Al 50 aniversario de la Ley de Moore, la nanoelectrónica en una encrucijada

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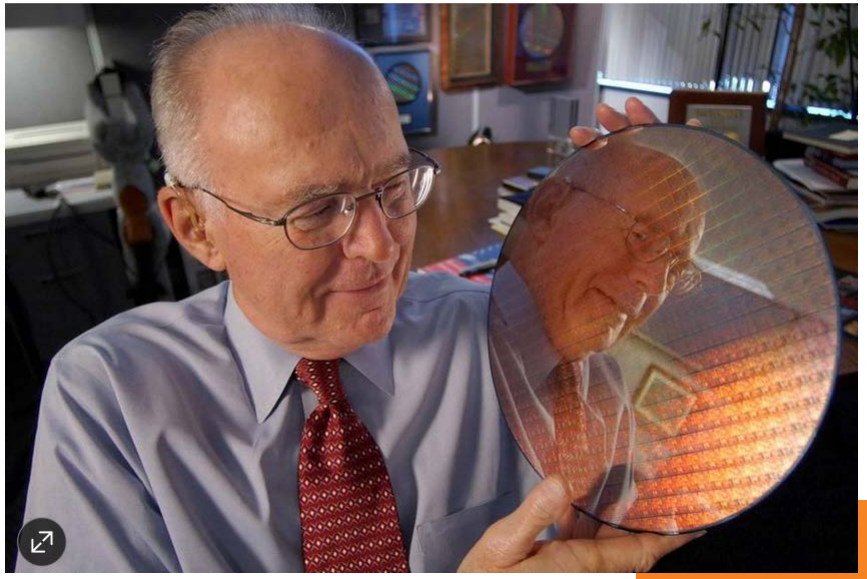
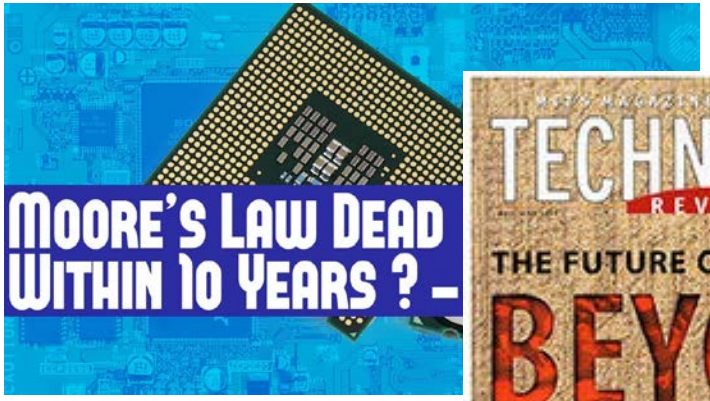
Moore's Law at 50: the end in sight?

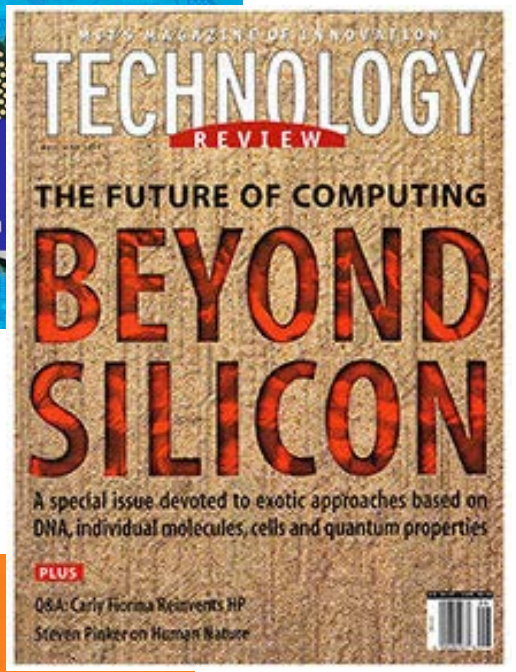
THE WALL STREET JOURNAL.

Moore's Law Is Showing Its Age

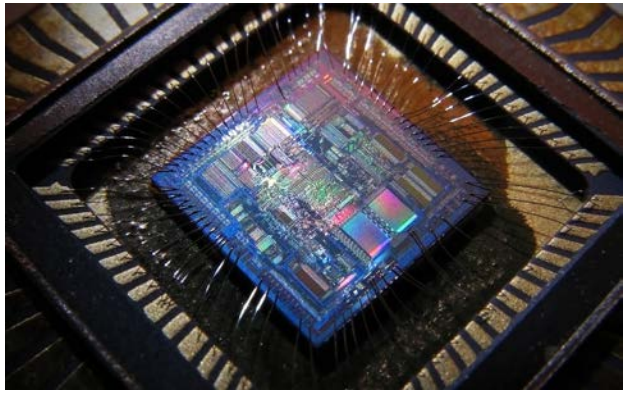
The prediction about squeezing transistors onto silicon has been revised again.



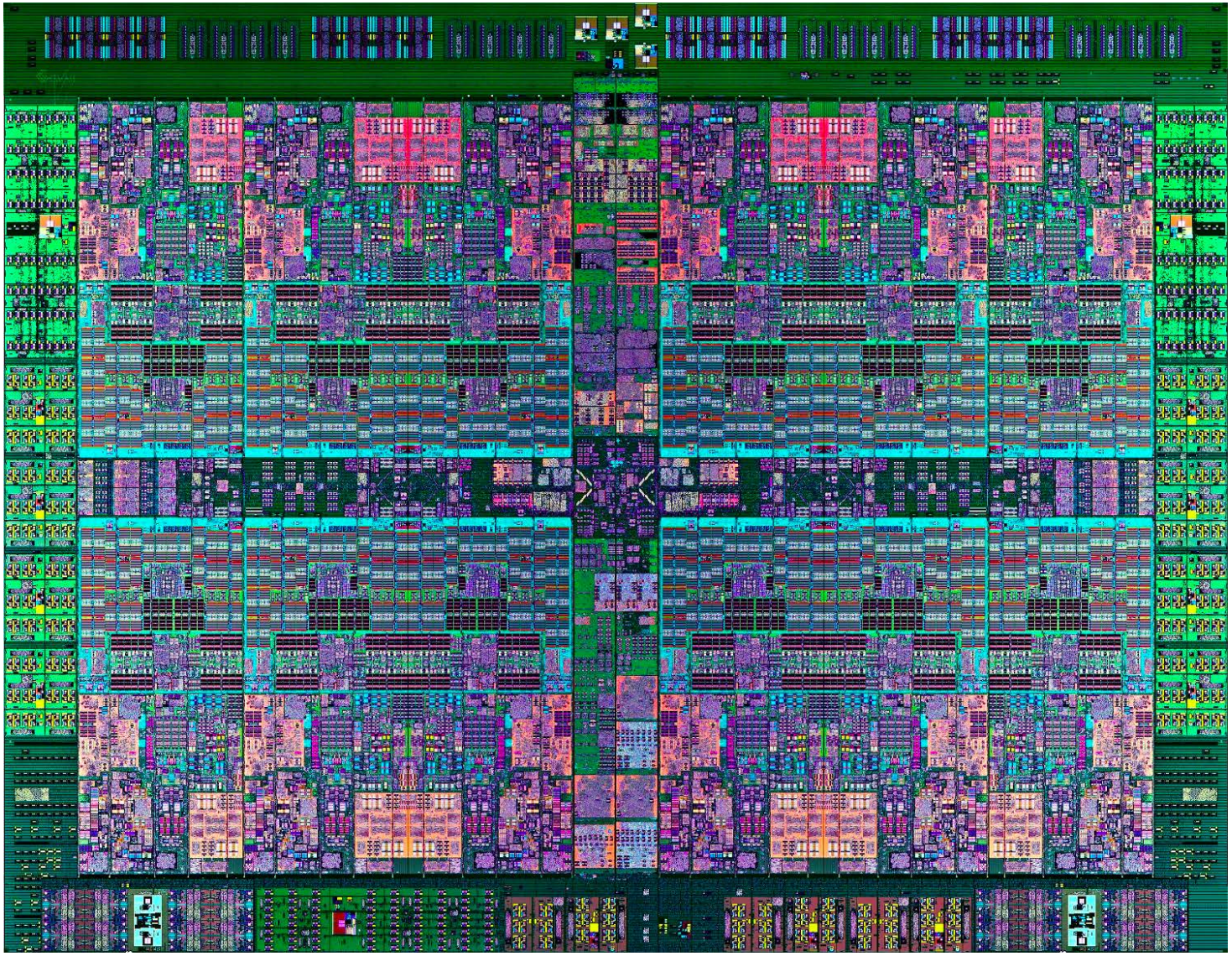




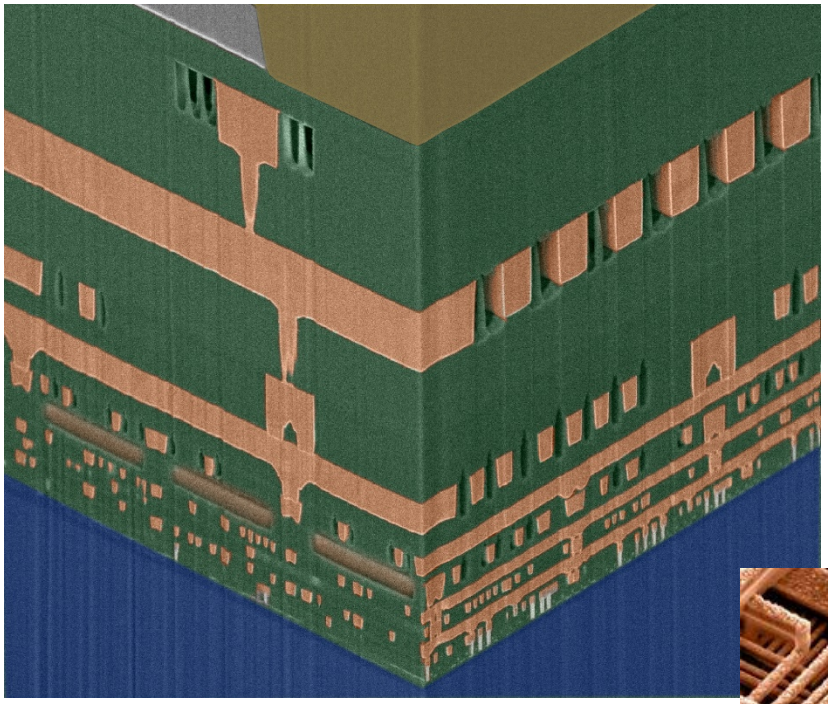
Nanoelectronics: the brains of our information society

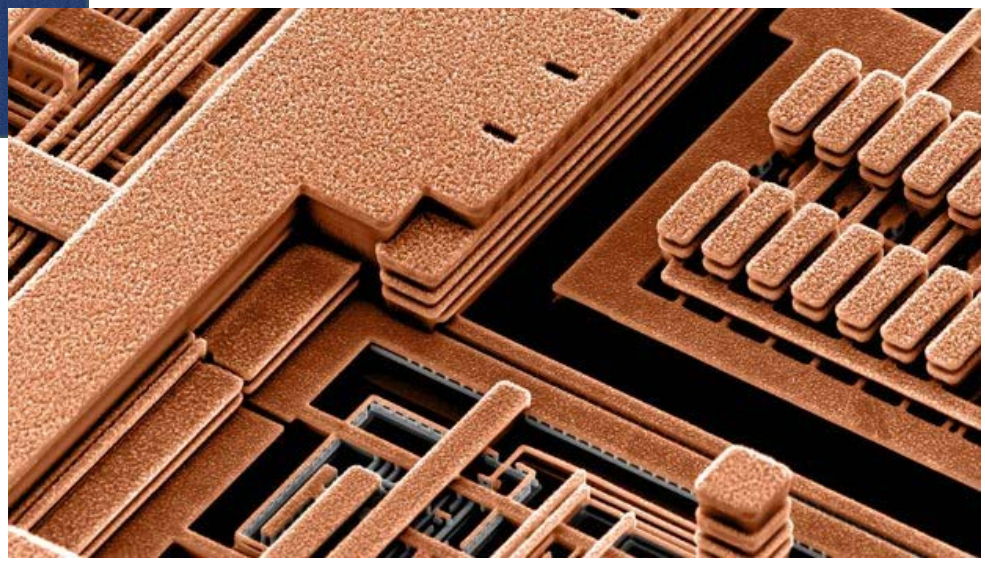


Integrated circuits



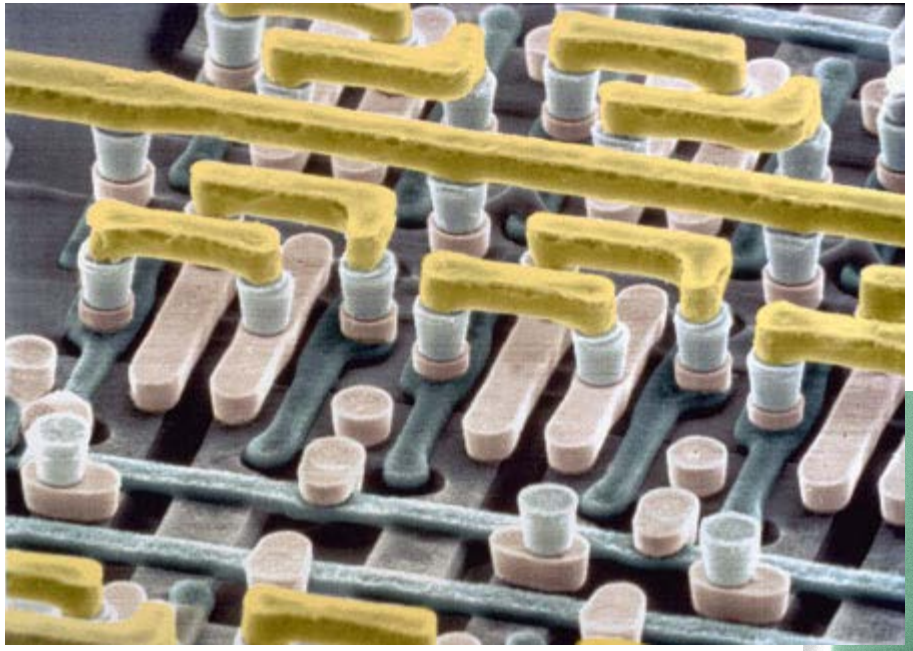
Interconnects

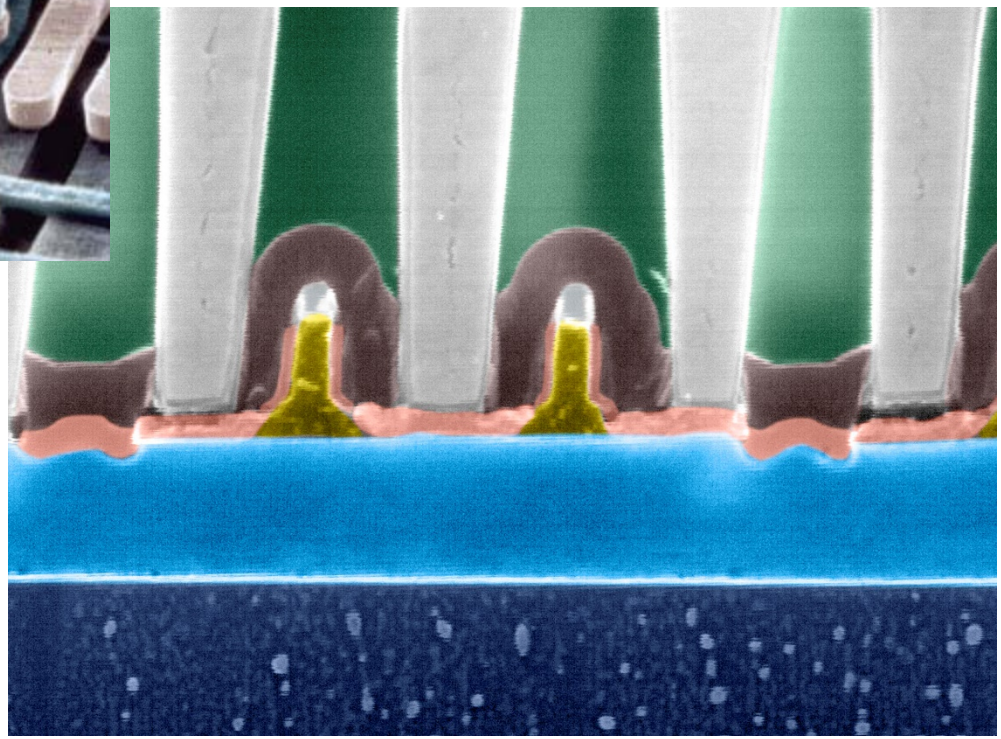




IBM Image Gallery

Transistors





IBM Image Gallery

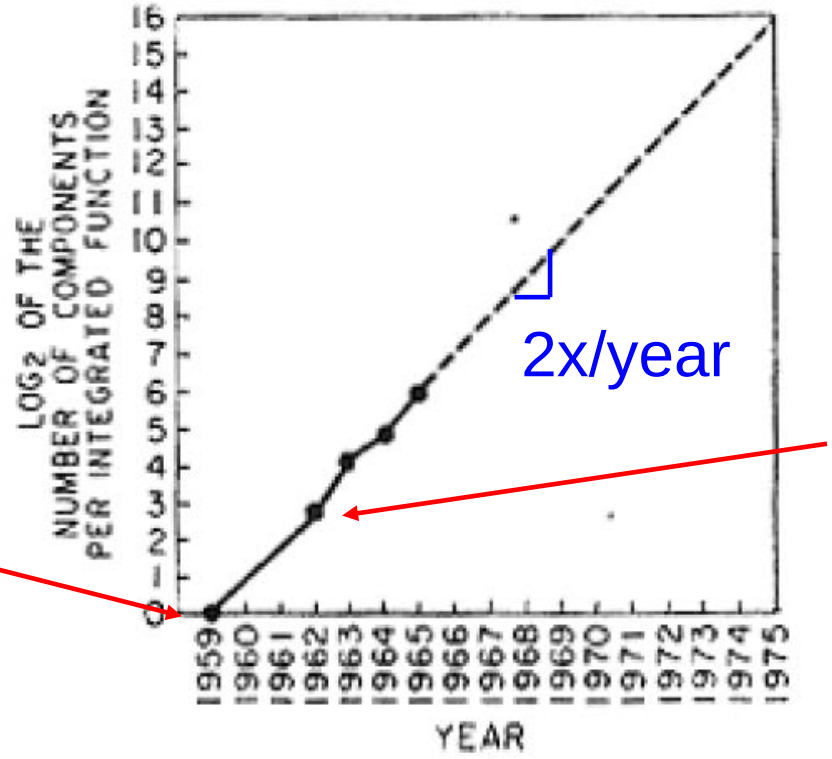
Moore's Law

"It's not a law in any real respect. It was an observation and a projection."

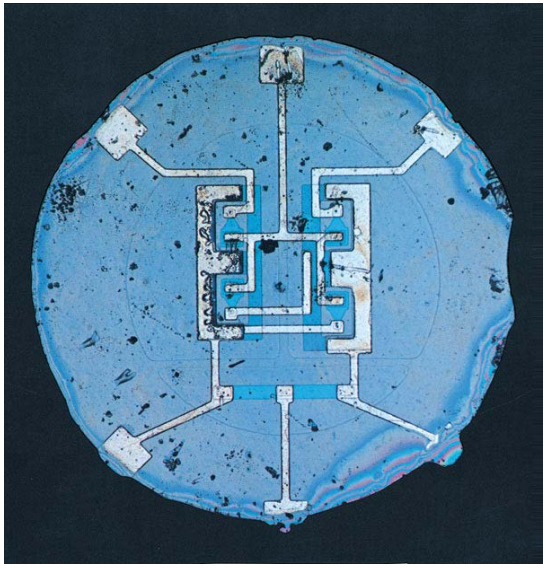
Gordon Moore, IEEE Spectrum 2015

Moore's observation, 1965

first planar transistor (1959)



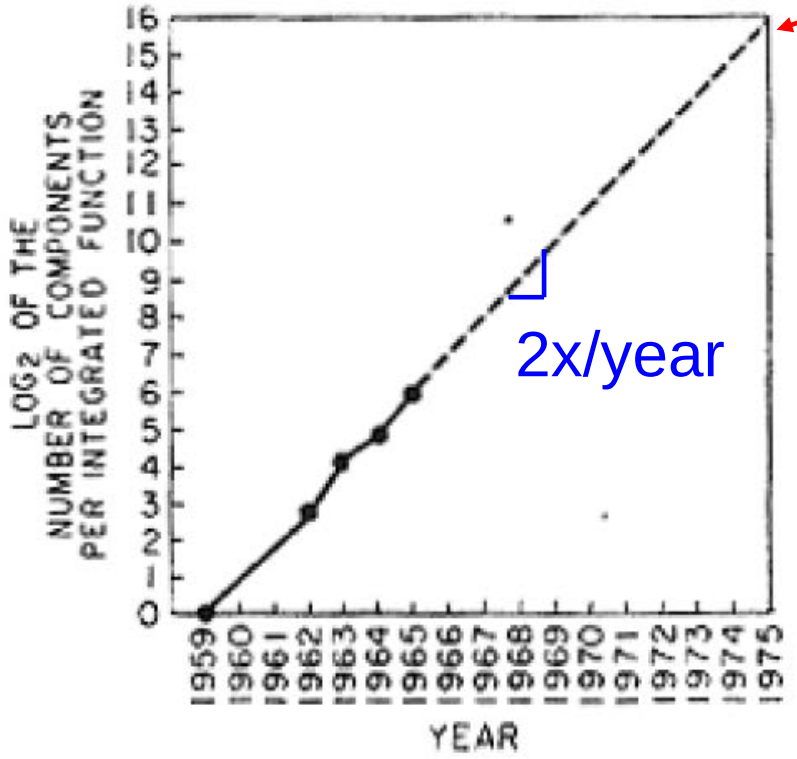
first commercial integrated circuit (1961)



Moore, Electronics 1965

Moore's prediction, 1965

Moore, Electronics 1965

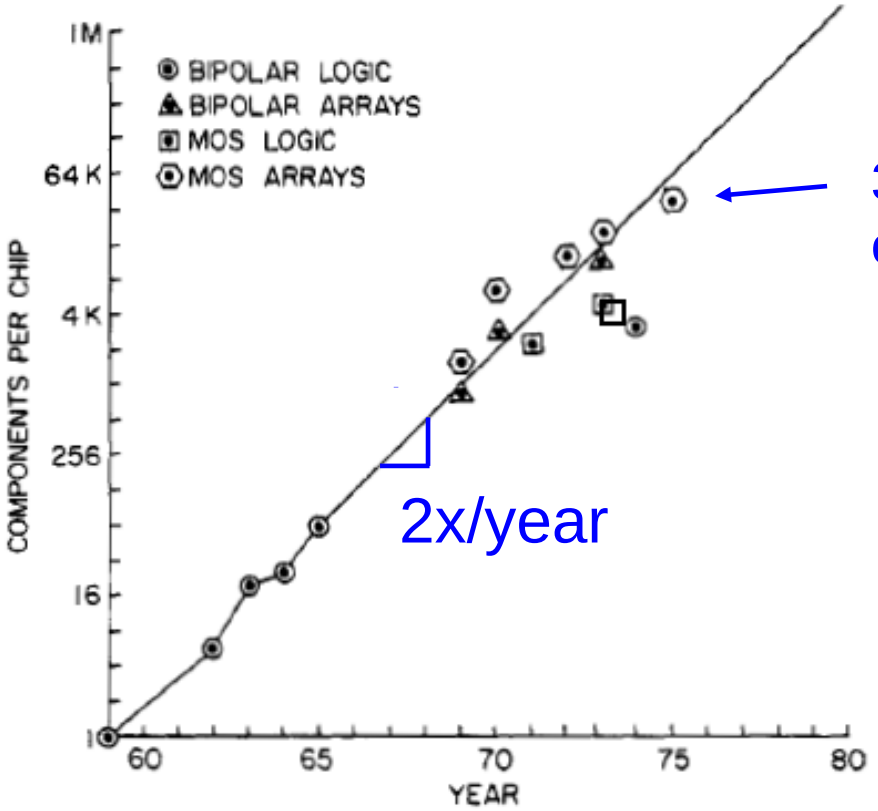


$2^{16} \sim$ 65,000 components by 1975

2x/year

"By 1975, the number of components per integrated circuit for minimum cost will be 65,000."

10 years later…

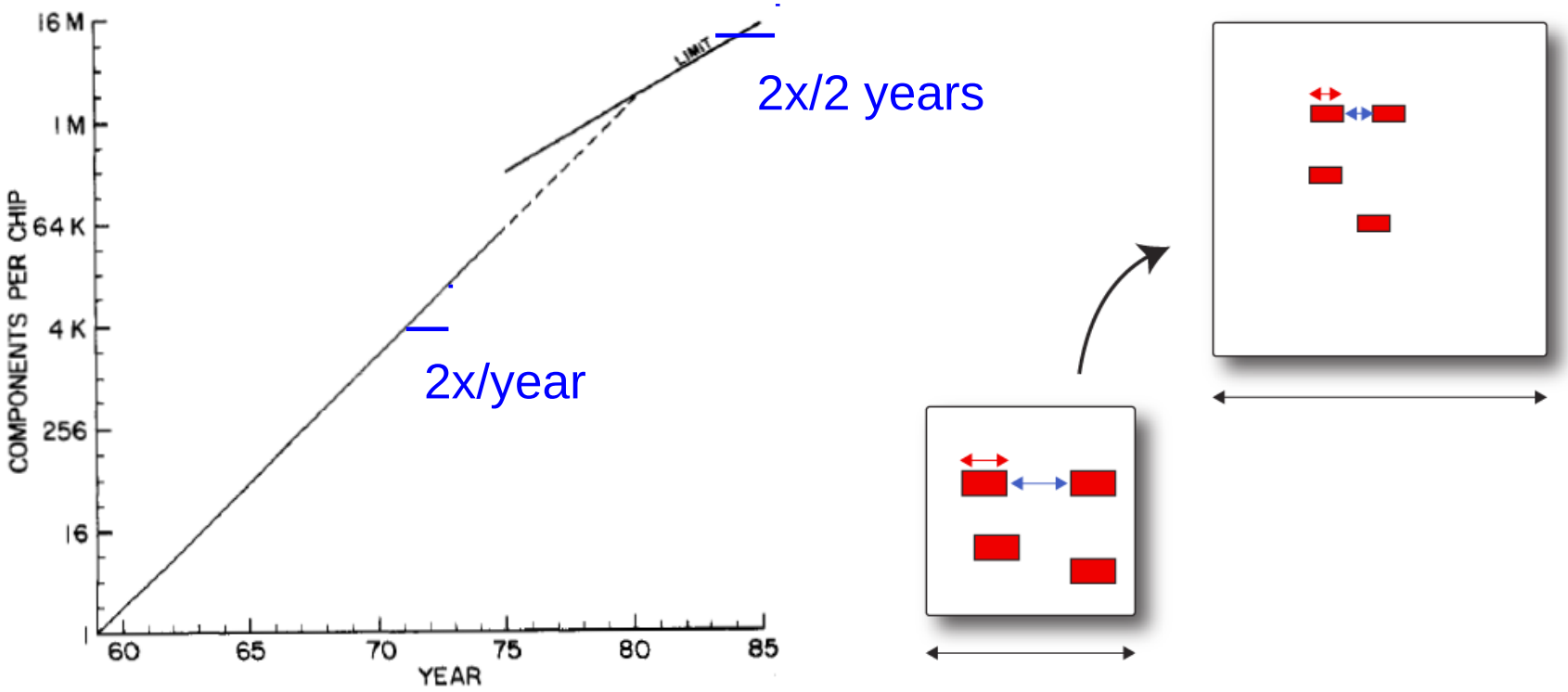


32,000
components/chip

2x/year

Moore, IEDM 1975

Moore's revised prediction, 1975



1975 prediction:

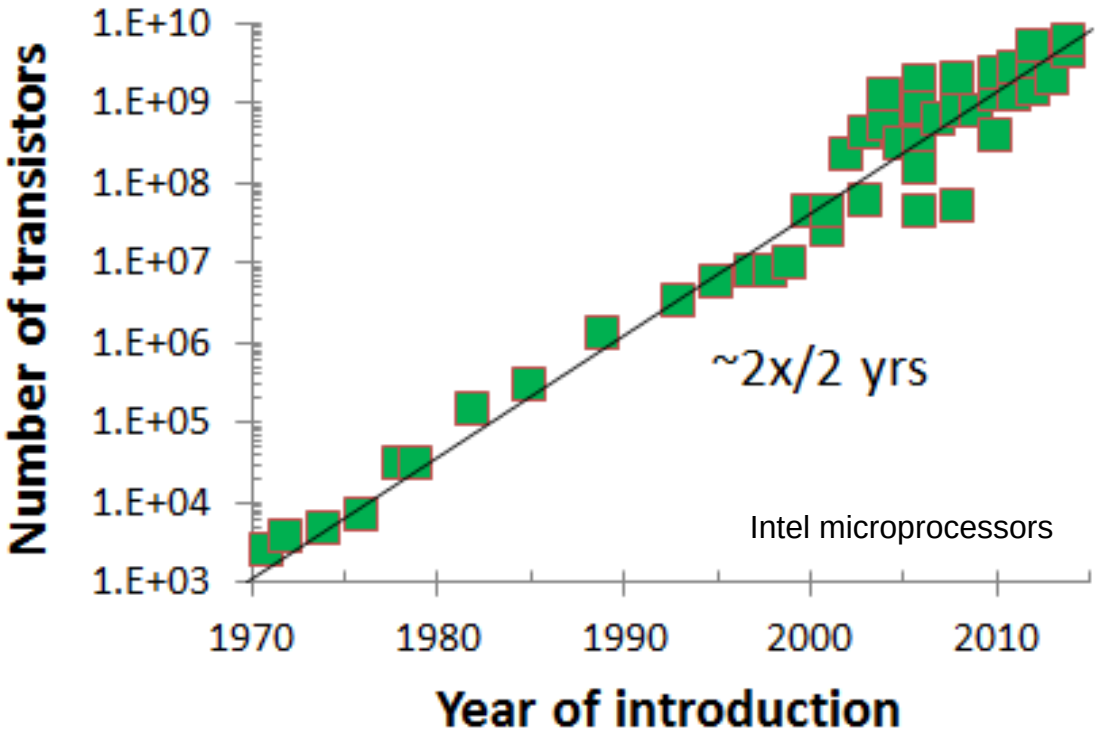
Moore, IEDM 1975

"By the end of the decade, the new slope might approximate a doubling every two years"

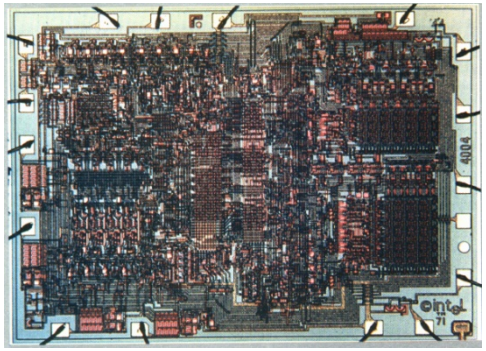
Moore's Law: 1970-2015

2x/2 years or

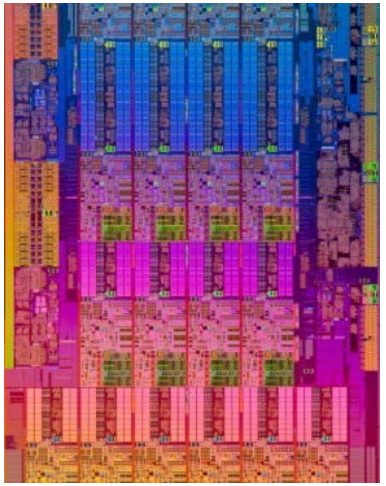
>40%/year for 45 years!



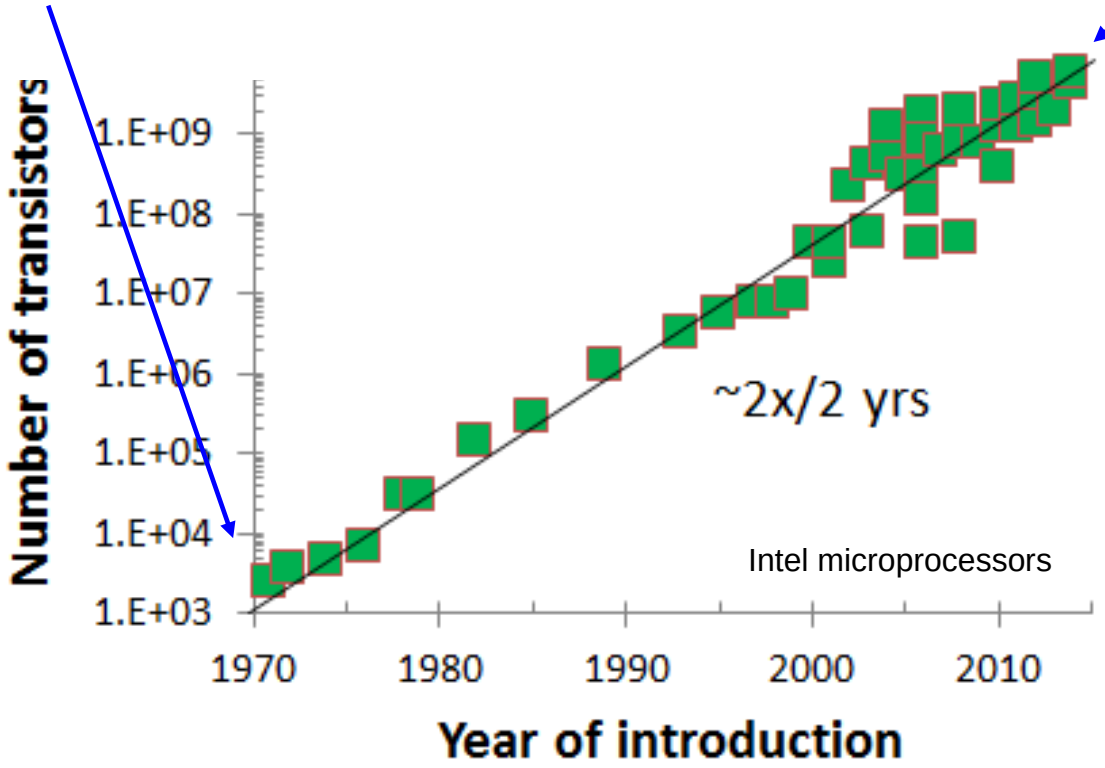
Moore's Law: 1970-2015



1971:
Intel 4004
2250 transistors



2014:
Intel Xeon Haswell-E5
5.6B transistors



After 50 years of Moore's Law

transportation

information

energy

medicine

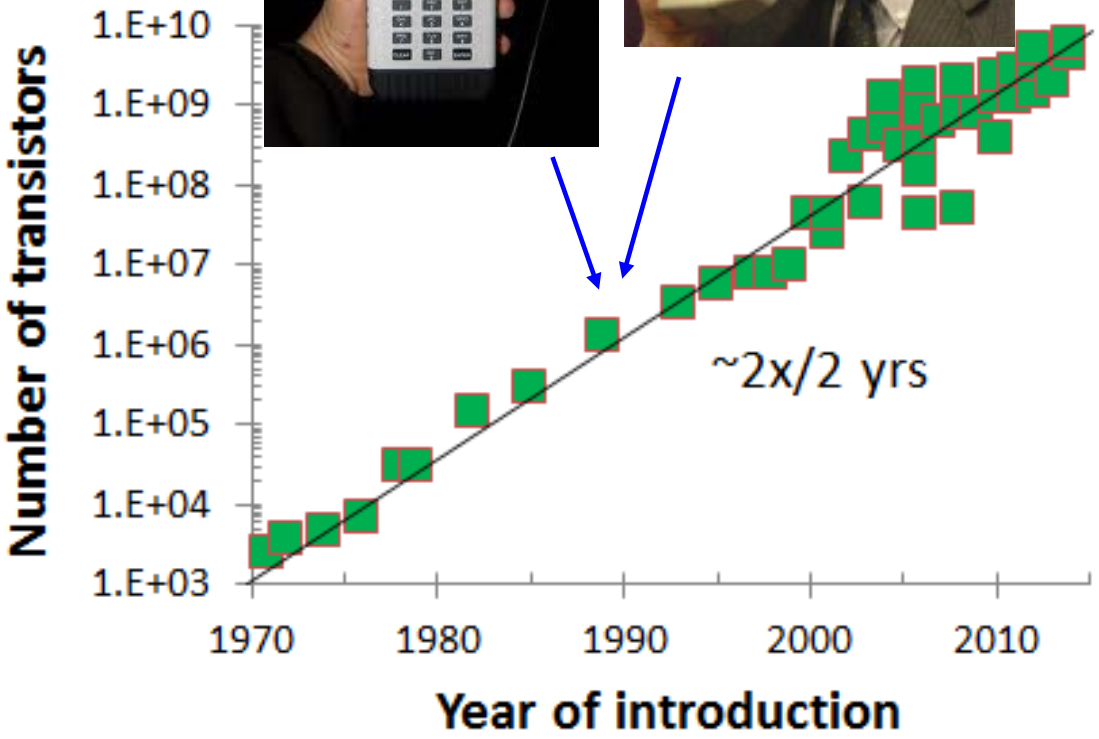
manufacturing

entertainment

What if Moore's Law had stopped in 1990?

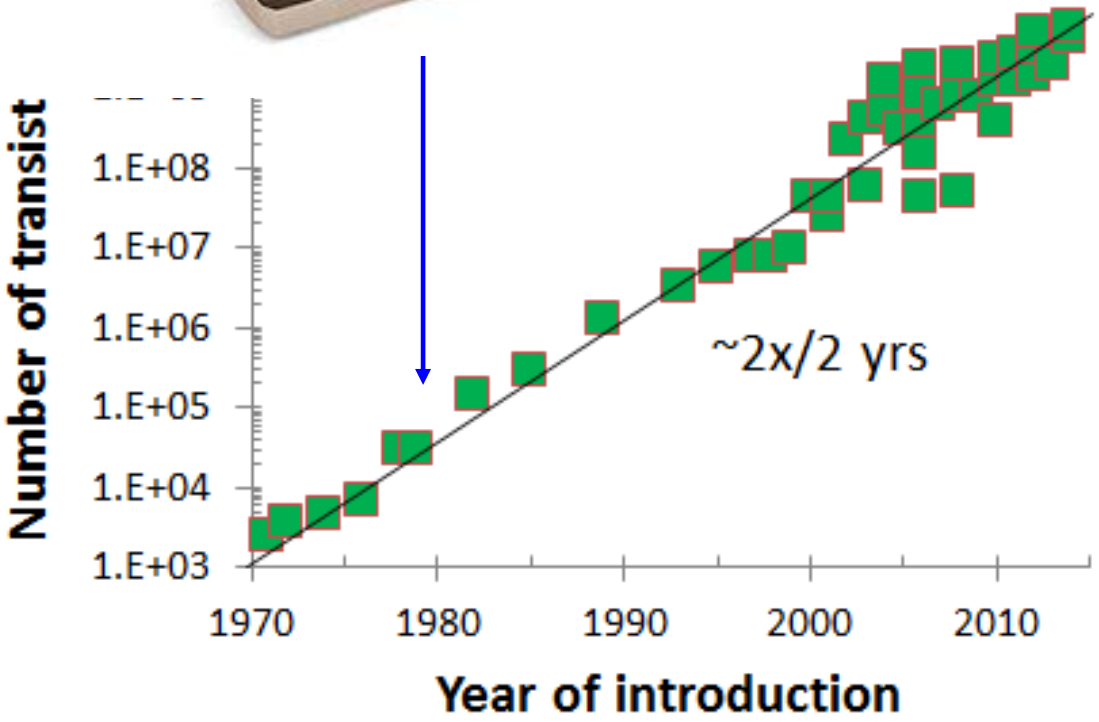
GPS handheld device circa 1990

Cell phone circa 1990



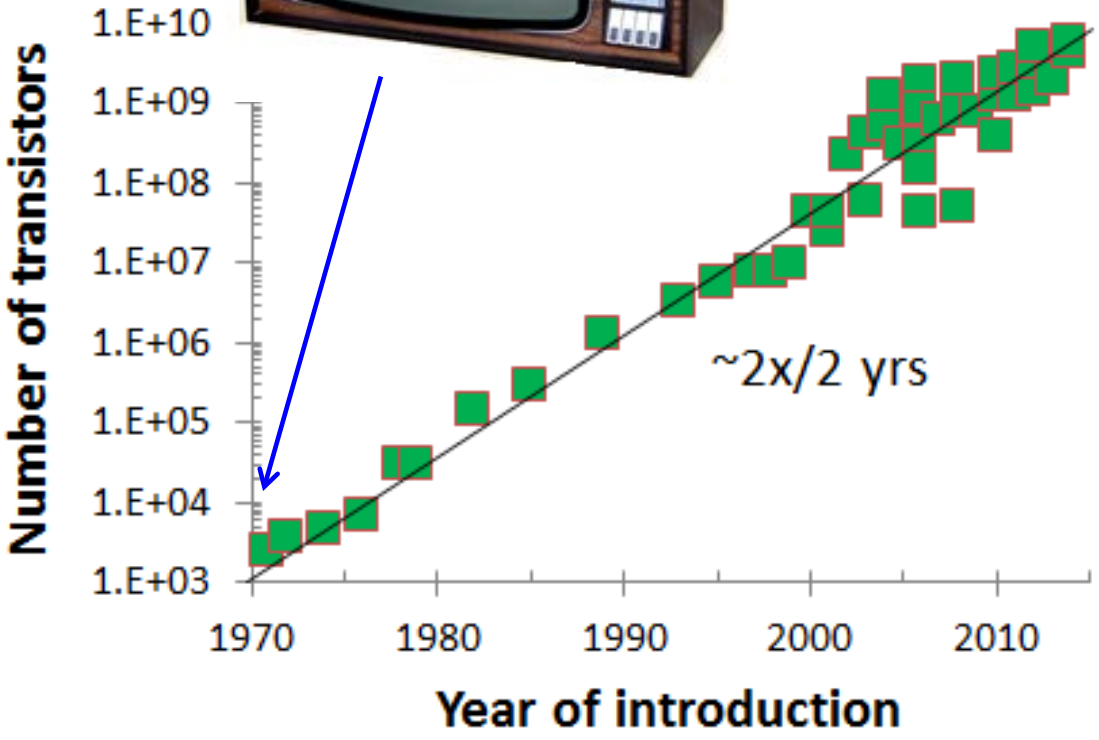
What if Moore's Law had stopped in 1980?

Laptop computer circa 1981

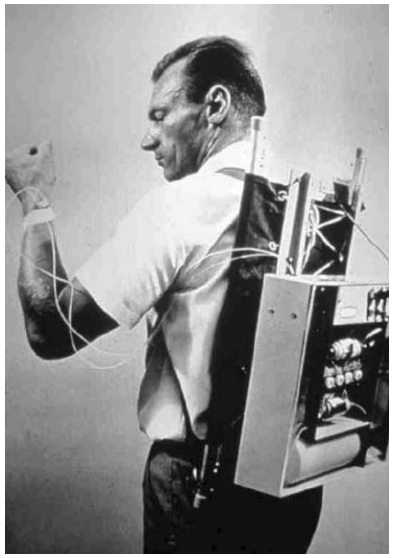


What if Moore's Law had stopped in 1970?

TV set, circa 1970

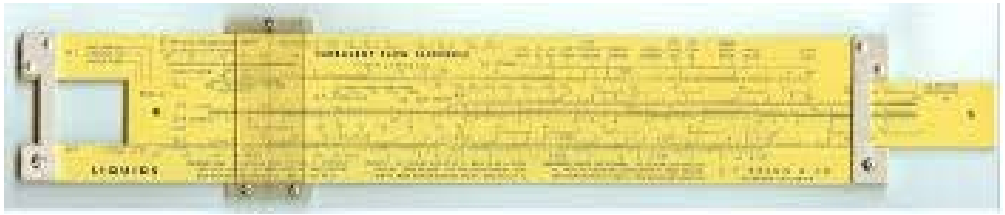


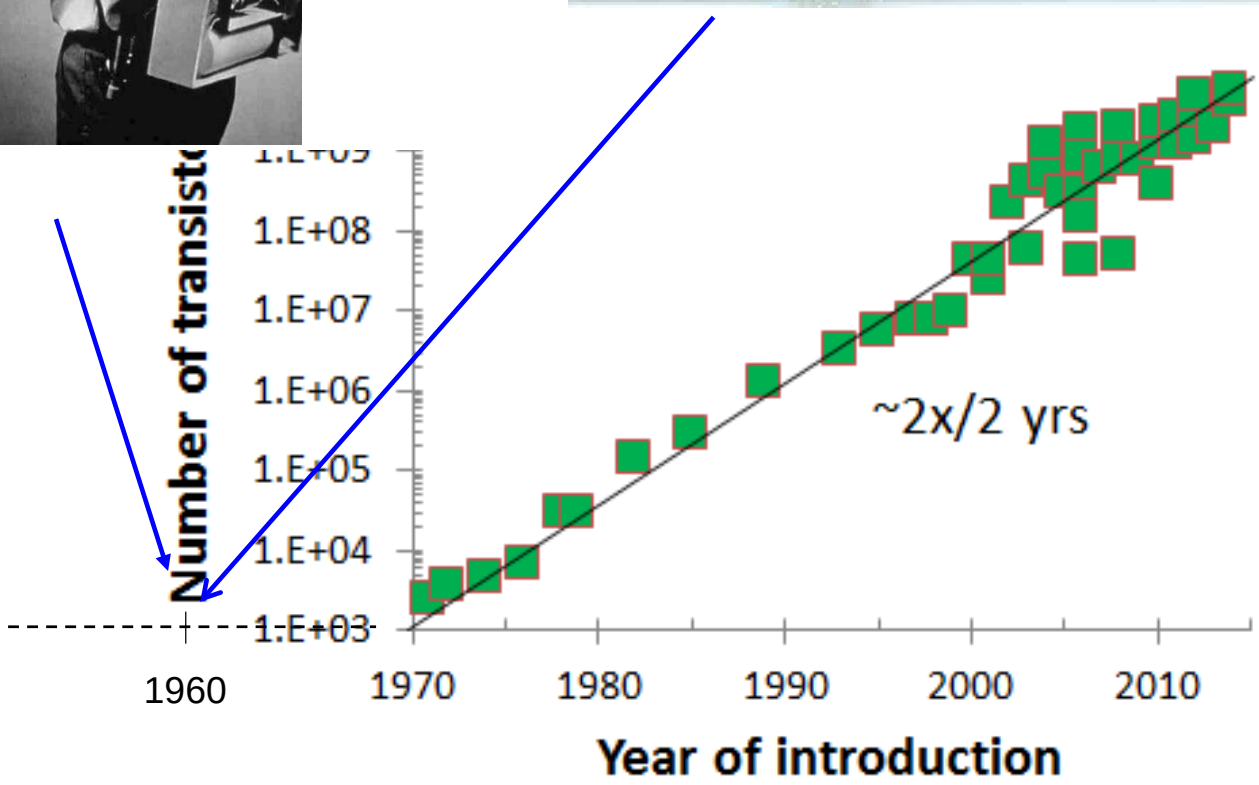
What if Moore's Law had never happened?



Insulin pump circa 1960

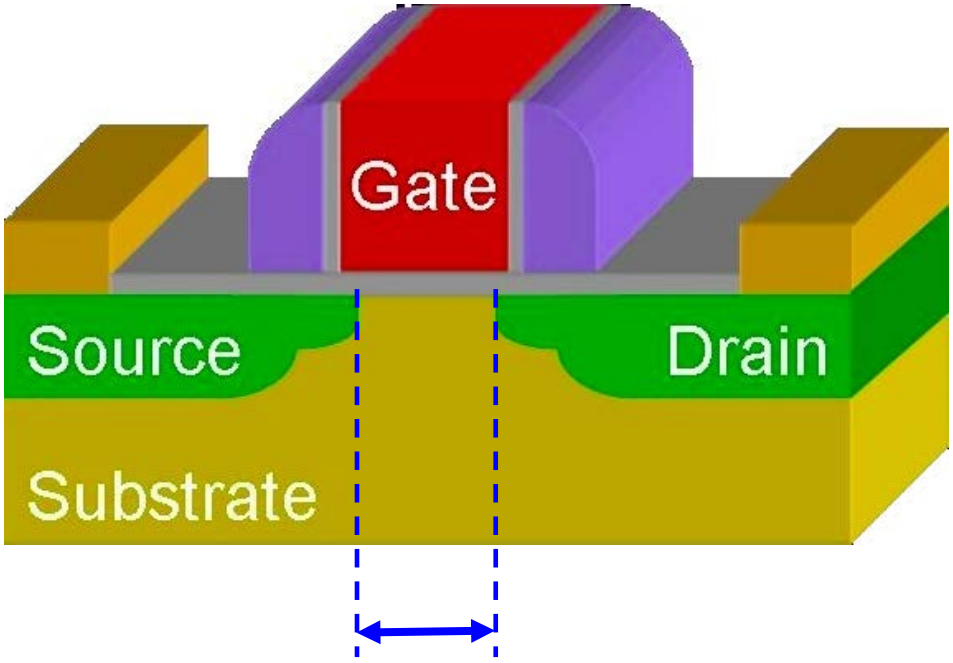
"Personal calculator" circa 1960





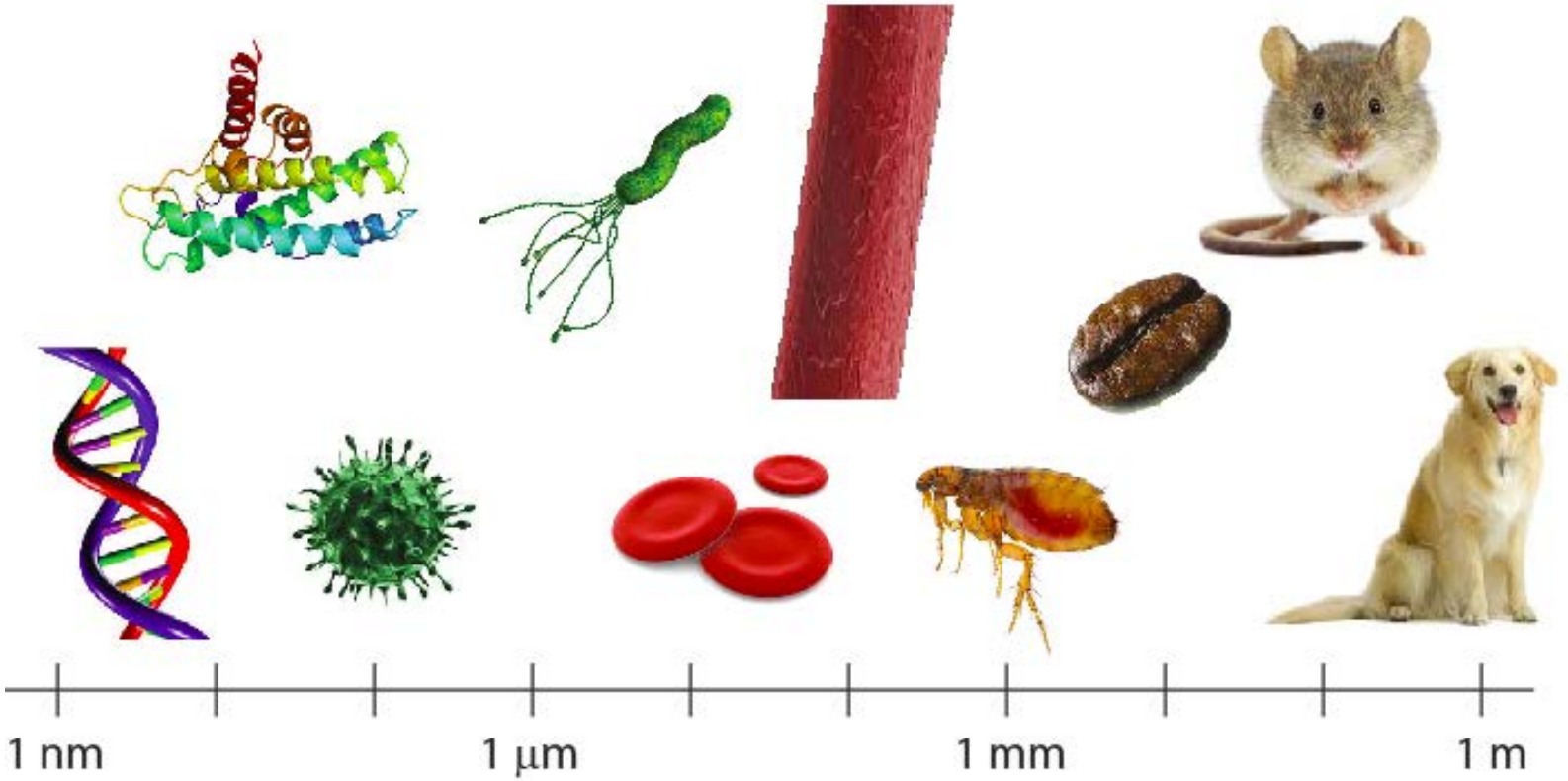
How transistors work

MOSFET =
Metal-Oxide-Semiconductor
Field-Effect Transistor

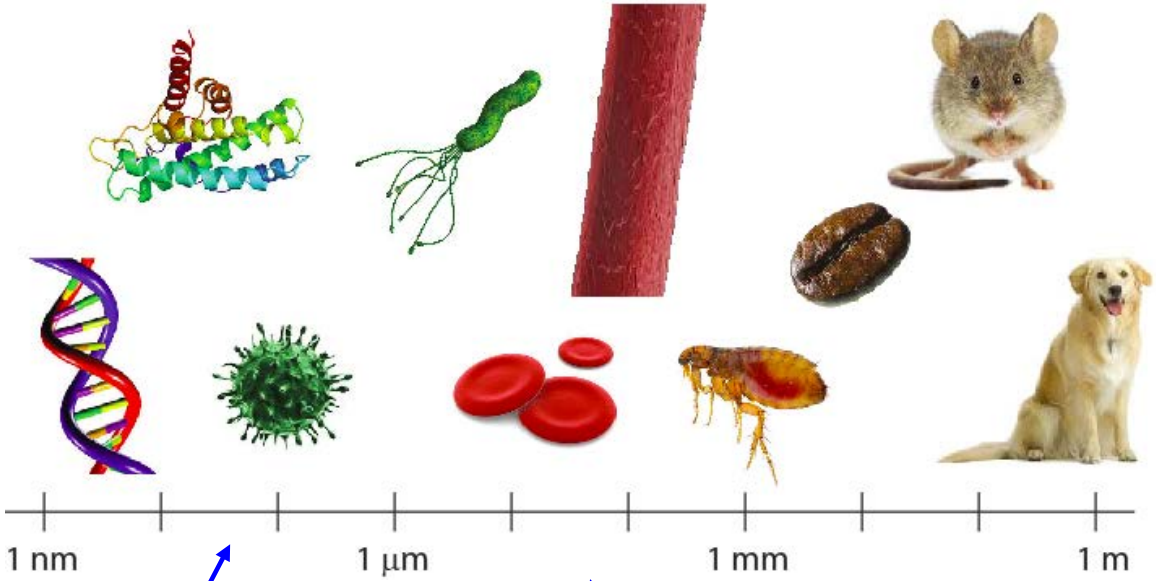


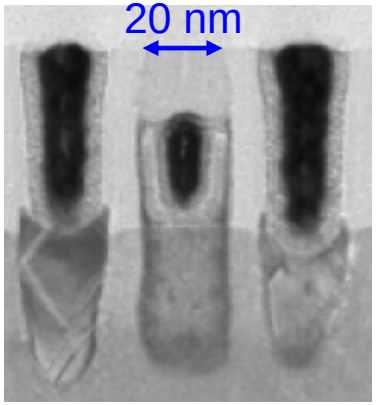
Switch

A sense of scale



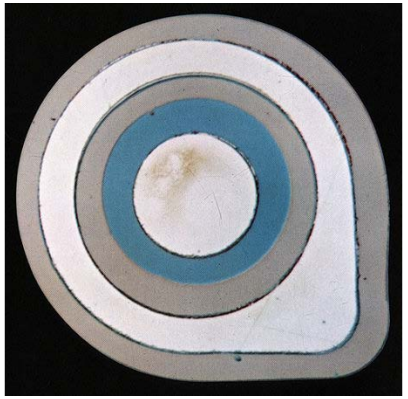
A sense of scale





2015 transistor

1971 transistor

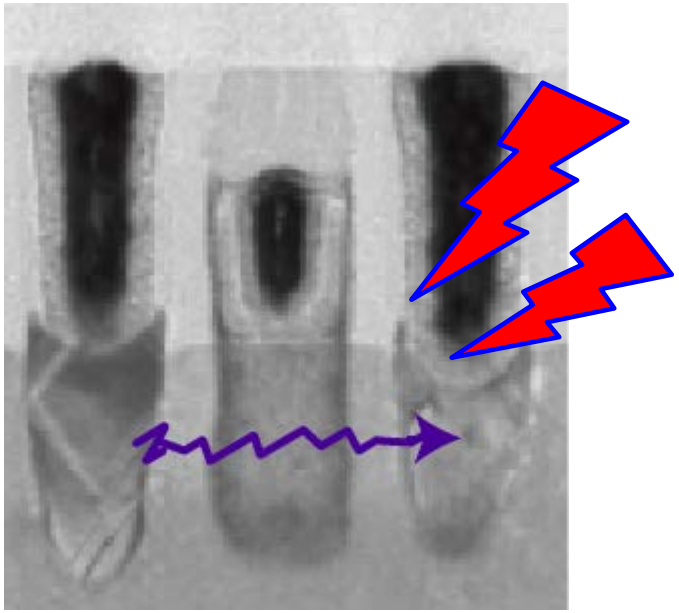


1959 transistor

Smaller is Better!

MOSFET performance improves as size scales down:

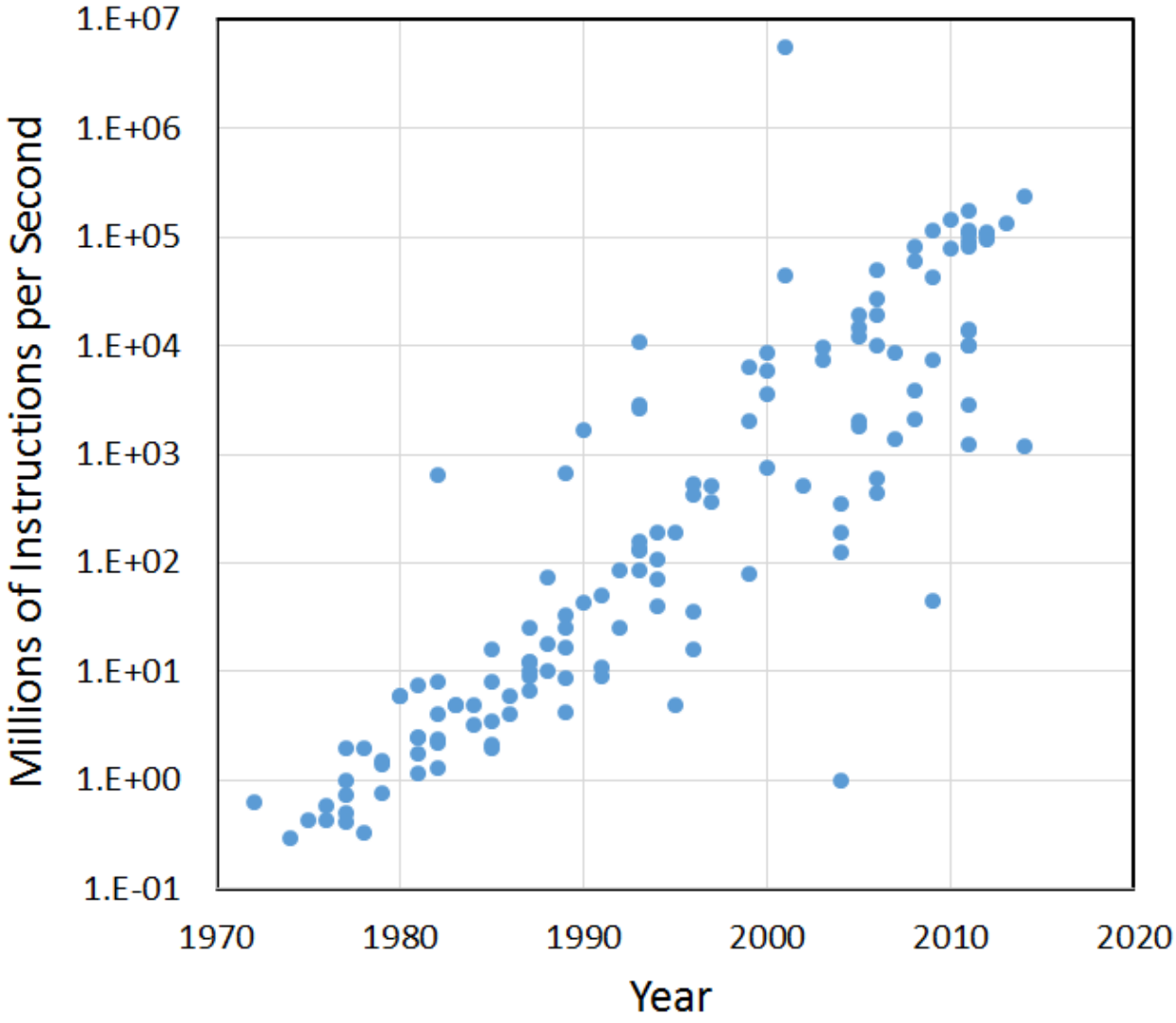
Switching speed ↑



Energy consumption ↓

“Triple dividends” of Moore’s Law

- Cost
- Performance
- Energy

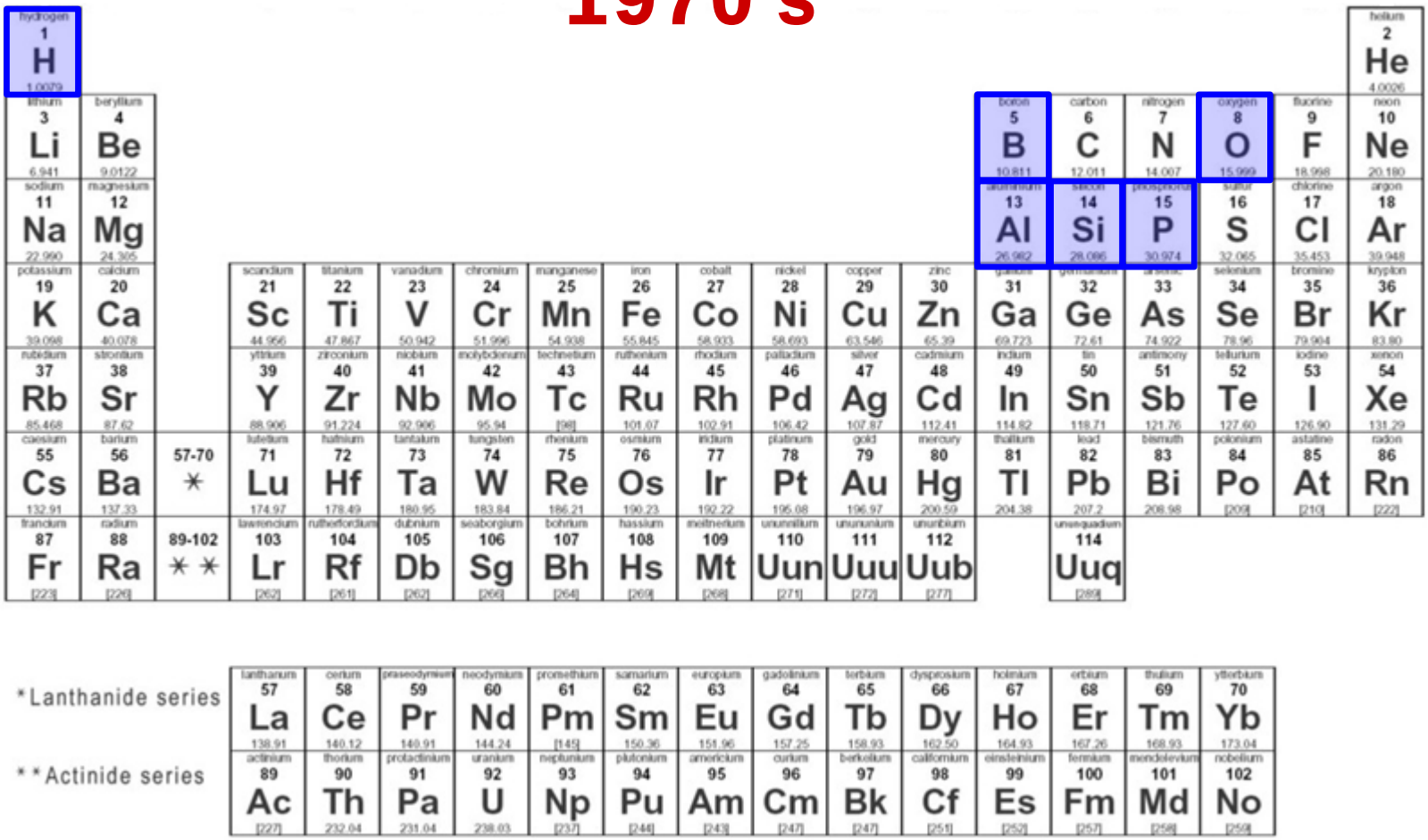


Wikipedia

Changing transistor architecture

Increasing chemical complexity

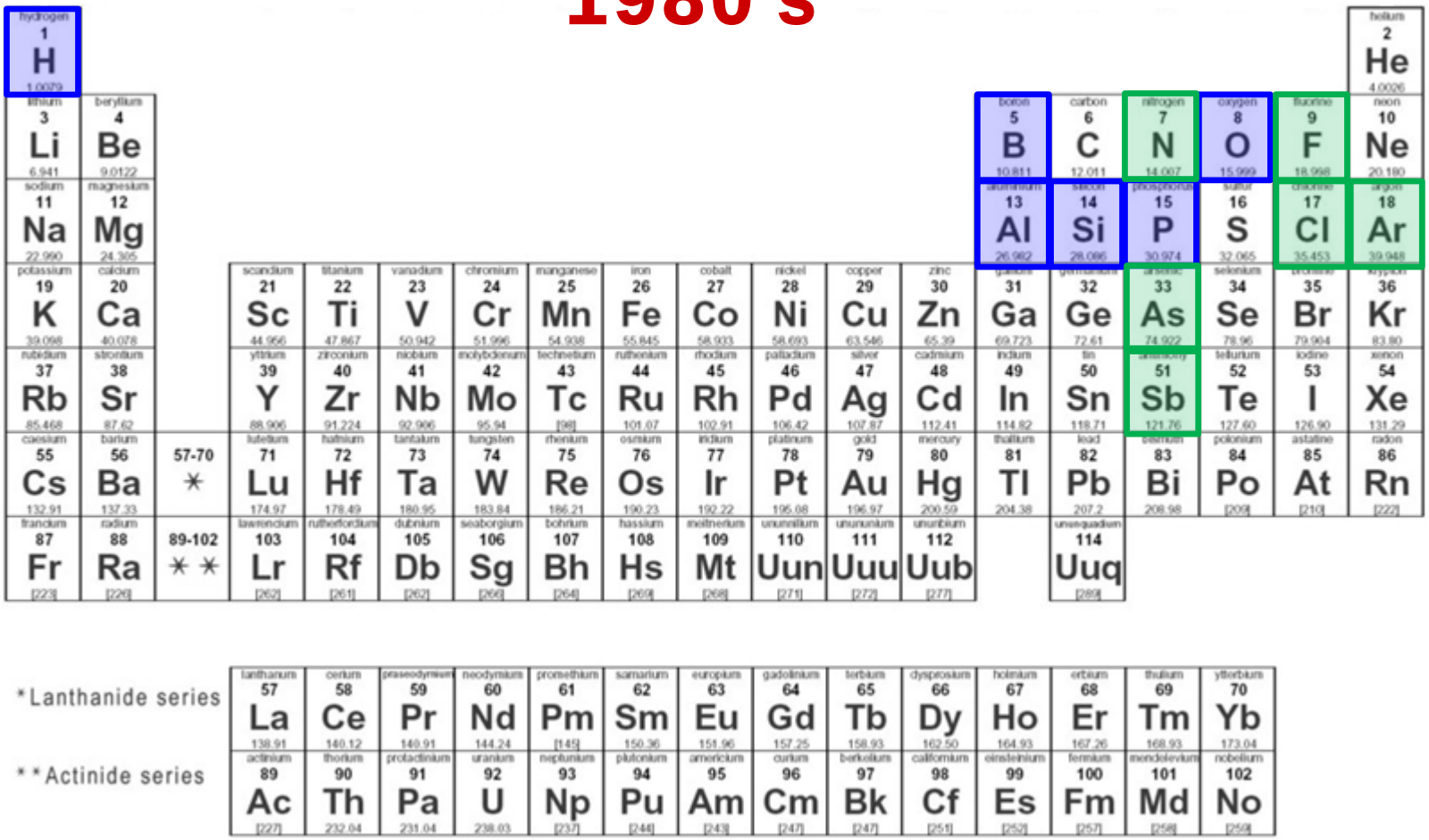
1970's



Intel

Increasing chemical complexity

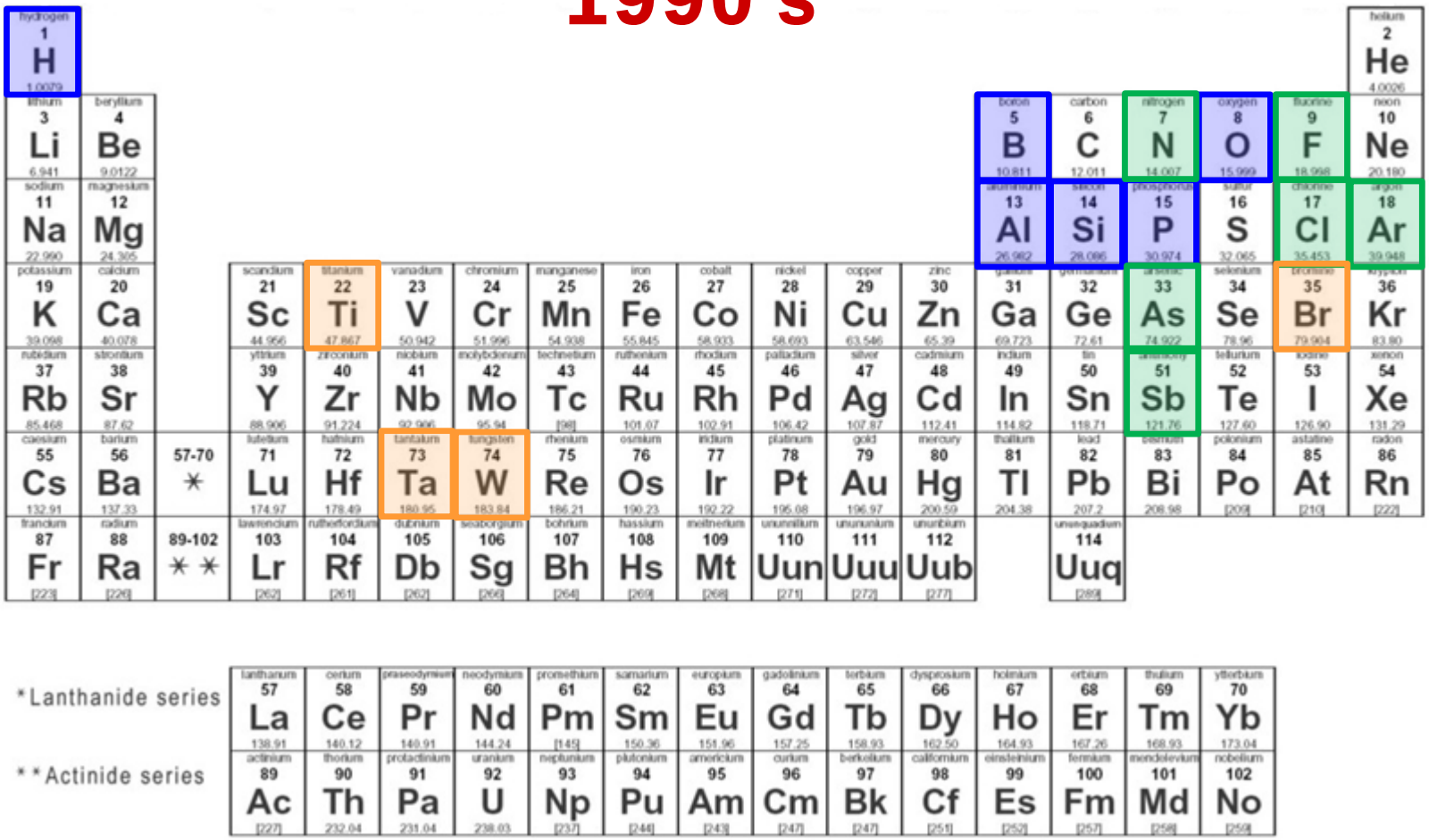
1980's



Intel

Increasing chemical complexity

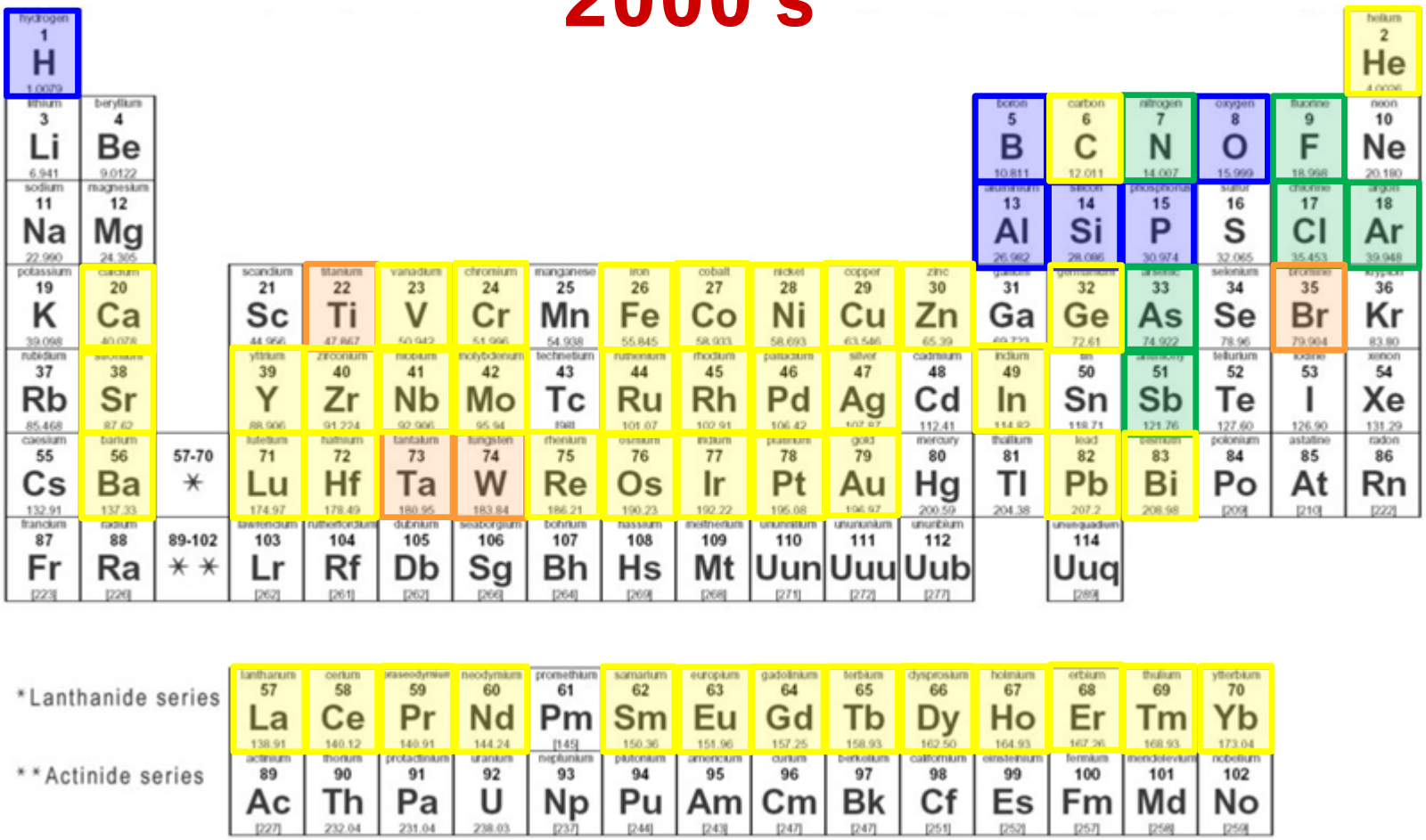
1990's



Intel

Increasing chemical complexity

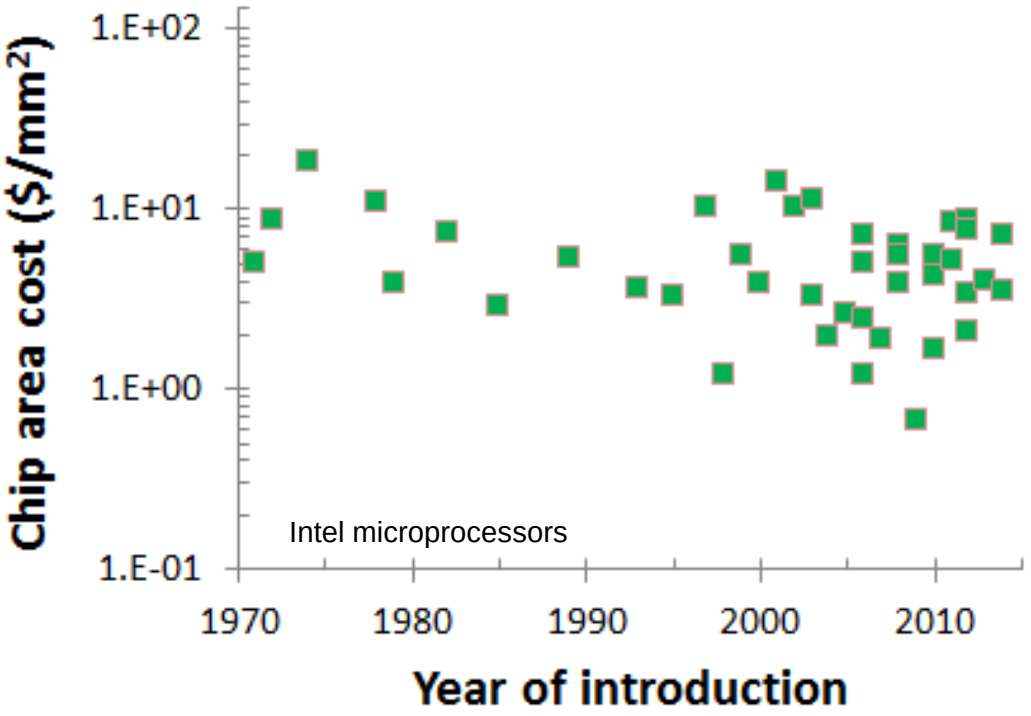
2000's



Intel

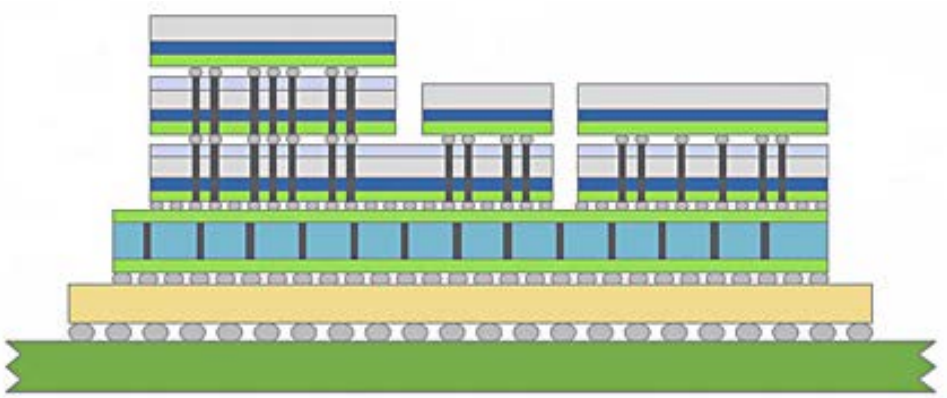
Increasing manufacturing complexity

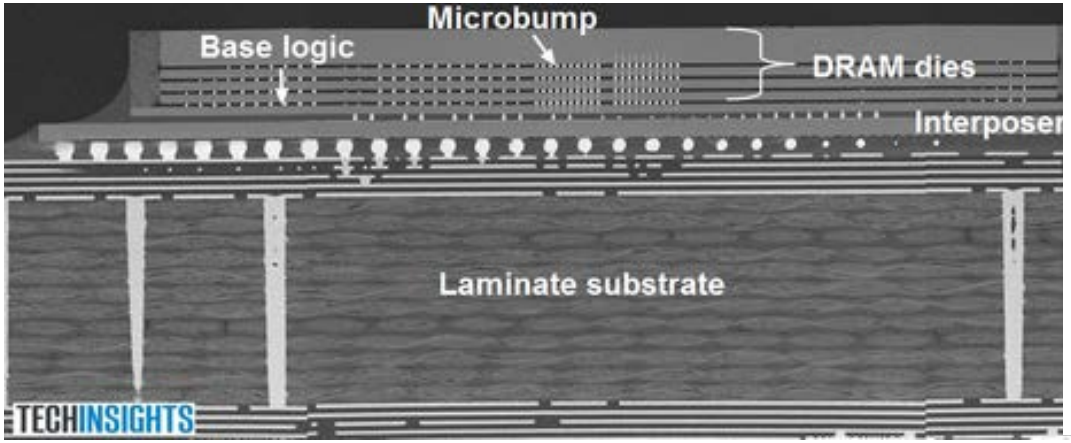
Moore's Law is really about economics

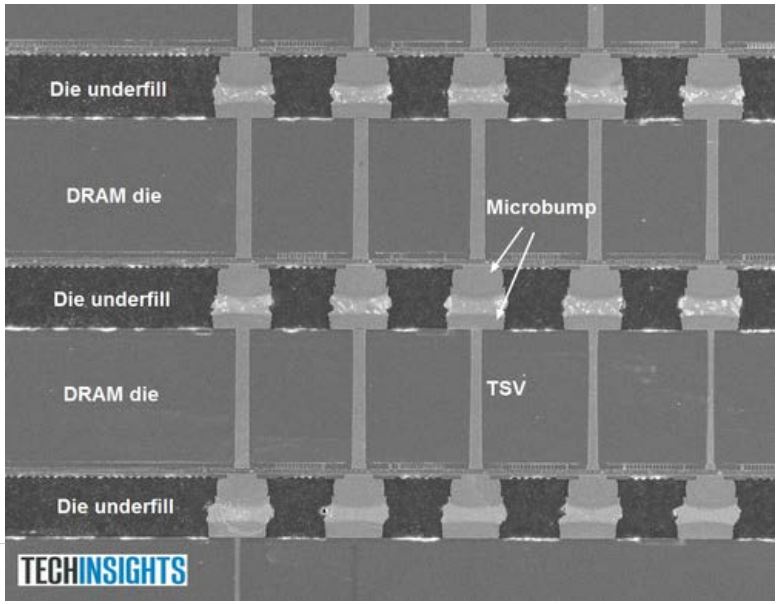



STOP
THE END IS
1980
1988
1999
2000
NEAR
ROBERTSON '10

3D System on Chip







Cadence
Hynix

Effective parallel computing

4K-by-4K Matrix Multiplication benchmark on state-of-the-art Intel processor:

Python

```
for i in xrange(n):
    for j in xrange(n):
        for k in xrange(n):
            C[i][j] += A[i][k] * B[k][j]
```

	Implementation	Time (s)	Speedup
1	Python	25,552.48	1
2	Java	2,372.68	11
3	C	542.67	47
4	Parallel loops	69.80	366
5	Parallel divide-and-conquer	3.80	6,724
6	+ vectorization	1.10	23,230
7	+ AVX intrinsics	0.41	62,323
8	Strassen	0.38	67,243

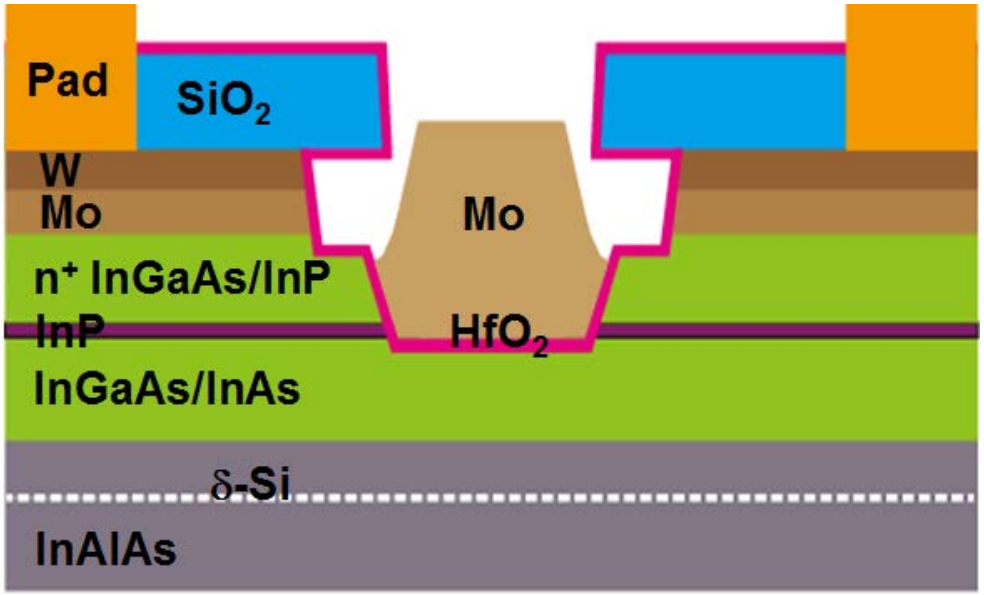
B. Kuszmaul, T. Schardl, S. Amarasinghe, C. Leiserson (MIT)

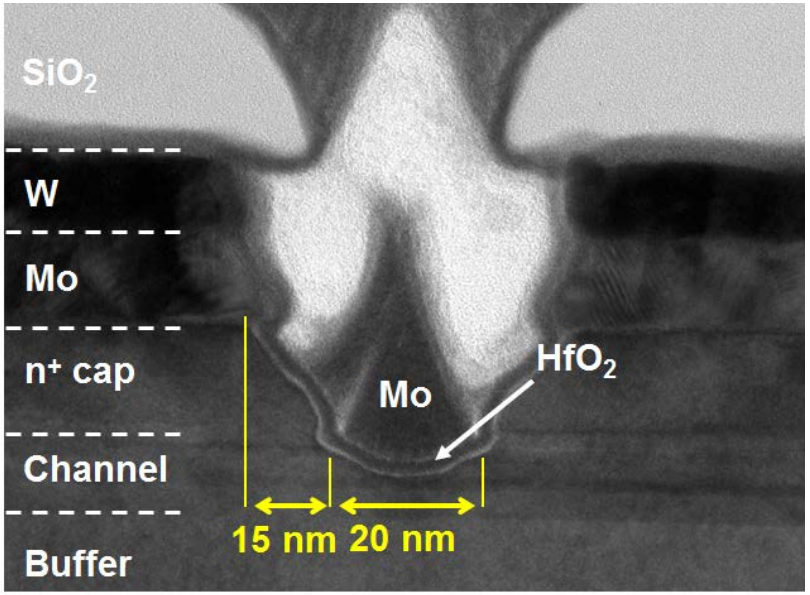
The next computing device?

?

Jianqiang Lin

Planar InGaAs MOSFETs

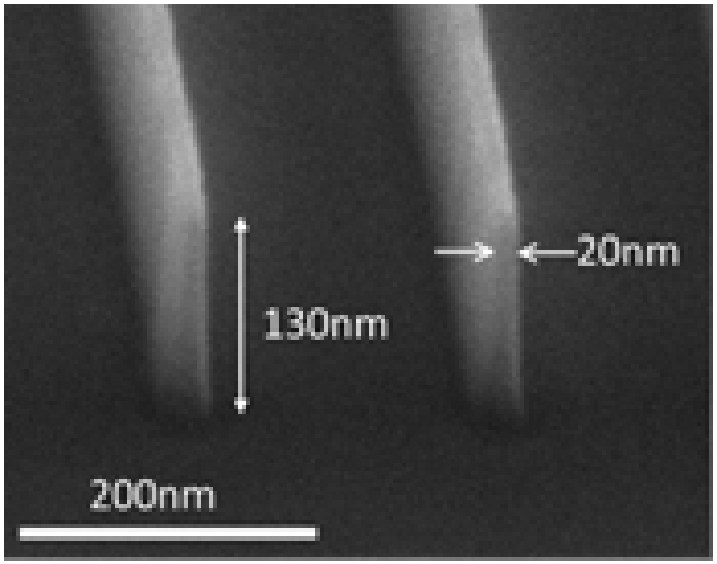


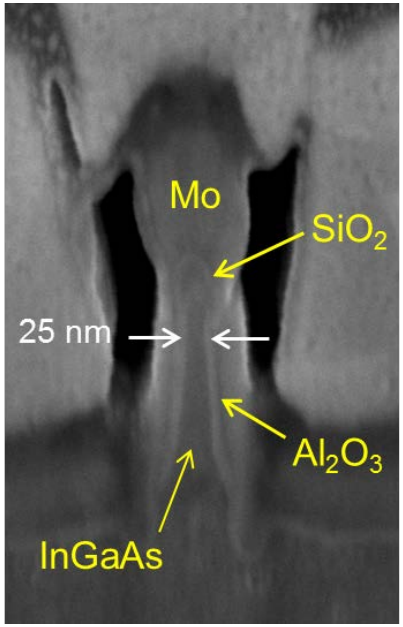


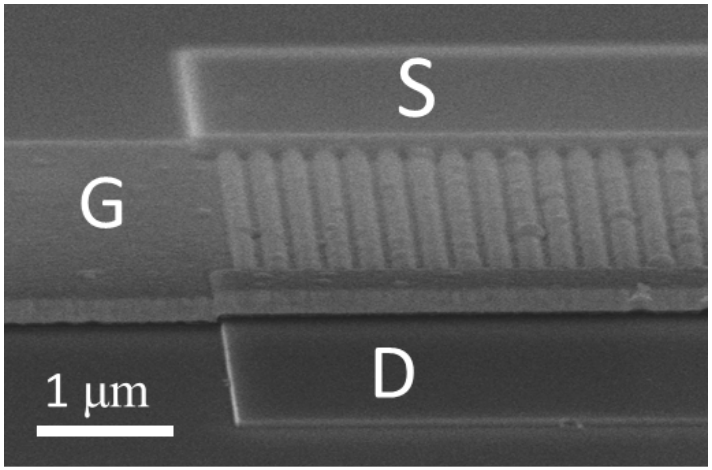
Lin, IEDM 2012, 2013, 2014

Alon Vardi

InGaAs FinFETs



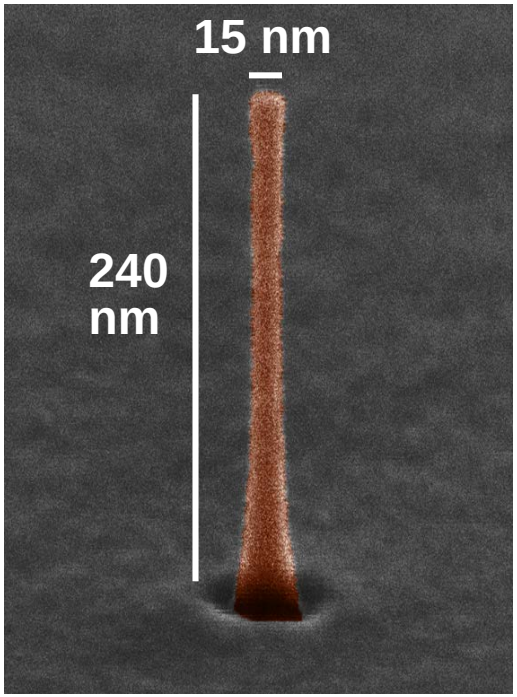


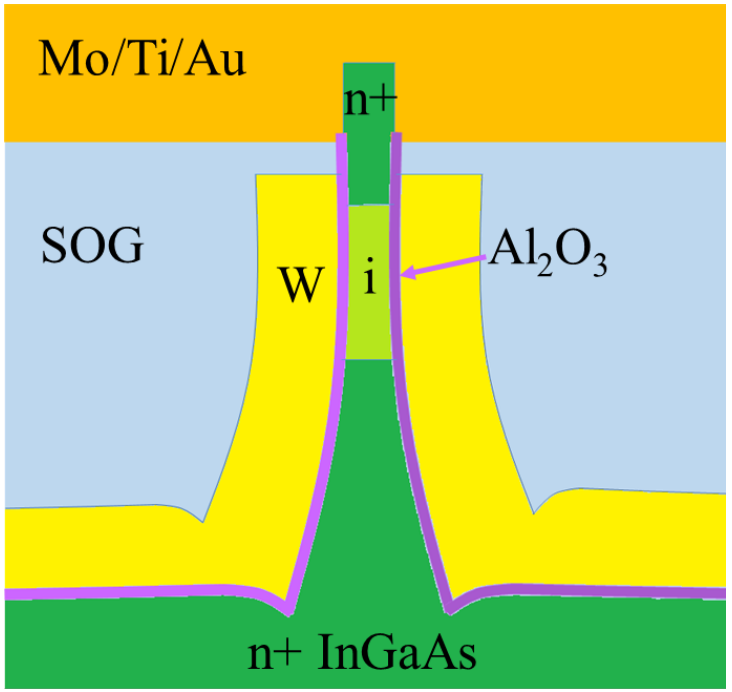


Vardi, DRC 2014, IEDM 2015

InGaAs Vertical Nanowire MOSFETs

Xin Zhao





Zhao, IEDM 2013