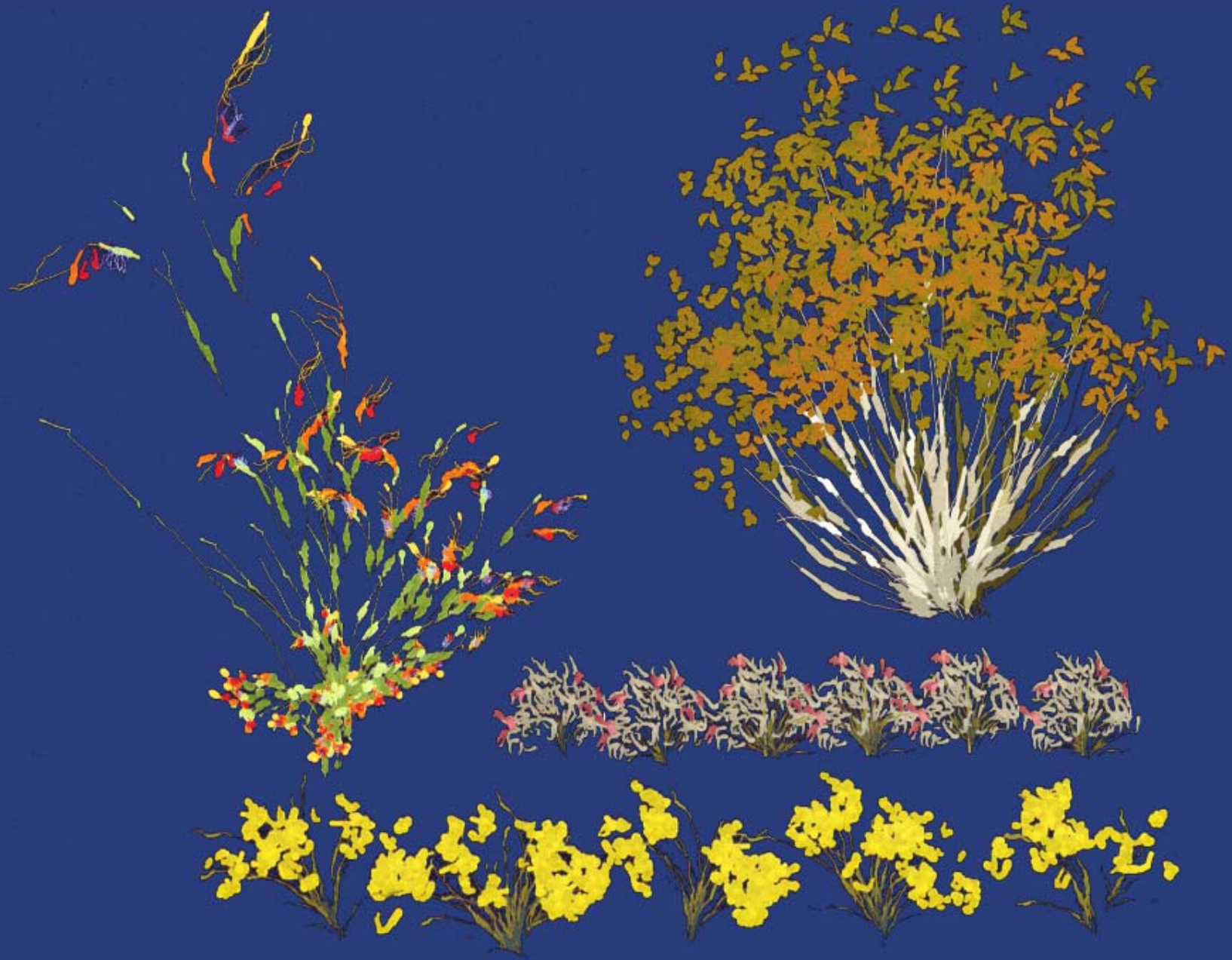
Doubling time: 16 years

















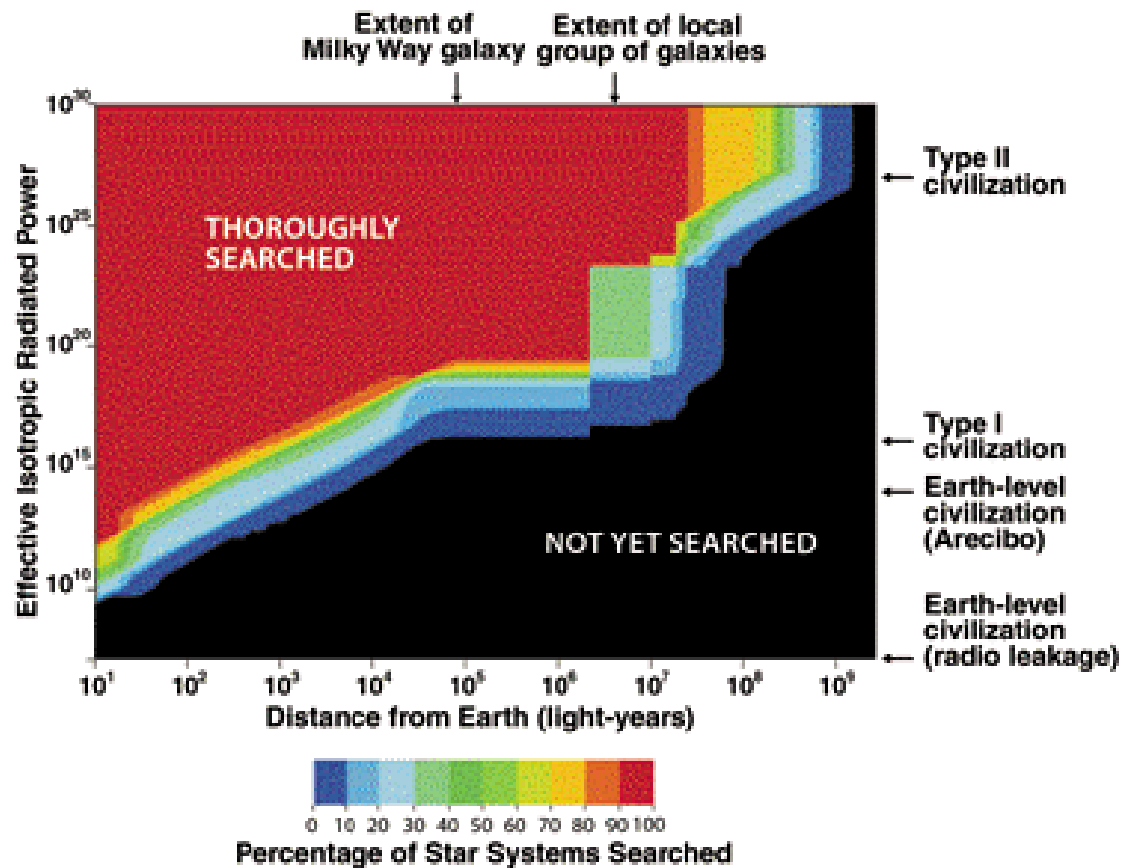












## 2010: Computers disappear

- Images written directly to our retinas
- Ubiquitous high bandwidth connection to the Internet at all times
- Electronics so tiny it's embedded in the environment, our clothing, our eyeglasses
- Full immersion visual-auditory virtual reality
- Augmented real reality
- Interaction with virtual personalities as a primary interface





## 2029: An intimate merger

- \$1,000 of computation = 1,000 times the human brain
- Reverse engineering of the human brain completed
- Computers pass the Turing test
- Nonbiological intelligence combines
  - the subtlety and pattern recognition strength of human intelligence, with
  - the speed, memory, and knowledge sharing of machine intelligence
- Nonbiological will continue to grow exponentially whereas biological intelligence is effectively fixed

## Nanobots provide...

- Neural implants that are:
  - Noninvasive, surgery-free
  - Distributed to millions or billions of points in the brain
- Full-immersion virtual reality incorporating all of the senses
  - You can be someone else
  - “Experience Beamers”
- Expansion of human intelligence
  - Multiply our 100 trillion connections many fold
  - Intimate connection to diverse forms of nonbiological intelligence

# The Challenge from Malthus: “Exponential trends eventually run out of resources”

However...

- The resources needed for computation and communication are close to zero.
- Based on current understanding, there are sufficient resources on Earth for these trends to continue through the 21<sup>st</sup> Century:
  - During which time nonbiological intelligence will become trillions of times more powerful than biological human intelligence
  - Beyond that: yet lower thresholds, and expansion beyond Earth

- Specific Paradigms do hit limits
  - e.g., the flat IC's of Moore's Law will hit atomic limits within 15 years
  - But then yield to other paradigms
    - Moore's Law is the fifth paradigm, not the first, to provide exponential growth for computing
    - The Sixth paradigm will be 3D molecular computing
    - The brain achieves its power because it computes in 3 dimensions despite an extremely bulky and slow information processing method (10 million times slower than today's electronic circuits)
  - Even Moore's Law by itself will be sufficient to exceed human intelligence

## The Challenge from Software: “We’re making exponential gains in hardware, but not software”

- However, we are making exponential gains in software, although the doubling time is indeed longer.



Software Price-Performance Has Also  
Improved at an Exponential Rate

Example: Automatic Speech Recognition Software

|                                        | 1985    | 1995   | 2000    |
|----------------------------------------|---------|--------|---------|
| Price                                  | \$5,000 | \$500  | \$50    |
| Vocabulary Size<br>(# Words)           | 1,000   | 10,000 | 100,000 |
| Continuous<br>Speech?                  | No      | No     | Yes     |
| User Training<br>Required<br>(Minutes) | 180     | 60     | 5       |
| Accuracy                               | Poor    | Fair   | Good    |

- There has been increased productivity from new languages, class libraries, software development tools:
  - Doubling time is about 6 years
- Software complexity required to emulate the human brain is manageable:
  - Compressed genome data that describes the human brain is 12 million bytes
    - 6 billion bits X compression factor of 30 X 50% devoted to the brain

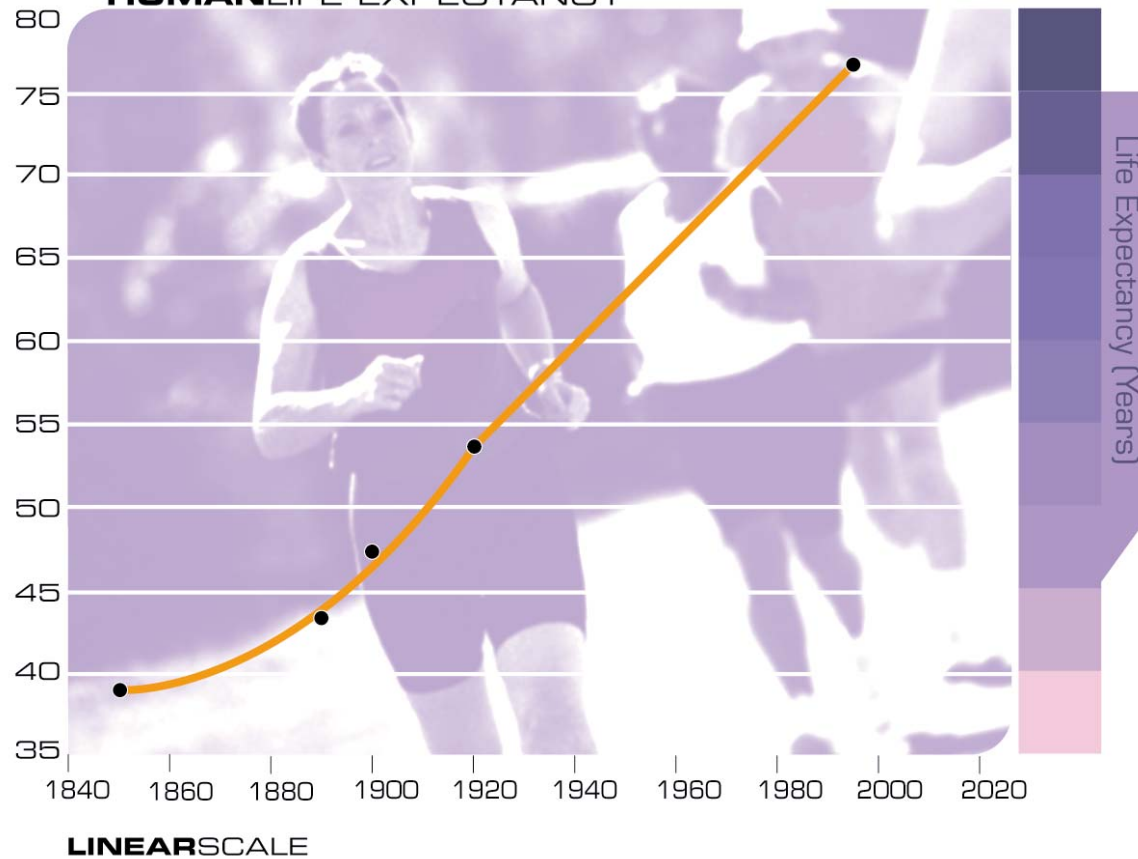
- We have a specific game plan to reverse engineer the human brain
  - Knowledge of the human brain at all levels is growing exponentially
- We will not program human-level intelligence link by link (e.g., the expert system “cyc”)
  - But rather as an elaborate architecture of parallel self-organizing systems
  - Educating such a system will be the hardest part of the software task

## The Challenge from Ethics

- There is far less ethical resistance to the development of nonbiological intelligence (including intimate connection with our bodies and brains) than to biological tinkering
- In any event, ethical concerns end up as stones in a stream: the economic and moral imperatives are too strong
- There ultimately will be grave dangers, but the biological downsides are more apparent today



## HUMAN LIFE EXPECTANCY



Life Expectancy (Years)

LINEAR SCALE

# Graphs available at:

KurzweilAI.net

“The Law of Accelerating Returns”



# Reference URLs:

Kurzweil Technologies (links to all Kurzweil companies)

[www.KurzweilTech.com](http://www.KurzweilTech.com)

AARON and Cybernetic Poet:

[www.KurzweilCyberArt.com](http://www.KurzweilCyberArt.com)

KAIN: [www.KurzweilAI.net](http://www.KurzweilAI.net)