Sustaining the Exponential Growth of Embedded DSP Capability†

High Performance Embedded Computing Workshop

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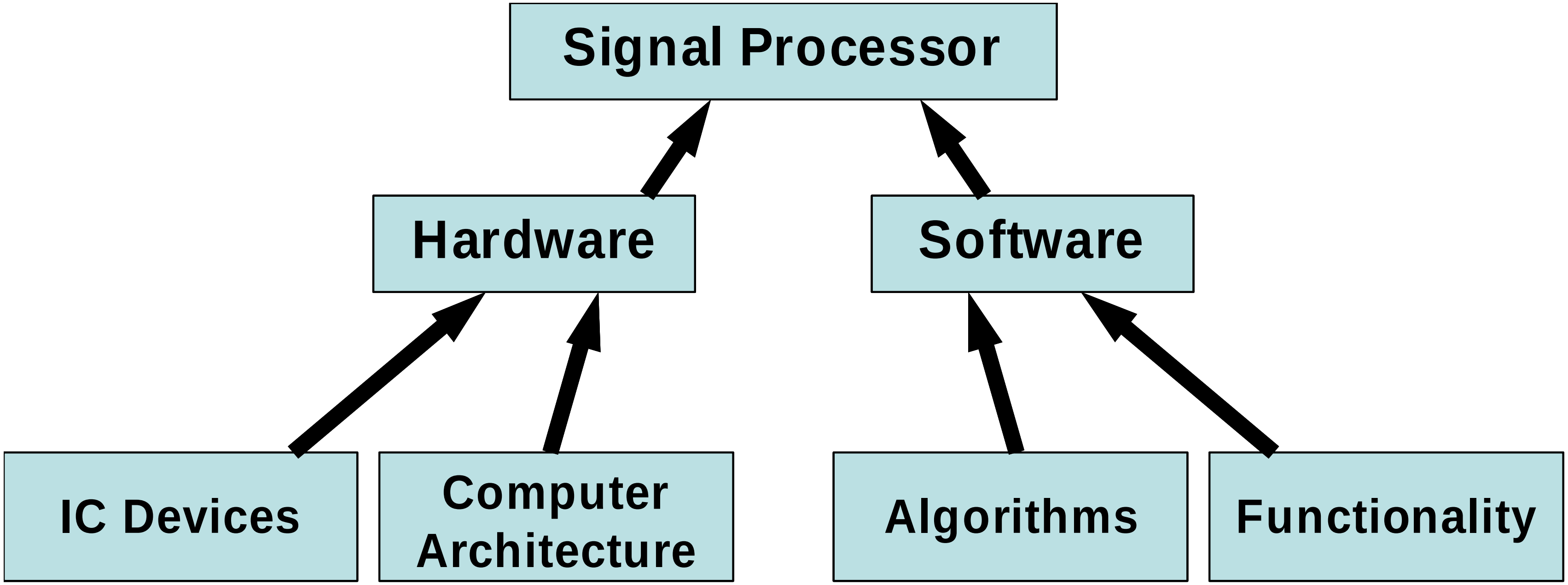
Elements Contributing to Embedded Processor Performance

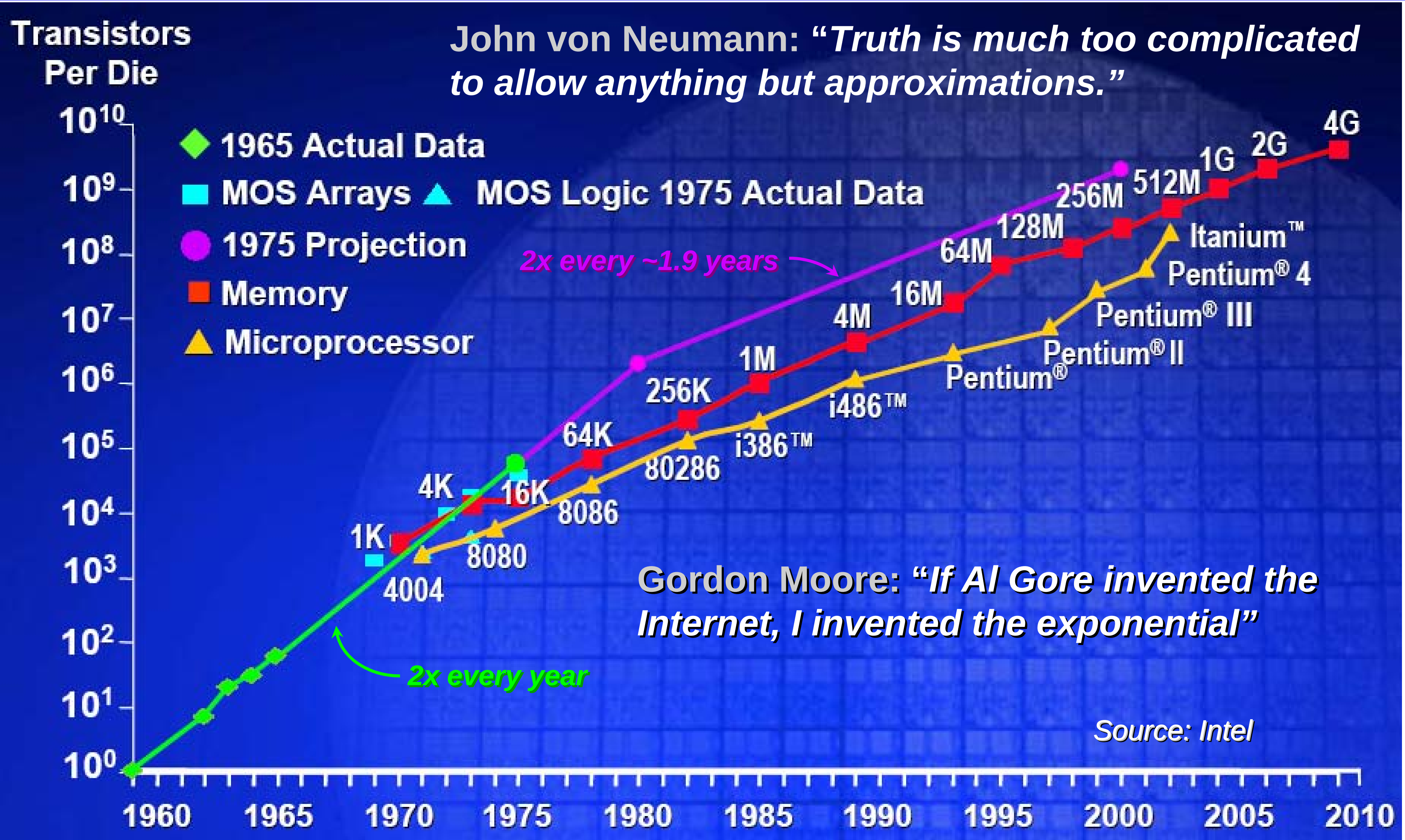


Outline

- Historical perspective – fulfillment of Moore's Law
- Impediments to continued IC density growth
- Algorithms – the softer side of exponential growth
- Implications regarding sustaining exponential growth
- Summary and Conclusions

Moore's Law: Prediction and Realization

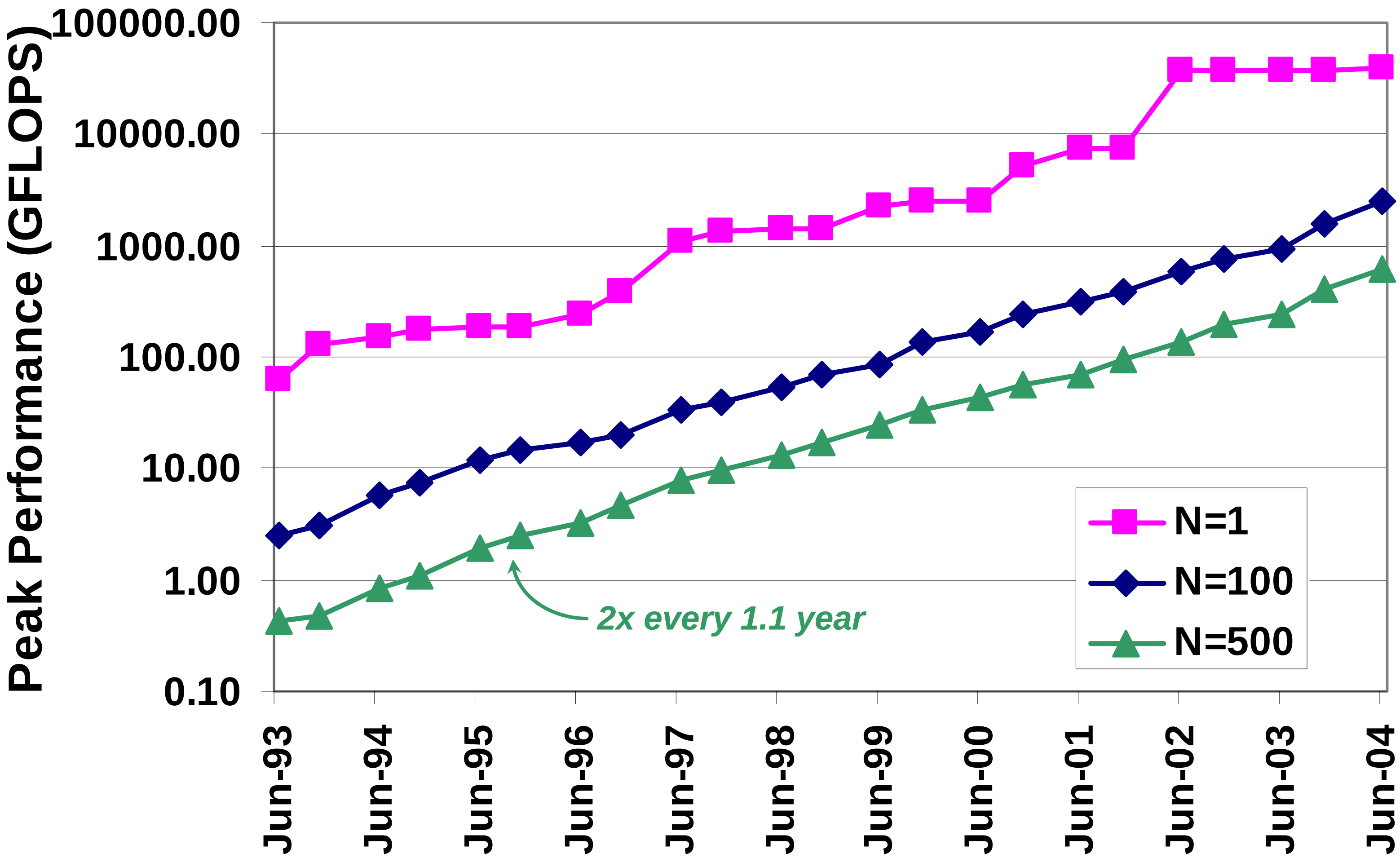
John von Neumann: "*Truth is much too complicated to allow anything but approximations.*"



Gordon Moore: "*If Al Gore invented the Internet, I invented the exponential*"

Source: Intel

Top 500 Computer Growth



Outline

- Historical perspective - fulfillment of Moore's Law
- Impediments to continued IC density growth
  - Heat dissipation
  - Quantum effects
  - Production technology
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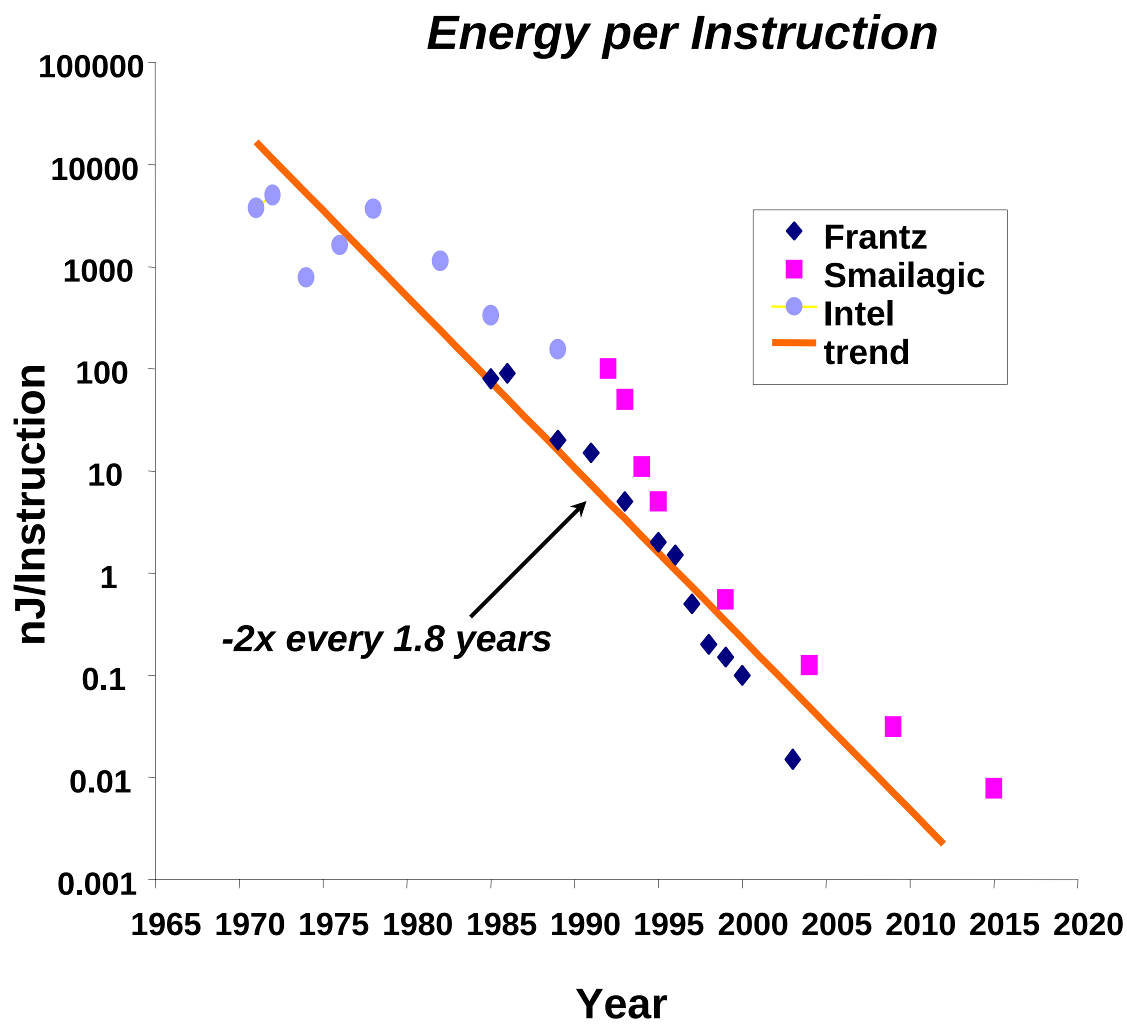
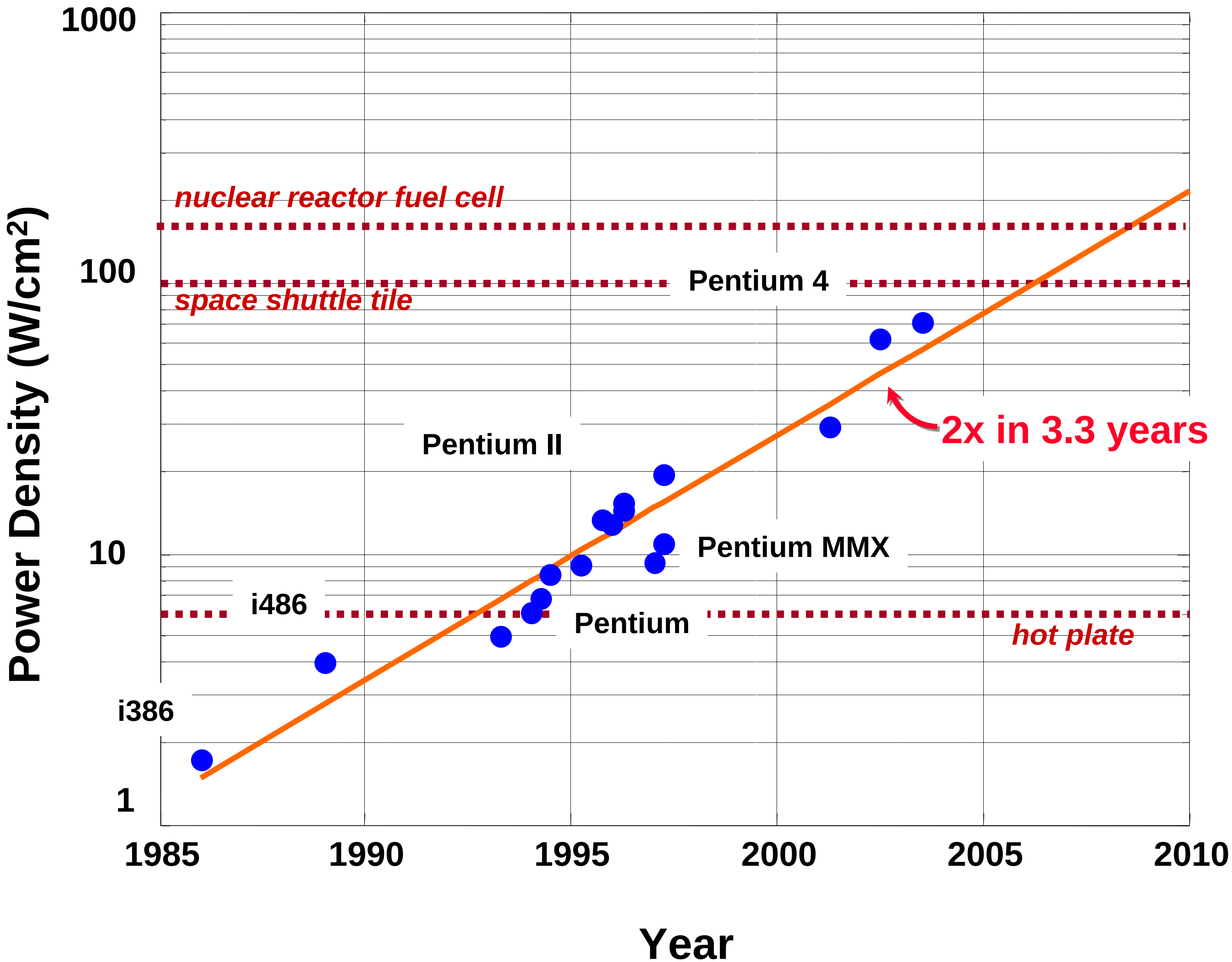
Performance Implications of Shrinking Feature Size

$\Delta \equiv$ feature size

Performance Metric	*Geometrical Dependency*
Clock Frequency	$1/\Delta$
Transistor Power	Δ
Transistor Density	$1/\Delta^2$
Total Device Power	$1/\Delta$
Power Density	$1/\Delta$
Energy/Instruction	Δ^2



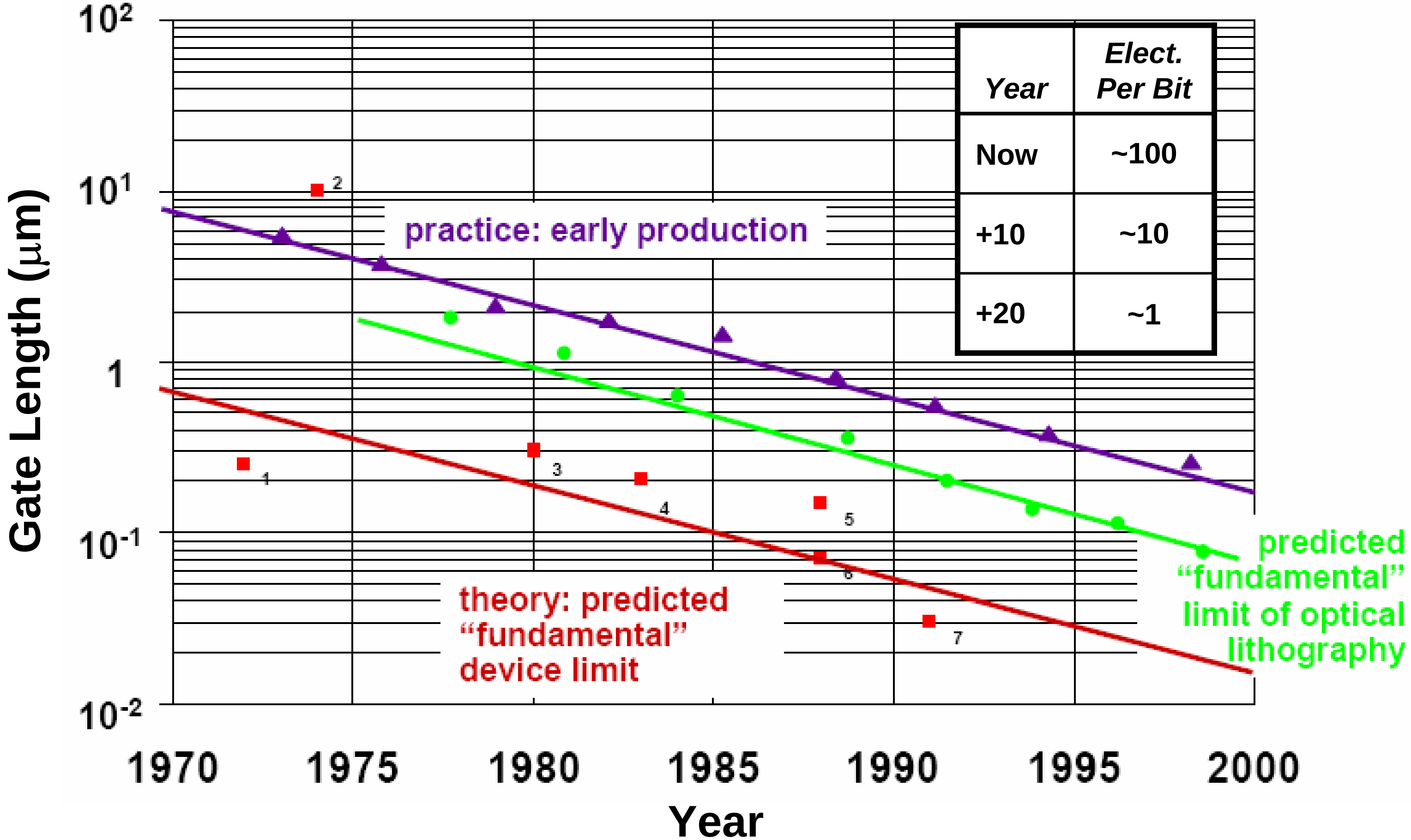
Moore's Law Growth in Power Density



Moore's Law is Dead, Long Live Moore's Law!

Theory & Practice: Feature Size for MOSFET Devices

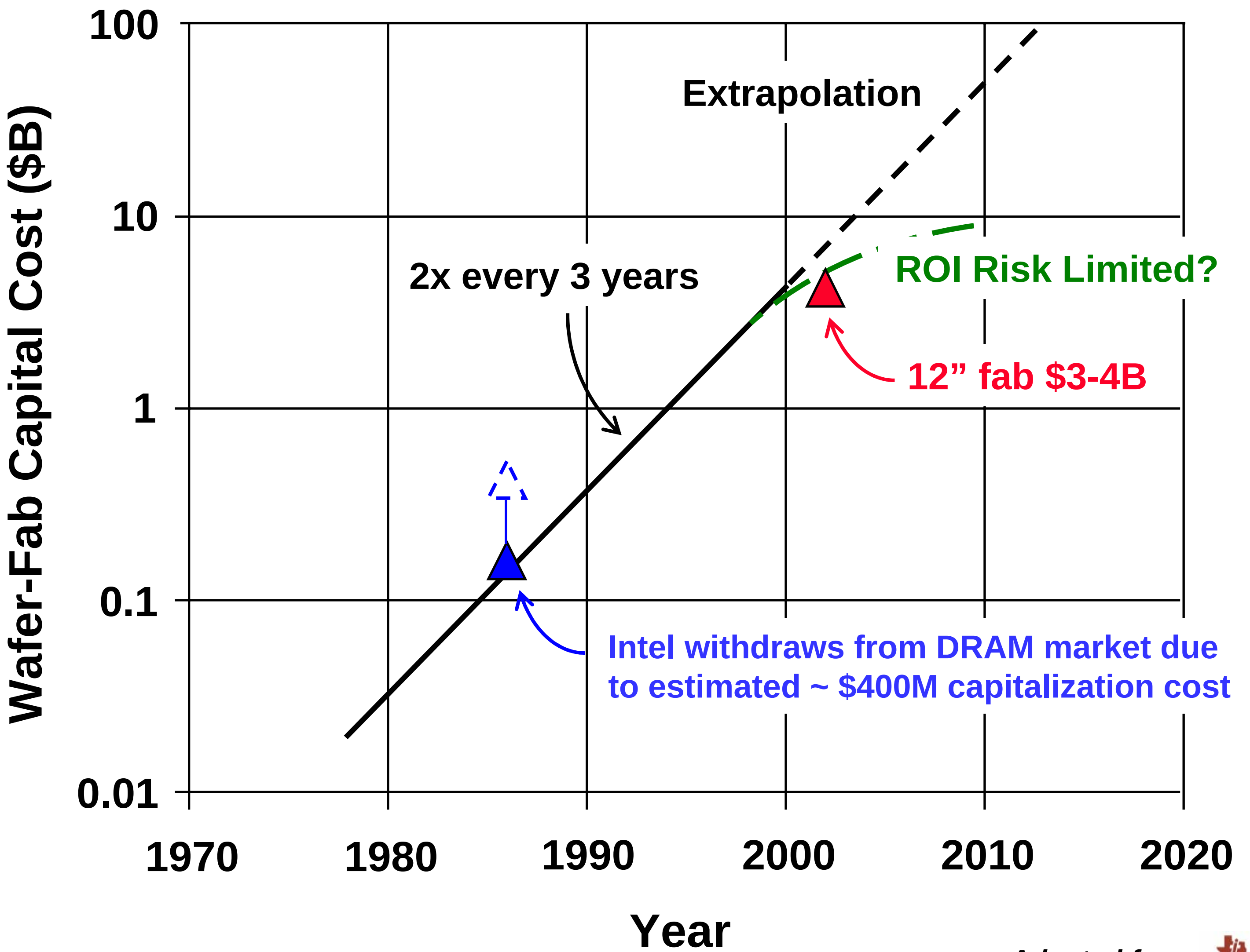
It's tough to make predictions, especially about the future. - Yogi Berra



Year	Elect. Per Bit
Now	~100
+10	~10
+20	~1

Sources:
Combined graph and original concept: Lance Glasser, former Director, DARPA/ETO
Theory: Provided by Prof. David Ferry, Arizona State University
Practice: *The National Technology Roadmap for Semiconductors* (SIA Publication, 1994)

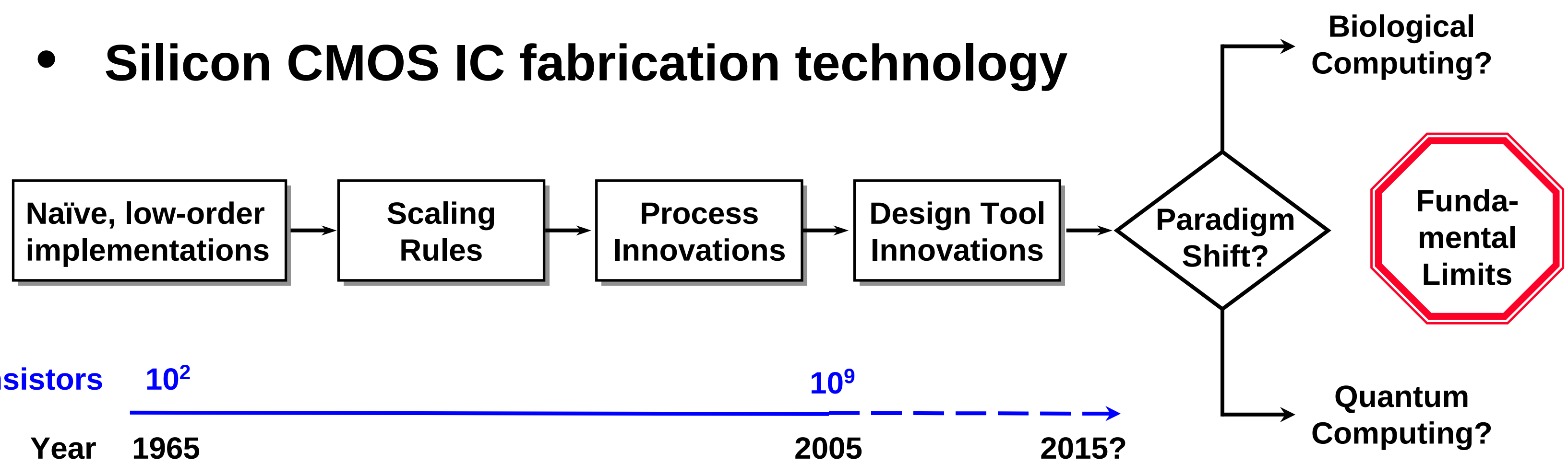
Capitalization Cost Impediments



Adapted from: Texas Instruments

Fulfillment and Impact of Moore's Prediction

- **Silicon CMOS IC fabrication technology**

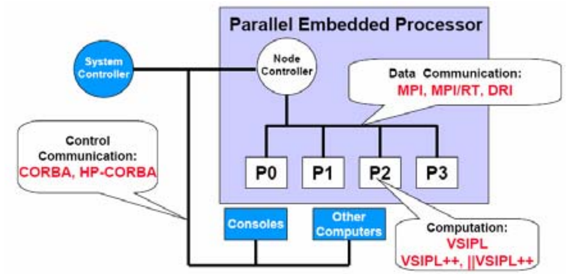


- **Examples of far-reaching impact**

Exponential Improvements In Computing at a Fixed Price Point

Embedded Processors For Real-time Digital Signal Processing

Low-power Wireless Applications



Loosely-Coupled Hardware & Software Design Methodologies

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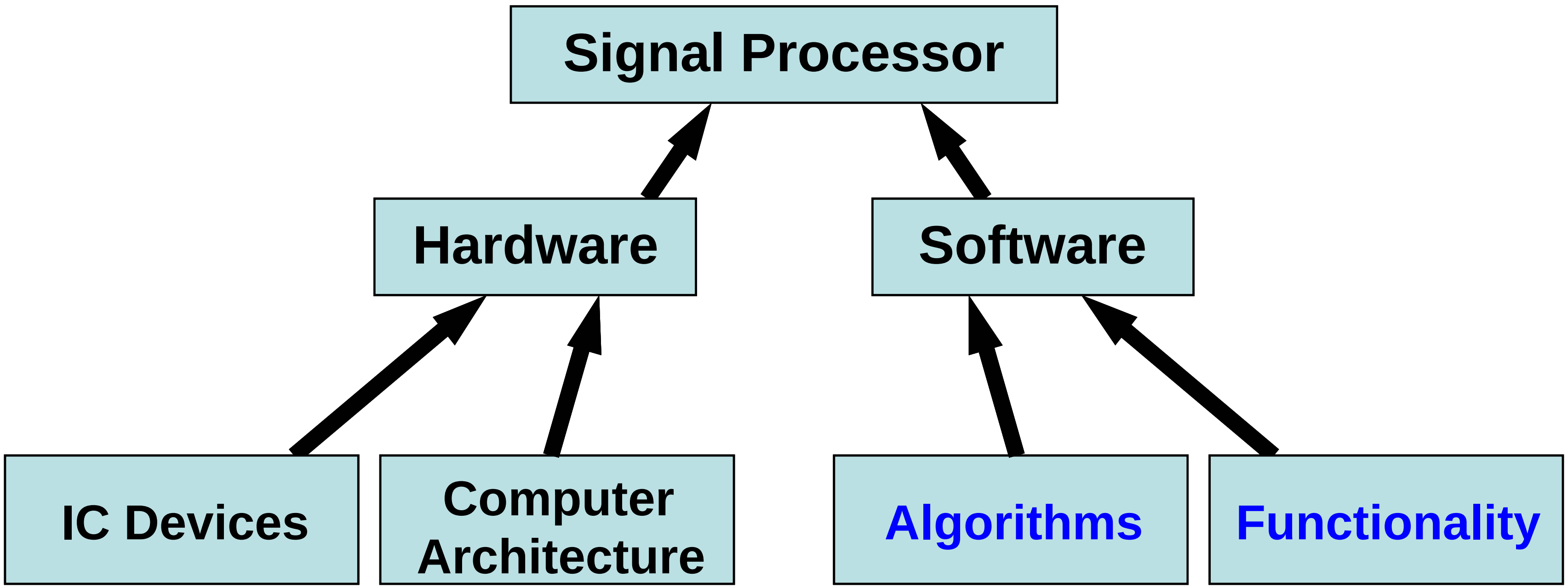
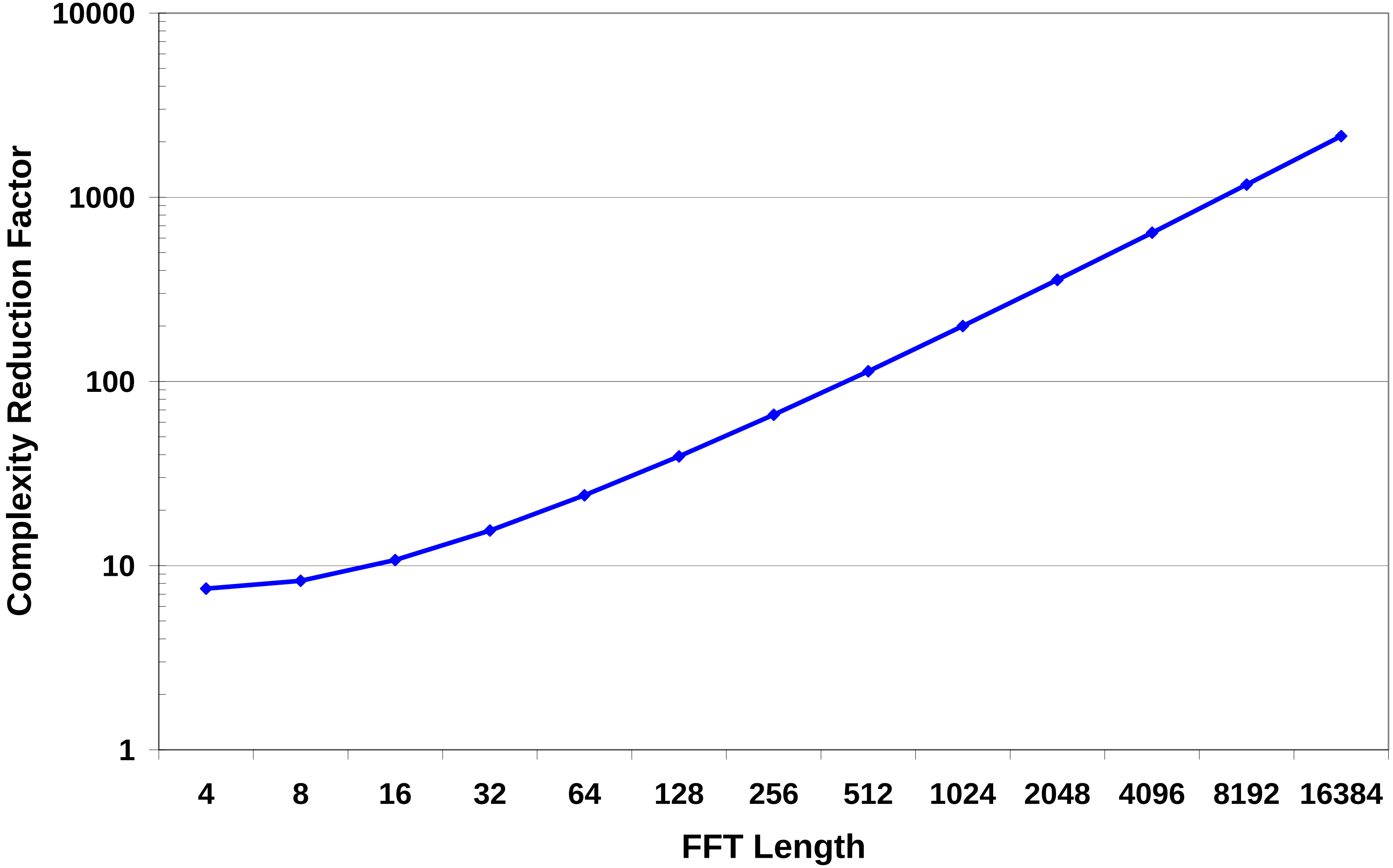
Elements Contributing to Embedded Processor Performance



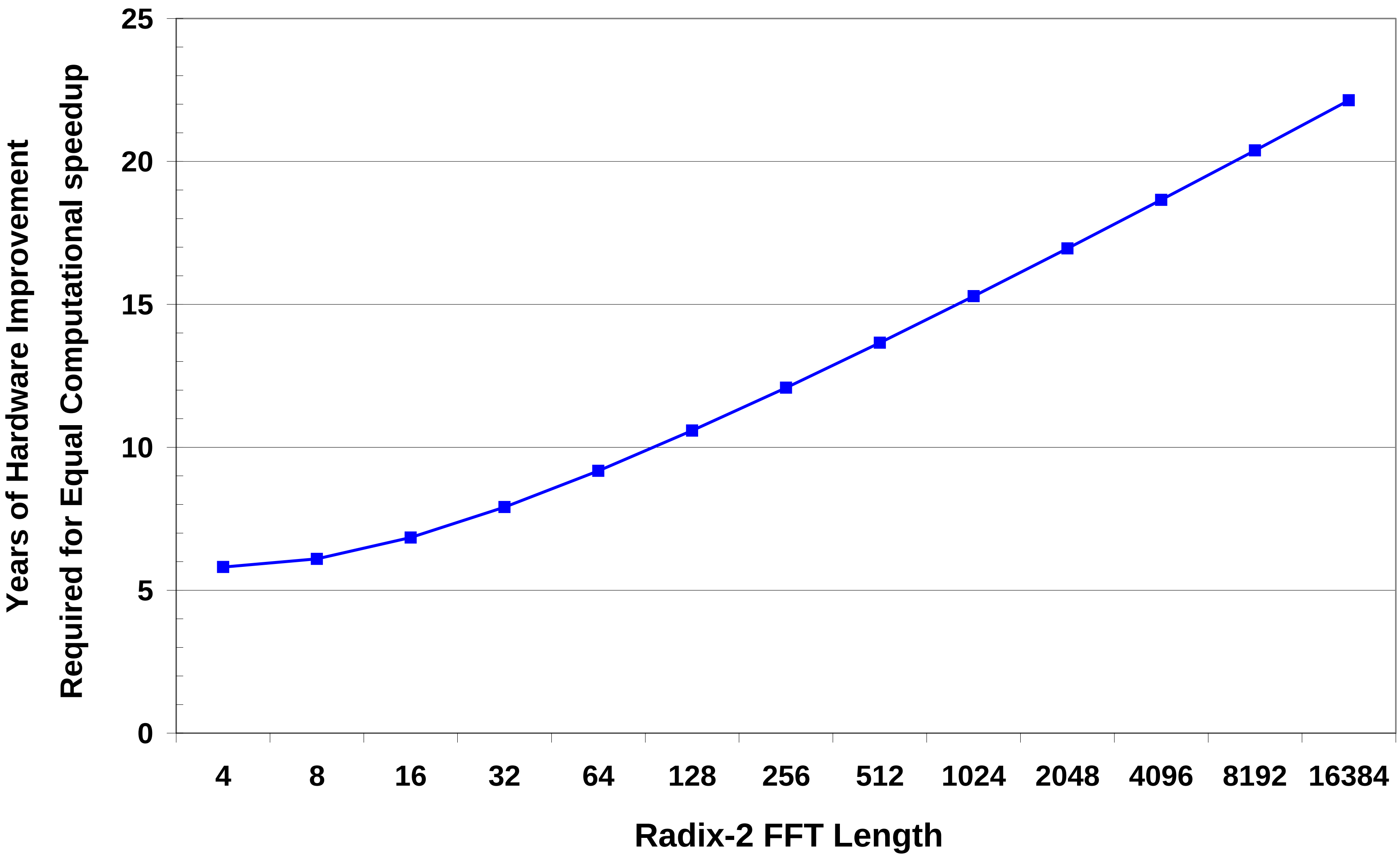
Different Character of Hardware (IC) Vs. Algorithm Improvements

Improvement Metrics	*Hardware*	*Algorithms*
Regularity	**Predictable**	**Unpredictable**
Dependent variable	**Time**	**Order complexity**
Impact on applications	**Incremental**	**Leap-ahead**
Useful lifetime	**3 years or less**	**10 years or more**
R&D Cost growth	**2x in 3 years**	**1.11x in 3 years**

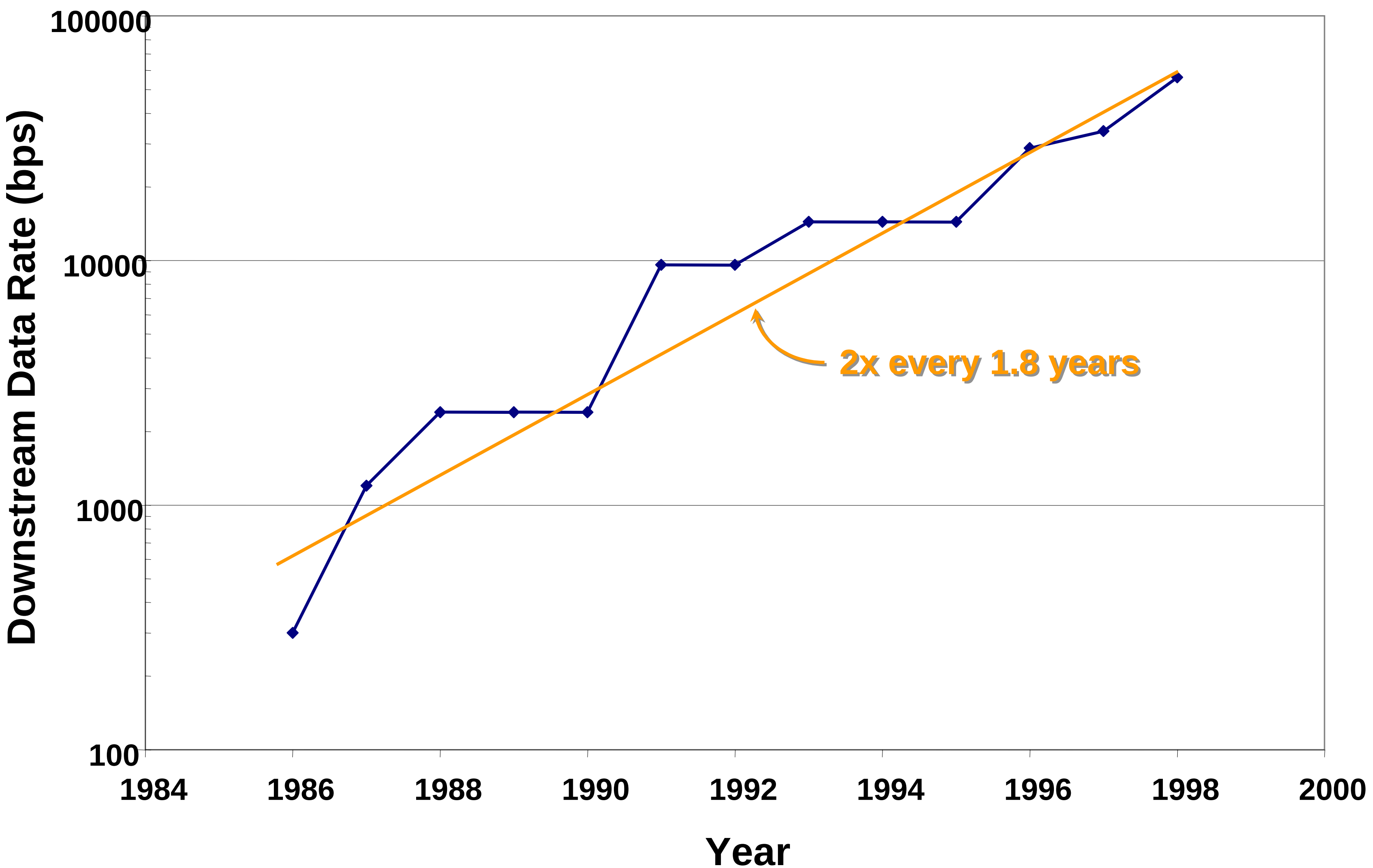
Computational Complexity Reduction Afforded by the FFT Over a Sum-of-Products DFT



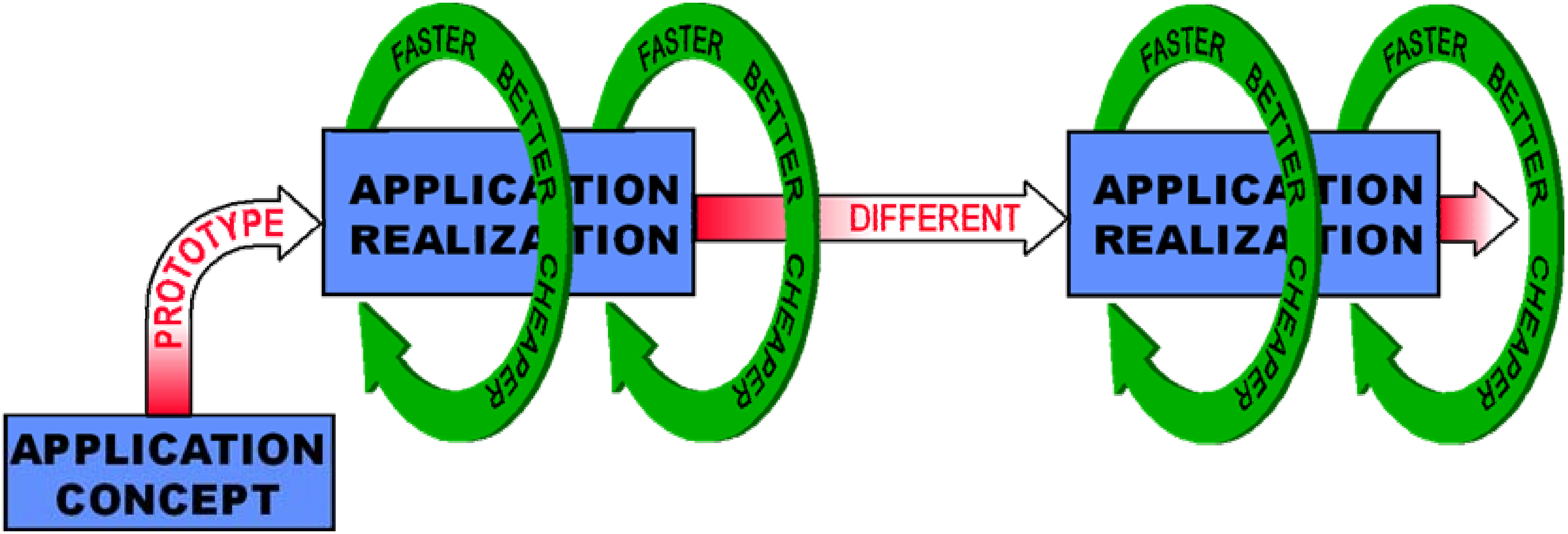
Moore's-Law Equivalent Years Required to Match FFT Computational Speedup



Exponential Improvement in Modem Rates

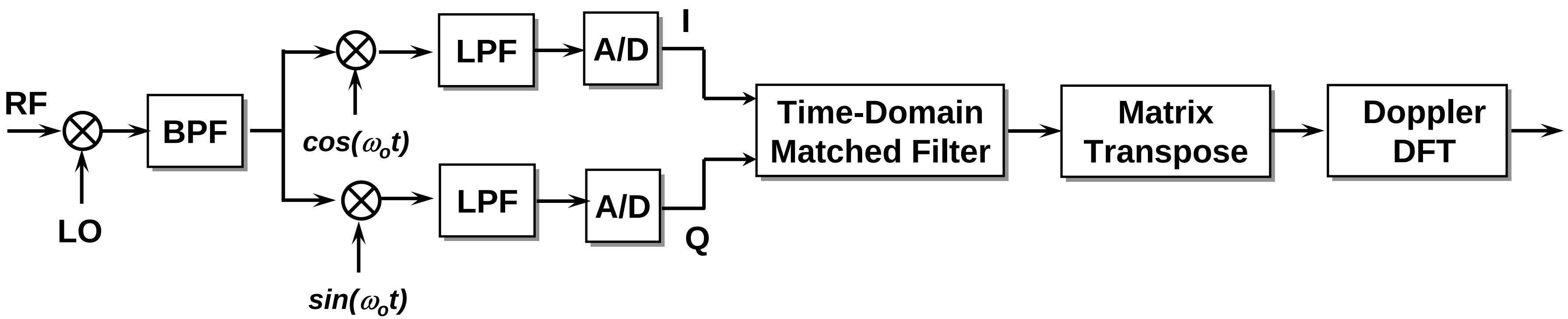


Application Maturation Cycle

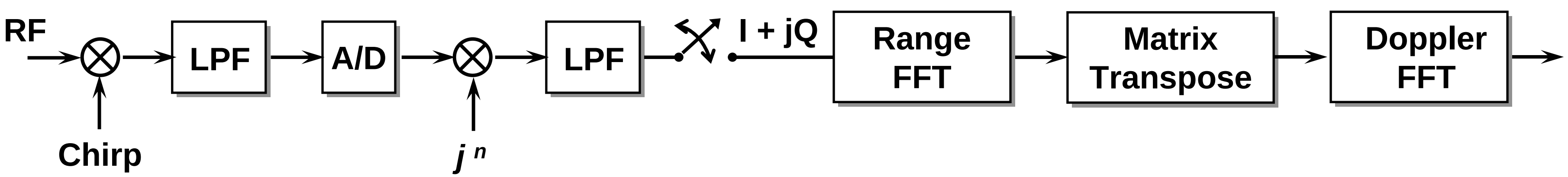


Pulse-Doppler Radar Example

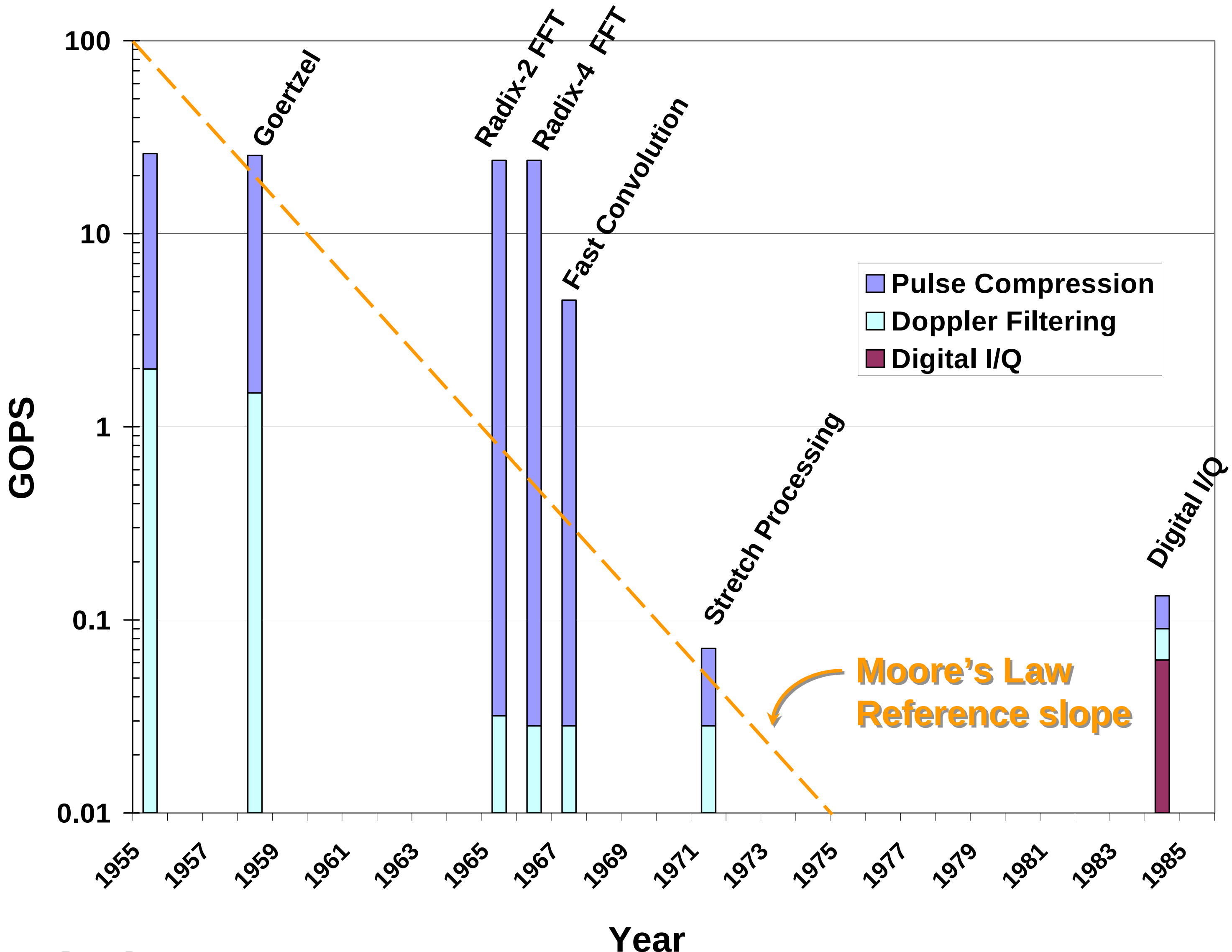
- Algorithmically naïve implementation



- Reduced-order implementation with digital I/Q



Pulse-Doppler Radar Algorithm Improvements



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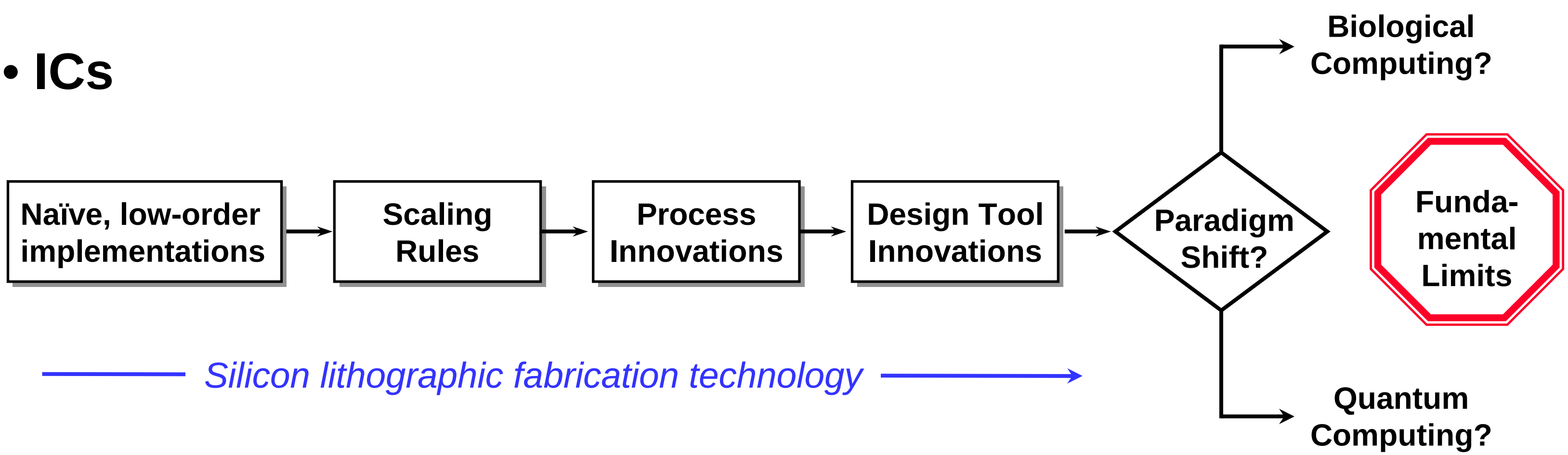
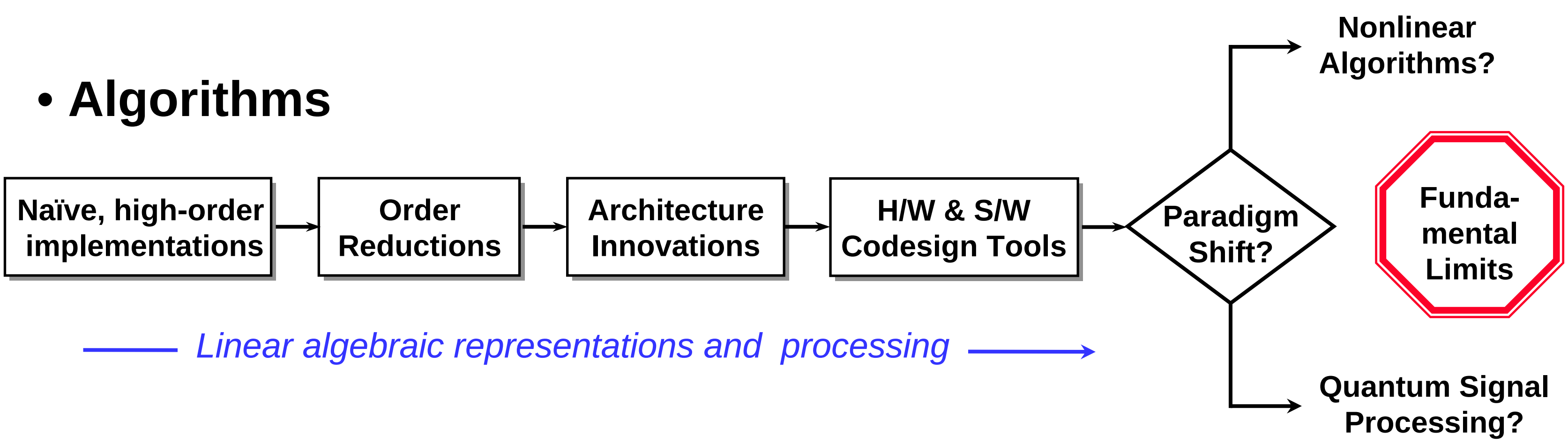
IC Vs. Algorithm Development

(A Contrived but Useful Analogy)

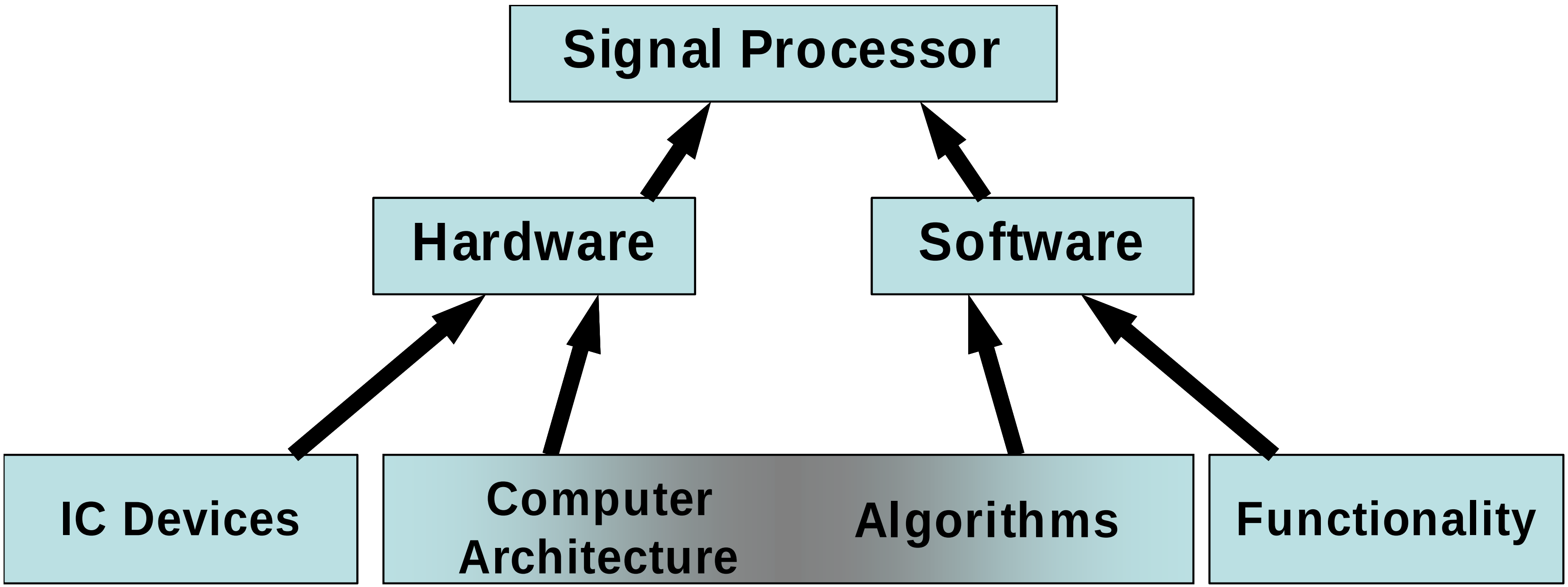
- **ICs**



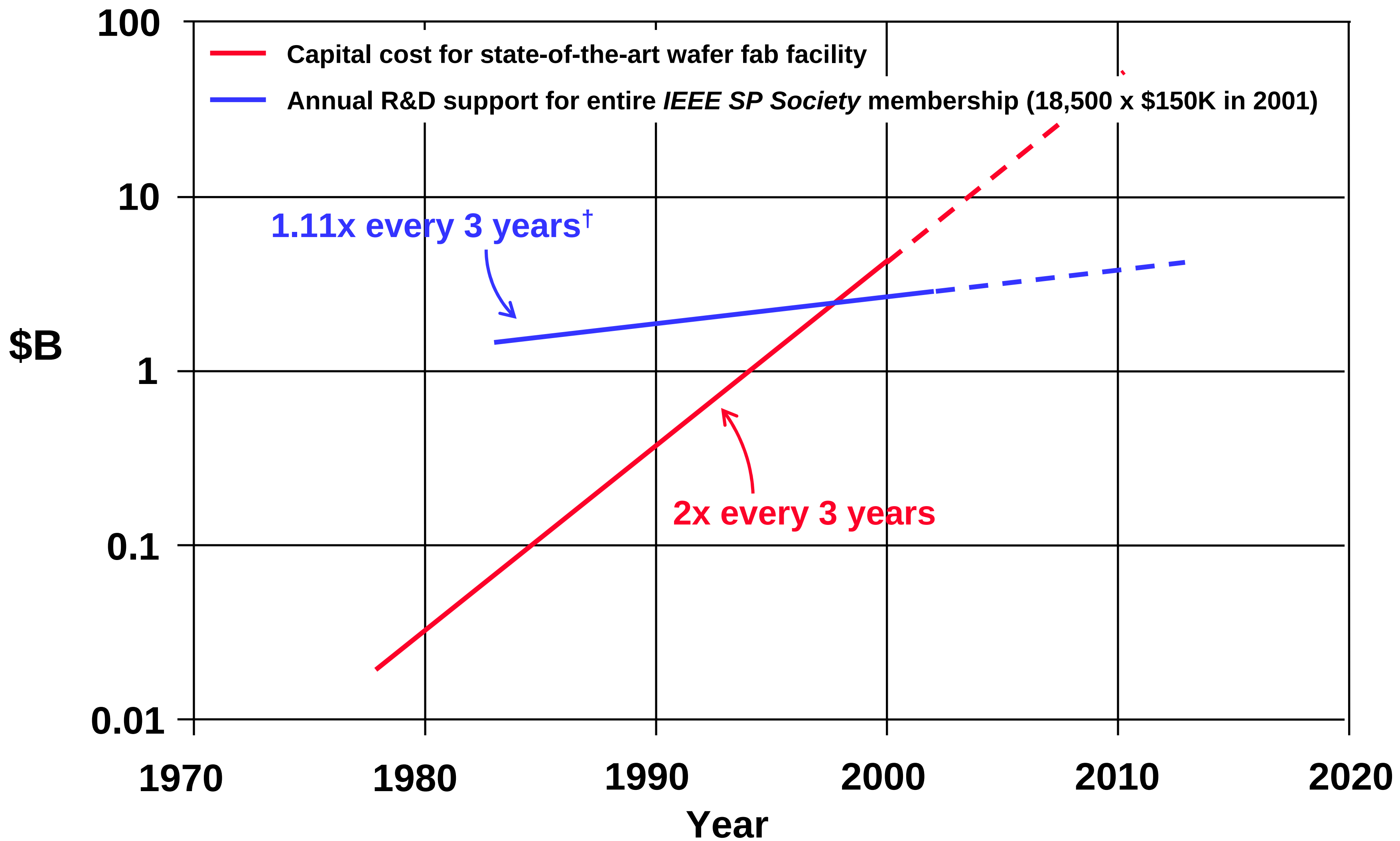
- **Algorithms**



Increased Emphasis on Codesign Methodologies



Wafer-Fab Capitalization Cost Compared to Annual DSP Algorithm R&D Costs



† *Salary inflation rate based on US Bureau of Labor and Statistics Median Engineering Salaries 1983-2003*

Summary and Conclusions

- **Fulfilling Moore's Law**
  - Enabled by diverse, innovative R&D aimed at realizing a common vision (ITRS semiconductor roadmap)
  - Continued improvements may be impeded by a combination of thermal, quantum, and capital cost limits
- **Taking up the slack**
  - Over same 40-year time frame as Moore's Law, algorithm innovation has yielded exponentially improving performance as well
  - Algorithm innovation also enabled by diverse R&D, but without as clear of an industry-wide common vision
  - Algorithm R&D cost growth significantly lower than fab capital cost growth (*1.1x* vs. *2x* every 3 years)
- **Increasing the effectiveness of algorithm R&D**
  - Develop better methods for quantifying the return on investment for algorithm R&D
  - Consider mechanisms for developing a broader industry vision and commitment to a long-term R&D roadmap
- **Hardware/software codesign methods increasingly important**