Informaatioteknologian seuraavat vallankumoukset
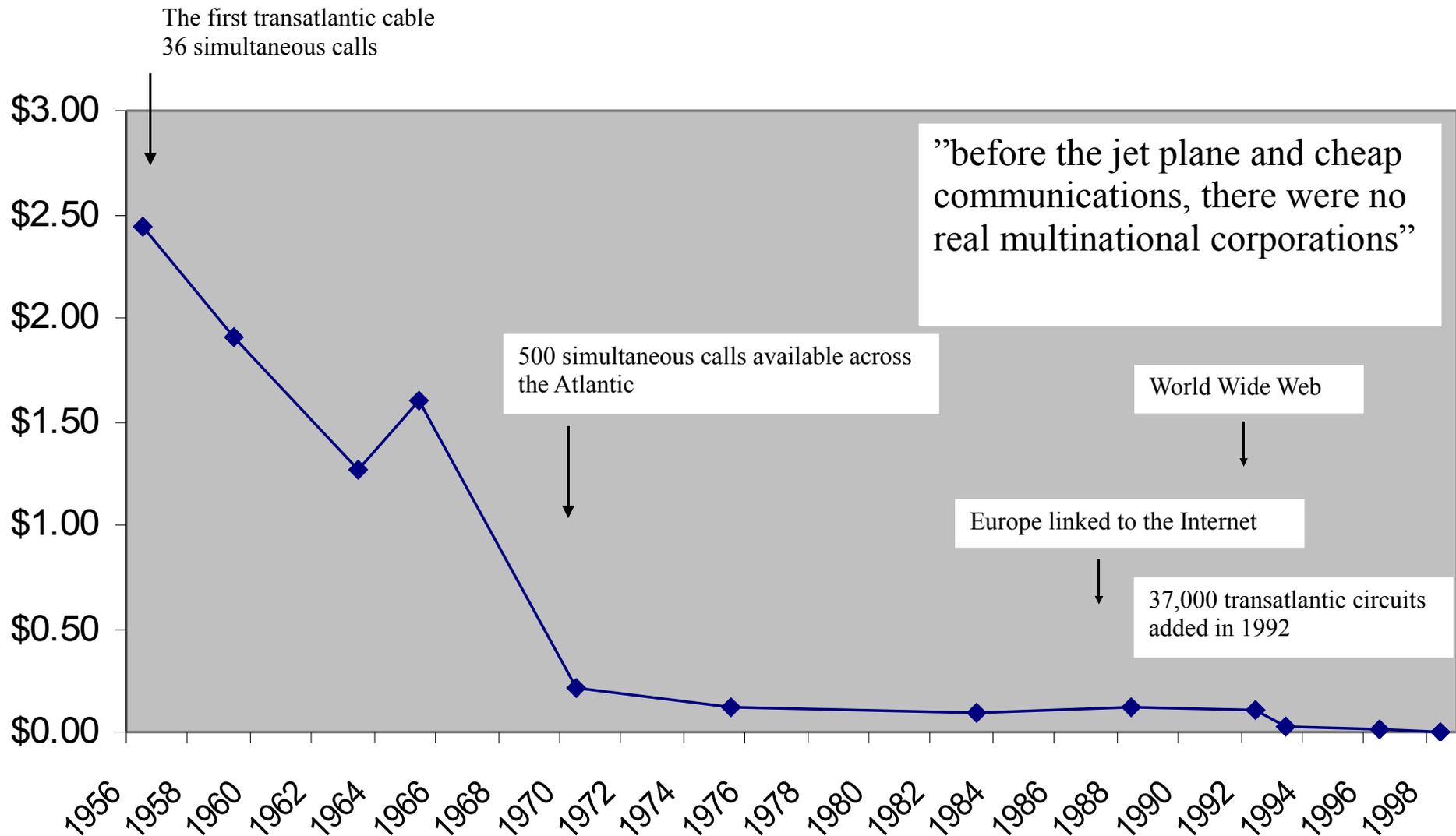
Ilkka Tuomi

Where Did We Come From?

The first transatlantic cable
36 simultaneous calls

"before the jet plane and cheap communications, there were no real multinational corporations"

500 simultaneous calls available across the Atlantic

World Wide Web

Europe linked to the Internet

37,000 transatlantic circuits added in 1992

$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$0.00

1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998

**Investment cost of transatlantic cable per minute of use**

"Kolmas globalisaatio"

- De-location, fragmentation and recombination of value chains using ICTs

  - First phase 1980-
    - Fax, international telephony
  - Second phase 1992-02
    - 8-bit email, intra-firm collaboration, Internet, ERP

  - Third phase 2003-
    - real-time fragmentation of production chains (call centres, eCommerce), knowledge-intensive collaboration & co-production
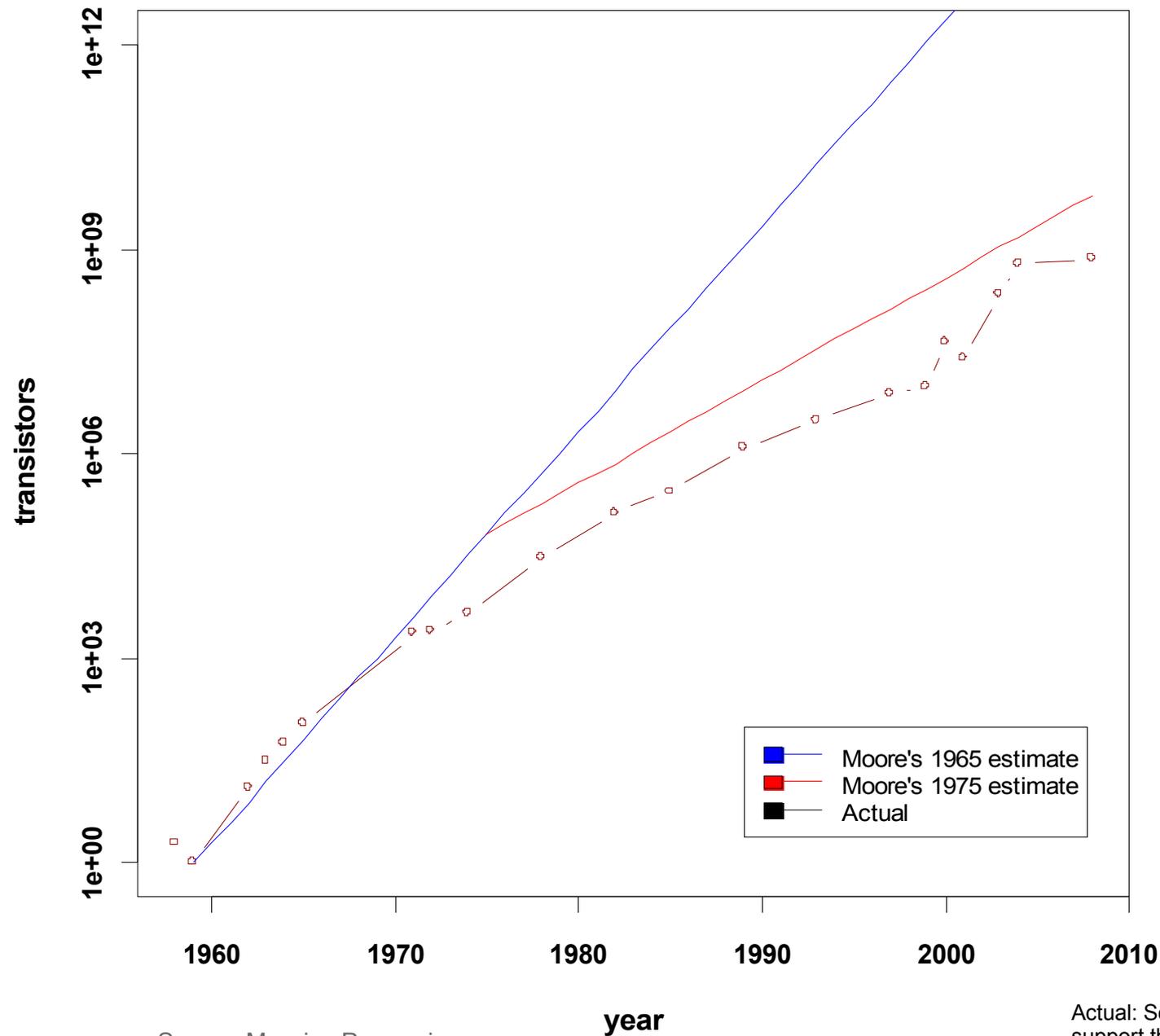
Semiconductor Scaling

- Since 1958, the ICT revolution has been driven by continuous miniaturization

30 % improvement in 2.9 years

30 % improvement in 2.0 years

nm
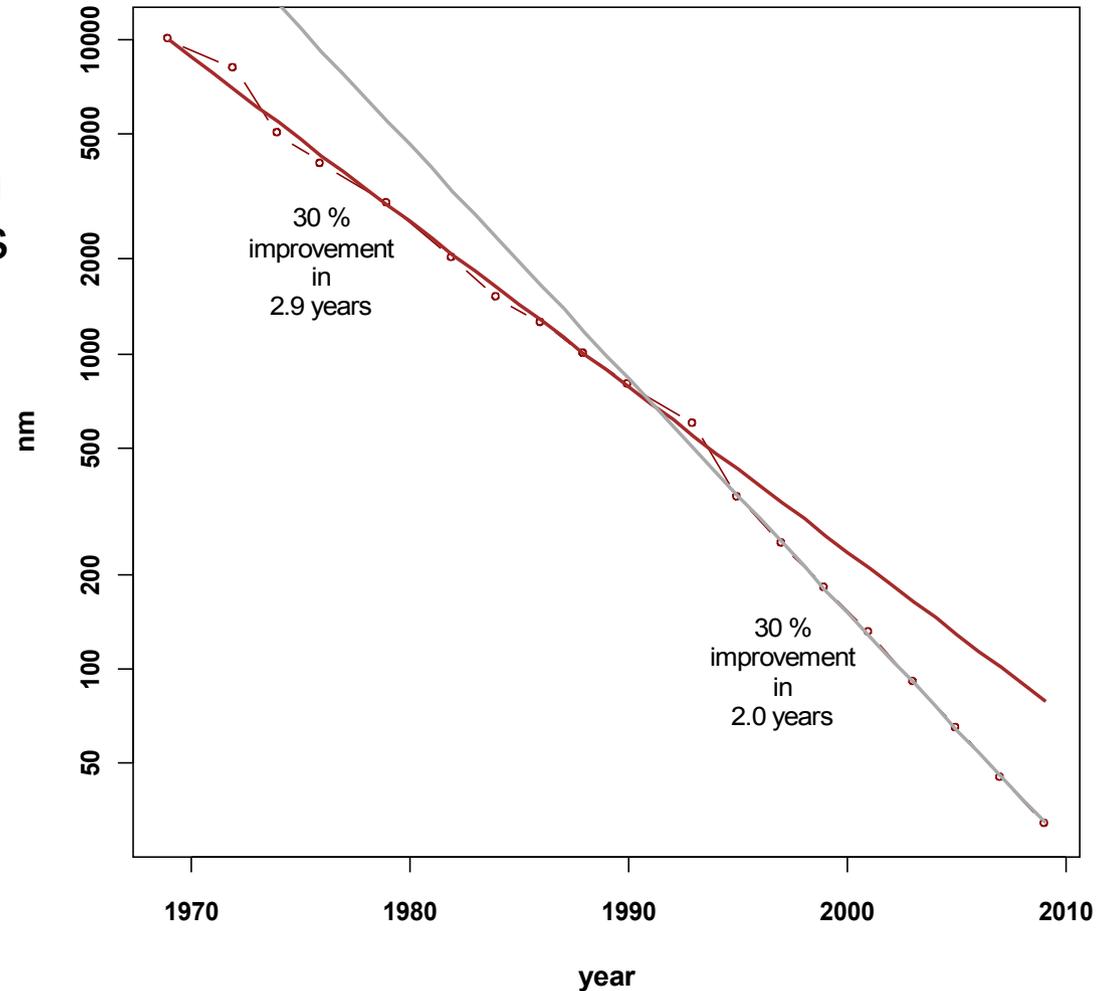
year

Lithography process nodes: first year of large-scale use

Source: Tuomi, I. (2009) The future of semiconductor intellectual property blocks and architectures in Europe. Luxembourg, European Commission, (in print).
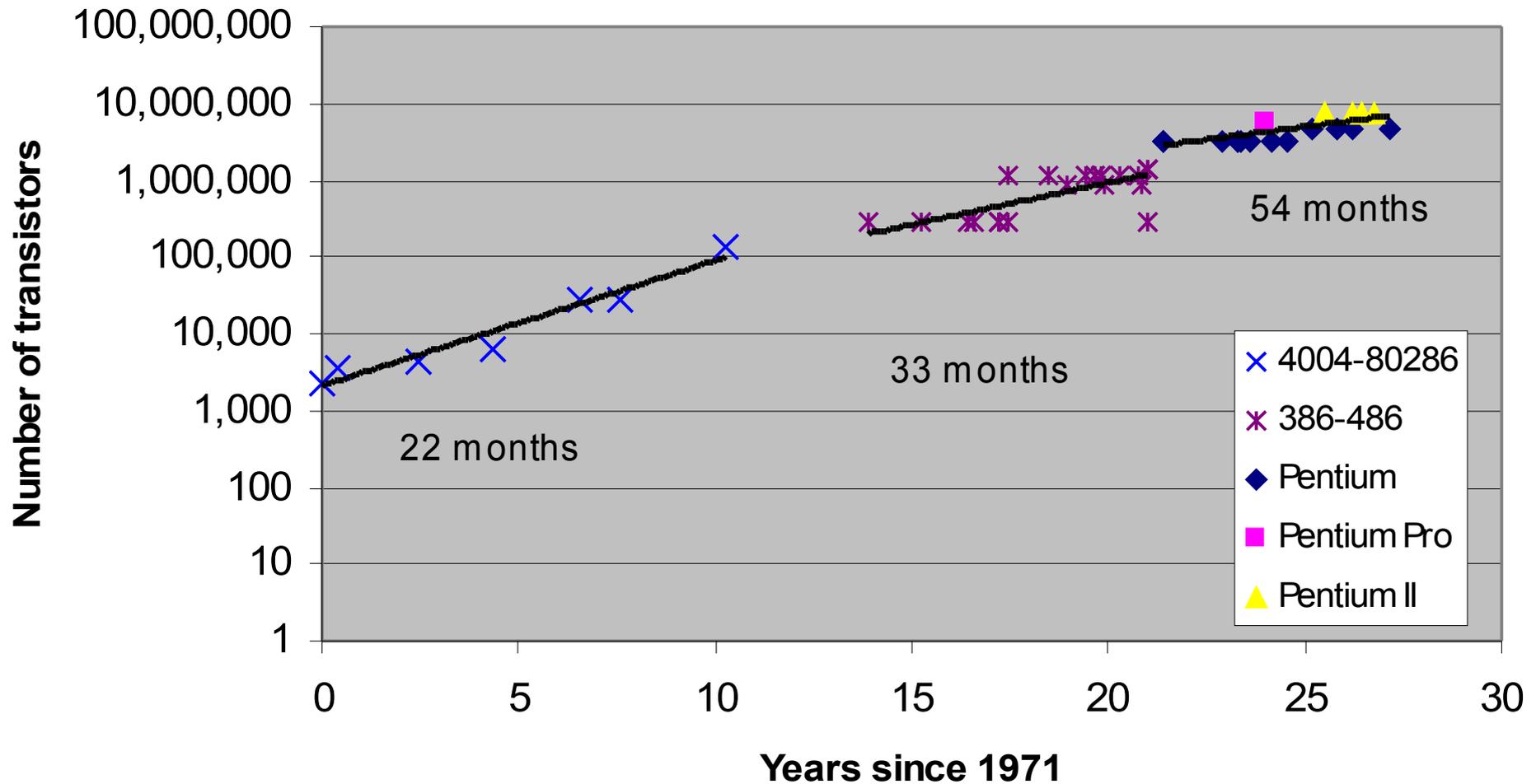
Moore's Laws

transistors

year

Legend:
- ■ (blue) Moore's 1965 estimate
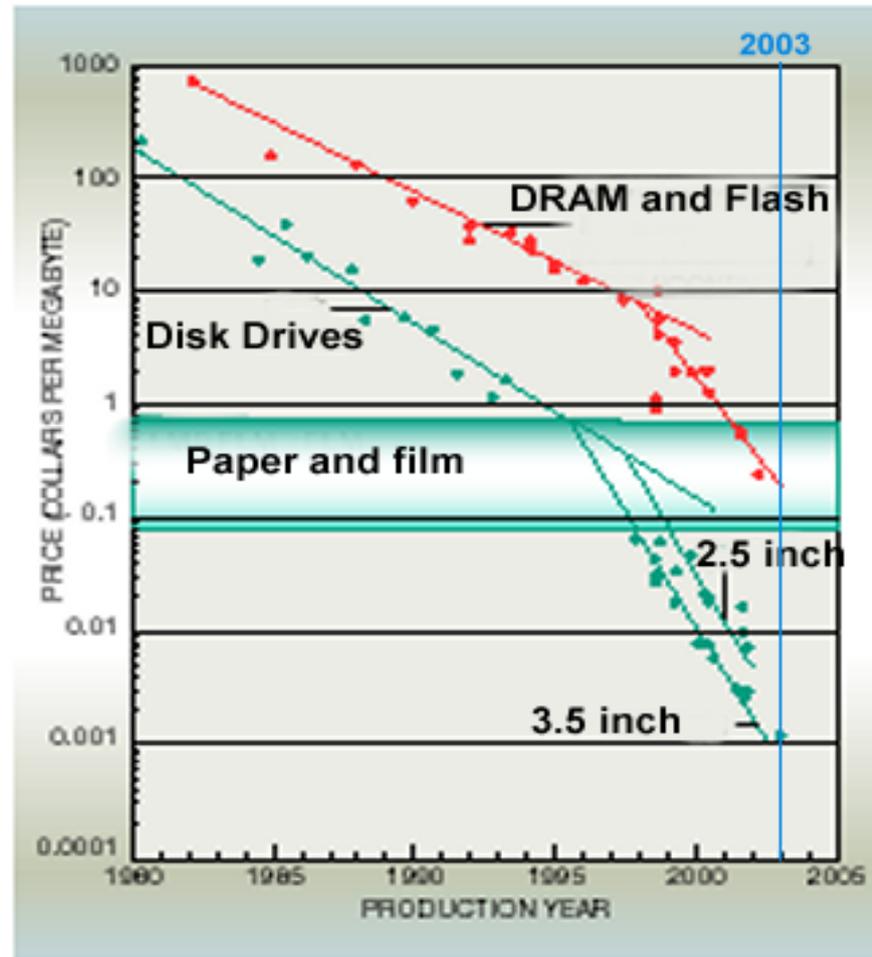- ■ (red) Moore's 1975 estimate
- ■ (black) Actual

Source: Meaning Processing

Actual: Selected processor data used to support the validity of Moore's Law by Intel; complemented by historical pre-1971 data.
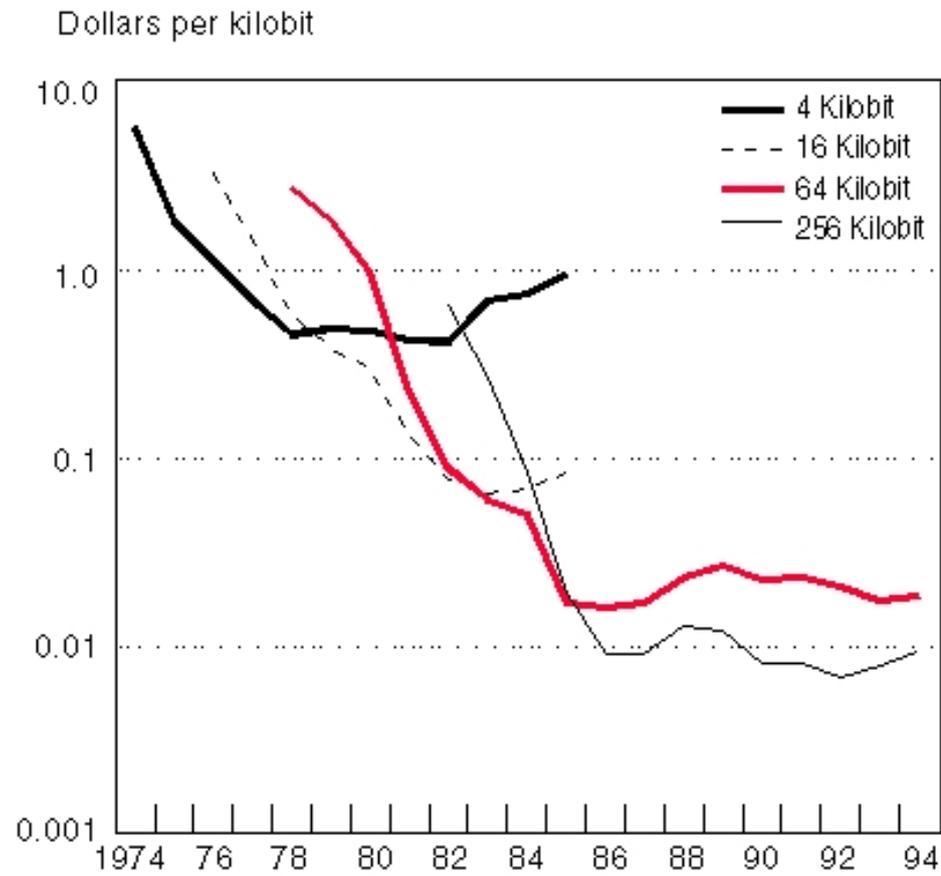
The "Laws" of Moore

The lives and death of Moore's law. *First Monday* 7 (11), 2002
http://www.firstmonday.org/issues/issue7_11/tuomi/

Price per Megabyte
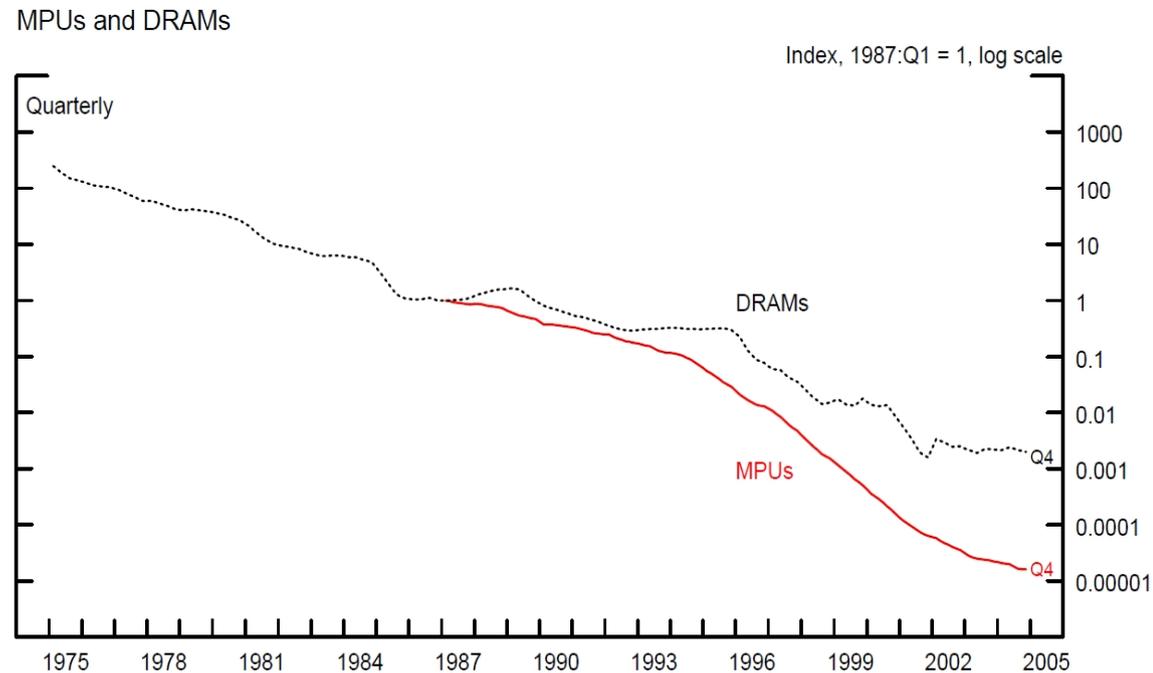

Source: Grochowski & Halem (2003) Technological impact of magnetic hard disk drives on storage systems. IBM Systems Journal 42(2).

Dollars per kilobit

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

Source: Grimm (1998)

The Impact of Scaling

- **All** positive benefits bundled together
  - Reduced component cost
  - Increased functionality
  - Higher performance
  - Reduced component size
  - Smaller energy consumption

MPUs and DRAMs

Index, 1987:Q1 = 1, log scale

Quarterly

1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001

DRAMs

MPUs

Q4
Q4

1975 1978 1981 1984 1987 1990 1993 1996 1999 2002 2005

Quality-adjusted price of semiconductors

Source: Aizcorbe, Oliner, Sichel (2006): Shifting trends in semiconductor prices and the pace of technical progress. Finance and Economics Discussion Series, Federal Reserve Board, Washington, D.C.

The Consequences of Scaling

- The Information Revolution
  - Rapid expansion of the use of integrated circuits in all products and services
  - Wide penetration of digital technologies in all areas of society and economy
- Expectations of extremely fast technical improvement combined with price declines
- "Fall-forward" business models, and industry mind-sets based on incremental innovation
- Rapid growth of macroeconomic labor productivity

Except...
The End of Scaling

- Rapidly increasing capital expenditure
    - Rock's Law: the cost of leading-edge plant doubles every three years (now at 3-4 billion USD)
- Rapidly increasing manufacturing costs
    - Total costs for creating a bleeding-edge chip ~ 40 – 80 million USD
    - Optical masks @ 32nm: 6-8 million USD
- And physics
    - Insulator thickness now < 5 molecular layers
    - Increasing variability at atomic component sizes; increasing complexity of verification and testing
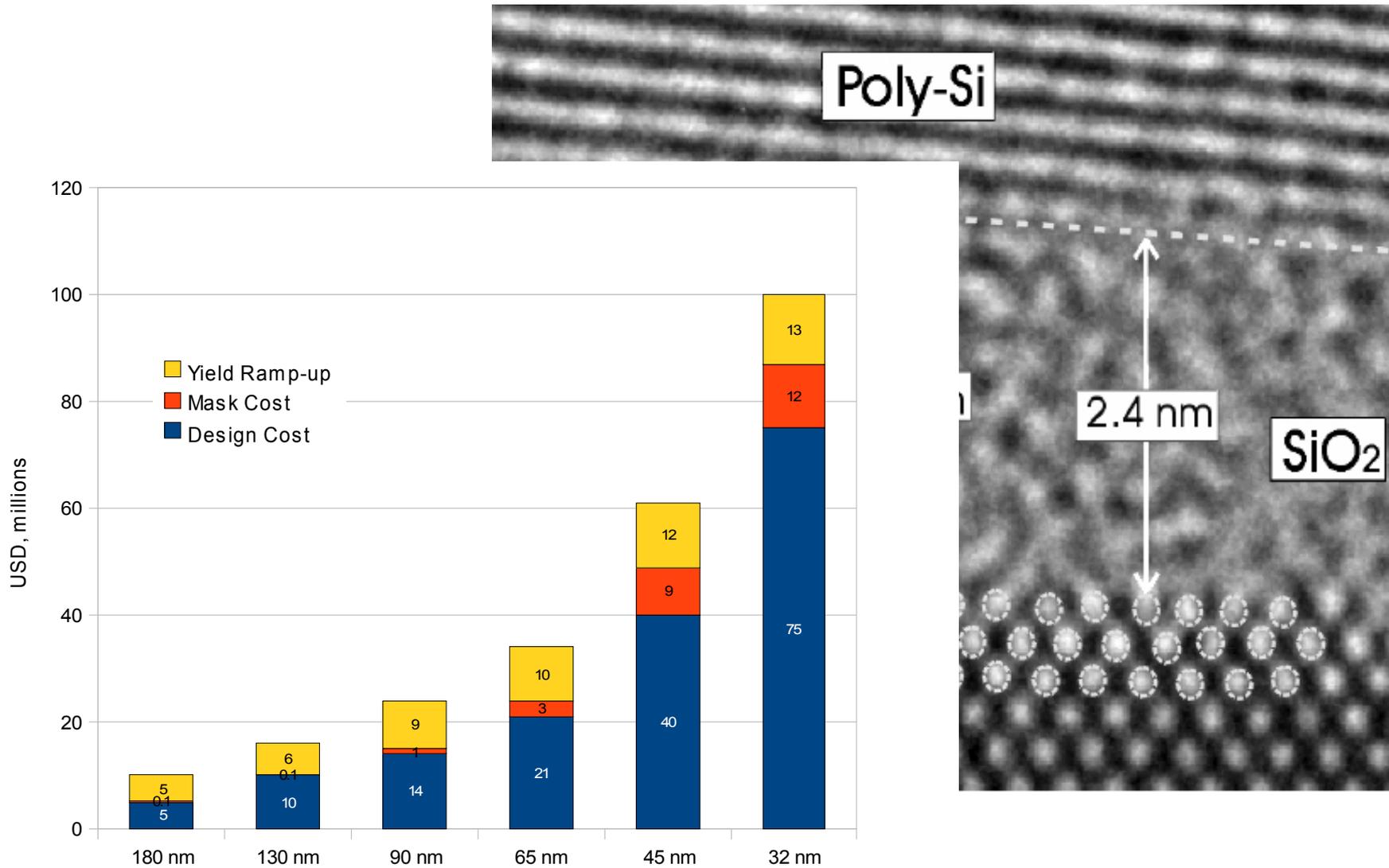   - Decreasing reliability and life-time
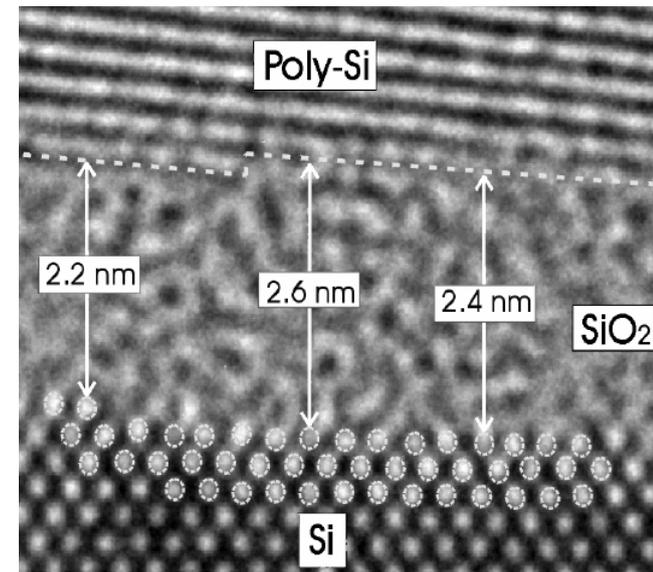
The escalating cost of design

Verification, software account for lion's share at 65 nm
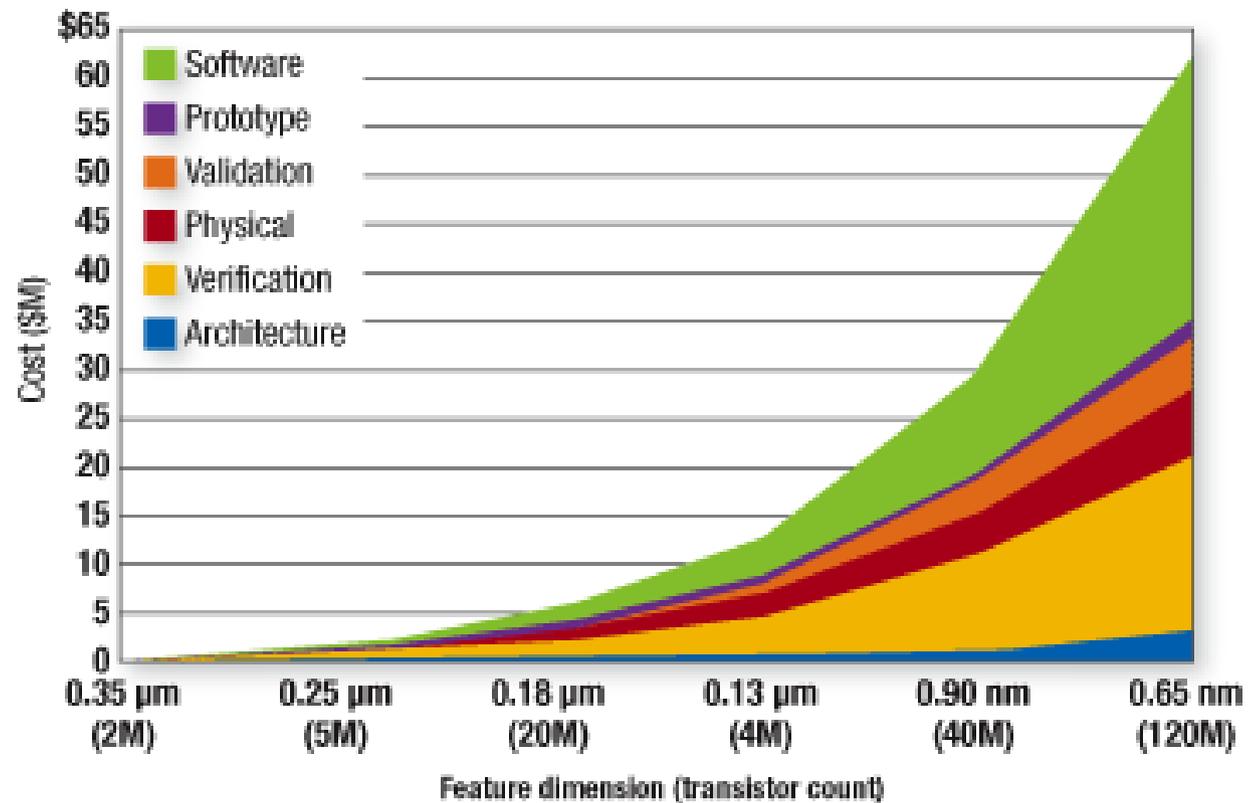
Source: Synopsys

The End of Integrated Circuit, As We Know It

IC Production Costs

Source: data from Chartered, Synopsys, GSA

Great Technology: No Demand

Because everything in her home is waterproof, the housewife of 2000 can do her daily cleaning with a hose

"Because everything in her home is waterproof, the housewife of 2000 can do her daily cleaning with a hose."

"Miracles You'll See In The Next Fifty Years," Popular Mechanics, 1950

The New Low-Cost Computing Paradigm

- Today, low-cost semiconductors are **very**, **very** expensive
  - A cheap transistor in a bleeding-edge chip costs over **50 million USD**
  - These "low-cost" transistors can **only** be used in very high-volume products that can be copied millions of times (PC, mobile phone, MP3, smart card, + n other products)
  - There are **very limited opportunities** to create such products from scratch, or by SMEs

- Real low-cost semiconductors mean **massive expansion of opportunities** for design-based business models
  - The influx of new designs and architectures will create many new products and services
  - Configurable and reconfigurable processor architectures will be the key
  - The current distinction between software and hardware will blur: when low-cost computing becomes possible, many designs will be compiled and configured to silicon (and organic + heterogeneous semiconductors) as this leads to optimal performance

Back to the Future

- Imagine a world where you could create processor hardware architectures on-demand, or in a mass-customized way:
  - What opportunities did we miss by focusing on the "leading edge"?
  - Why, indeed, did we call it the "leading edge"?

- For most processing applications, low-cost, reliable and configurable technologies are the best
  - There is abundance of excess capacity at old CMOS process nodes
  - Many interesting functions do not scale easily (e.g. analog & RF, sensors, ...)
  - Printed electronics are becoming practical
  - "Structured silicon combined with printed electronics"?

The Long Tail of ICs
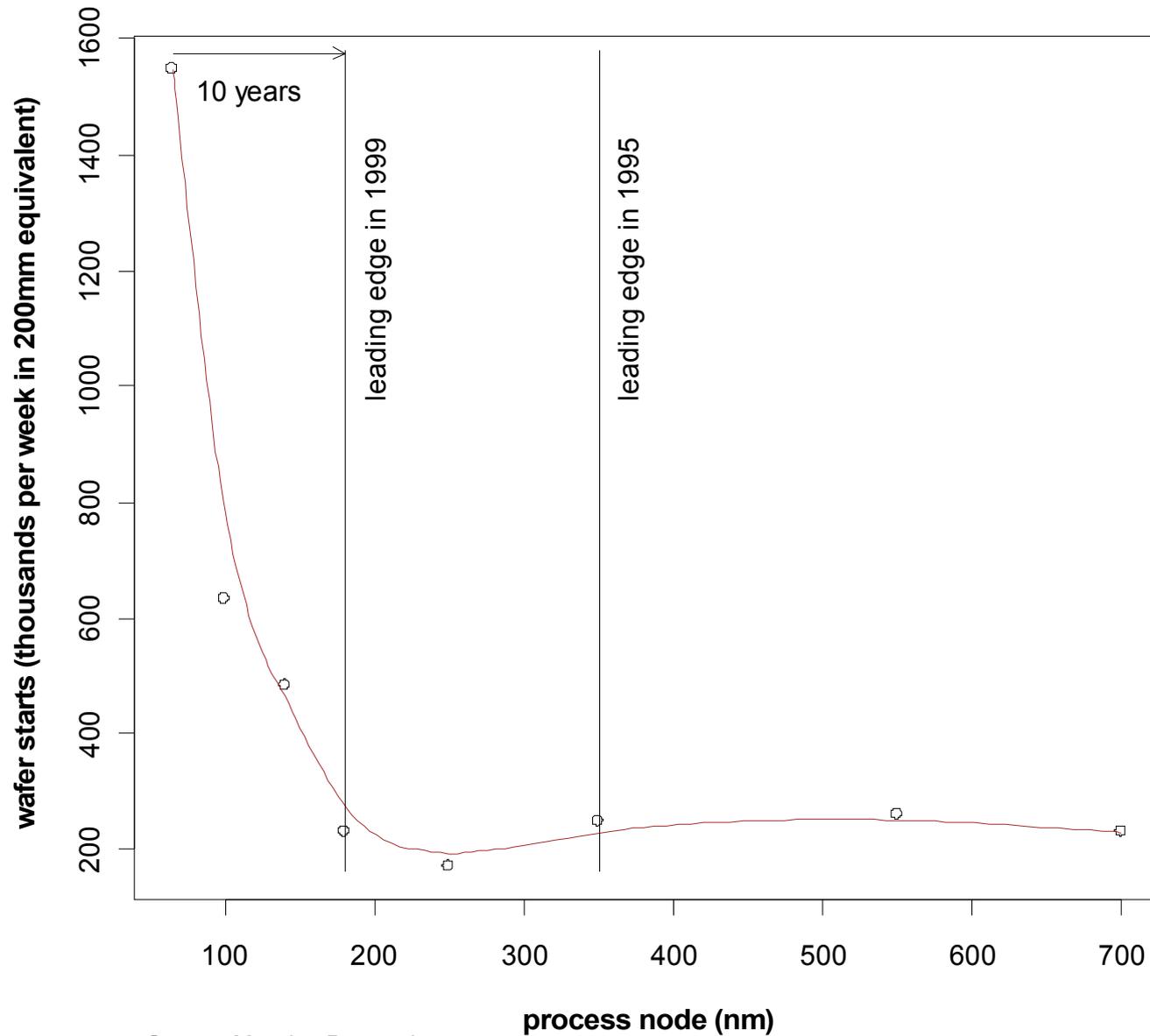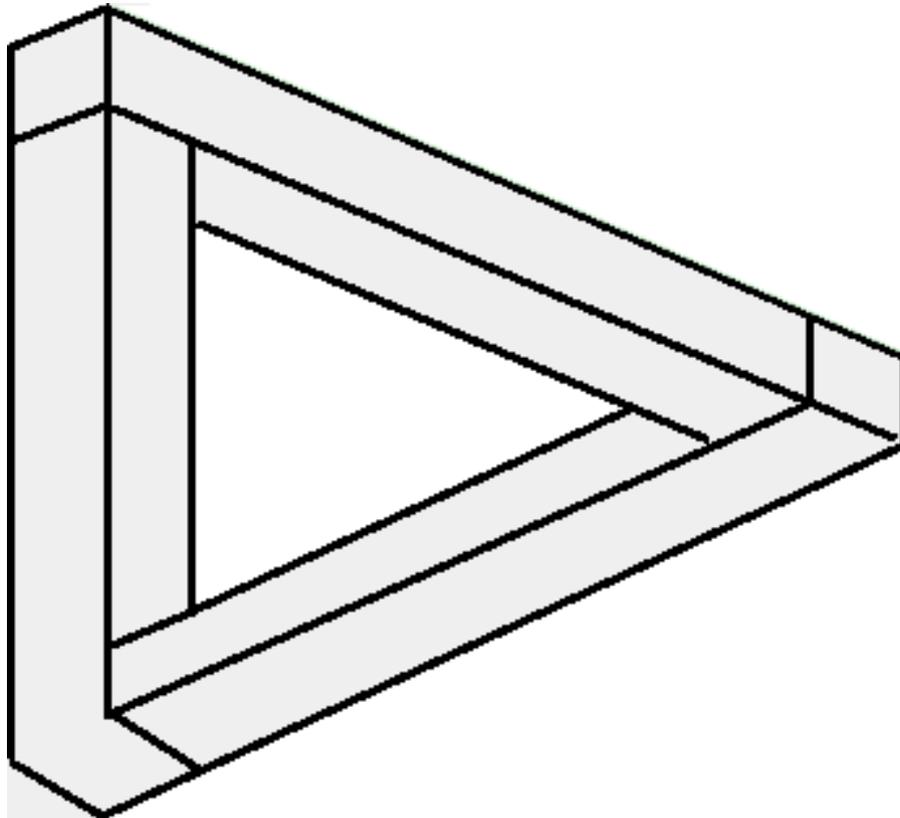

Source: Meaning Processing

Blinded by 50 Years of Success
We Didn't Ask
Why Smaller Transistors
Are Better

The technical disruption in the traditional semiconductor technology means that the road ahead ends.
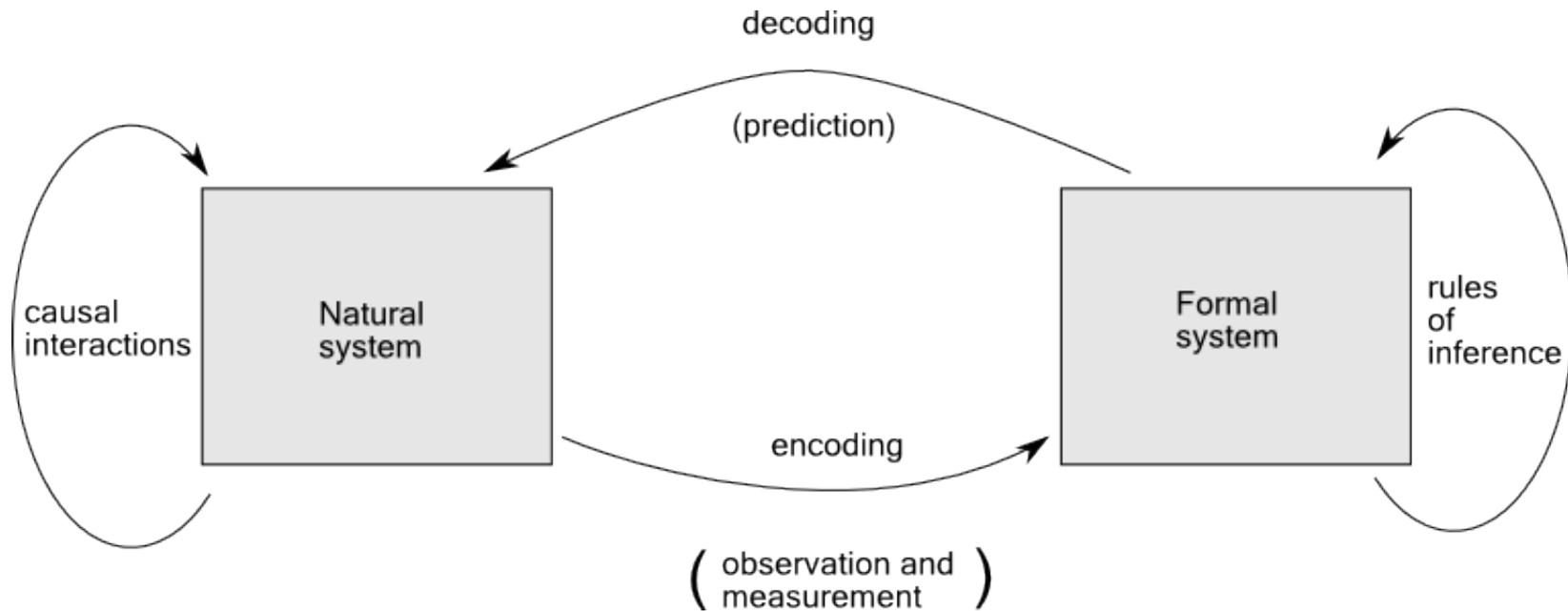
Now we can invent new computational and information processing models.

Computer is a Very Special Machine

- It was developed for two specific tasks
  - Differential equations of motion (artillery trajectories, radioactive decay)
  - String manipulation (census data, decryption)
- It was shown to be equivalent to "universal" logical machines
  - Computer is as good as the best of all formal machines
- In the 1950s, and after, it was generally believed that computers can do even more: artificial intelligence, natural language processing, machine vision, weather forecasts, etc.
- The class of problems that the "universal" machine can handle is, however, very small
- The reason:
  - Computer is a purely syntactic machine that requires a specific form of modeling the world and its causal structures

The Modeling Relation

decoding

(prediction)

causal interactions   Natural system

Formal system   rules of inference

encoding

(observation and measurement)

Rosen, R. (1985) Anticipatory Systems. Oxford: Pergamon Press, p. 74.

Purely Syntactic Objects

- Why can a computer solve differential equations of motion?

$$dx/dt = f(x)$$

$$x(t) = x_0 + \int_0^t f(x(\tau), \alpha) \, d\tau$$

- The answer: Dynamical systems are local. The same program works independent of the system state.

- Most systems are of a different kind: vector fields, inhibitory-excitatory systems, ecosystems, non-reductionist systems

Rosen, R. (1987) On the scope of syntactics in mathematics and science: the machine metaphor. In Casti & Karlqvist (eds.), Real Brains, Artificial Minds North-Holland, pp. 1-23.

For this

we need
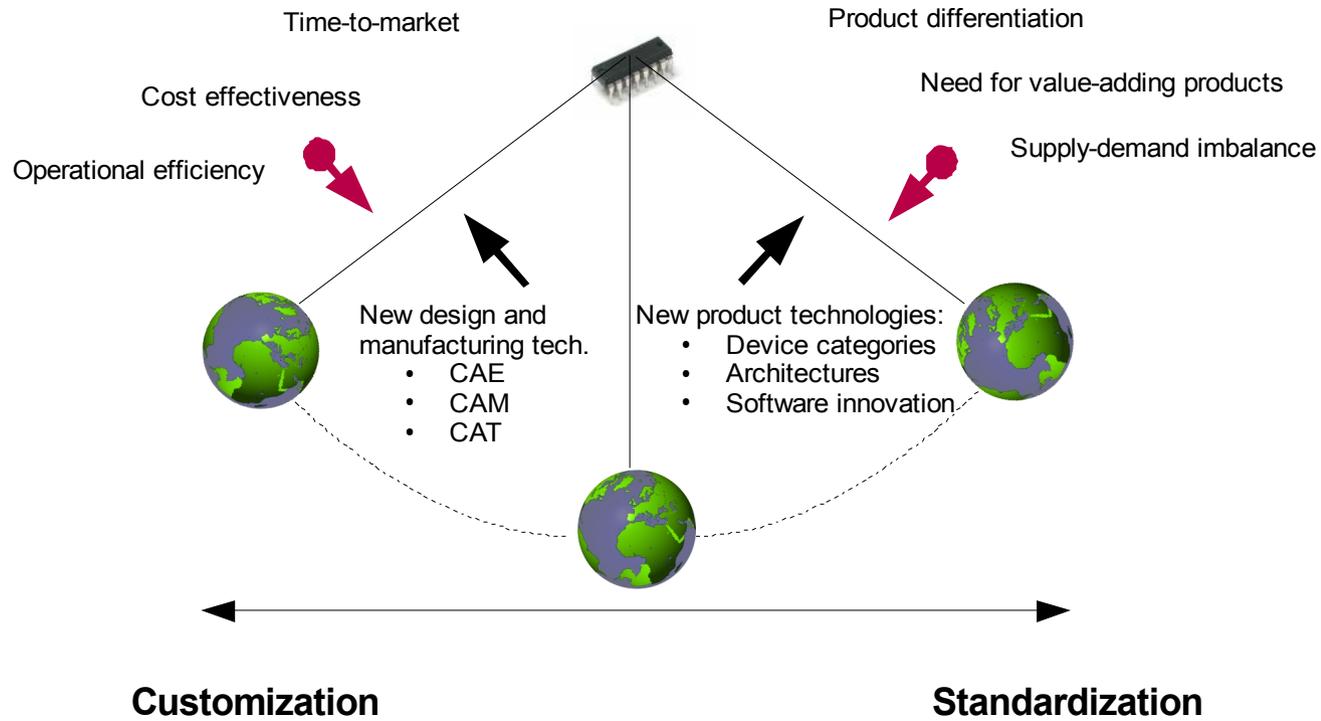
new

information processing

models

Revolutionary Ideas, Anyone?

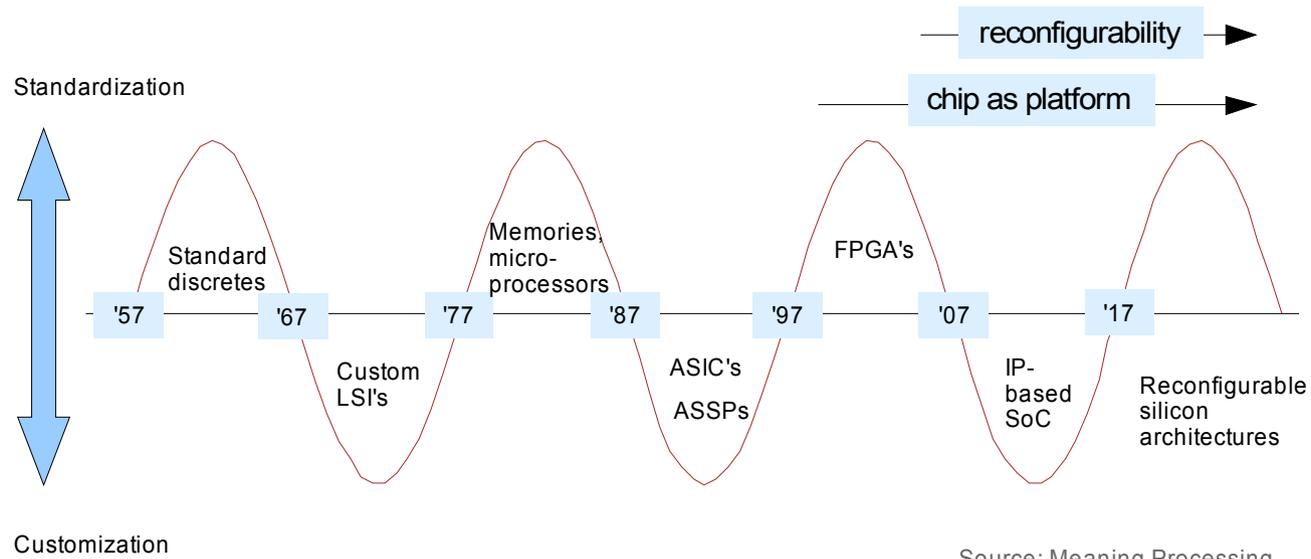# The Semiconductor Value System
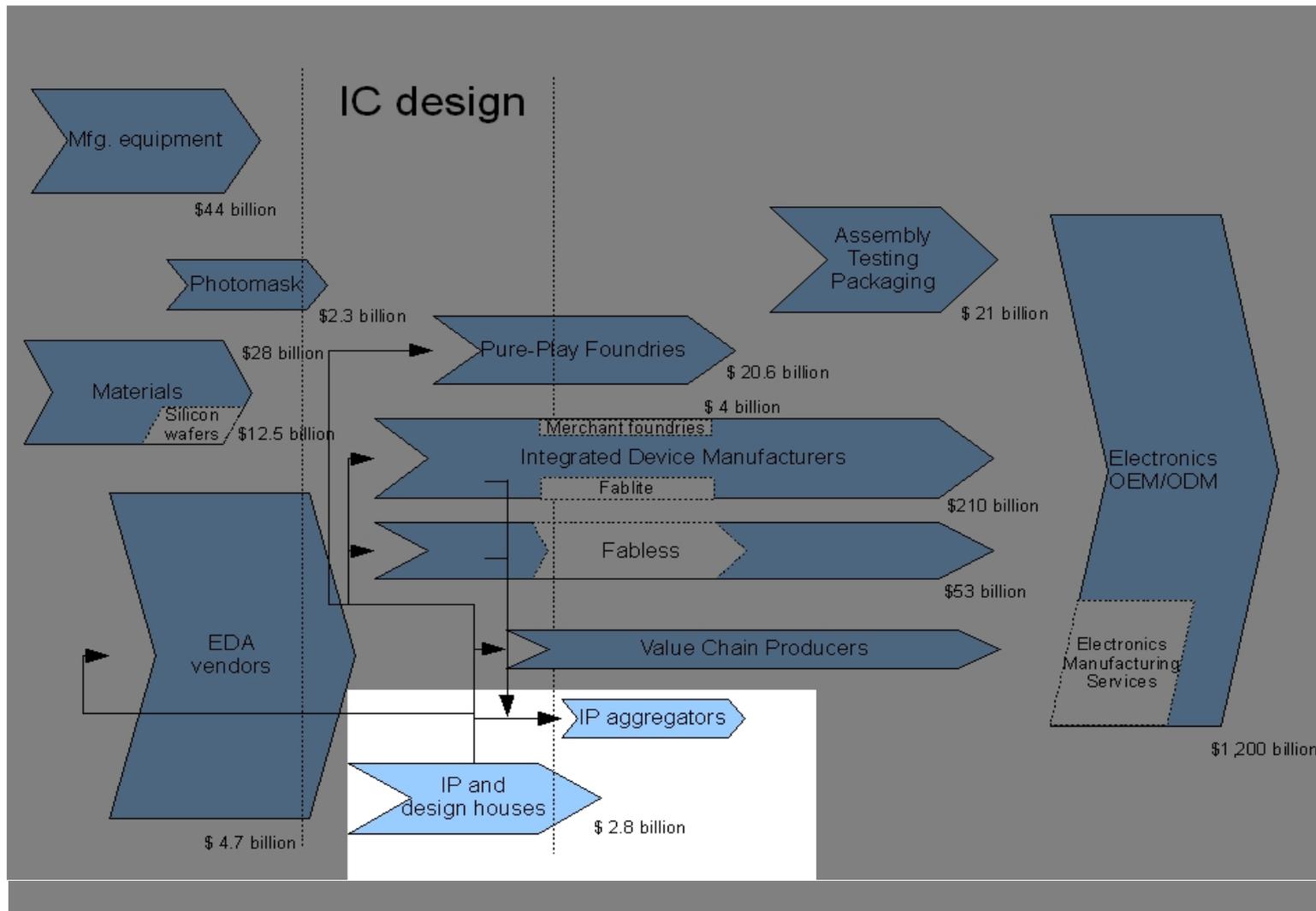
Source: Tuomi, I. (2009) The future of semiconductor intellectual property blocks and architectures in Europe. Luxembourg, European Commission, (in print).

Makimoto pendel

Time-to-market

Product differentiation

Cost effectiveness

Need for value-adding products

Operational efficiency

Supply-demand imbalance

New design and manufacturing tech.
- CAE
- CAM
- CAT

New product technologies:
- Device categories
- Architectures
- Software innovation

Customization

Standardization

Source: Meaning Processing

Makimoto Wave

Standardization

reconfigurability →

chip as platform →

'57   '67   '77   '87   '97   '07   '17

Standard discretes

Custom LSI's

Memories, micro-processors

ASIC's

ASSPs

FPGA's
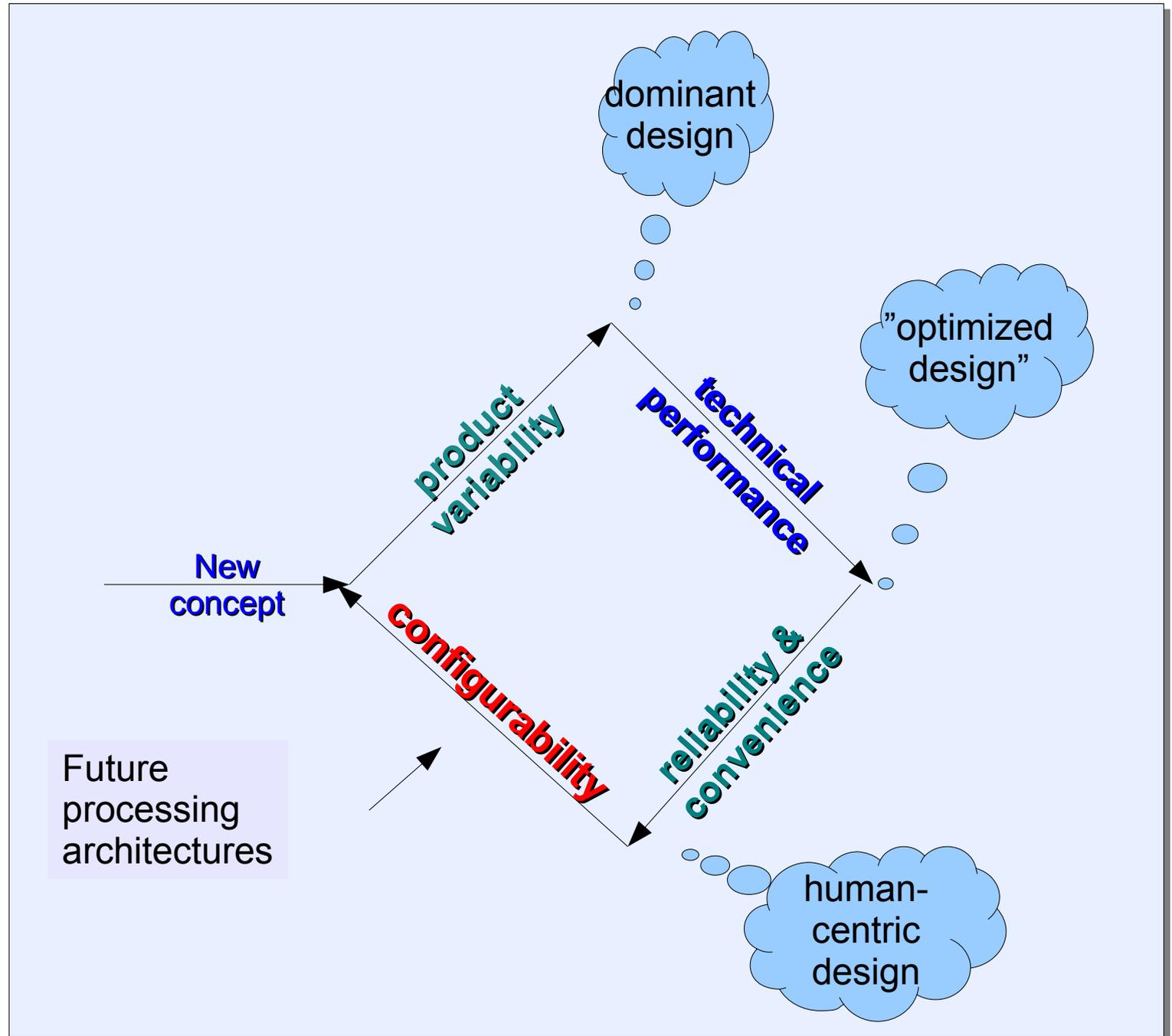
IP-based SoC

Reconfigurable silicon architectures

Customization

Source: Meaning Processing

Life-Cycles of General-Purpose Technologies

Printed semiconductors can create a new domain of innovation that has radically different economics from conventional ICs.

"Low processing capacity" can be compensated by problem-oriented configurable processing architectures.

The wrong approach is to try and copy "leading-edge" silicon; much of that leading-edge technology is used to overcome and compensate for problems created by inadequate computational models and the 50-year success of incremental innovation.

We are at the beginning

of the computer revolution,

but the future just isn't anymore

what it used to be.

Kiitos!   Thank You!

http://www.meaningprocessing.com/personalPages/tuomi/