



Moore's Law over the Next Decade

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Cadence Design Systems, Inc.

Introduction

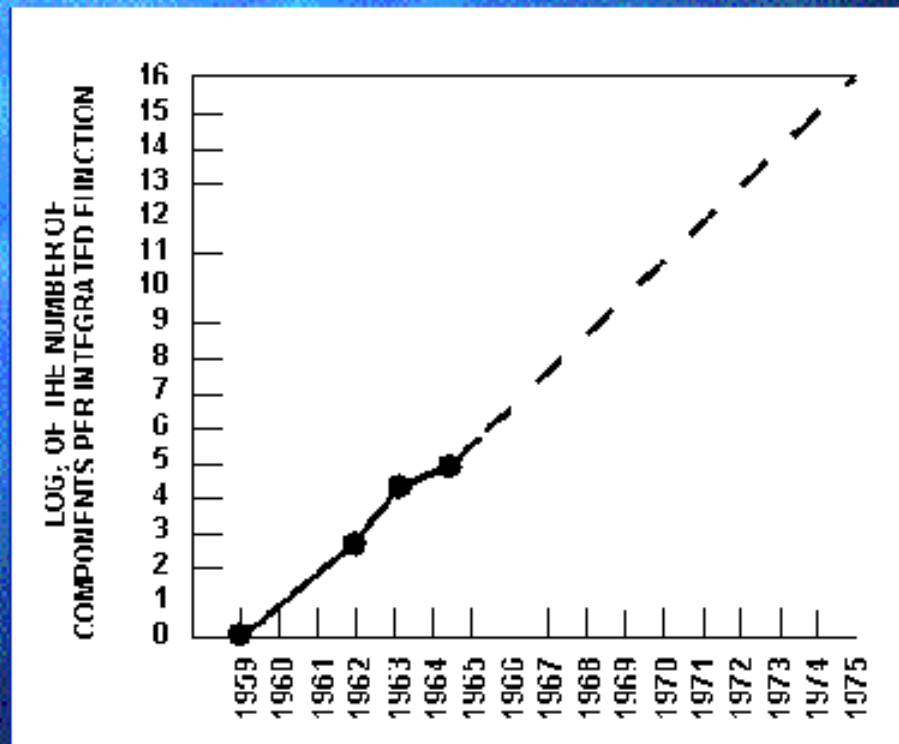
- What is Moore's Law?
- Physics of scaling
- Economics of the electronics industry
- Industry roadmaps
- Conclusions

What is Moore's Law

- An Empirical Observation about increasing chip capabilities
 - See, for example "**An Update on Moore's Law**"
Intel Chairman Emeritus Gordon Moore , 1997
 - Available on the Intel Web Site
- Original form
 - Twice the number of transistors on a chip every 18 months
- Many variants; most relevant to SKA is:
 - Twice the processing power every 18 months for constant cost

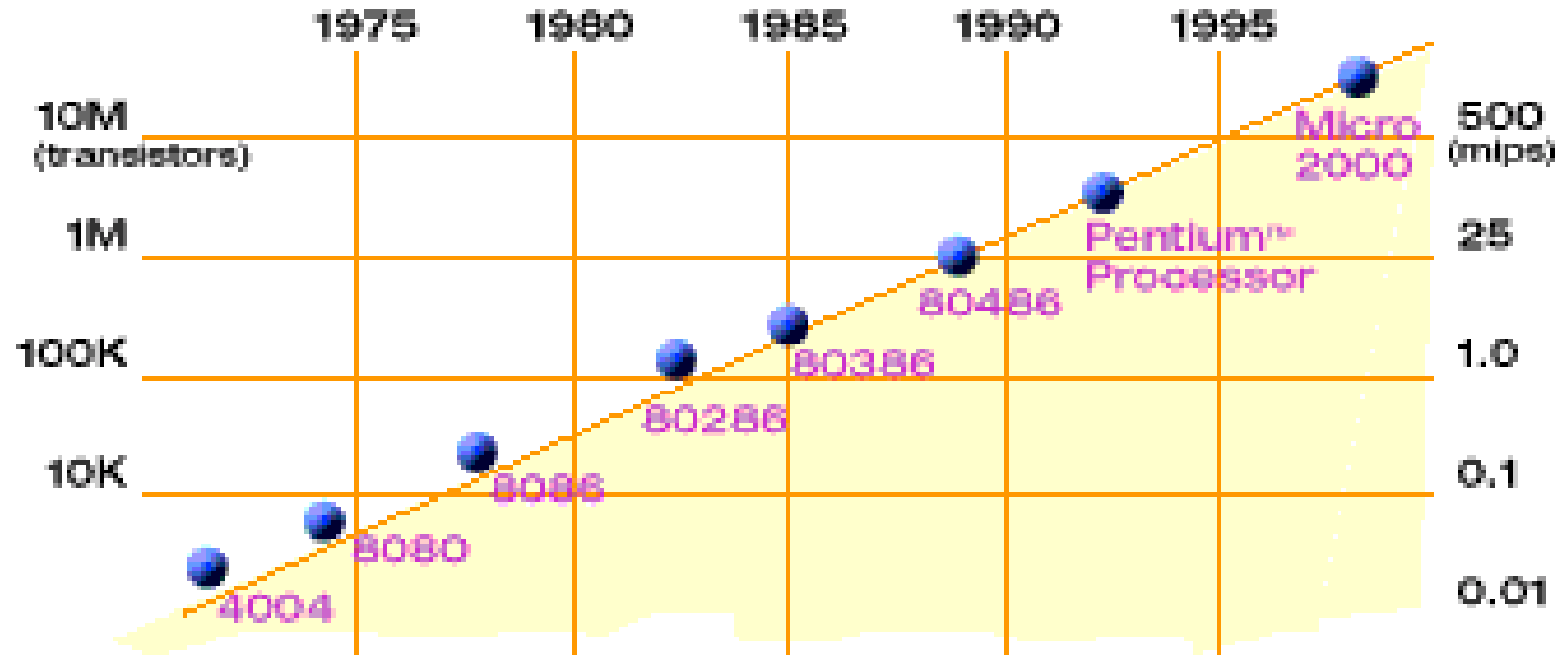
Original hypothesis was from few points....

The Original Moore's Law Plot



Source: *Electronics*, April 1965

But it has been good for 30 years

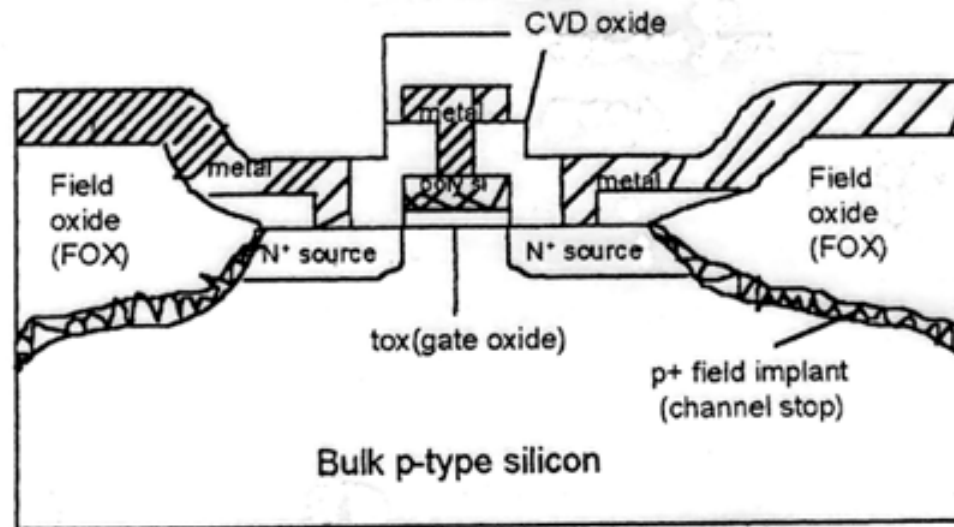


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Plot from Intel

Physics

- Based on feature scaling (and bigger chips)
- Basic idea – if you scale everything down, it works better



Typical transistor cross section

(from ICE, Taiwan)

Physics of scaling

- Scale all 3 physical dimensions and voltage
 - Field strengths unchanged
 - Drive strength unchanged
 - C is half as much
- Twice the speed
- 1/4 the power ($\frac{1}{2} V \times \frac{1}{2} Q$) (per operation)
- 4 times the transistors on a chip of the same size
- 8 times the computing power for the same cost! (More or less)
- Practice is not so simple, but general idea holds

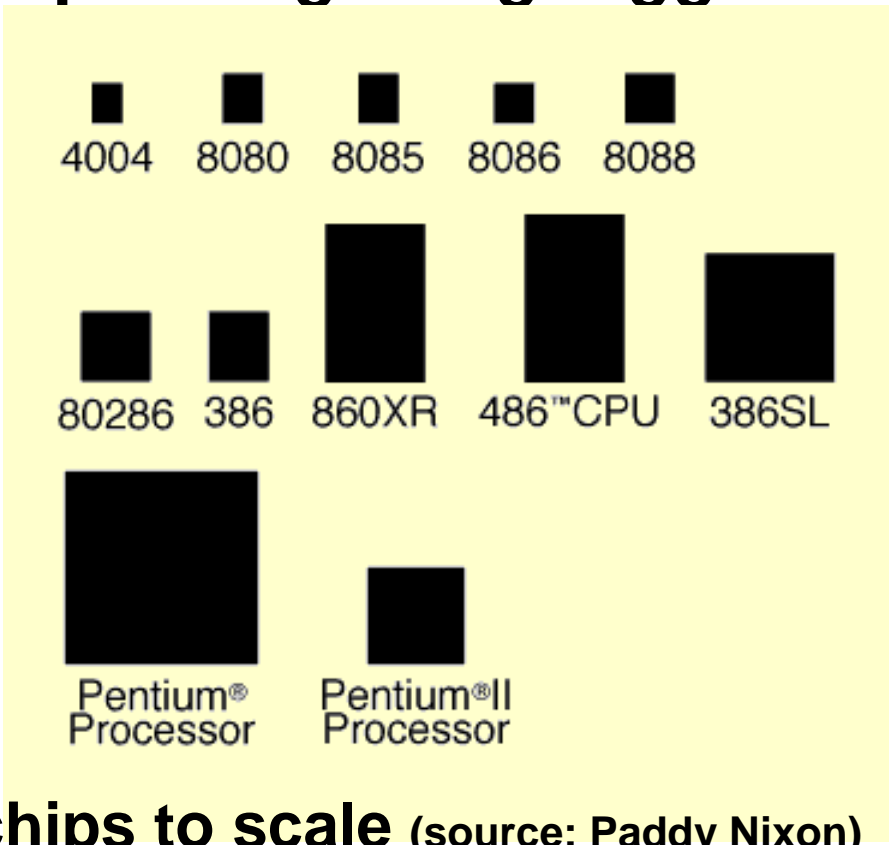
How far can Moore's law be extrapolated?

- Two major physics problems:
 - Do smaller devices still work?
 - Can we manufacture them by optical lithography?
 - Or, failing that X-ray or electron beam?
- Pure technology questions
 - How big of a chip can we make profitably?
- Economic questions
 - Who will pay for the billions in R&D required?
 - Who will pay for the factories?

Do smaller devices work?

- Current state of the art is 0.13 micron transistors
- Individual transistors with a size of 0.02 microns work well
 - See recent Intel press release
- Some problems, but nothing fatal
 - Leakage, soft errors, wire and via resistance
- So scaling provides (at least) a factor of 42 more transistors
- A more detailed look shows clock speeds may only go up as $\sqrt{6.5} = 2.5x$
- So we can expect at least $40 \times 2.5 = 100x$ more processing, from a chip of the same size

But, chips are getting bigger, too



Intel chips to scale (source: Paddy Nixon)

Max size determined by technology, not physics

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So why wait? Why not build chips with 0.02 micron transistors now?

- Why not make transistors smaller right away?
- Easy to say
- Relatively easy to do (in the lab, quantity one, cost is not an object)
- But we don't know how to do it cheaply (yet....)

Economics

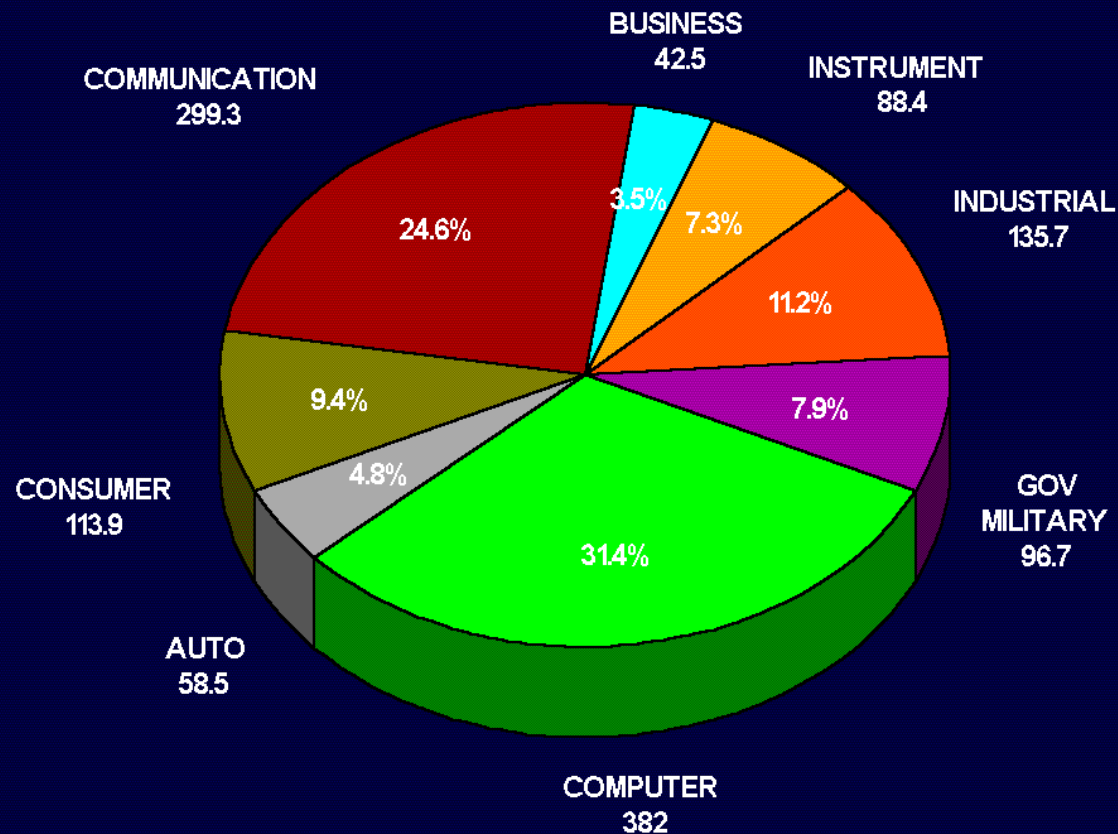
- Chips are cheap because we print transistors, not make them one at a time.
- Moore's law relies on improvements in lithography
- R&D in lithography sets the pace of Moore's law
- So far, it has been able to keep up
- Demise of optical lithography has been predicted many times
 - Electron beam or X-ray are possible but expensive

Economics

- We need R&D to make IC production better
 - But there are lots of things we'd like to make cheaper, too....
- Why can we count on someone doing the needed R&D?
 - Billions in R&D will be required
 - Billions in capital in manufacturing facilities will be needed
- Historically, the investment has been made (and resulted in big profits, so it will probably continue)
 - Electronics is a huge business and can support this investment
- There are large coordinated efforts to make this plan come true
- Companies know that if they don't invest, they will fail
 - In this respect, Moore's law is a self-fulfilling prophecy

From IPC as of 2000

ELECTRONIC EQUIPMENT PRODUCTION WORLD - 2000 ESTIMATE (\$B)



ELECTRONIC OUTLOOK 10/2000

TOTAL \$1,217 B

A plan exists for the needed improvements

- ITRS – International Technology Roadmap for Semiconductors
 - Some quotes from <http://public.itrs.org>
- The objective of the ITRS is to ensure advancements in the performance of integrated circuits. ... The ITRS identifies the technological challenges and needs facing the semiconductor industry over the next 15 years.
- It is sponsored by the Semiconductor Industry Association (SIA), the European Electronic Component Association (EECA), the Japan Electronics & Information Technology Industries Association (JEITA), the Korean Semiconductor Industry Association (KSIA), and Taiwan Semiconductor Industry Association (TSIA) .
- ... groups are made up of volunteer technology experts from chip manufactures, supplier companies, universities and academia, technology labs, and semiconductor technology consortia.

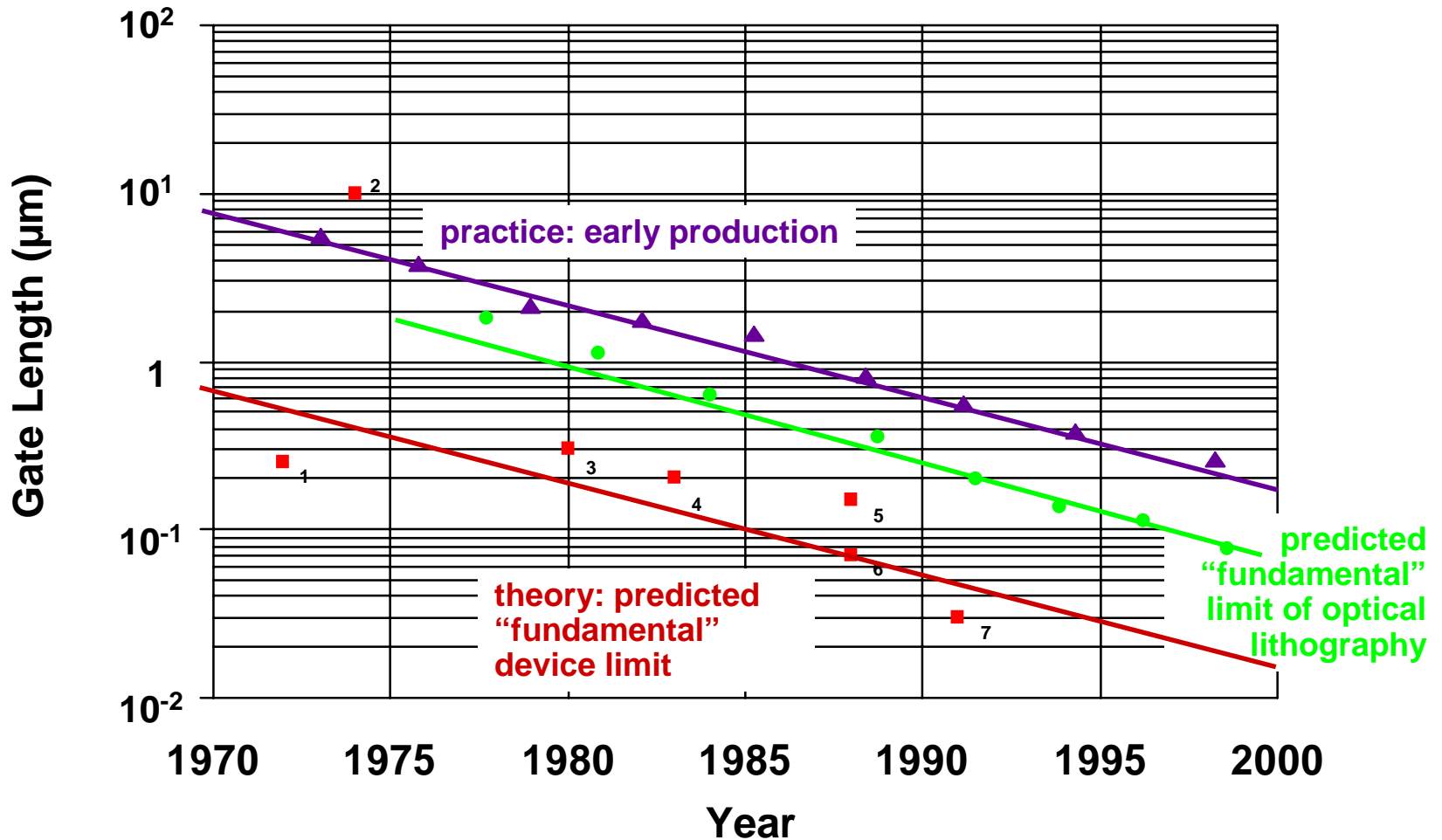
ITRS sub-groups

- The Technology Working Groups, also known as TWGs, are comprised of the technical disciplines of
 - *Design*
 - *Test*
 - *Process Integration,*
 - *Devices and Structures*
 - *Front End Processes*
 - *Lithography*
 - *Interconnect*
 - *Factory Integration*
 - *Assembly and Packaging*
 - *Environment, Safety, and Health*
 - *Defect Reduction*
 - *Metrology and*
 - *Modeling and Simulation.*

Will the R&D succeed?

- Historically, it always has...

Theory and Practice: Minimum Feature Size for MOSFET Devices



Sources:

Combined graph and original concept: Lance Glasser, Previous Director, DARPA/ETO

Theory: Provided by Prof. David Ferry, Arizona State University (see notes for references)

Practice: *The National Technology Roadmap for Semiconductors* (SIA Publication, 1994)

Conclusions

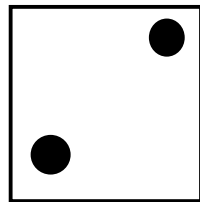
- The physics supports further miniaturization
- There are sound economic motivations for the needed R&D
- There are well organized plans outlining the required tasks

- Moore's law should be reliable up through 2011 at least
- Moore himself predicts at least 2017

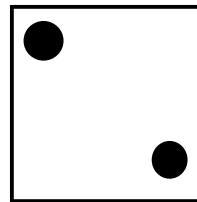
- And what after that?

Speculation

- Miniaturization fails when QM effects become important
- But this is the same scale where QM effects become useful!
- For example, look at energies of electrons confined in a box.



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- To use this for digital logic, need to distinguish states reliably.
- The smaller the box, the bigger delta-E between states
- At 0.25 microns, states are closer than room temp kT.
 - Devices work, but only at cryogenic temperatures.
- At very small feature sizes, works without cooling

- More speculative – QM computers that use superposition.