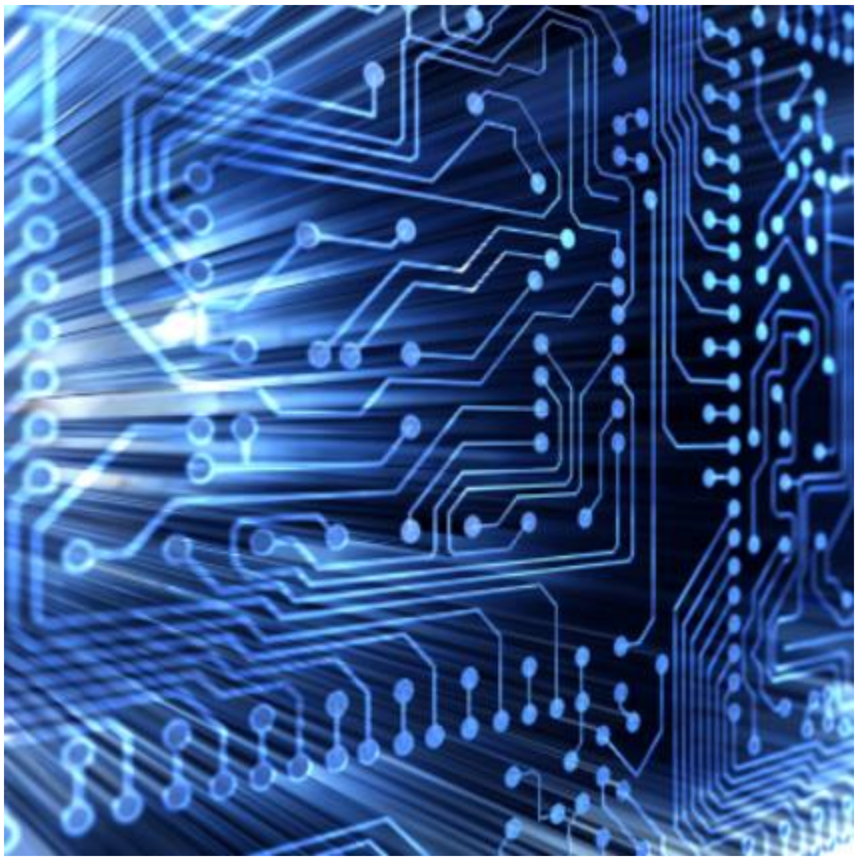
Digital Microelectronic Circuits
(361-1-3021)

Presented by:
Adam Teman



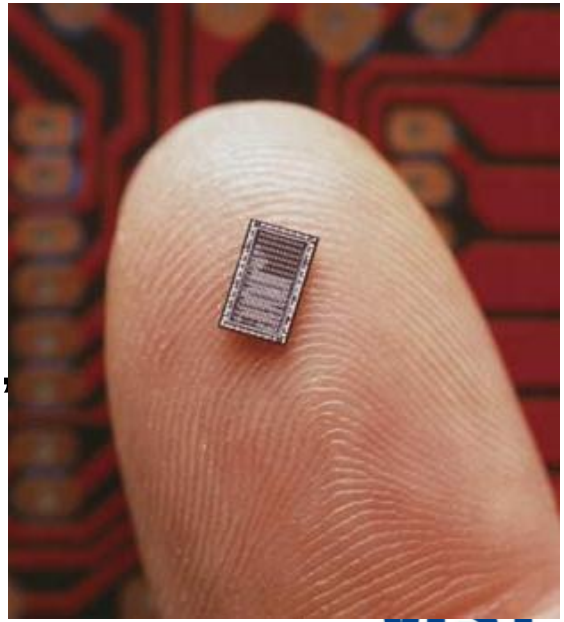
Lecture 1:
Introduction

Before we start…

WHAT IS THIS CLASS ALL ABOUT?

What is this class all about?

- Digital Microelectronic Circuits
  - Finally, we will implement and use the theory we've learned in prior courses.
  - *Digital Logic Systems* and *Introduction to Computers* taught us the theory needed to assemble digital circuits.
  - *Introduction to Semi-Conductors* taught us about the physical elements needed to make switches.
  - This class will take us to the next step, integrating the physical and logical theory we've learned in prior courses.



There's no Free Lunch

- Microelectronic design always trades-off the following four major factors:
  - » Speed (Performance)
  - » Cost (Area)
  - » Power (Energy)
  - » Reliability (Robustness)

- Every aspect of digital design will have to consider these trade-offs, aiming at a win-win situation!

What will we learn today?

- 1.1 Practical Information
- 1.2 Course Syllabus
- 1.3 History of Digital Circuits
- 1.4 Moore's Law
- 1.5 Where Are We?
- 1.6 A Little Humor

1.1

What, where, why, when…?

Here's some

PRACTICAL INFORMATION

Practical Information

- Lecturer
  - » Adam Teman
    - – Email: teman@ee.bgu.ac.il
    - – Office Hours: Sunday 11:00-12:00

- Teaching Assistants
  - » Itamar Levi
    - – Email: leit@bgu.ac.il
    - – Office Hours: Monday 15:00-16:00, VLSI Center (room 5)
- Lecture Hours
  - » Sunday, 13:00-16:00, Building 90, Room 326
- Exercise Sessions
  - » Monday, 08:00-09:00 Building 34, Room 007
  - » Monday, 09:00-10:00 Building 34, Room 103
  - » Monday, 16:00-17:00 Building 32, Room 306

Practical Information

- Printing Material
  - » Lectures and Exercises will be published on Moodle.
  - » Lectures will be recorded. Annotated slides will be published.
  - » Recorded Lectures, practice sessions, material from last semester are on the web; however, these will change!
- Grading
  - » ~7 homework “quizzes” on the Moodle site (15%)
    - – Quizzes will be about Lectures and Practices
  - » Final Exam (85%)

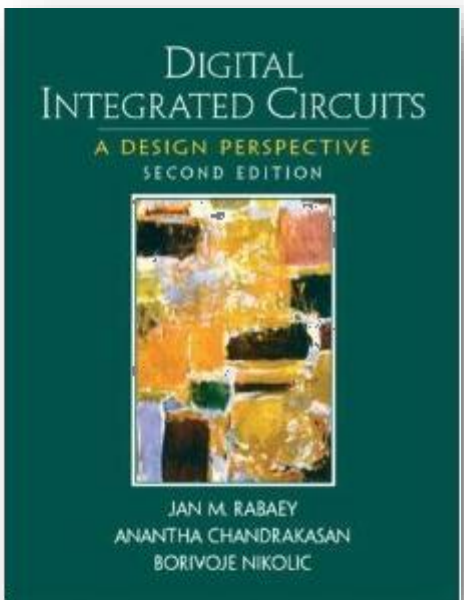
Practical Information

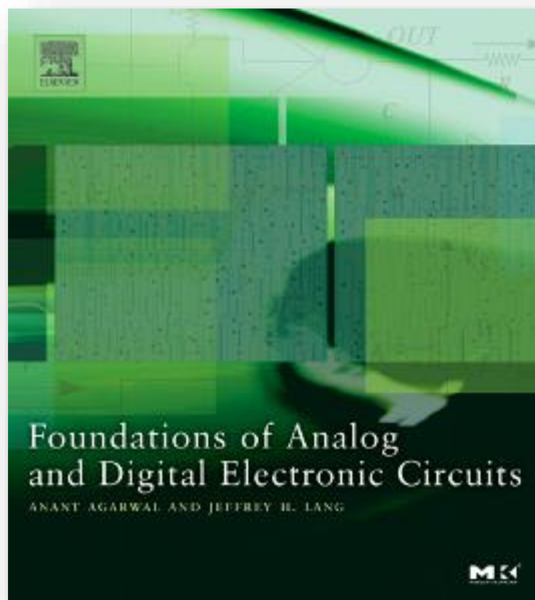
- Moodle Forum:
  - Use the forum discuss course material and homework.
  - By answering your friends’ questions and forming a healthy discussion, your understanding will improve.
  - A volunteer (and only him/her) will direct unanswered questions towards the course staff, and we will answer the questions on the forum.

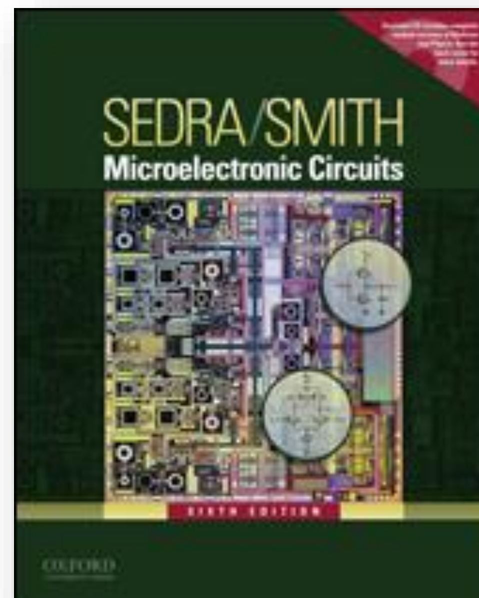
Direct questions to the course staff via email will not be answered!

Bibliography

1. Rabaey J., Chandrakasan A., Borivoje N.,
   "***Digital Integrated Circuits: A Design Perspective, 2nd Edition***"
2. Agarwal A., Lang J.,
   "Foundations of Analog and Digital Electronic Circuits, 1st Edition"
3. Sedra A., Smith K.,
   "***Microelectronic Circuits***"







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What are we going to learn?

Here is the

COURSE SYLLABUS

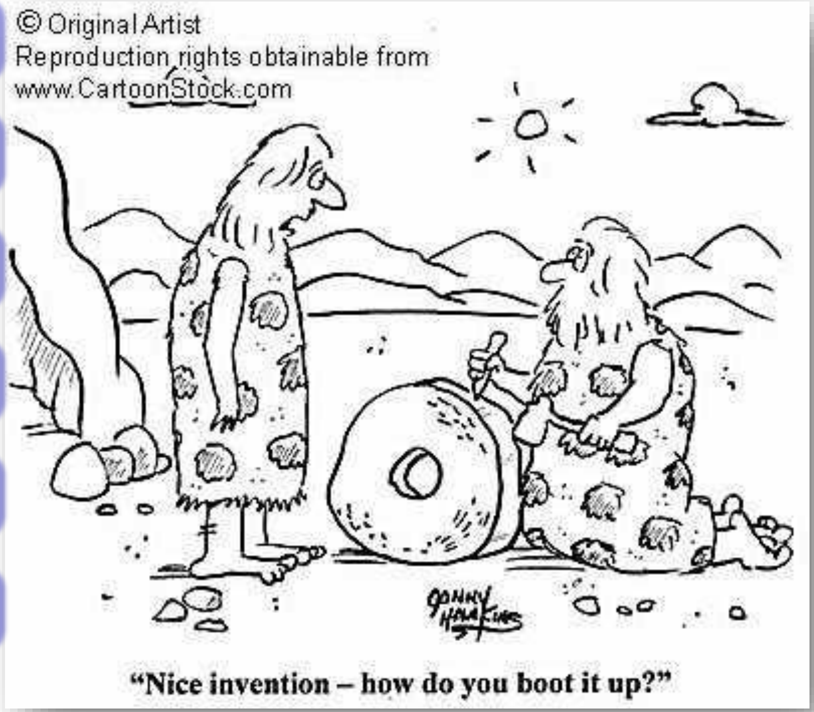
Course Syllabus

Date	Lecture #	Subject
21/10	1	Introduction
28/10	2	Terminology and Design Metrics
4/11	3	The MOSFET Transistor
11/11	4	The CMOS Inverter
18/11	5	Capacitance / Driving a Load
25/11	6	CMOS Digital Logic
2/12	7	Logical Effort
9/12	*No Lecture*	*Hanukah*
16/12	8	Ratioed Logic
23/12	9	Dynamic Logic
30/12	10	Pass Transistor Logic
6/1	11	Sequential Circuits
13/1	12	Memory

Some Emphasis

- This course looks *easy*, but experience shows that it's *very hard*!
- The fundamentals learned in this course are *critical* for future VLSI courses/jobs.
- Work hard throughout the semester!
  - Hard work leads to intuitive understanding of the concepts.
  - If you don't work hard, you will not succeed in the future VLSI courses.

1.4

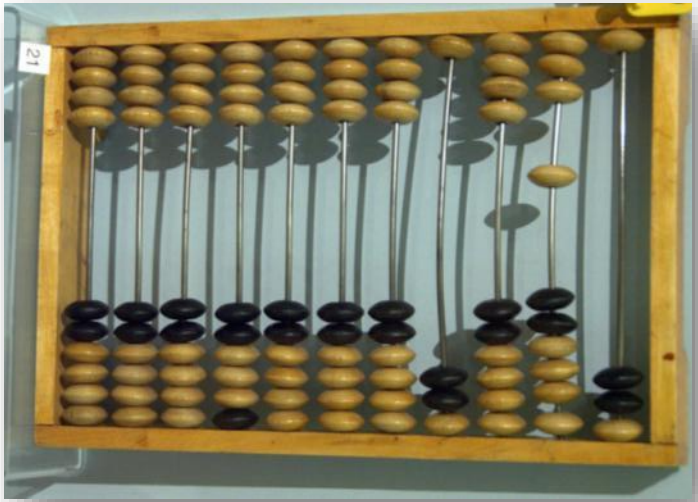


Where did it all start…

HISTORY OF DIGITAL CIRCUITS

History of Digital Circuits

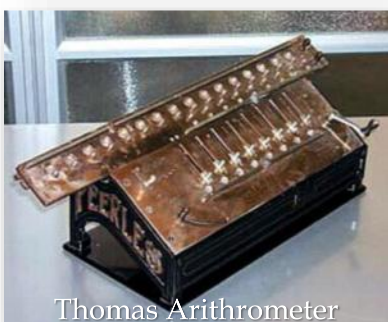
- The Abacus:
  - » The first computation device
  - » Invented around 2400 BCE
  - » Still in use today
- Napier's Bones:
  - » Invented by ***John Napier*** (~1590)
  - » Addition, Multiplication, Logarithms
- Slide Rule:
  - » Introduced in 1620
  - » Analog Computer



History of Digital Circuits

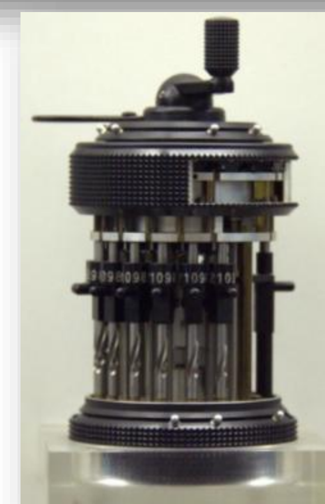
Gottfried Wilhelm von Leibniz

- Binary Logic
  - » ***Pingala*** discovered the ***Binary Numeral System*** (~300 BCE India)
  - » ***Leibniz*** described ***Binary Logic*** (~1650 Germany)
  - » ***Boolean Algebra*** was published by ***George Boole*** in 1854
- Mechanical Calculators



Thomas Arithrometer

  - » First ***calculator*** by ***Schickard*** (1623), followed by ***Pascal*** and ***Leibniz***.
  - » First ***mass-produced calculator*** by ***Thomas*** (1820)

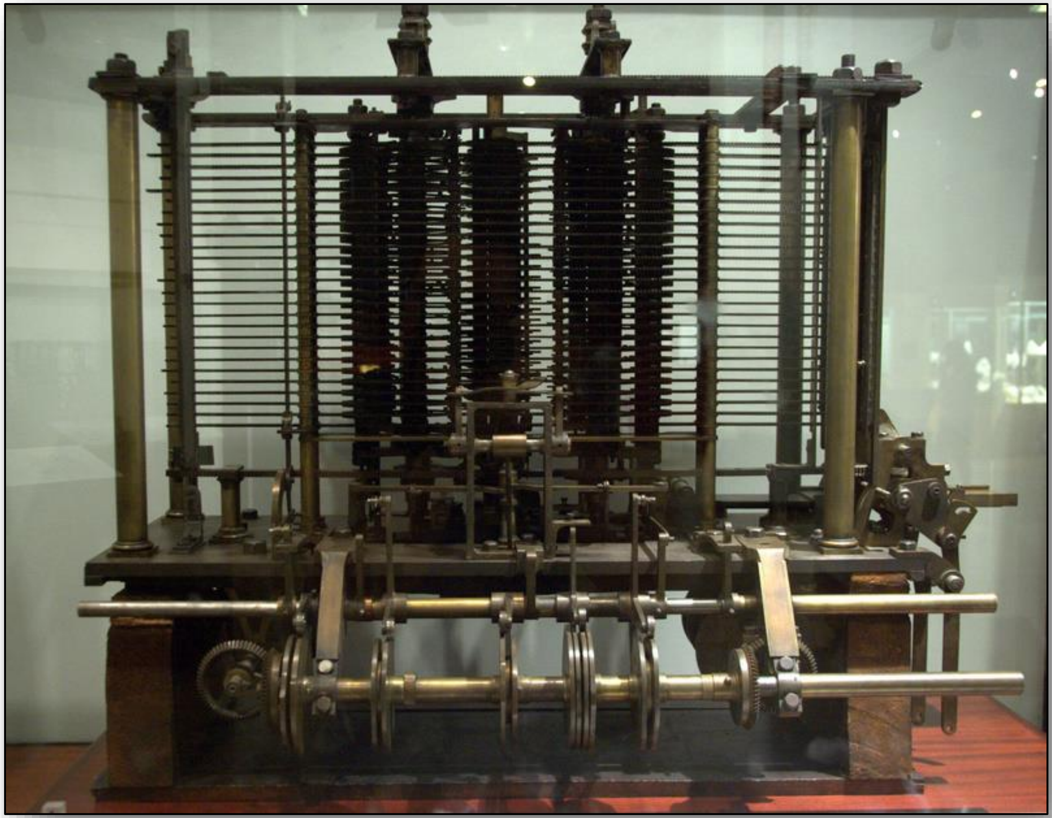


History of Digital Circuits

- Punch Cards
  - In 1725 ***Bouchon*** developed an ***Automatic Loom*** based on holes in paper.
  - In 1801, ***Jacquard*** enabled using ***punch cards*** to control such a loom.
  - In 1822, ***Charles Babbage*** described the ***Difference Engine,*** which is considered the first real computer design, though it was only made in 1991 (it is still operational at the London Science Museum).
  - In 1834, ***Babbage*** described the ***Analytical Engine*** based on punch cards and a steam engine. It was the first general purpose programmable computer.

Hand Loom with Jacquard Machine

Charles Babbage (1791-1871)



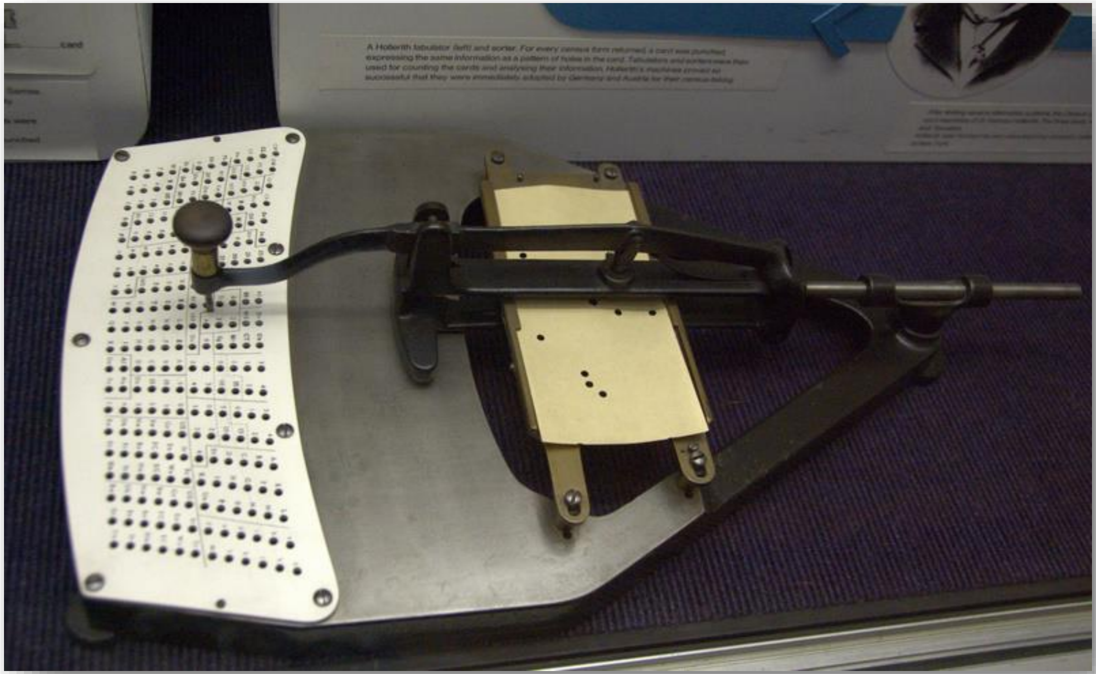
The Analytical Engine
(incomplete and incorrect)

The Difference Engine II
(made in 1991)

A bit more Babbage…

History of Digital Circuits

- 20th Century Milestones
  - » 1896 - ***Herman Hollerith*** establishes the ***Tabulating Machine Company***, later to become ***IBM*** (1924).



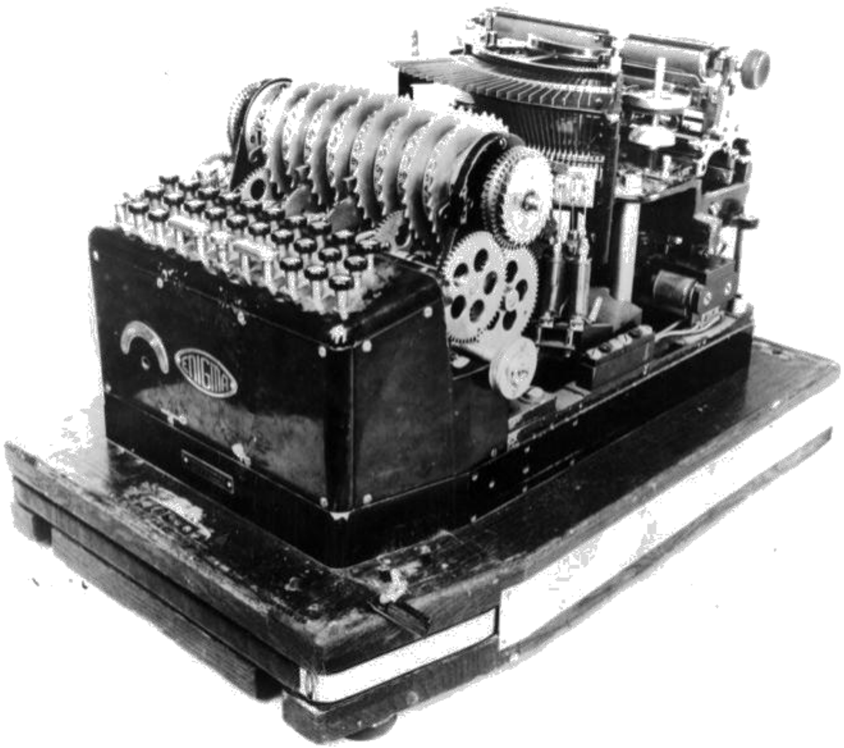
Hollerith Punch Card Machine

History of Digital Circuits

- 20th Century Milestones
  - » 1906 – The ***Electronic Valve (Triode)*** is invented (***De Forest***). This is the switch that enabled the development of the digital computer. (Improved by Schottky in 1919)
  - » 1919 – The ***Flip Flop*** was proposed (***Eccles***, ***Jordan***).
  - » 1937 – ***Alan Turing*** publishes paper describing the "***Turing Machine***" and sets the basis for computer theory. Turing is considered "The Father of Modern Day Computing"

History of Digital Circuits

The Alan Turing Memorial Statue in Manchester

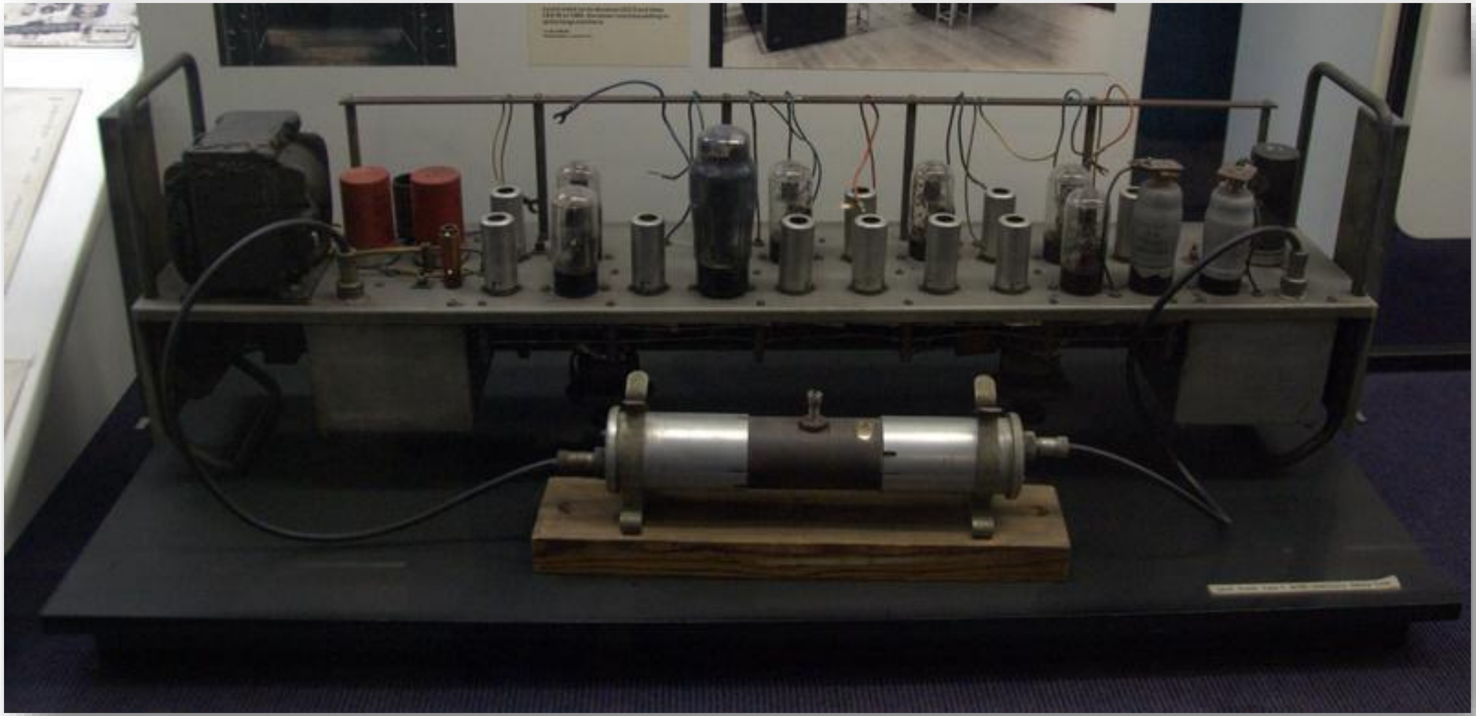


The Enigma

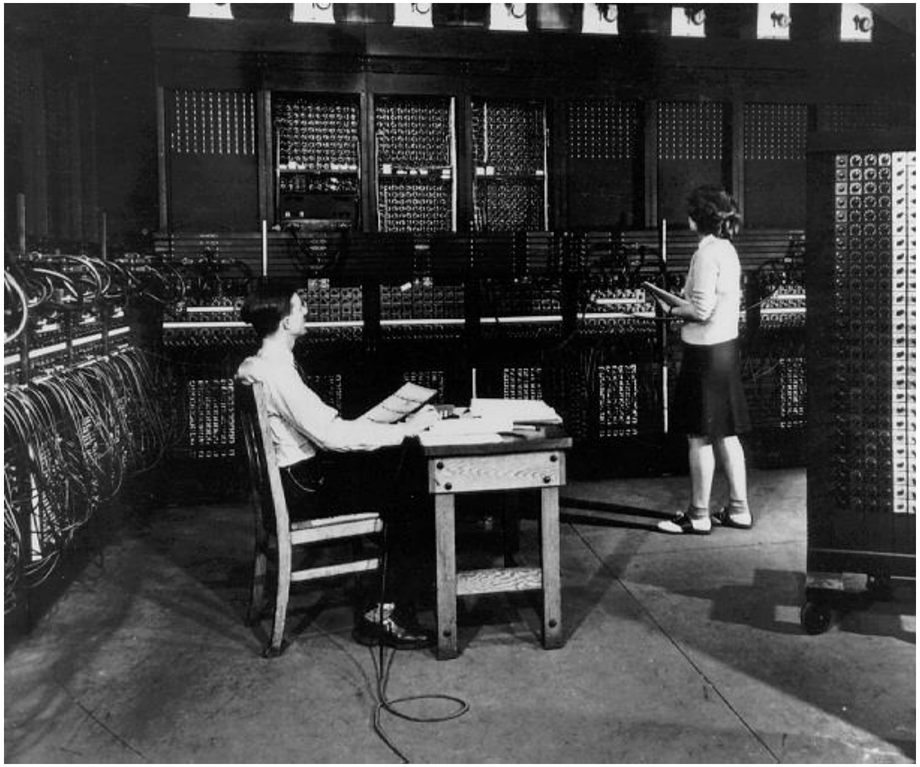
German Encryption Machine that Turing helped decipher

History of Digital Circuits

- 20th Century Milestones
  - 1939 - First machine to calculate using ***vacuum tubes*** developed.



History of Digital Circuits



ENIAC (1946)

Considered the first Universal Electronic Computer. Used 18,000 electronic valves, weighed 30 Tons and consumed 25kW of power. Could do approximately 100,000 calculations a second.

UNIVAC-1 (1951)

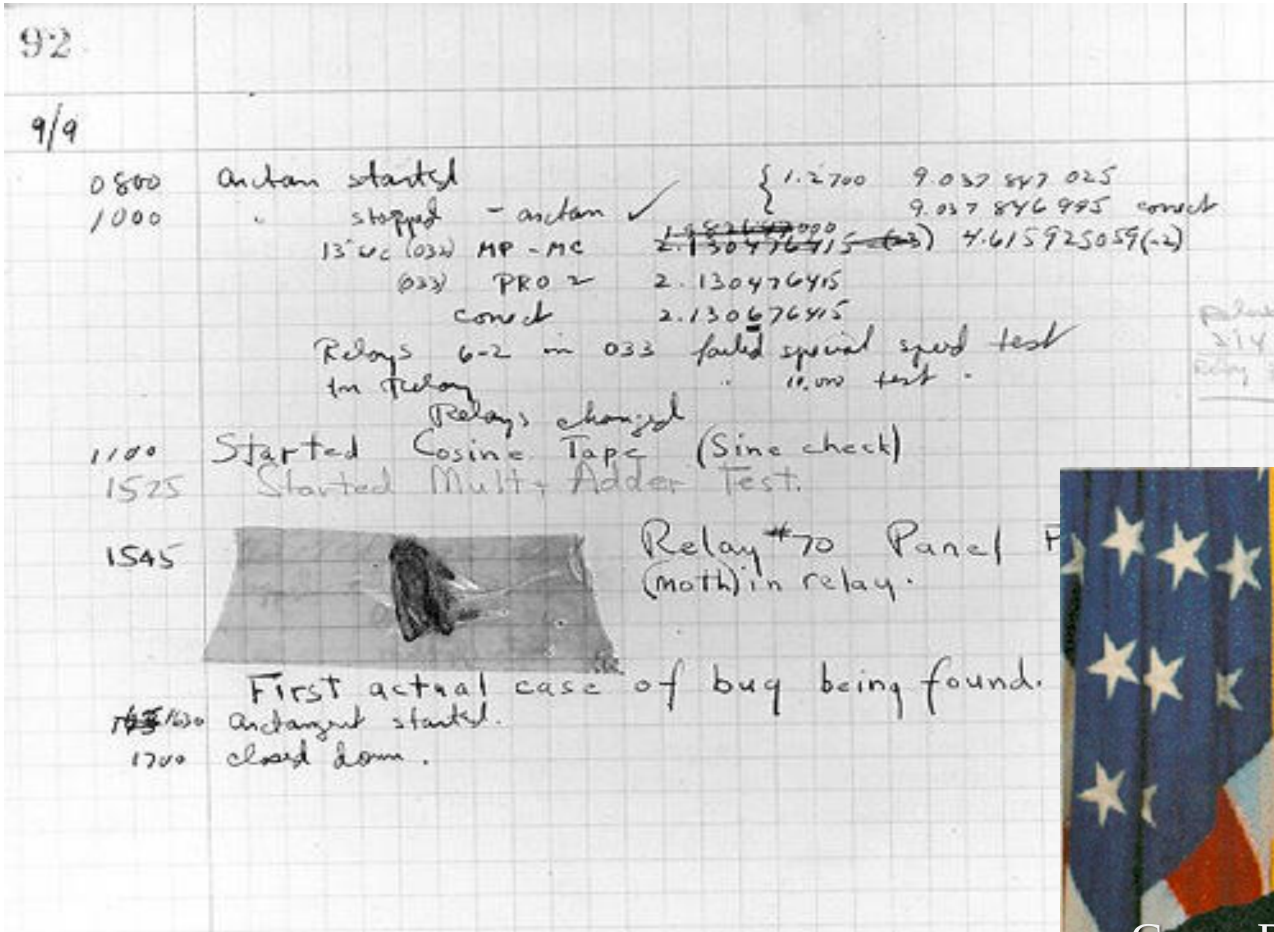
First commercially successful electronic computer. Also, first general purpose computer. Worked with magnetic tapes.

Pilot ACE (1950)

- Automatic Computing Engine

ERNIE

- Electronic Random Number Indicator Equipment



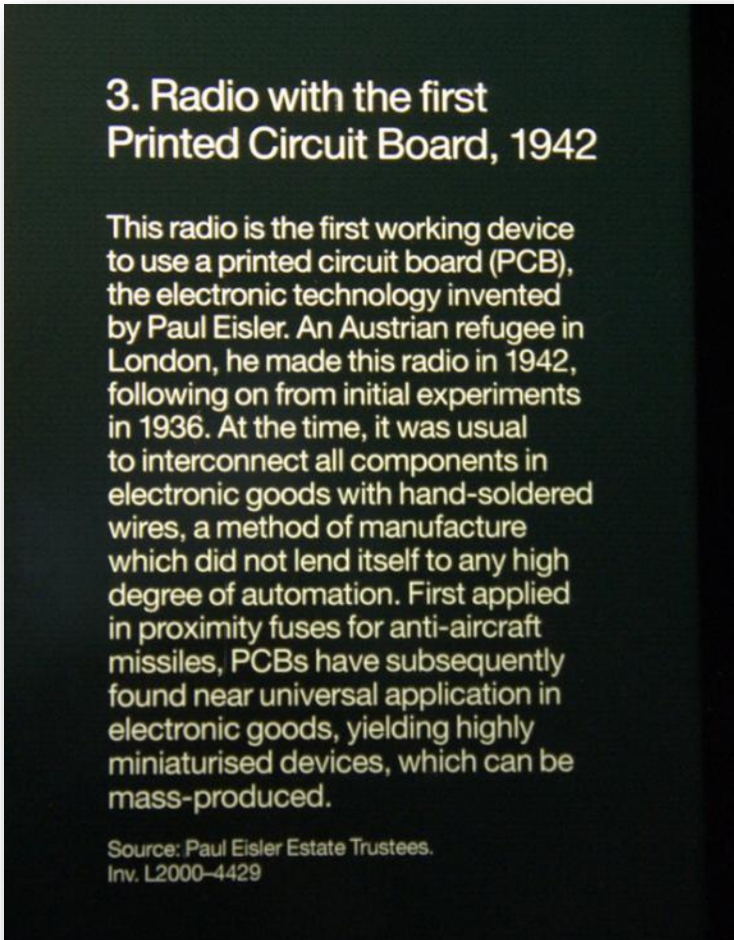
The first “Bug”

Grace Brewster Murray Hopper

Inventor of the infamous Bug!

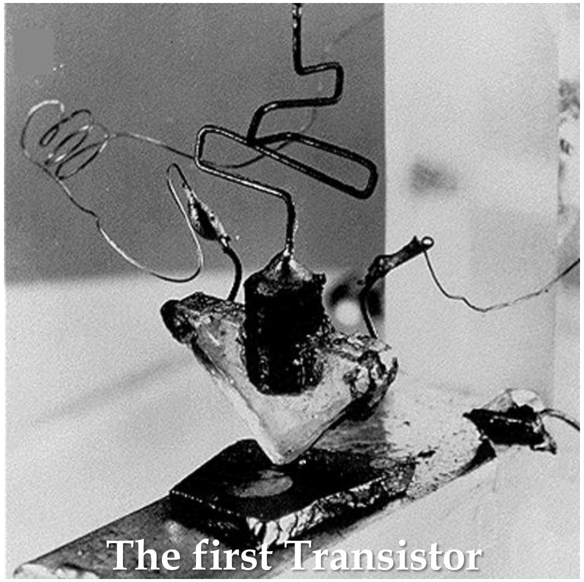
History of Digital Circuits

- Radio with first Printed Circuit Board (1942)

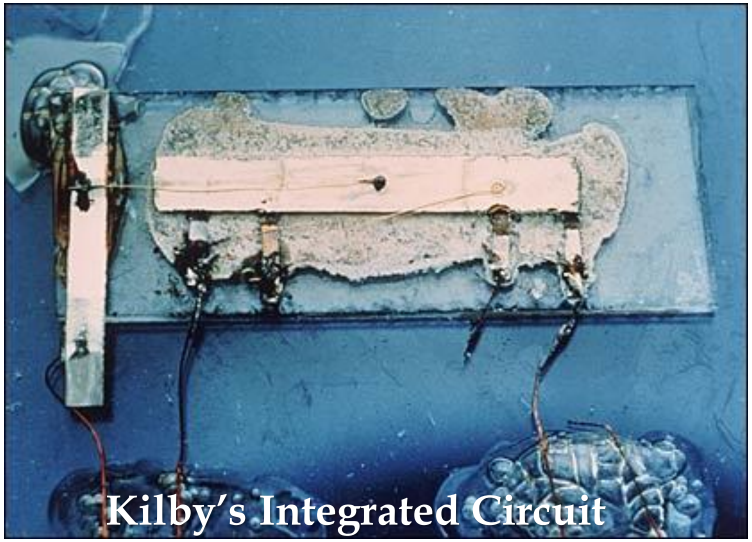


History of Digital Circuits

- The Transistor Era
  - 1947 – A group at Bell Labs, headed by ***Shockley***, invent the first ***transistor*** to replace the inefficient vacuum tube.
  - 1952 – The idea of the ***Integrated Circuit*** was conceived by ***Dummer***.



The first Transistor



Kilby's Integrated Circuit

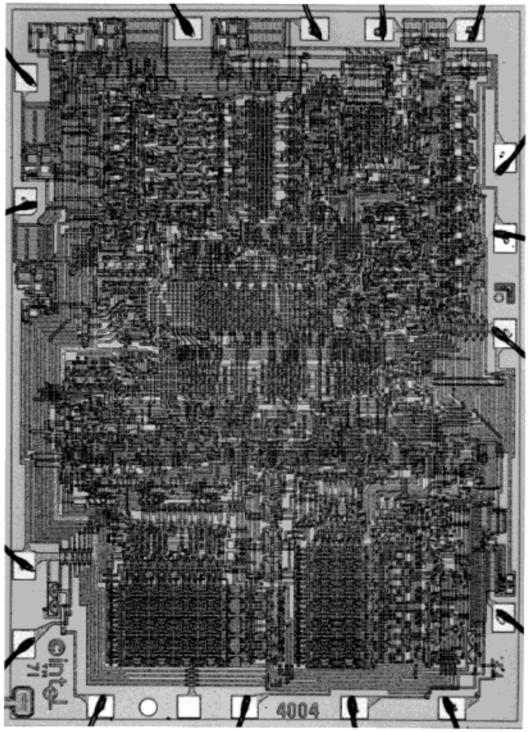
  - 1958 – The first integrated circuit was invented by ***Jack Kilby*** of TI. The first ***silicon IC*** was invented by ***Robert Noyce*** of Fairchild half a year later.

Shockley's Nobel Prize

Bardeen, Shockley, Brattain 1948

History of Digital Circuits

- The Transistor Era
  - » 1960 – First ***MOSFET*** Fabricated
  - » 1962 – ***TTL*** Invented
  - » 1963 – ***CMOS*** Invented
  - » 1964 – 1-inch silicon wafers introduced
  - » 1965 – ***Moore's Law*** (more in a minute…)
  - » 1967 – ***Floating Gate*** invented
  - » 1970 – First commercial ***DRAM*** (1Kbit)
  - » 1971 – ***Microprocessor*** invented
  - » 1978 – Intel 8086/8088
  - » 1981 – ***IBM PC*** is introduced



Intel 4004 (1971)
1000 transistors
1MHz operation

History of Digital Circuits

- The Xerox Alto (1973)
  - » Mouse
  - » Graphical Display
  - » LAN
  - » WYSIWYG Editor
  - » Drawing Program
  - » Windows UI

History of Digital Circuits

- Cray Supercomputer (1976)

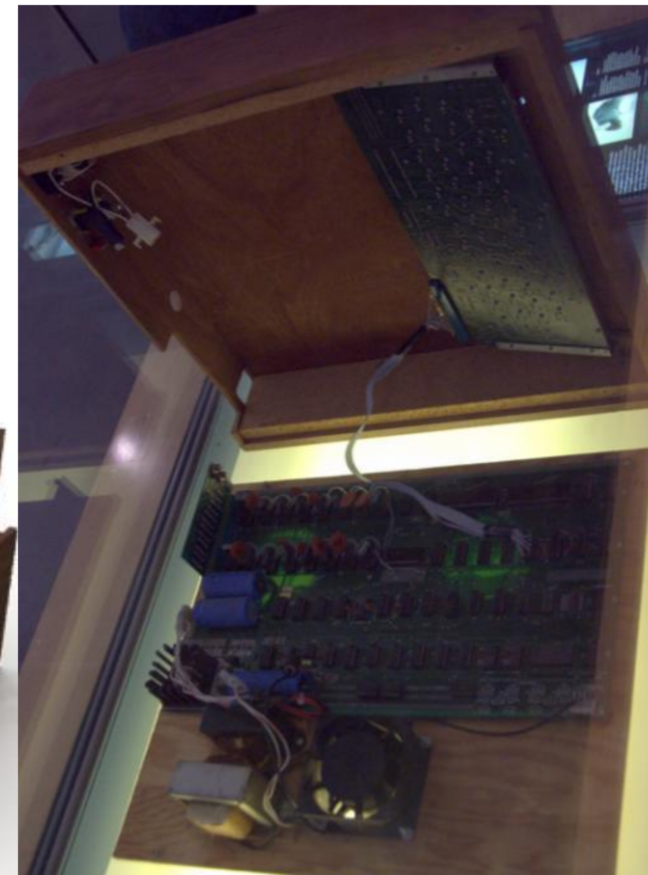
“Small” Computers

DEC PDP-8

The first “minicomputer”

The Apple 1

Great Great Great Grandfather of the iPhone…



History of Digital Circuits

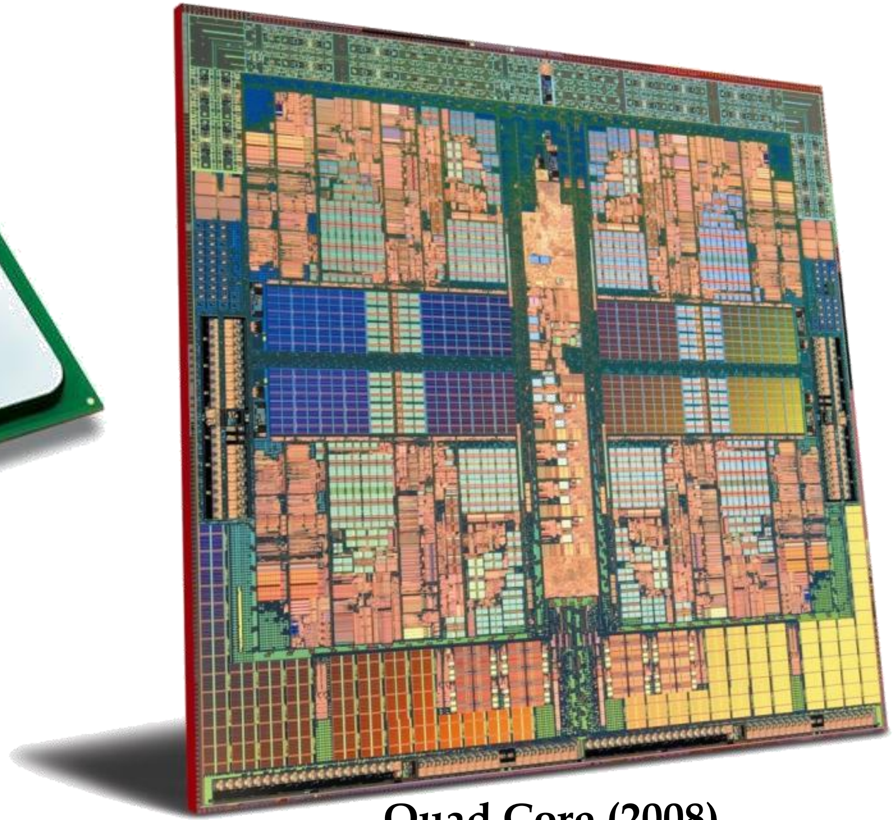
- The IBM PC 5150 (1981)

Intel 8088

History of Digital Circuits

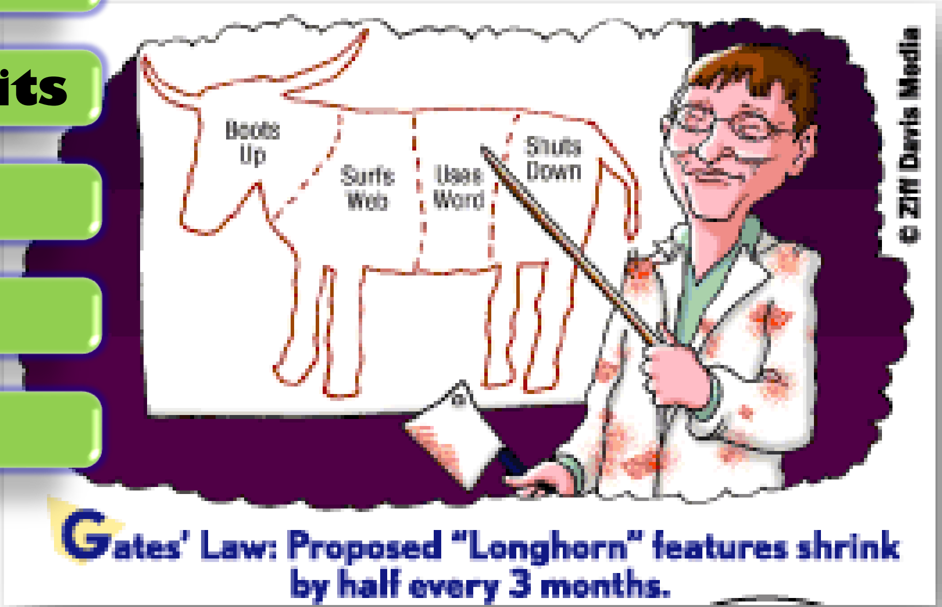
Pentium 1 (1993)
3.1M transistors
66MHz
264mm^2 die

Pentium 4 (2000)
42M transistors
1.5GHz
224mm^2 die



Quad Core (2008)
820M transistors
3GHz x 4 processors
286mm^2 die

1.5

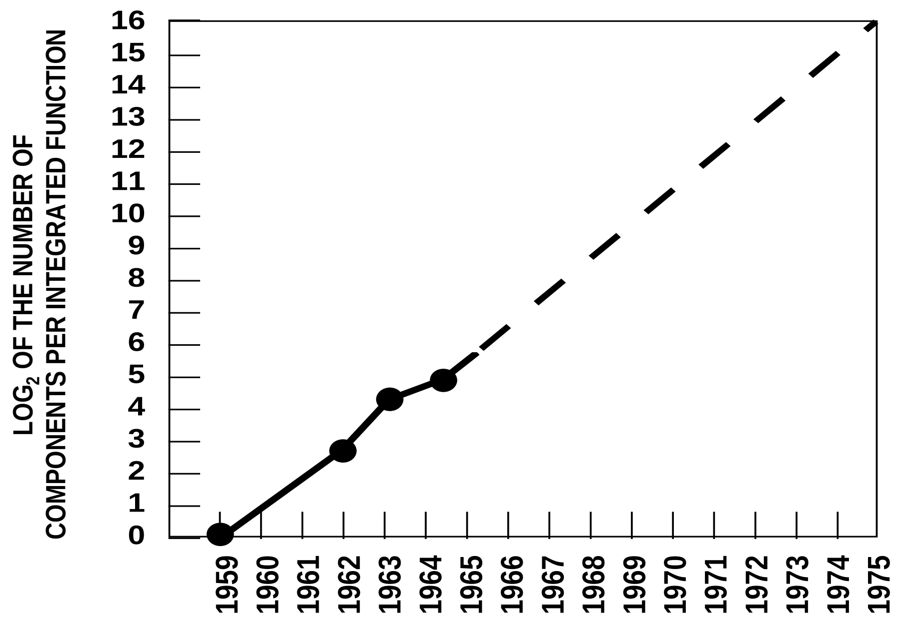


And how can we discuss the history of computers and microelectronics without taking a look at the prophetic

MOORE'S LAW

Moore's Law

- In 1965, ***Gordon Moore*** noted that the number of transistors on a chip doubled every 18 to 24 months.
- He made a prediction that semiconductor technology will double its effectiveness every 18 months



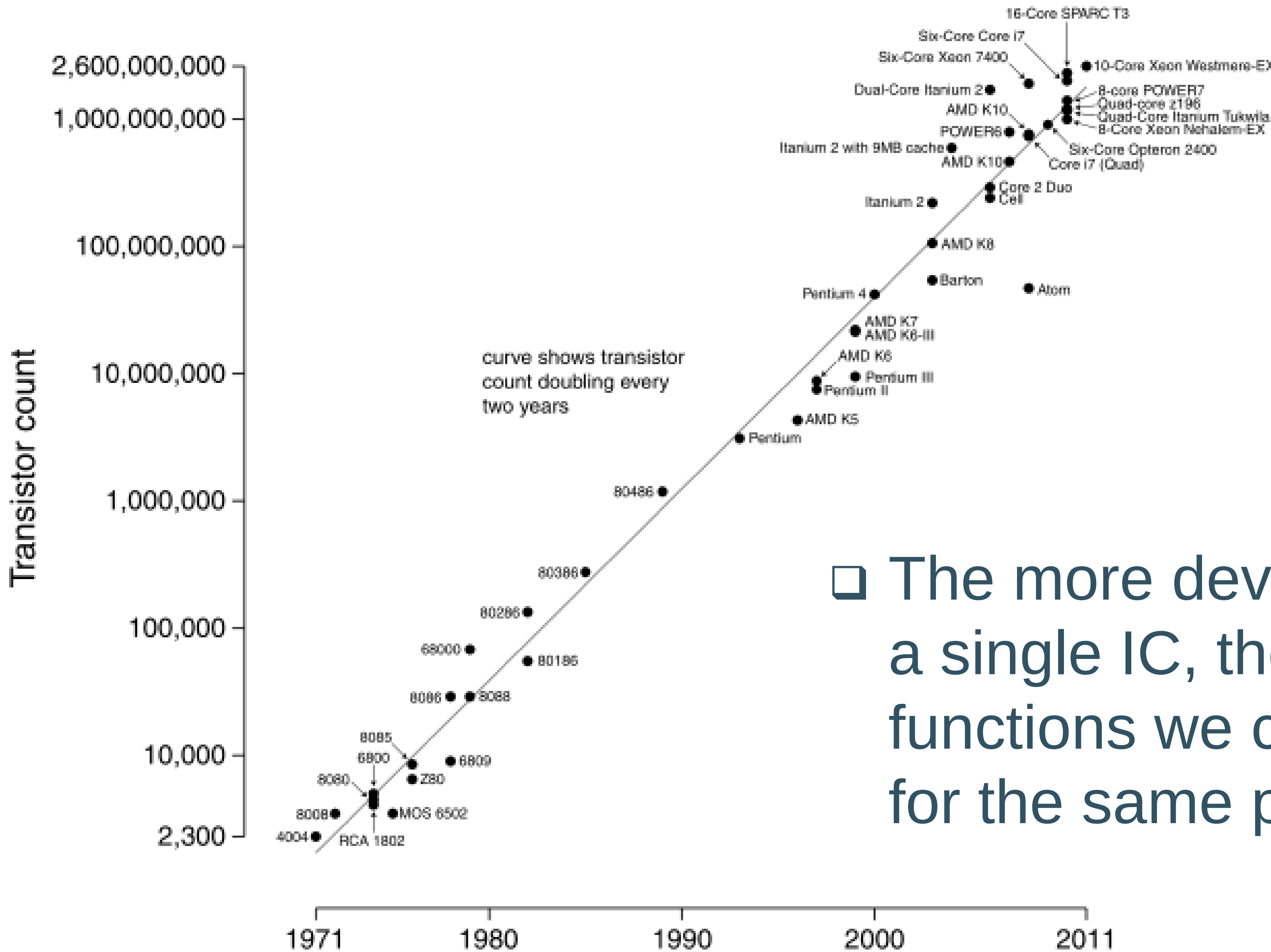
Electronics, April 19, 1965.

Moore's Law

"*The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term, this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000*."

Gordon Moore, Cramming more Components onto Integrated Circuits, (1965).

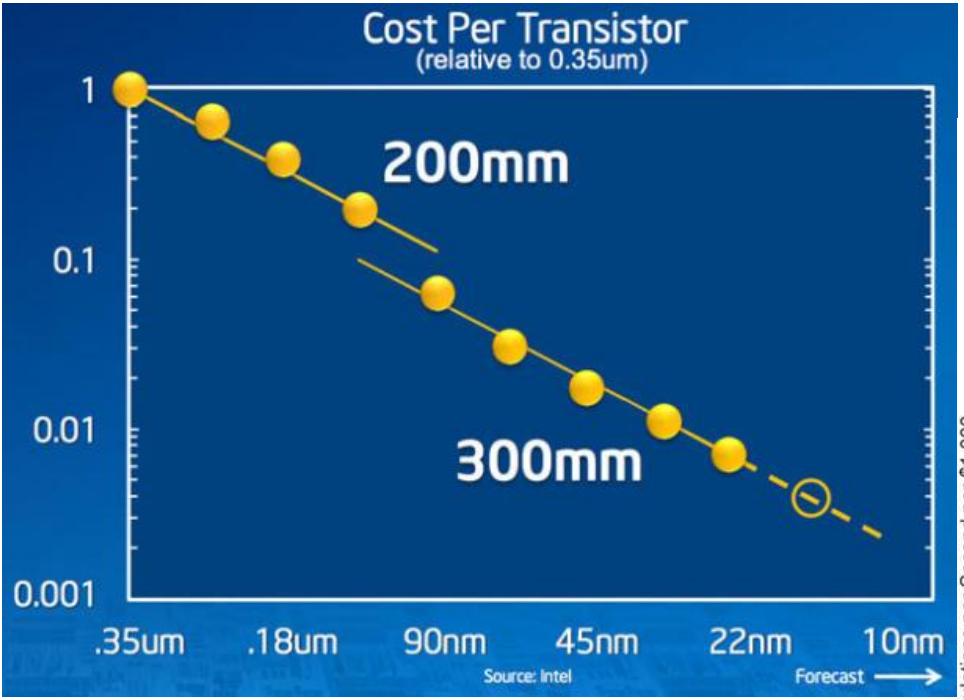
Moore's Law – Transistor Count

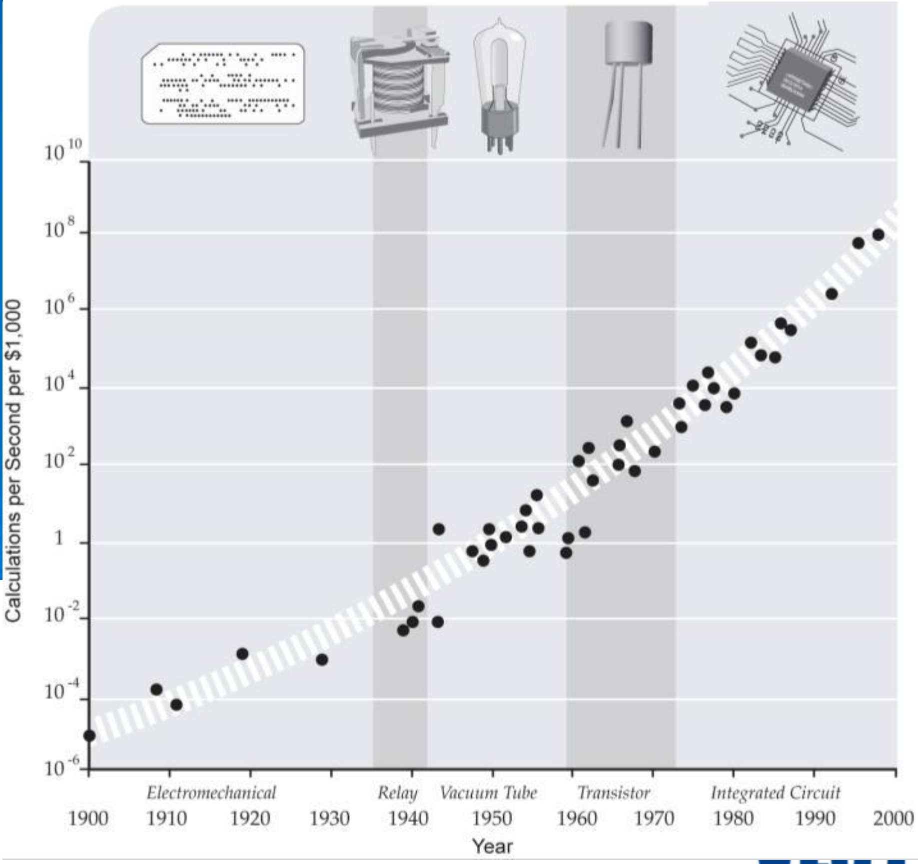


- The more devices on a single IC, the more functions we can sell for the same price.

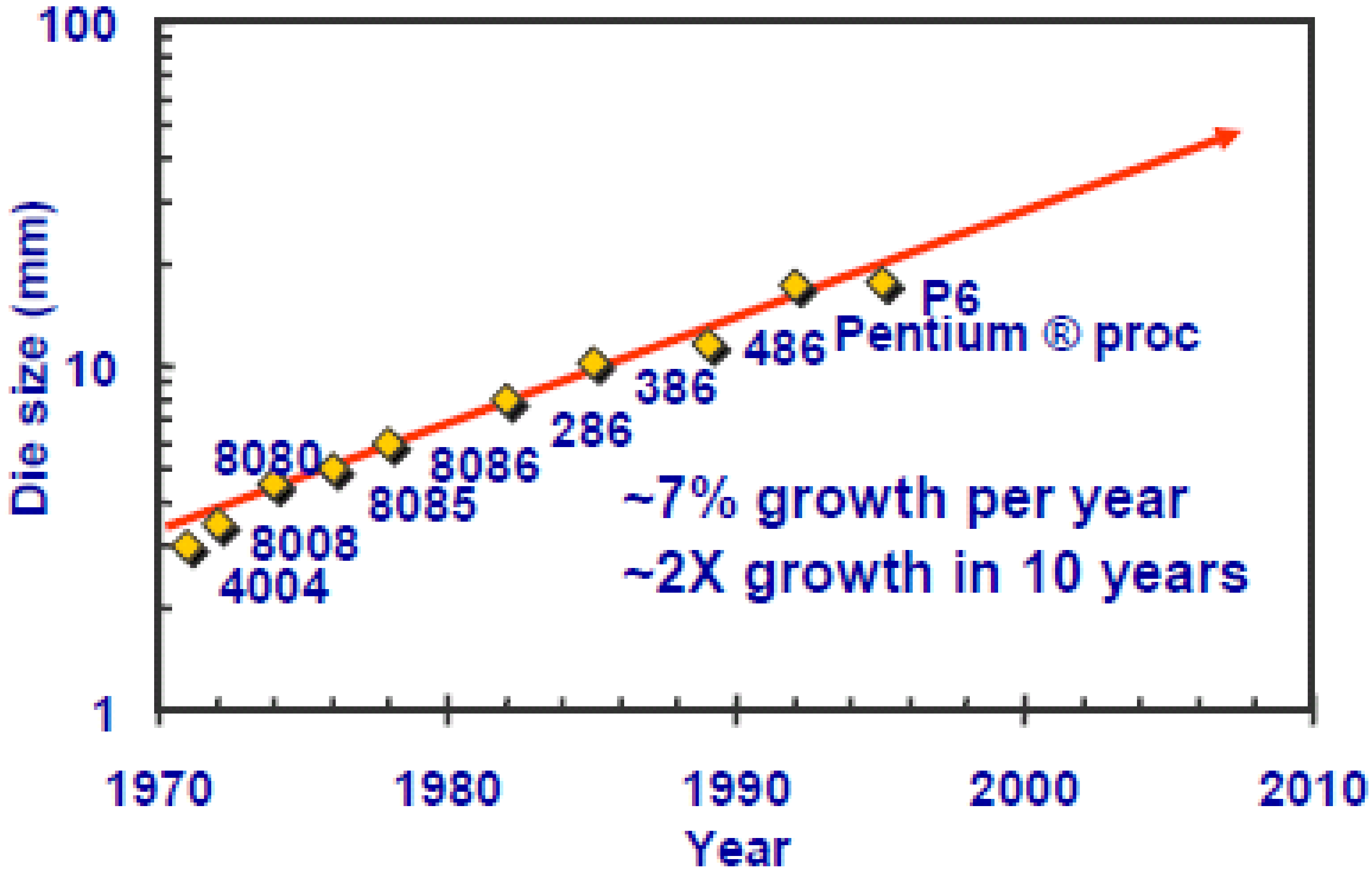
Moore's Law – Transistor Cost

- Moore's Law is, at its base, an *Economical* law.





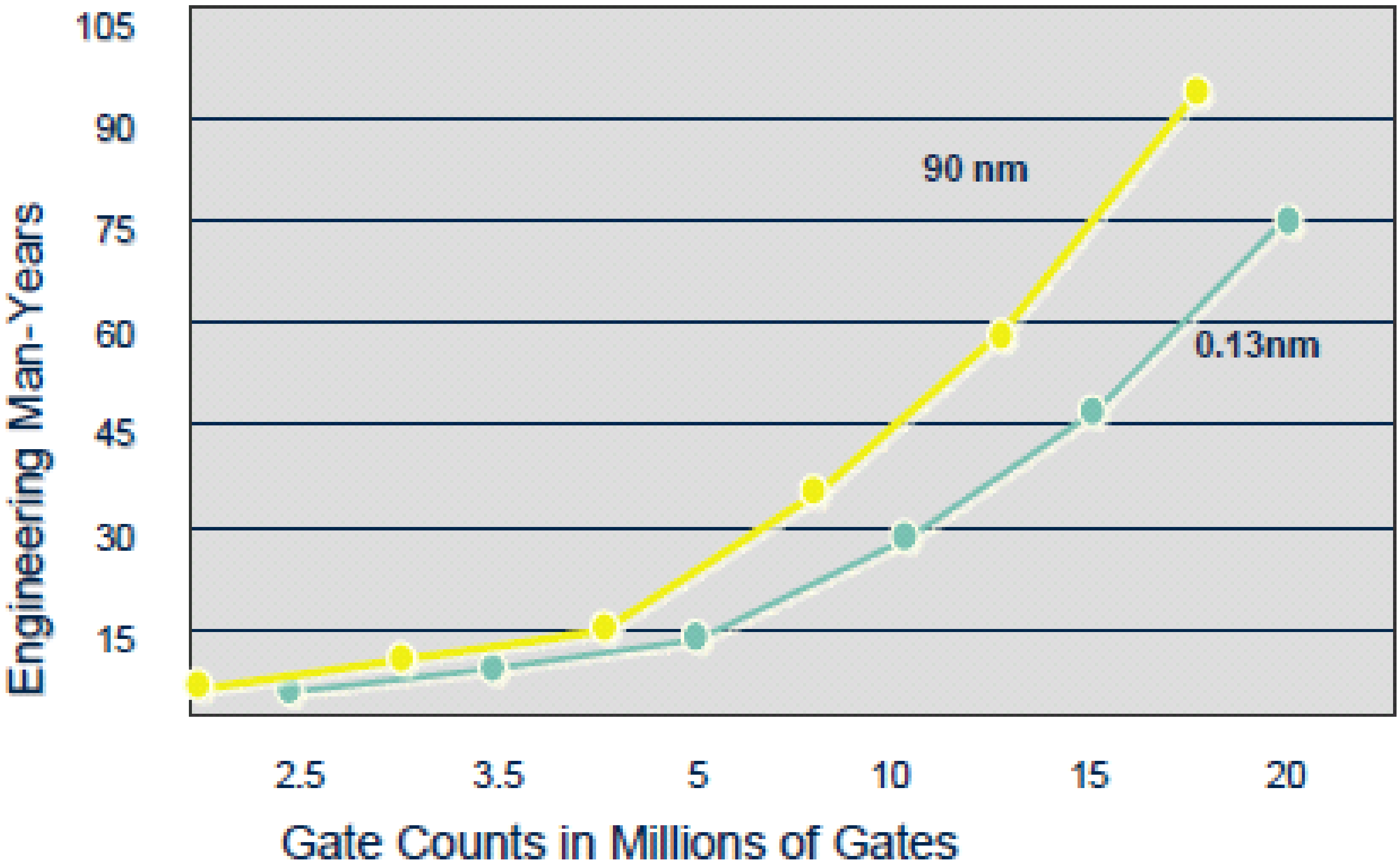
Moore's Law – Die Size



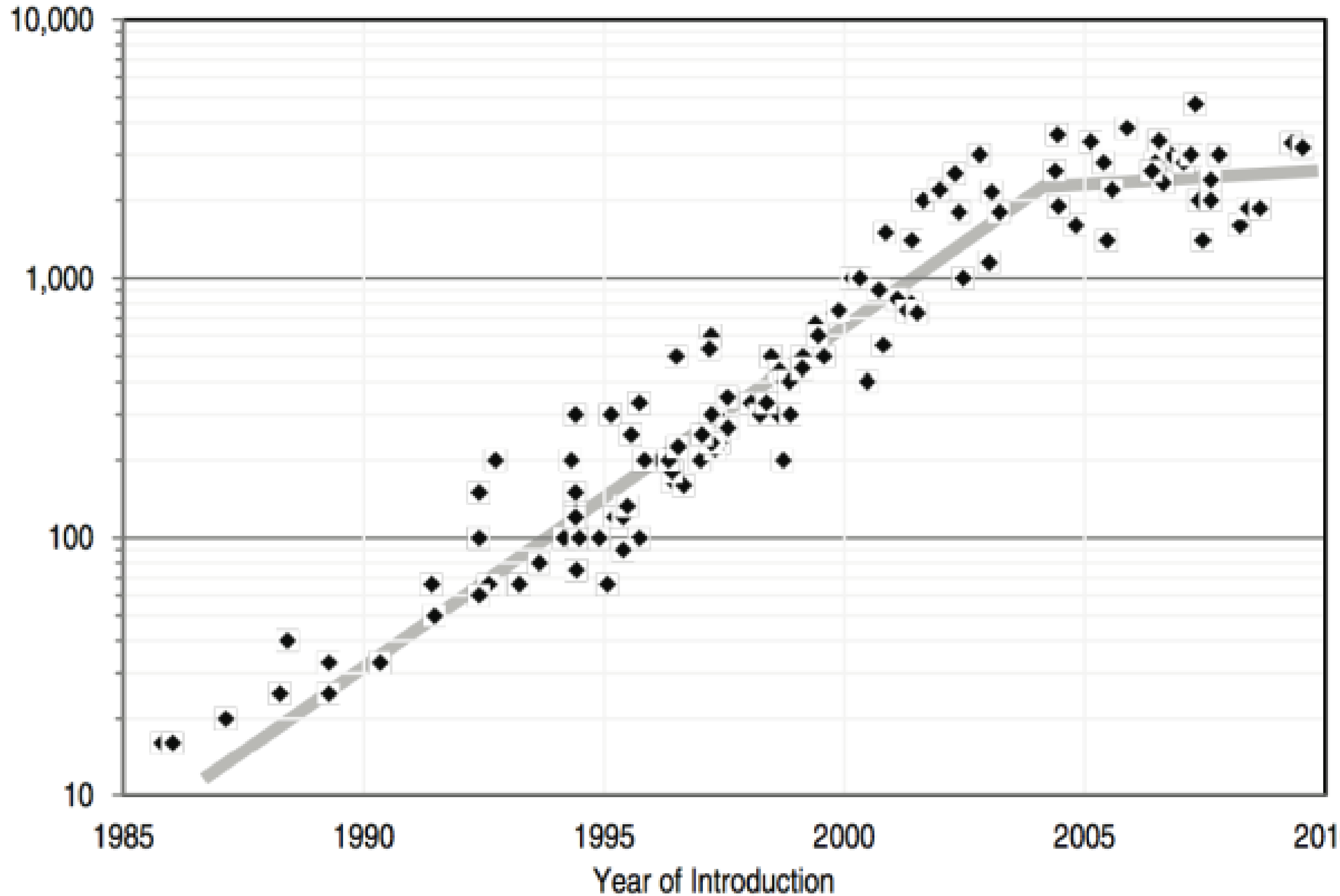
S. Borkar

Die size growth by 14% to satisfy Moore's law

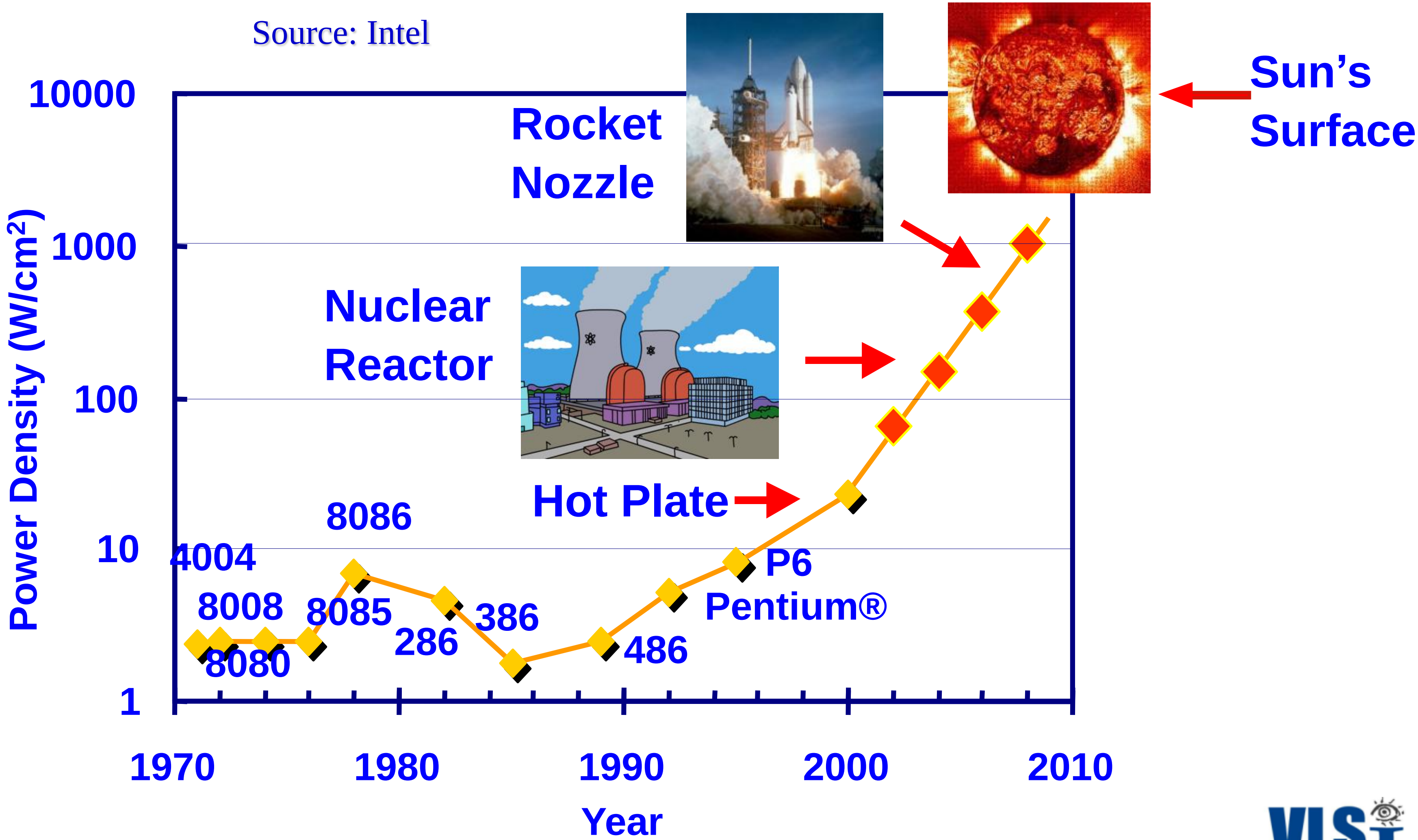
Moore's Law of Engineers



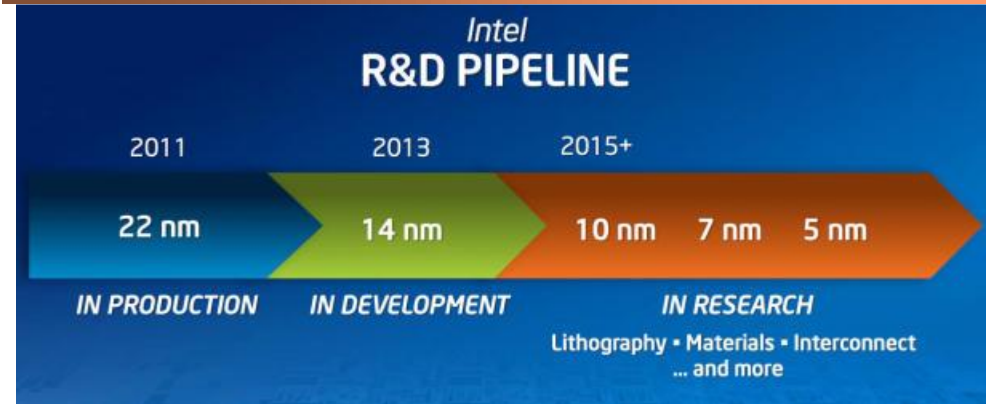
Moore's Law - Frequency



But, there's no Free Lunch!



Moore's Law is Alive and Well



Moore's Law - Summary

- Moore's Law has driven the semiconductor industry for the last 50 years.
- The feats achieved by the microelectronics community are unlike any other field over this span.
- However, in order to continue Moore's Law, we've had to "play tricks" – ingeniously manipulating physics, chemistry, and electronics.
- This course will teach you the fundamental concepts, but they are far from the methods used today.

1.6

During our three years of EE studies, we've learned a lot.
To understand this class, you should now ask…

WHERE ARE WE?

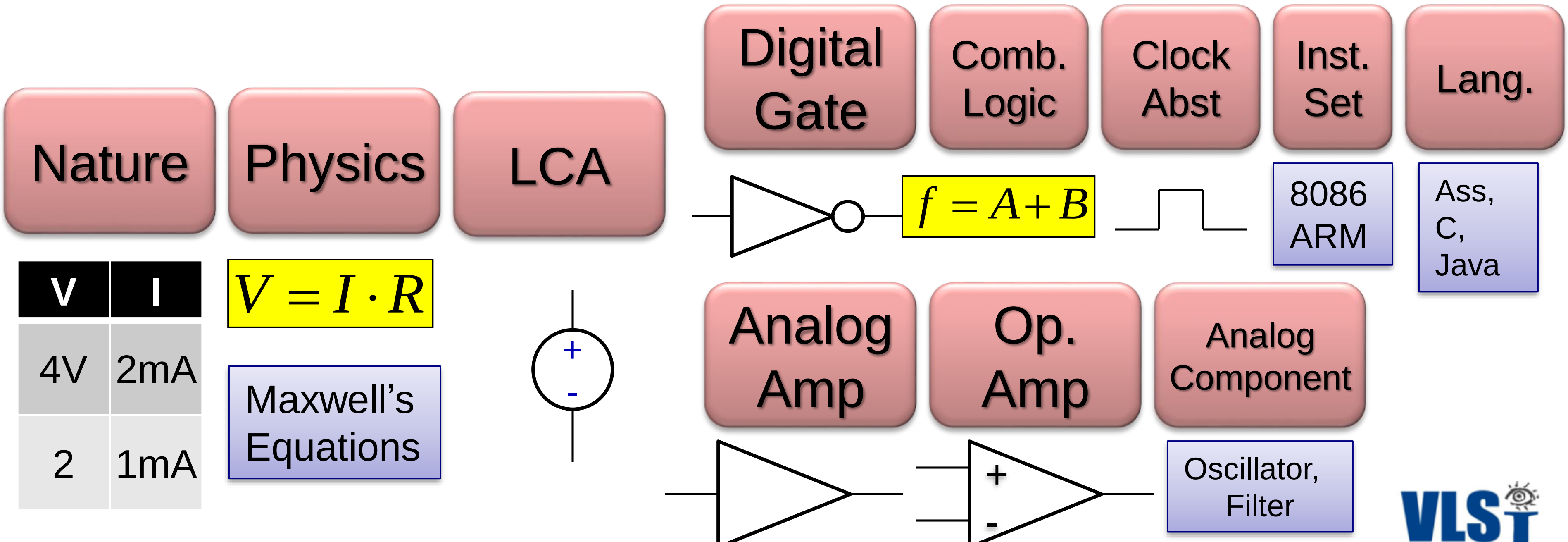
Where Are We?

- We’ve already learned about:
  - Digital Logic
  - Semiconductors
  - Basic Analog Circuits

- This course will teach us:
  - How to turn Semiconductors into Digital Logic.
  - How to design and analyze the “building blocks” of a computer.
  - We will advance from the physics law abstraction into the digital abstraction to simplify life.

Engineering Abstraction

- What is Engineering?
  - » The Purposeful Use of Science.
- How do we achieve this?
  - » By simplifying our lives → ABSTRACTION!



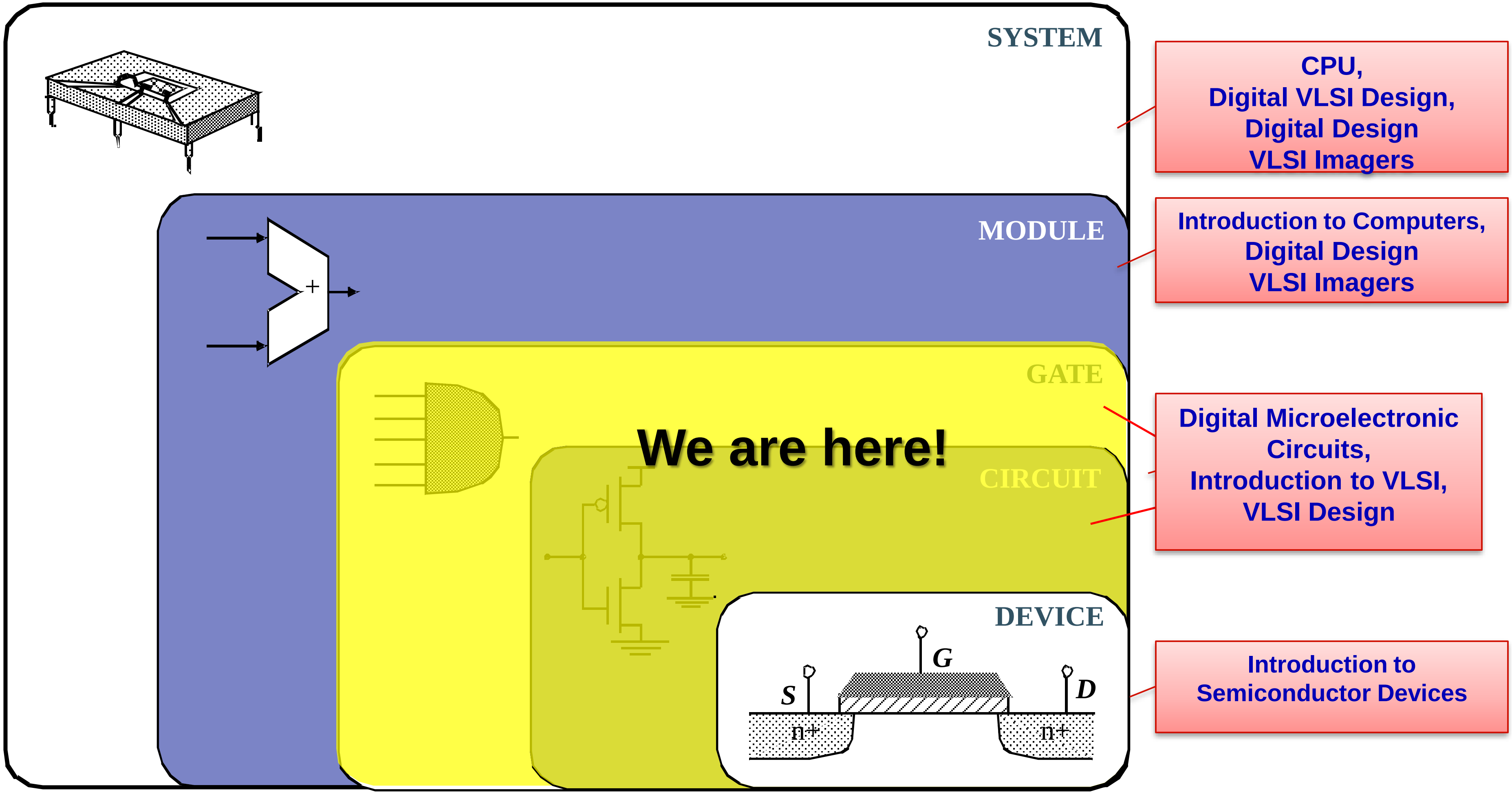
V	I
4V	2mA
2	1mA

$$V = I \cdot R$$

$$f = A + B$$

The Circuit Design Playground

Where Are We?


SYSTEM
MODULE
+
GATE
We are here!
CIRCUIT
DEVICE
G
S
D
n+
n+
CPU,
Digital VLSI Design,
Digital Design
VLSI Imagers
Introduction to Computers,
Digital Design
VLSI Imagers
Digital Microelectronic
Circuits,
Introduction to VLSI,
VLSI Design
Introduction to
Semiconductor Devices

How a chip is born…

A&A and Specification

↓

Logic Design & IP Integration

↓

Logic Verification

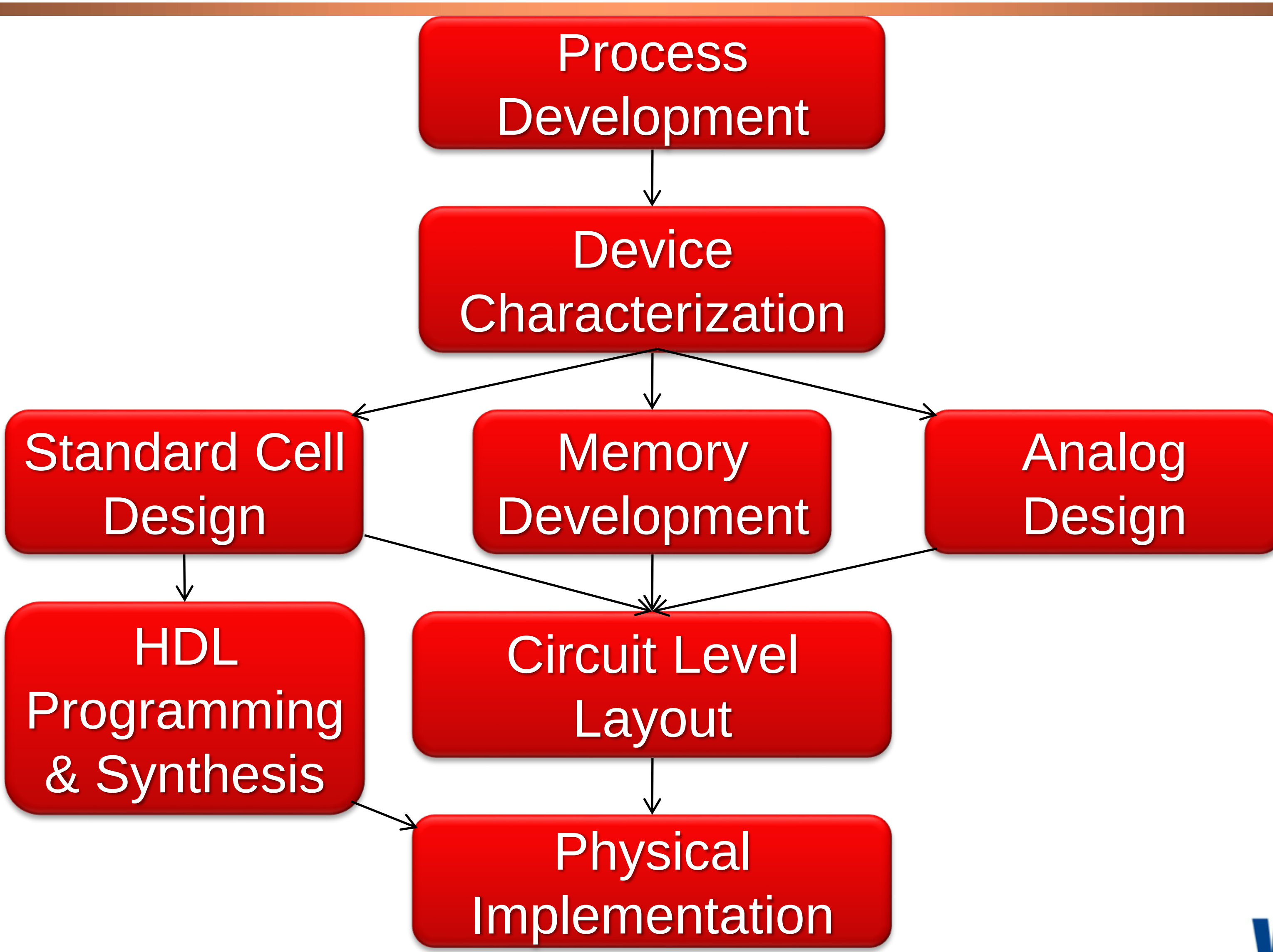
↓

Physical Design

↓

Sign-off & Tape Out

How is it all implemented?



1.7

And before we finish our introduction and start the "Tachles"

A LITTLE HUMOR…

A Little Humor

- Famous Quotes in Computer History
  - 1899 - "**Everything that can be invented has already been invented.**", Charles H. Duell, director of the U.S. Patent Office
  - 1943 - "**I think there is a world market for maybe five c**... s Watson, chairman of IBM.
  - 1...

Thomas Watson

Microchip Jewelery….

...ness books for ...

...**at ... is it goo**...

...stems Division

...casted for 2004

Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems. With teletype interface and the Fortran language, the computer will be easy to use.

A Little Humor

- Famous Quotes in Computer History
  - » 1977 - "**There is no reason anyone would want a computer in their home**." Ken Olson, president, chairman and founder of Digital Equipment Corp.
  - » 1980 - "**DOS addresses only 1 Megabyte of RAM because we cannot imagine ar** **ding more**." Microsoft on the development of D
  - » 1981 - "**640k ough** **anybody**.", Bill Gate
  - » 1992 - "**Windows N** **abytes of RAM which is n** **cation will ever need**". Mi ment of Windows NT