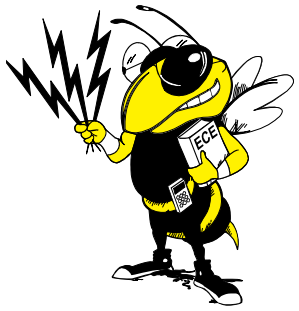
Silicon Earth:
The Miracle of the Micro/Nanoelectronics Revolution

John D. Cressler

Ken Byers Professor
School of Electrical and Computer Engineering
777 Atlantic Drive, N.W., Georgia Institute of Technology
Atlanta, GA 30332-0250 USA
cressler@ece.gatech.edu / Tel (404) 894-5161
http://users.ece.gatech.edu/~cressler/



The Information Age

A Functional Definition:

The **"Information Age"** is characterized by the acquisition, processing, manipulation, storage, and **global** exchange of information (knowledge).

Q: Why Age?

A: Civilization is profoundly defined by an historical "Age"
(technology, but also: culture, commerce, art, politics, socialization, etc.)

Some Defining Features of the Information Age?

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Some Defining Features of the Information Age:

- the ubiquitous computer

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- the internet

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Some Defining Features of the Information Age:

- the ubiquitous computer **(593,085,000 personal computers)**
- the internet **(687,593,600 internet users)**
- wired and wireless communications
- microprocessors in everything

A Bit of Trivia …

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How Much Information Flow Occurred Electronically Last Year?

And The Answer Is …

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There Was Approximately

17,905,340,000,000,000,000,000 bytes

(17,905,340 Terabytes = 17.9 Exabytes)

Of Information Moved On Planet Earth!

For Comparison:

- the entire print collection of Library of Congress = 10 Terabytes!
- a DVD holds 4.7 Gigabytes!
- one typewritten page takes 2 kilobytes!

The Information Age

Some Facts:

- The Information Age exists **ONLY** because of the virtues of a particular class of materials called **semiconductors**

- **Silicon** is the most important semiconductor ($200B)

Silicon

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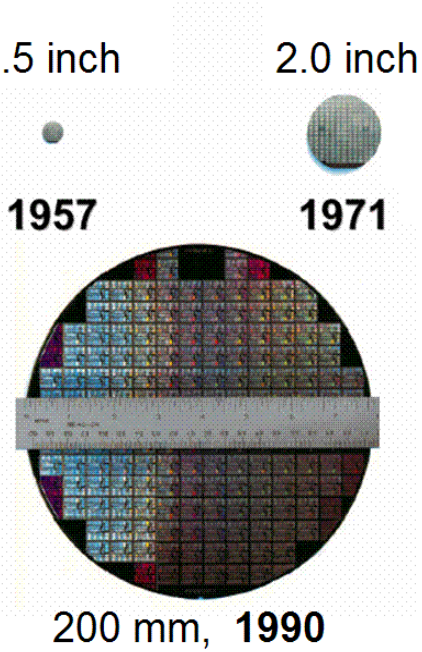
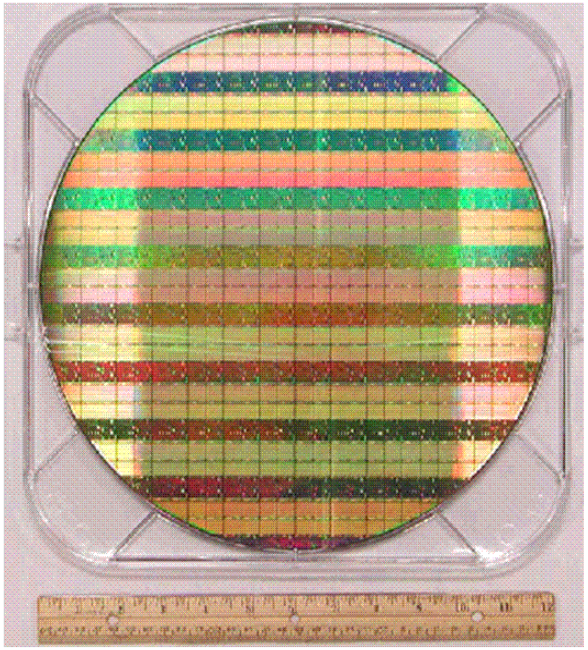
Some Facts About Silicon (Si):

- Si is a Group IV element, and crystallizes in the diamond structure
- Perfect Si crystals can be grown very large (12 inches by 8 feet!)
- Si can be made extremely pure (< .000001 ppm impurities!)
- Si is very abundant and non-toxic (70% of the earth's crust are silicates!)
- Si oxidizes trivially to form one of nature's most perfect insulators (SiO_2)
- Si is a great conductor of heat (better than many metals!)





The Information Age

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Some Facts:

- The Information Age Exists **ONLY** because of the virtues of a particular class of materials called **semiconductors**
- **Silicon** is the most important semiconductor ($200B)
- **Silicon** can be cleverly manipulated to perform many modern miracles

The State-of-the-art in Microelectronics (2007):

- 4,000 MHz 64 bit µP (uses 200,000,000 transistors!)
- 16Gbit (16,000,000,000) DRAM on a single Si chip

Some Questions You Should Be Asking:

How have we accomplished this?

How will civilization, and our lives, be changed forever as a result?

What are the limits? Where will it end?

Cressler's PC's

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Year	Processor	Memory	Hard Drive
1992	33 MHz	4M	128M
1993	50 MHz	8M	256M
1995	100 MHz	16M	512M
1996	150 MHz	32M	2.1G
1997	133 MHz	24M	1.4G laptop!
1999	350 MHz	96M	6.0G laptop (MMX)
2002	1600 MHz	512M	30G laptop (DVD)
2004	2.4 GHz	1G	60G laptop (wireless)
04/92	72x	250x	468x

And … my 1992 PC and my 2004 laptop cost the same!

… How Has This Been Possible??

Moore's Law (1965)

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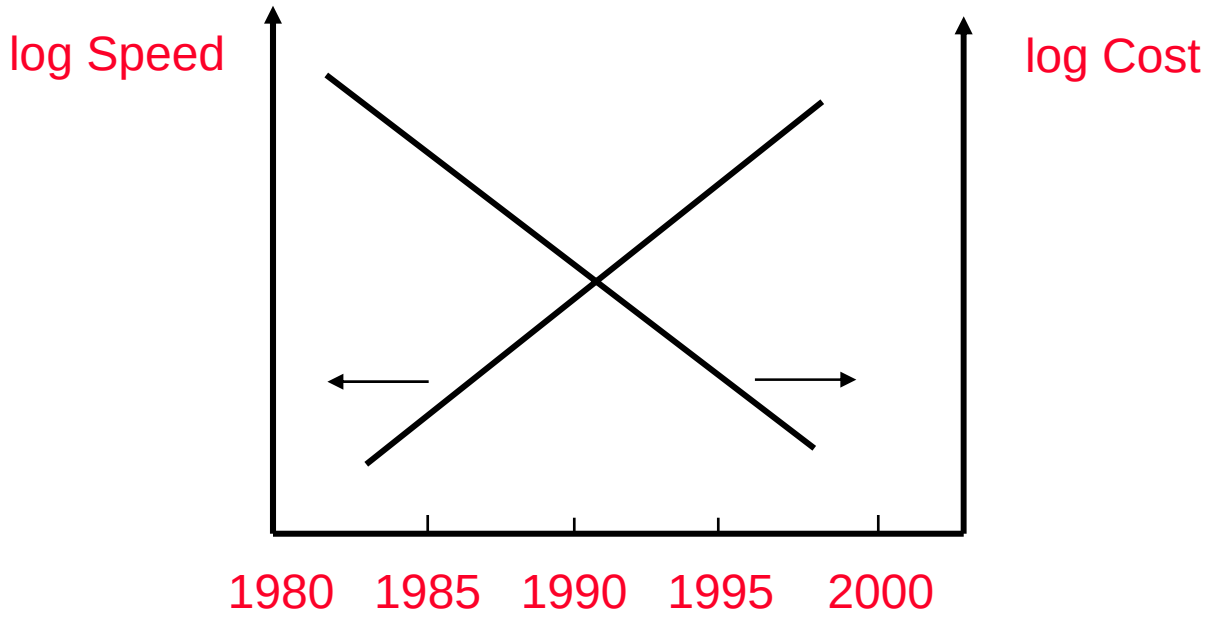
Moore's Law:

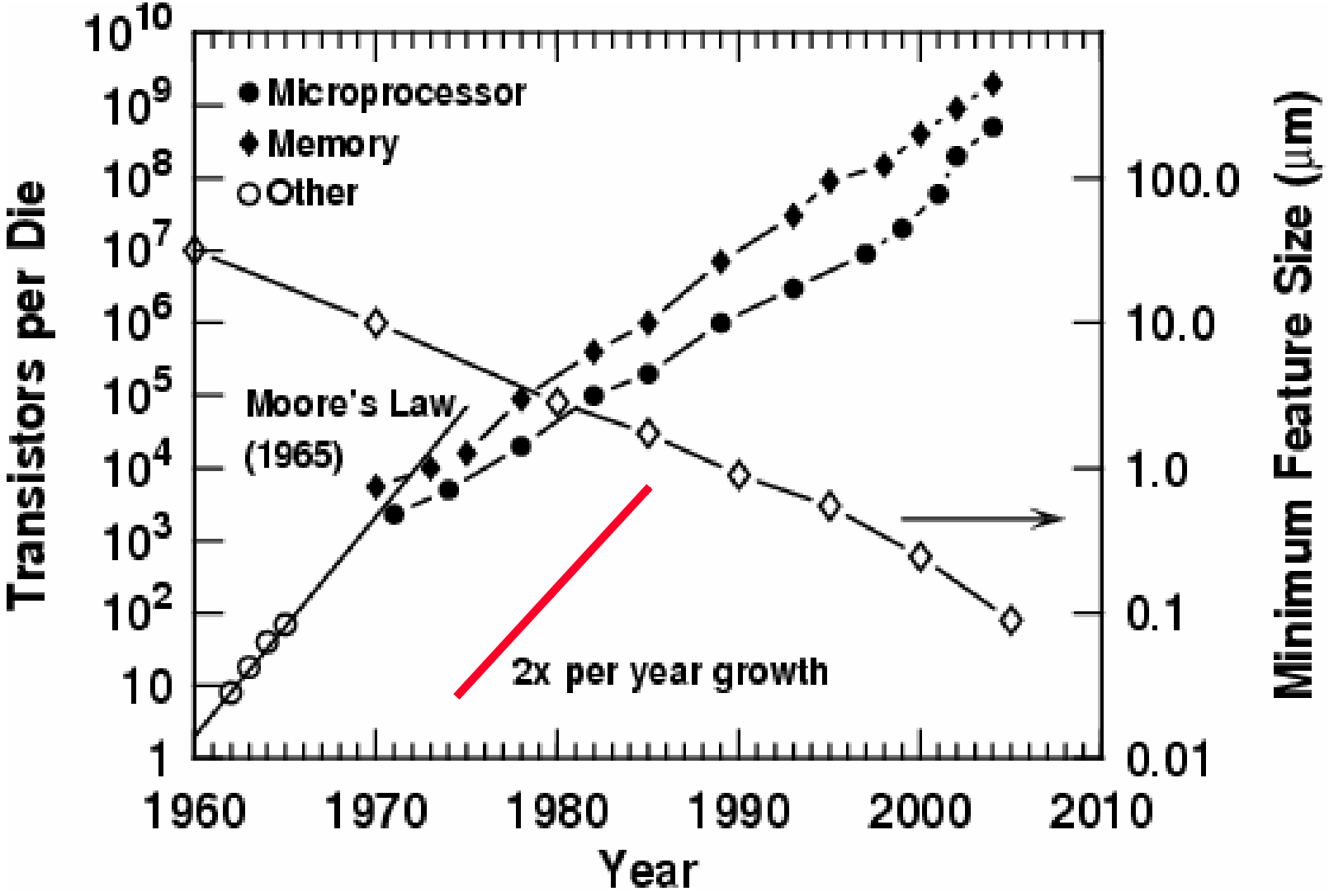
The defining features of the integrated circuit technology follow an **exponential** growth pattern over time.

Moral: Computing power ↑ and cost ↓ exponentially!



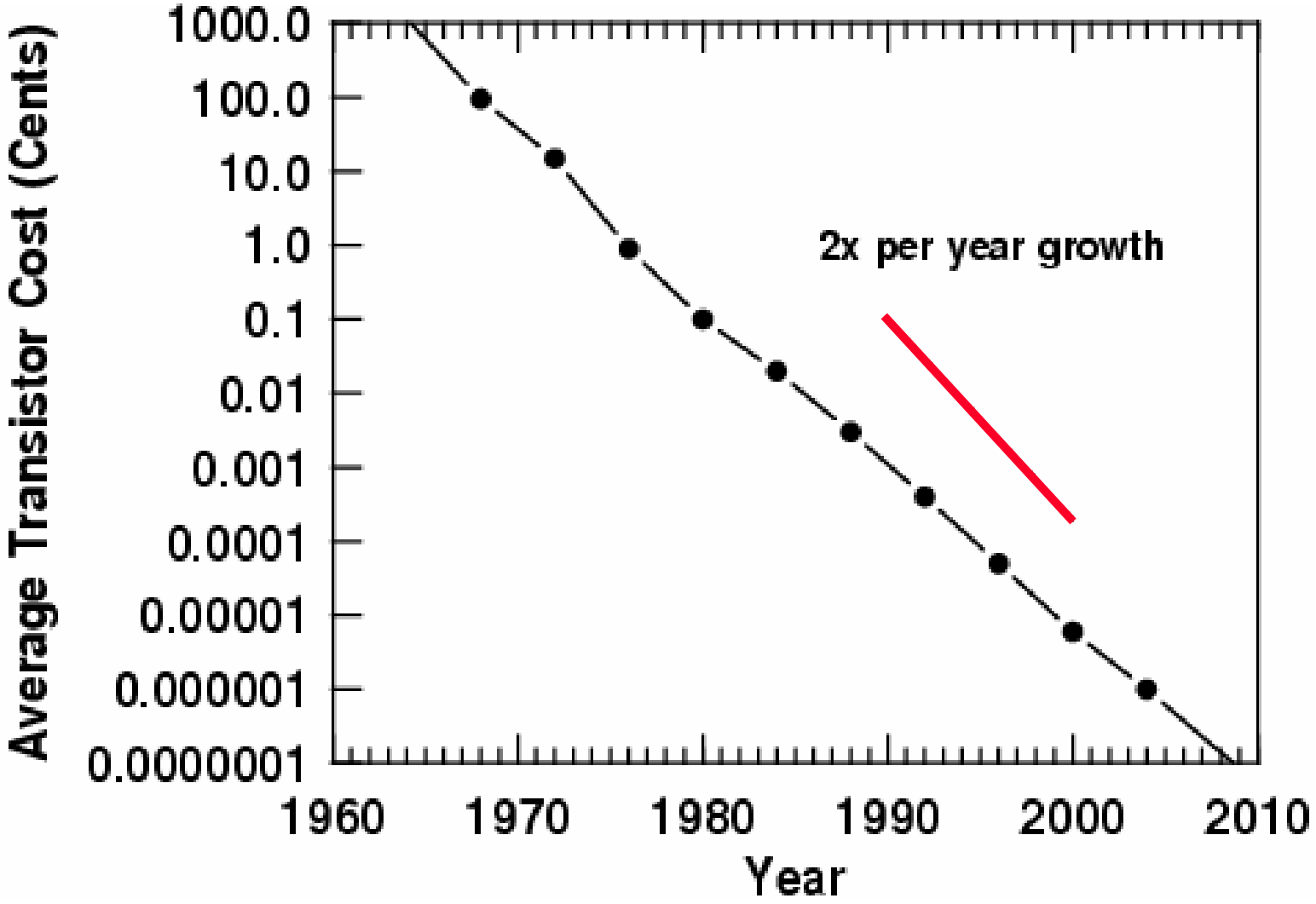
Examples: µP speed, logic gates, memory density, lithography, cost, etc.

Examples



after G. Moore

Examples



after G. Moore

A Concrete Example

What a Model T Ford would look like today, if it had improved at the same rate as computer technology (2x per 18 months)?

Parameter	Model T (1913)	Today
Speed (mph)	50	145,361,703,700,000,000,000,350,000
Efficiency (mpg)	20	58,144,681,470,000,000,000
Cost (1993 $)	20,000	0.000,000,000,000,006,88
Mass (kg)	1,000	0.000,000,000,000,000,343
Luggage (ft^3)	18	52,330,213,320,000,000,000

1913 Ford
Model-T Runabout

A Bit of Trivia …

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What Date Marks The Birth Of The Information Age?

And The Answer Is …

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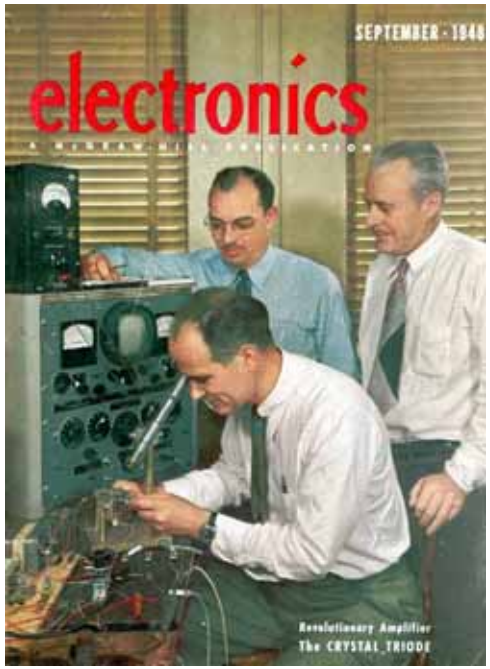
The Invention of the Transistor by: Shockley, Brattain, and Bardeen at Bell Labs

When?



And The Answer Is …

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The Invention of the Transistor by: Shockley, Brattain, and Bardeen at Bell Labs

1947

And The Answer Is …

Georgia Institute of Technology

The Invention of the Transistor by:
Shockley, Brattain, and Bardeen
at Bell Labs

December 23rd, 1947

And The Answer Is …

Georgia Institute of Technology

The Invention of the Transistor by:
Shockley, Brattain, and Bardeen
at Bell Labs

December 23rd, 1947

… at 5:00 pm

The First Transistor

Only 50 Years Later!

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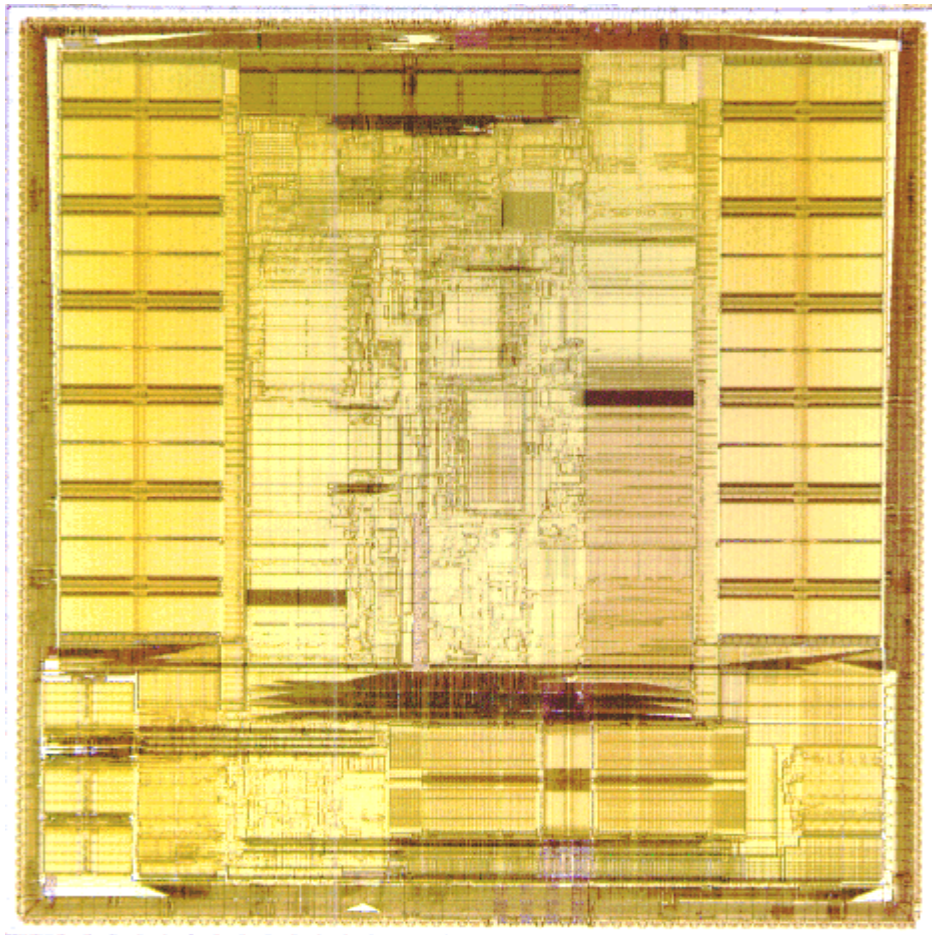
- DEC Alpha 21164 (1,000,000,000 instructions per second)
- 9,300,000 transistors!



Some More Trivia!

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How Many Transistors Are There

On Planet Earth?

???

The Number's Game

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In 2007, There Are Approximately

10,000,000,000,000,000,000

($1x10^{19}$)

Transistors On Planet Earth!

For Comparison:

- the universe is about $4.2x10^{17}$ sec old (13.7 billion years)!
- there are about $1x10^{21}$ stars in the universe!
- the universe is about $4x10^{23}$ miles across (15 billion light-years)!

The Number's Game

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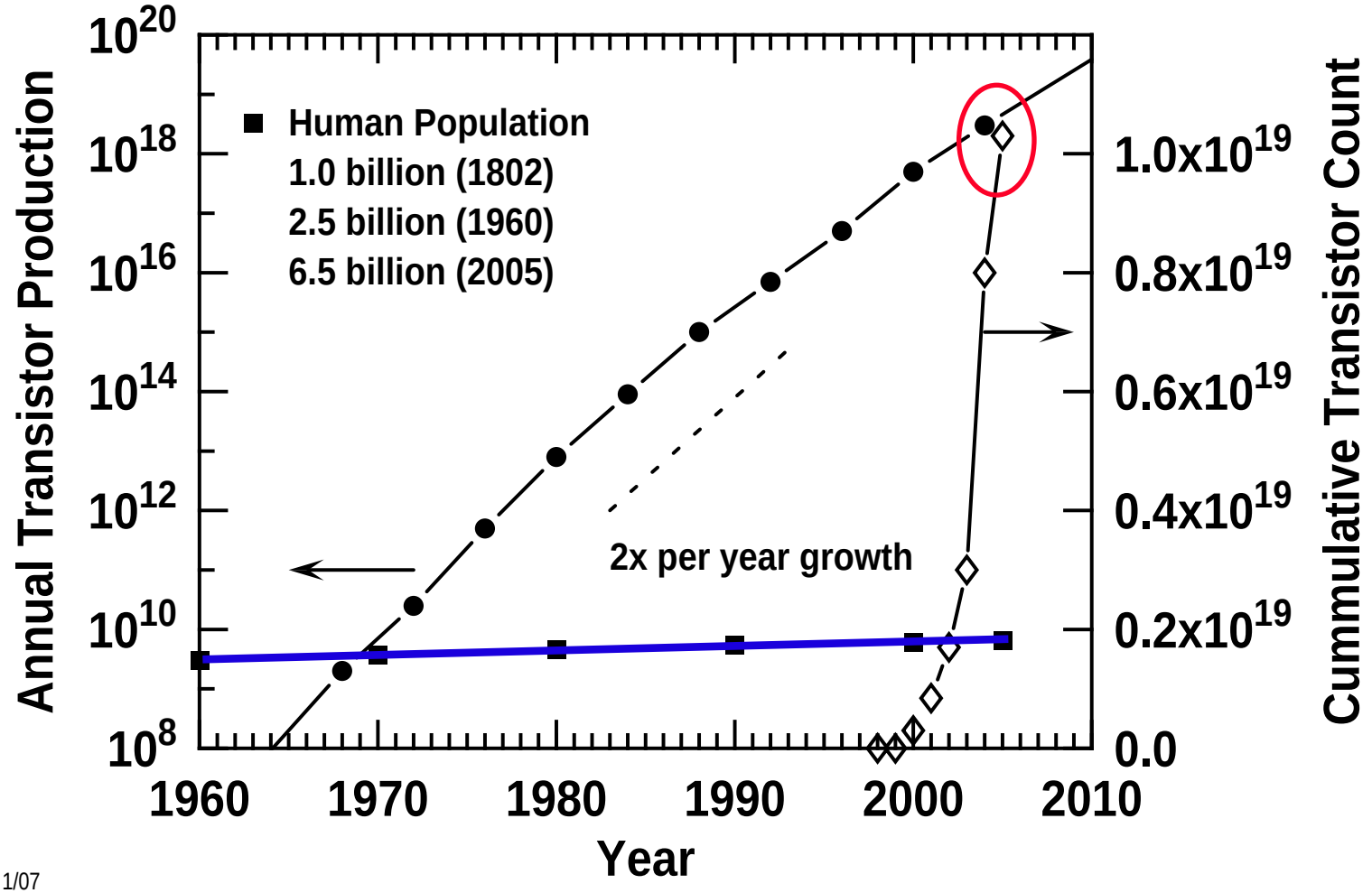
From 0 Transistors to 10,000,000,000,000,000,000 … in only 60 years!



The Number's Game

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That Is Roughly …

1,538,461,538 Transistors

For Every Person on Planet Earth!

The Number's Game

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And … You Could Hold Those

1,538,461,538 Transistors

In The Palm Of Your Hand!

A Deeper Look

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How ?

Redefining Fast & Small

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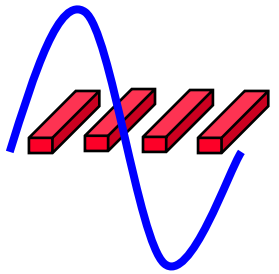
Our Digital World:

- A “transistor” is simply a very tiny, very fast on/off switch (“1” or “0”)
- In 2006, one transistor is about 0.10 microns (100 nm) wide

The Size of Transistors:

- The wavelength of visible light is 0.4 - 0.7 microns.
- 4 transistors could fit inside one wavelength of blue light!



The Speed of Transistors:

- This 0.10 micron transistor can switch from a logical “1" (on) to a logical “0" (off) in about 10 picoseconds (0.00000000001 seconds).
- For comparison, light (186,000 miles/sec) travels only 3 mm during the time it takes to switch this transistor from a “1” to a “0”

A Silicon IC Zoom In …

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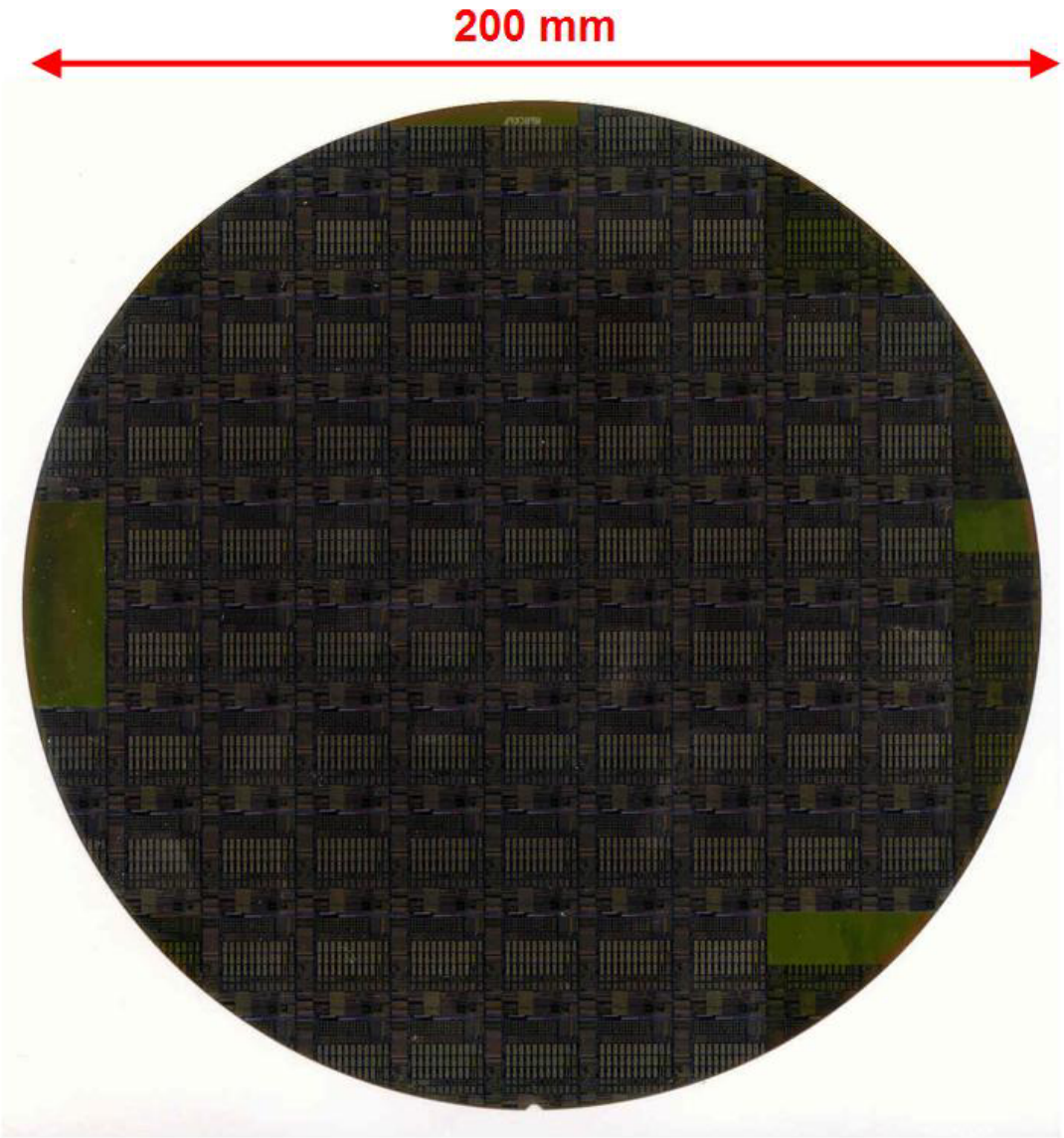
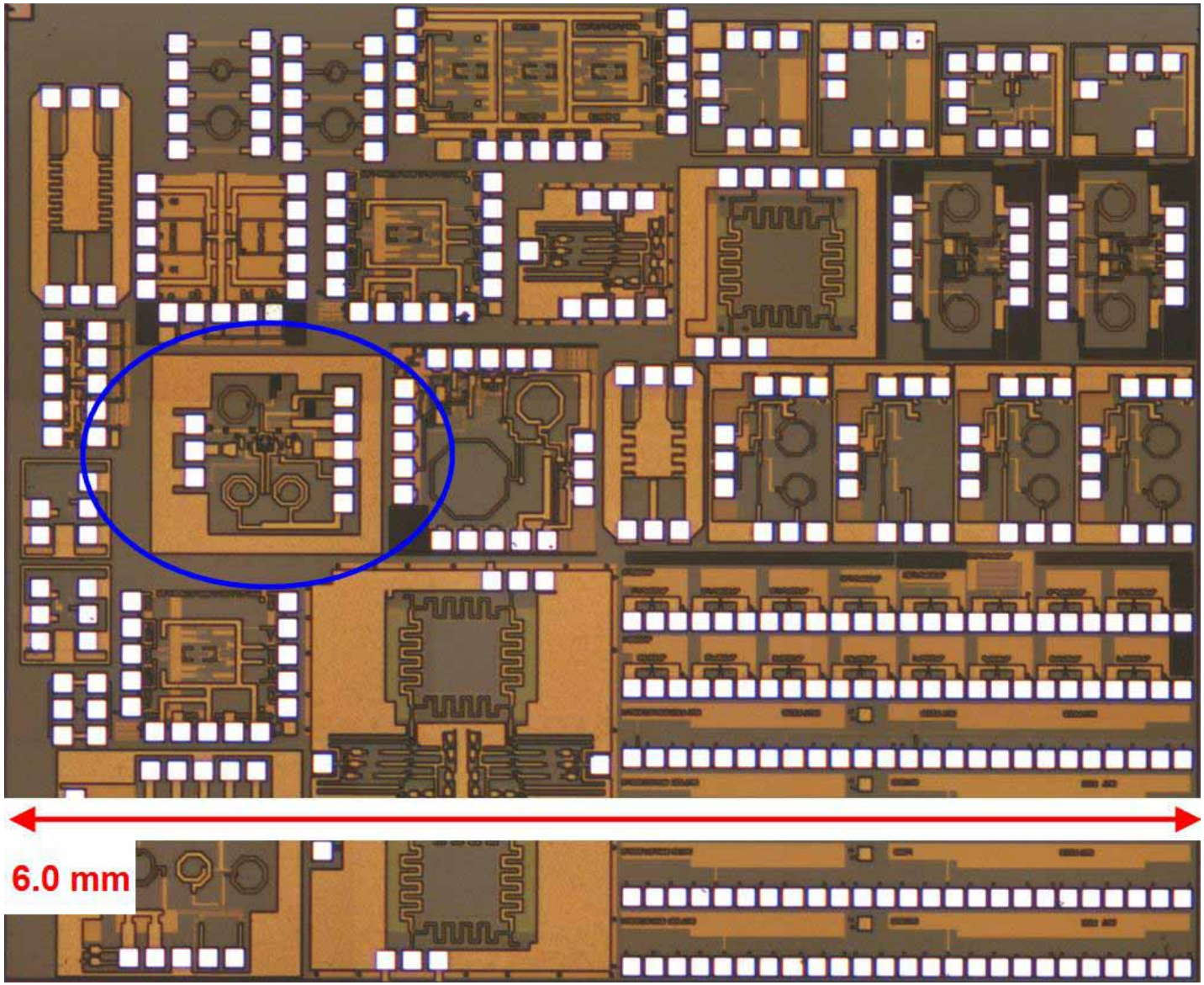


A Closer View



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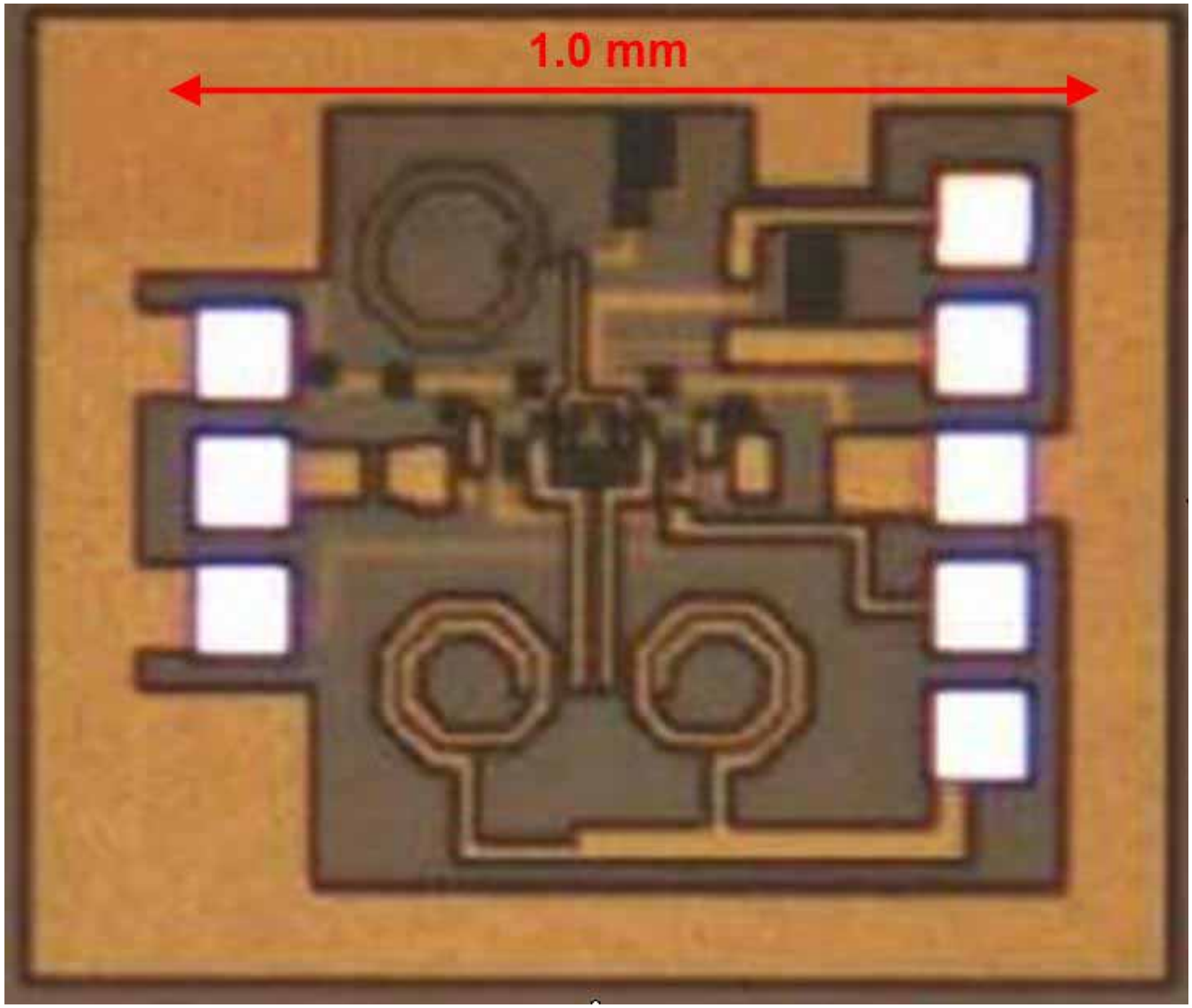

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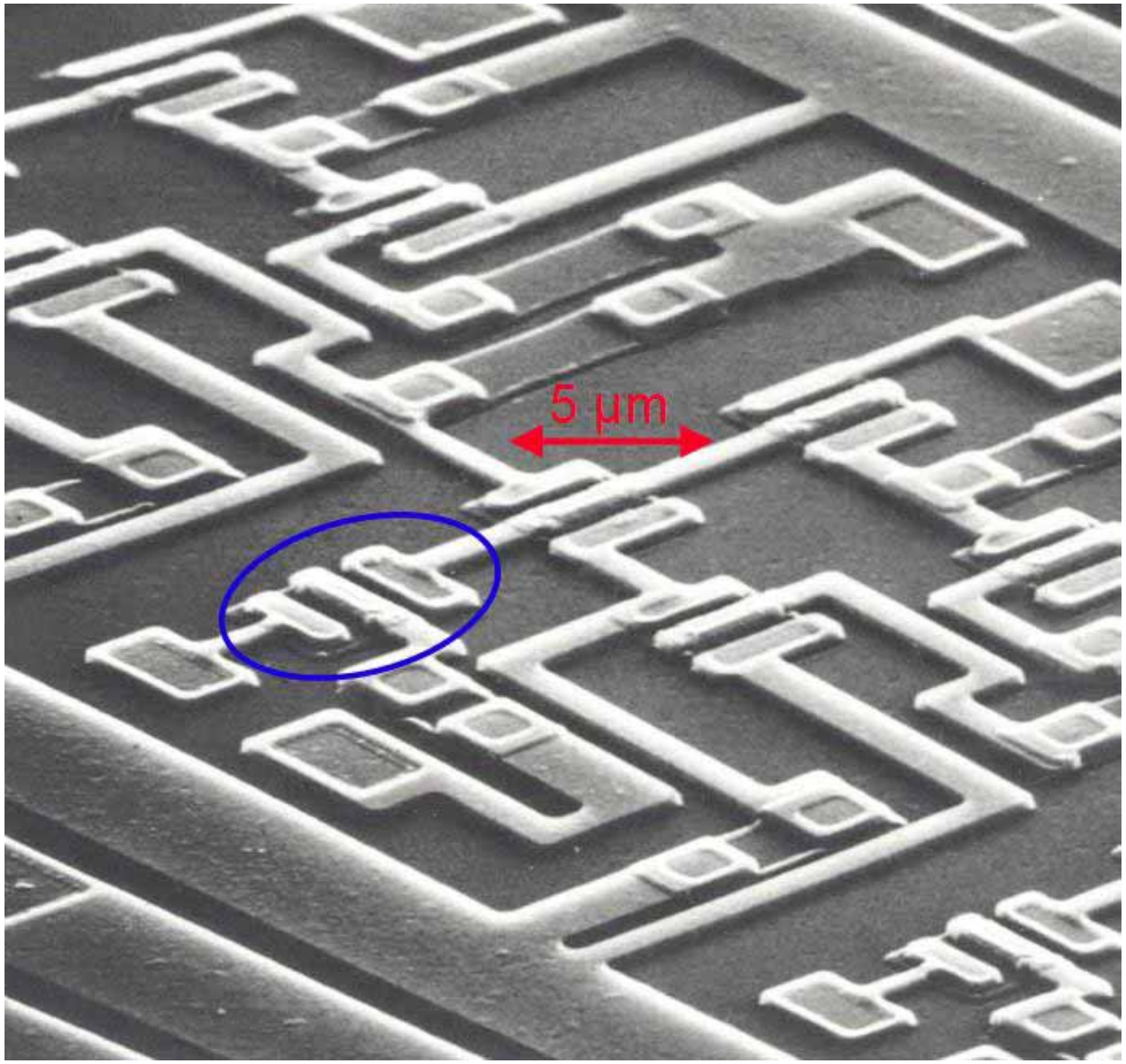

Mr. Transistor

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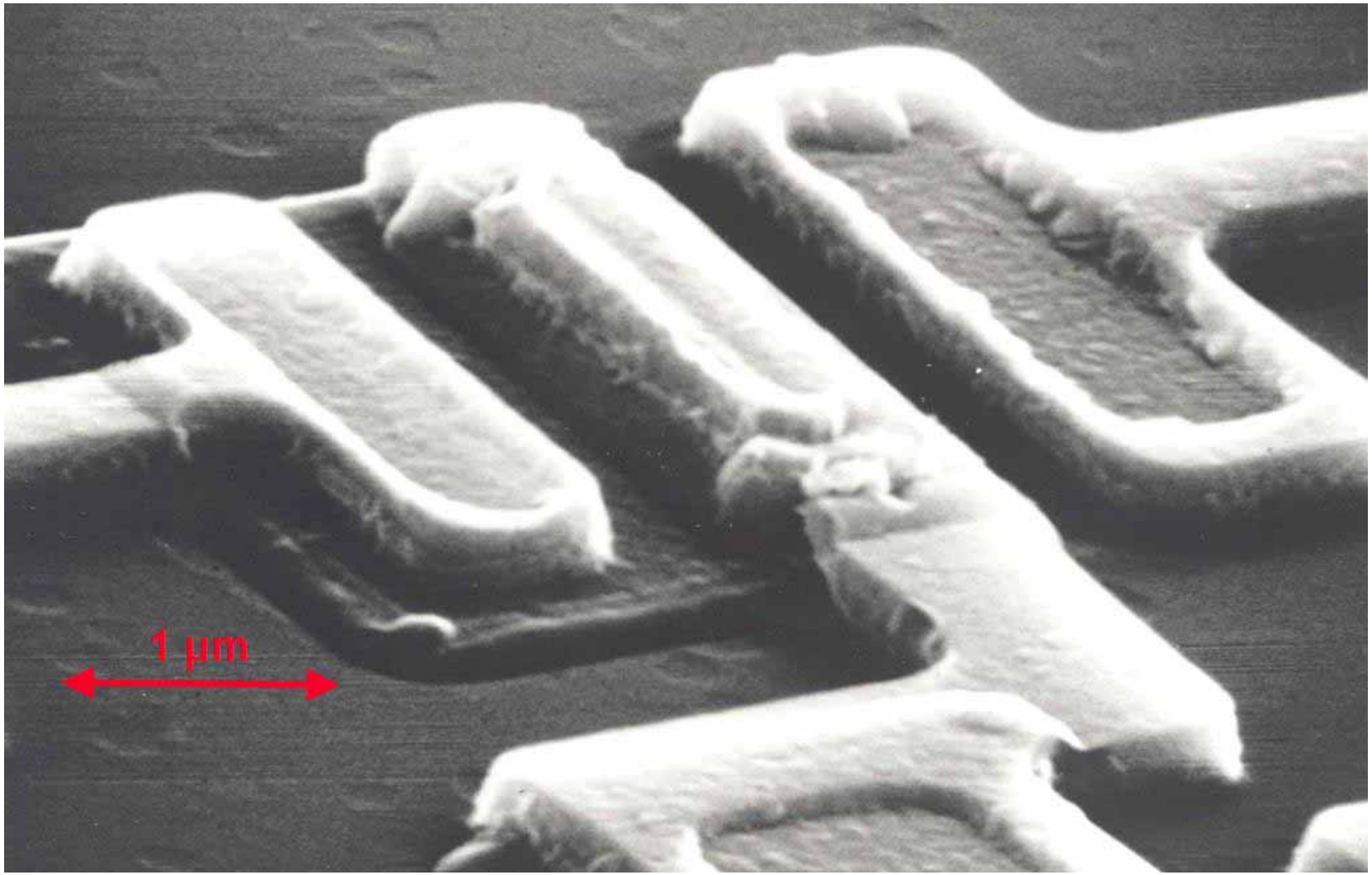
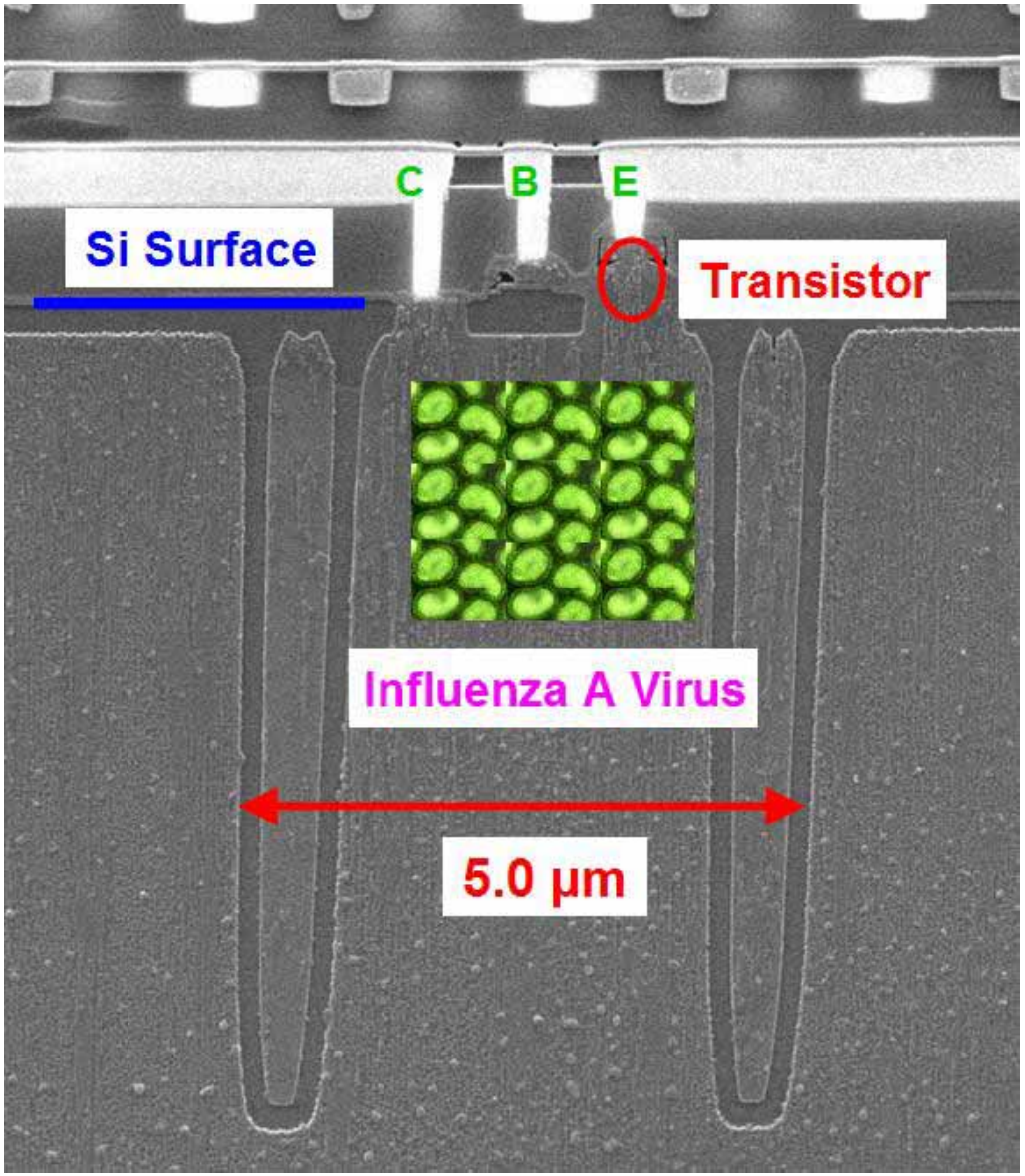
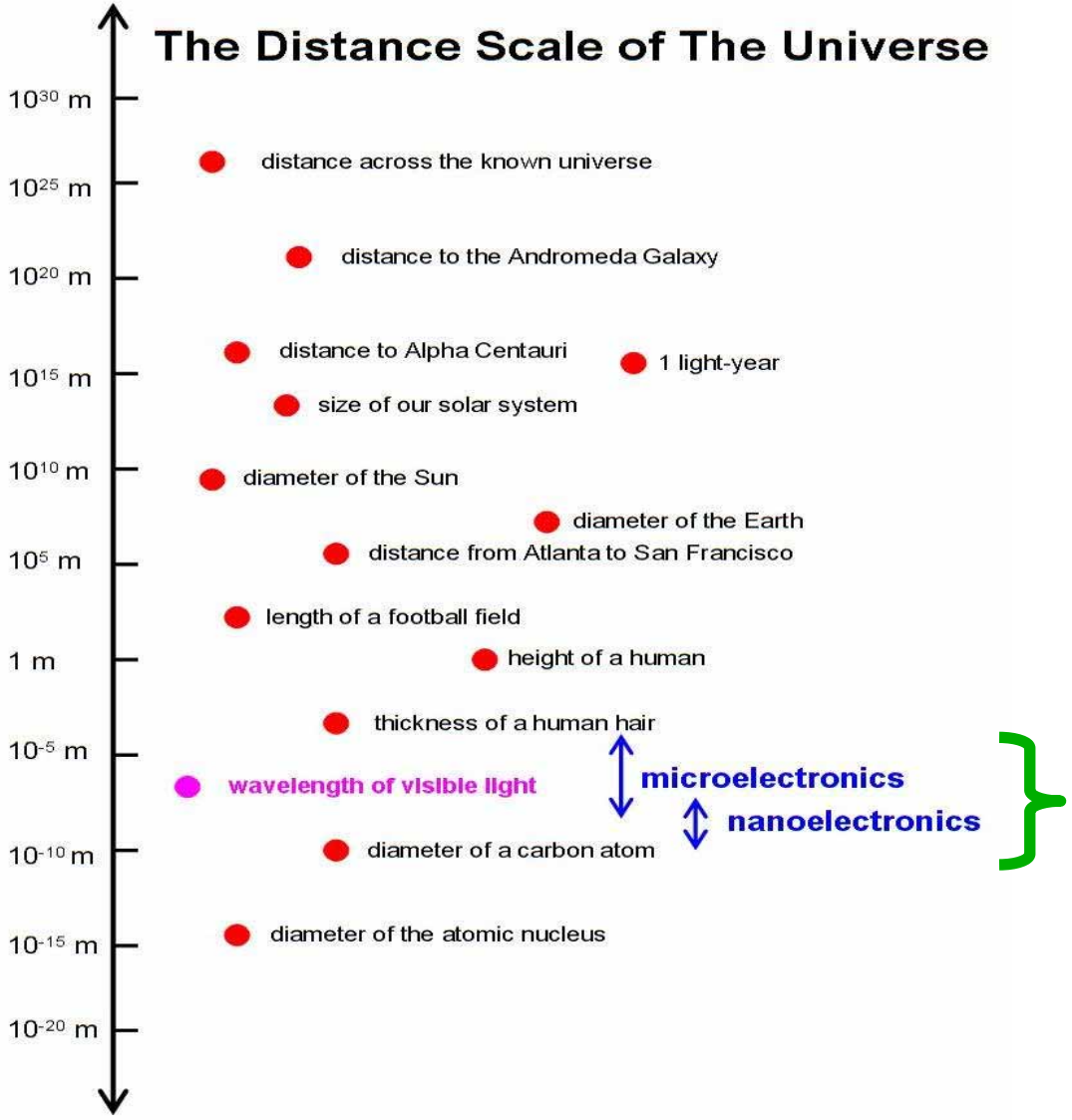


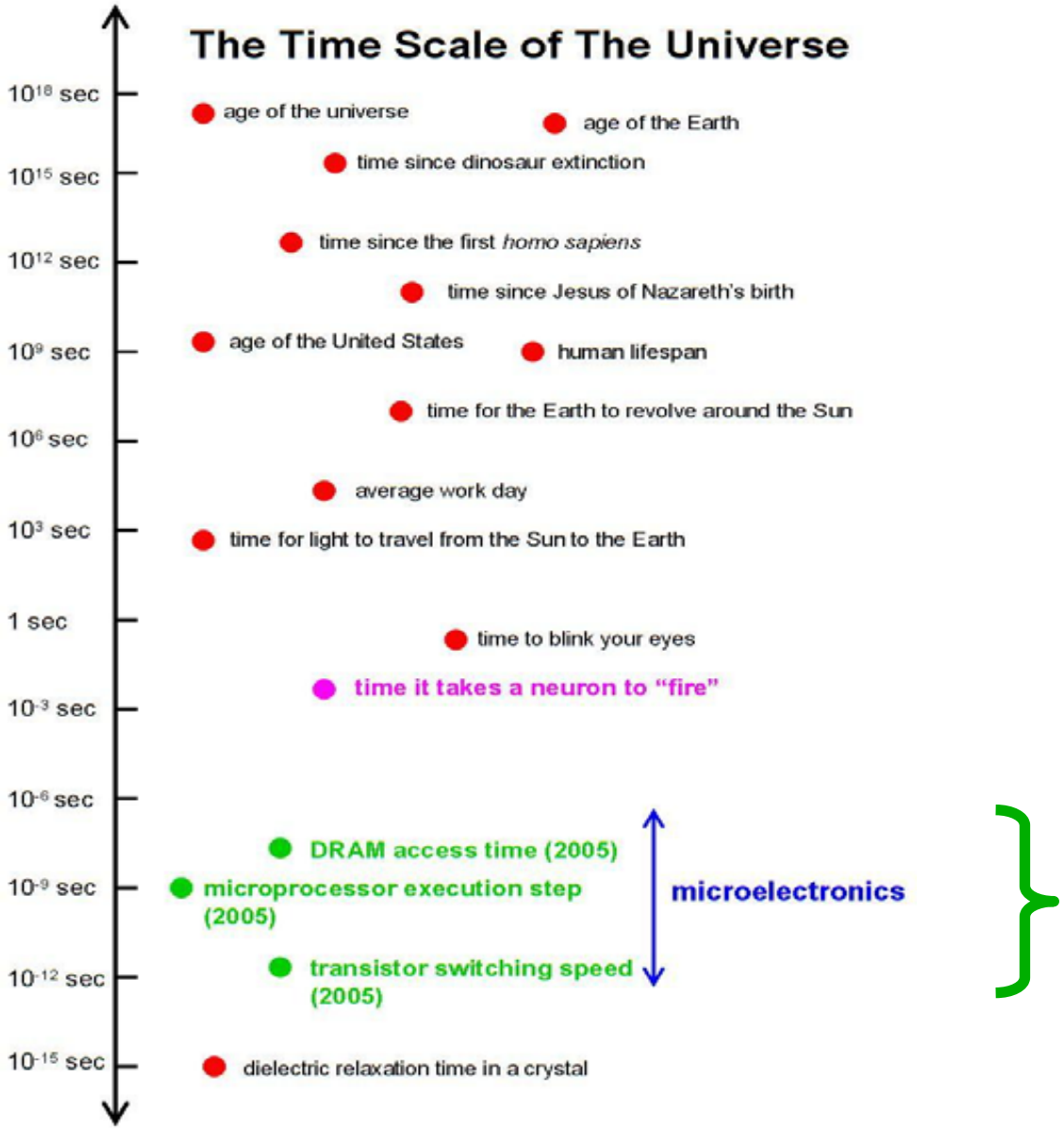
Inside Mr. Transistor



Universal Distance Scale



Universal Time Scale



Where Will It All End?

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- **Semiconductor Industry Association Projections (ITRS Roadmap)**

Metric	In 2011
Transistor Size	0.05 μm (< 100 atoms)
Memory Bits / Chip	16,000,000,000 bits
Logic Transistor Count / Chip	100,000,000 devices
Number of I/O's	4,800 I/O pins
Power Supply Voltage	0.6 V

What's on the Horizon?

Data Bandwidth:

40Gb/sec electronics + 128 colors = 1,500,000,000,000 bits/sec (1.5Tb/sec) on one optical fiber line

Bandgap Engineering of Electronic Devices:

Mix different semiconductors together at the atomic level to speed them up **(SiGe)**

Quantum Effect Devices:

Store information on a single electron!

Molecular Electronics:

Biologically-inspired computing and the silicon / tissue interface (living machines?)

ECE and Microelectronics

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The Major ECE Sub-Disciplines:

Microsystems: IC device and circuit fabrication, MEMS, IC packaging, nanotechnology …

Electronic Design: amplifiers, analog, digital, and RF integrated circuits …

Signal Processing: information extraction, data compression, coding, error correction …

Communications: wired and wireless data transmission, signal modulation …

Control Systems: feedback techniques for process control, motor control, aerodynamics …

Electromagnetics: generating and receiving electromagnetic waves, antennas, radar …

Power Systems: generation, transmission, and distribution of electrical power …

Computer Engineering: architecture, VLSI design, verification and test, CAD …

Biomedical Engineering: ECE + biology for health care, nanotechnology, etc …

Photonics: generating, transmitting, and receiving optical signals

Moral: ALL sub-disciplines of ECE require microelectronics!

Food For Thought …

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We Predict The Future …
By Inventing It.

Motto of Xerox PARC