Digital Electronics: from Gate to System

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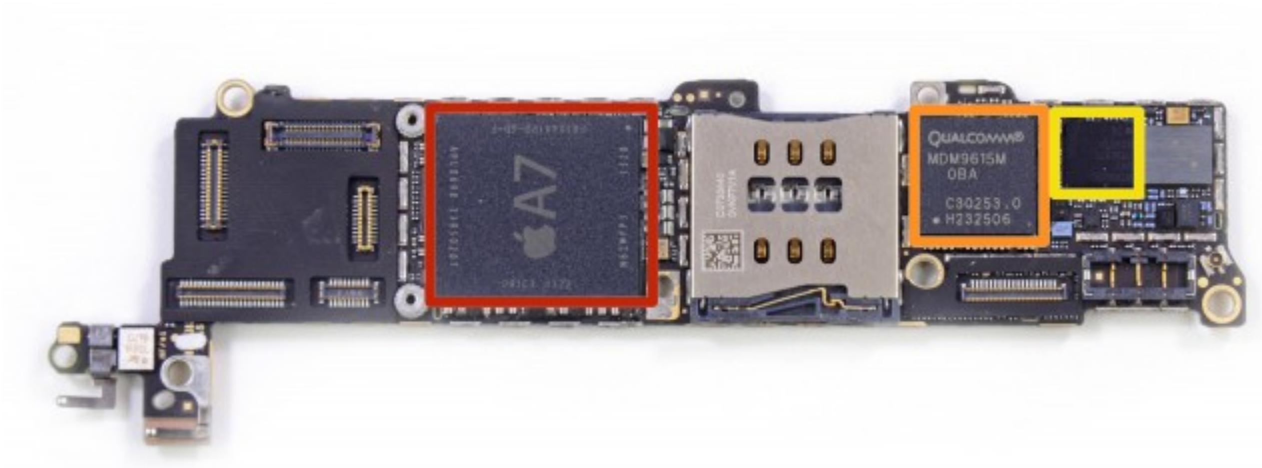
Why Digital Electronics

- Digital systems play a prominent role in our everyday life.
- Communication, computing, entertainment, traffic control, medical treatment, etc..
- Telephone, computer, ipod, digital camera, digital TV, games, etc..
- Today is ***digital age***.

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QUALCOMM
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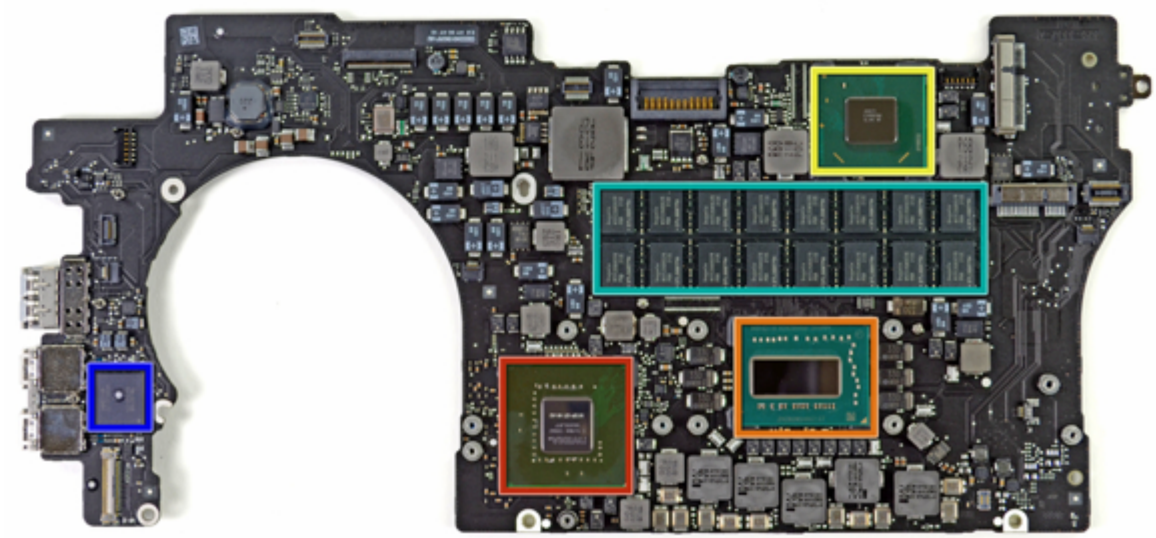

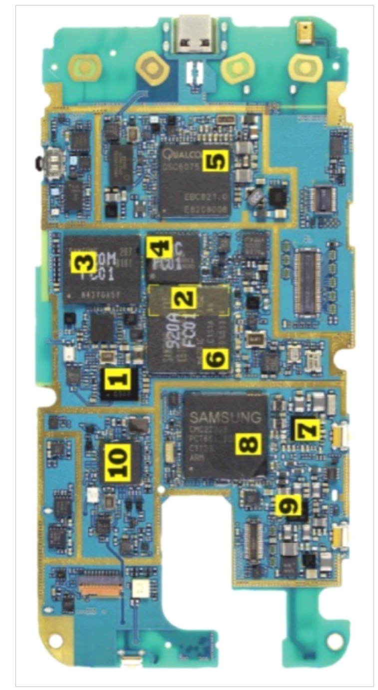
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1
SAMSUNG
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8
10
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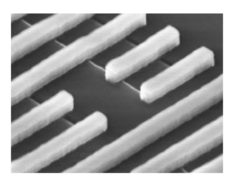
Semiconductor Technology

- Technology accelerated by the rapid development of semiconductor industry in the past half century
- From sand to transistors to integrated circuits (IC)

Silicon

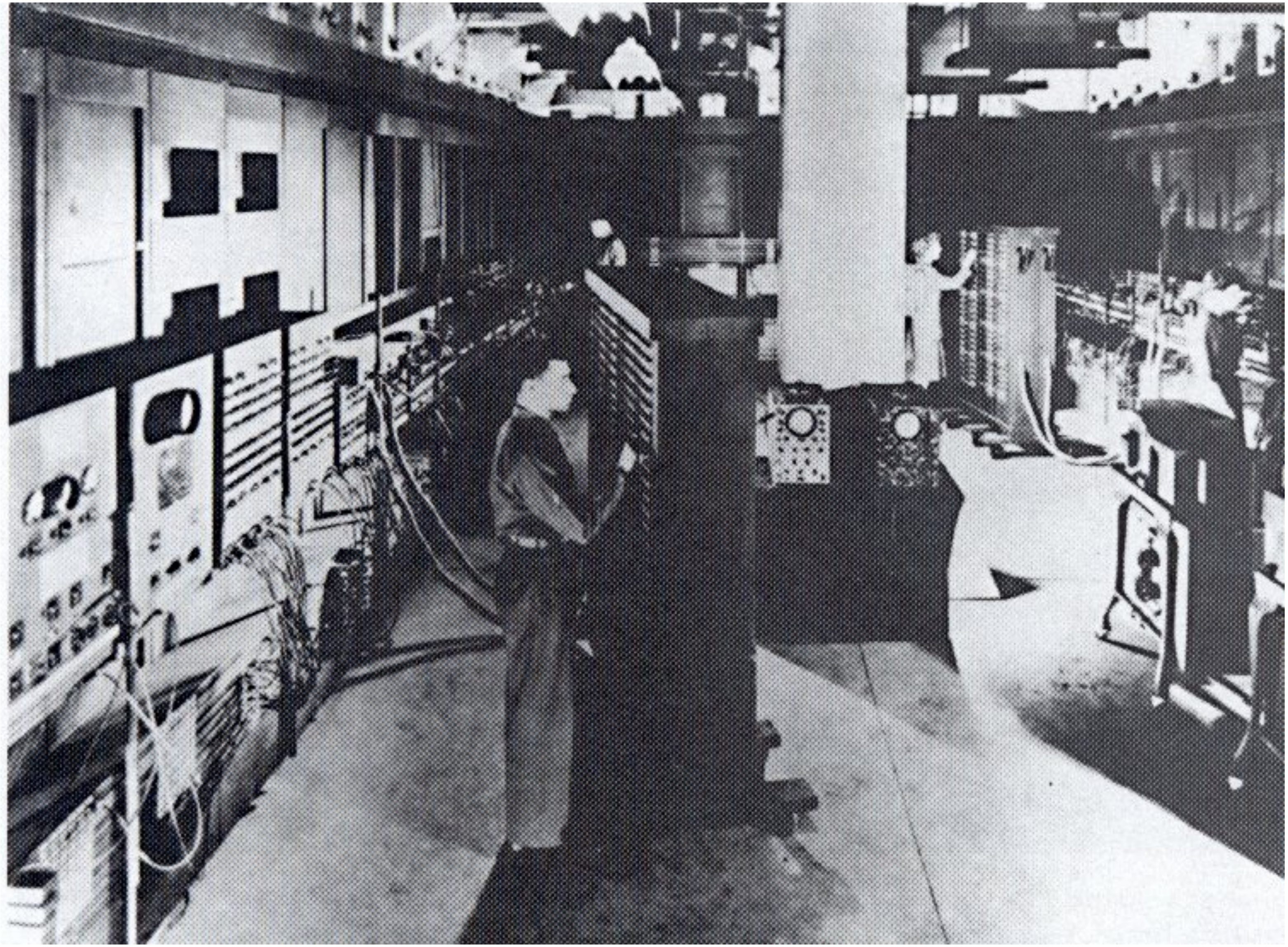


Transistor

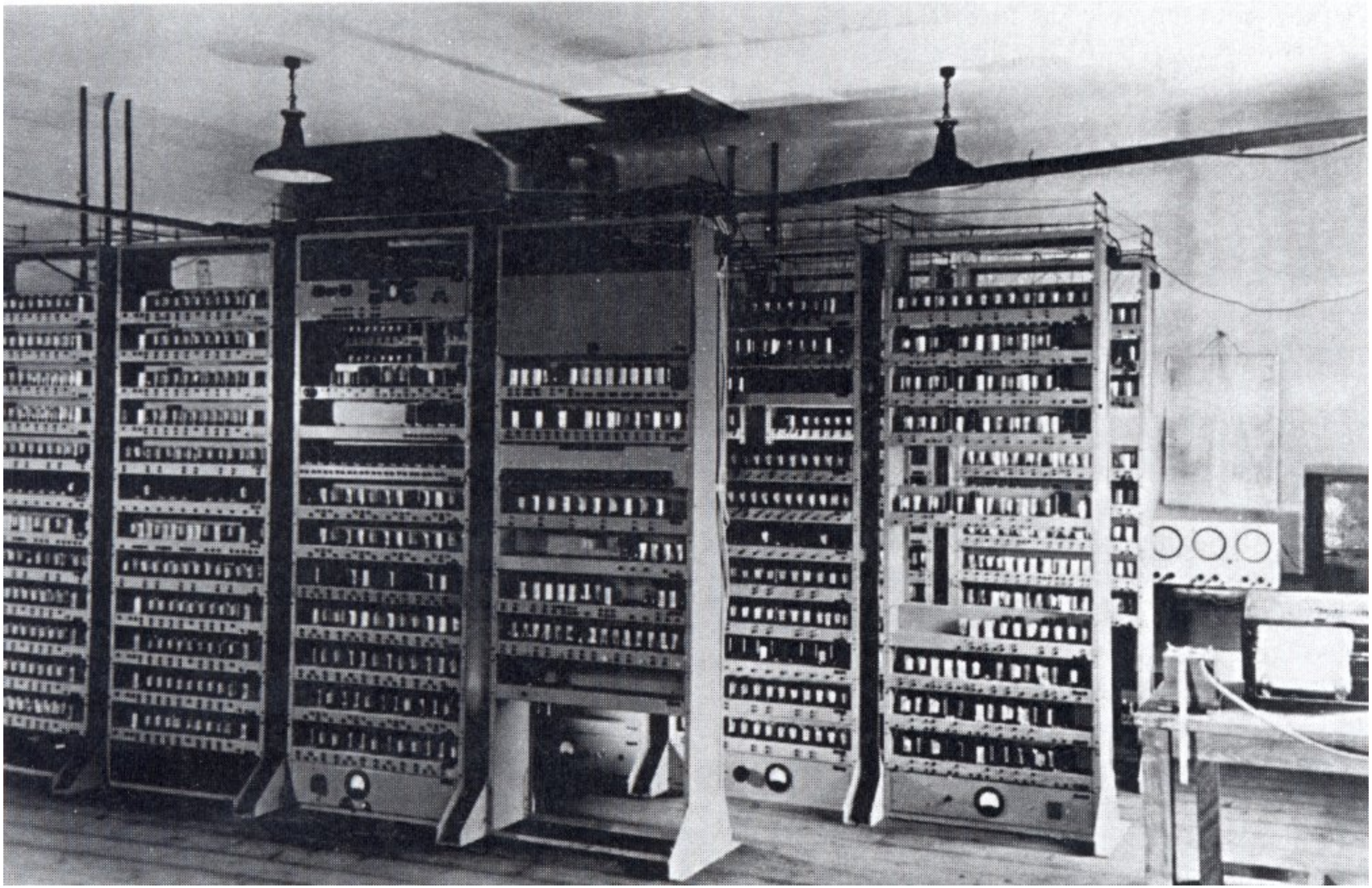
IC chips

History of Computing

- COLOSSUS 1943
  - First valve based computer
  - Built by British during WW II to decode messages
- ENIAC (Electronic Numerical Integrator and Calculator) 1946
  - Intended for calculating range tables for aiming artillery
  - 18000 valves, 1500 relays, weight 30 tons, 140kW of power
  - Programmed with multi-position switches and jumper cables
- John von Neumann
  - Leader of ENIAC development team
  - location of program storage from external to internal
    - speed not limited by reader but by electronic logic
    - computer could take decisions based on results and modify their action accordingly.

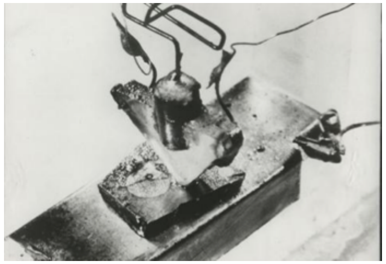


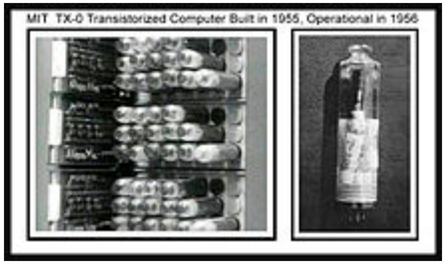
ENIAC 1946 occupied 1,000 M^3 with 18,000 Valves



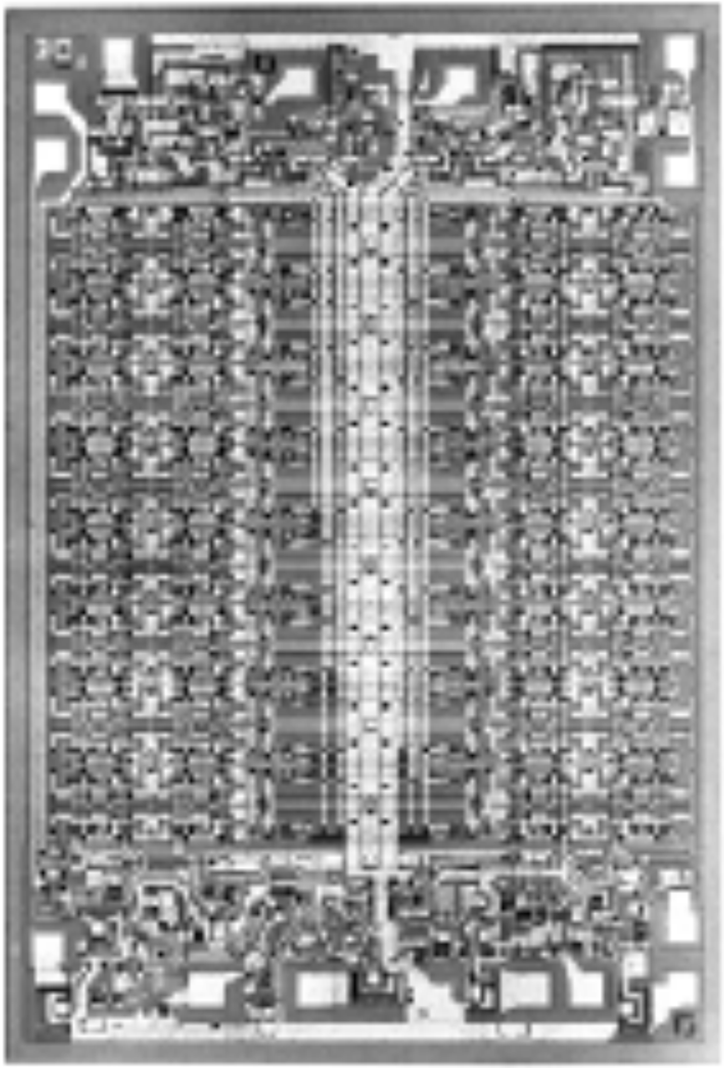
ENIAC 1946 occupied 1,000 M^3 with 18,000 Valves

- Transistor
  - Invented 1948 at Bell Labs
  - John Bardeen, Walter Brattain, and William Shockley
- TX-0 (Transistorised eXperimental computer 0),
  - first transistor computer, built at MIT Lincoln Labs
- DEC PDP-8
  - first "affordable" minicomputer $120K. 50% performance of IBM 7090 which cost millions.
- Burroughs B5000
  - first to emphasise software and high-level programming languages (Algol 60)

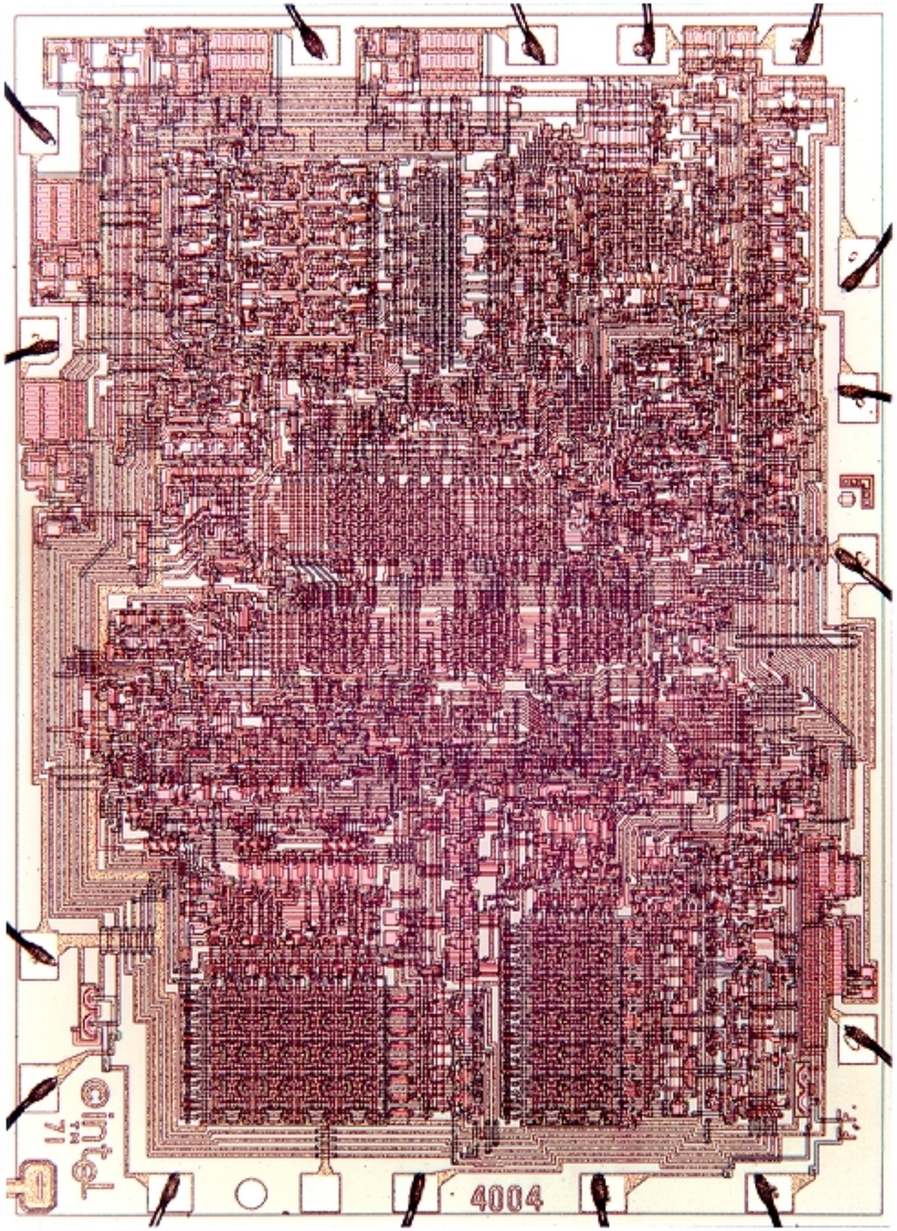


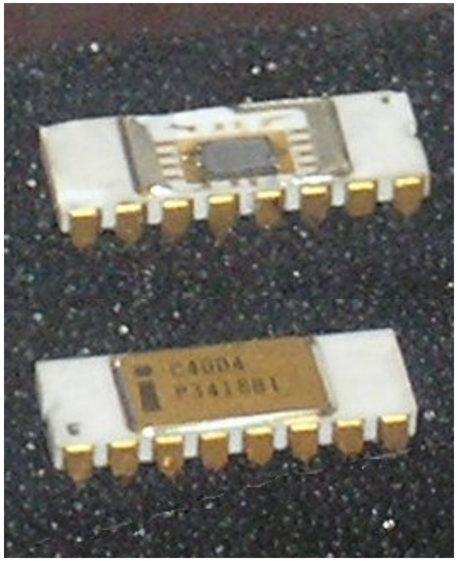


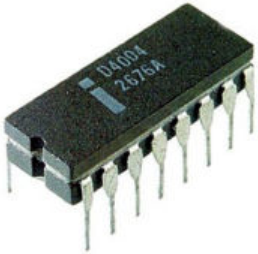
- IBM System/360
  - Family of machines with same assembly language
  - Designed for both scientific and commercial computing
- DEC PDP-11
  - Very popular with universities, maintained DEC's lead in minicomputer market
- Integration
  - Improvement of reliability of transistors offset by huge number of inter-component connections.
    - SSI Small Scale Integration (10-100 gates per chip)
    - MSI Medium Scale Integration (100-1,000 gates per chip)
    - LSI Large Scale Integration (1,000-10,000 gates per chip)



3101 Schottky bipolar 64-bit static RAM 1968



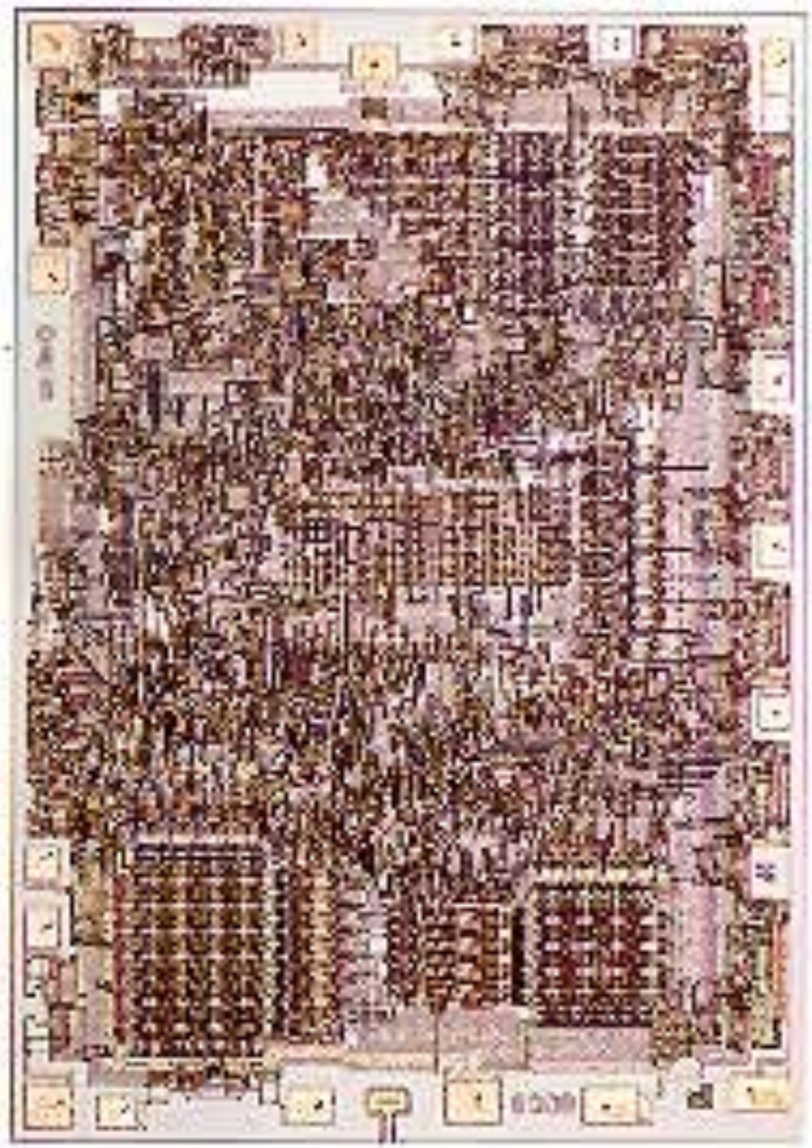


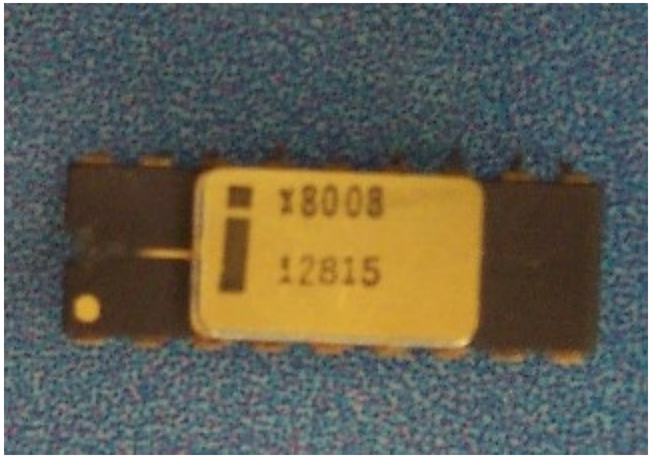


4004

1971

2 x 4mm with
2,300 Transistors



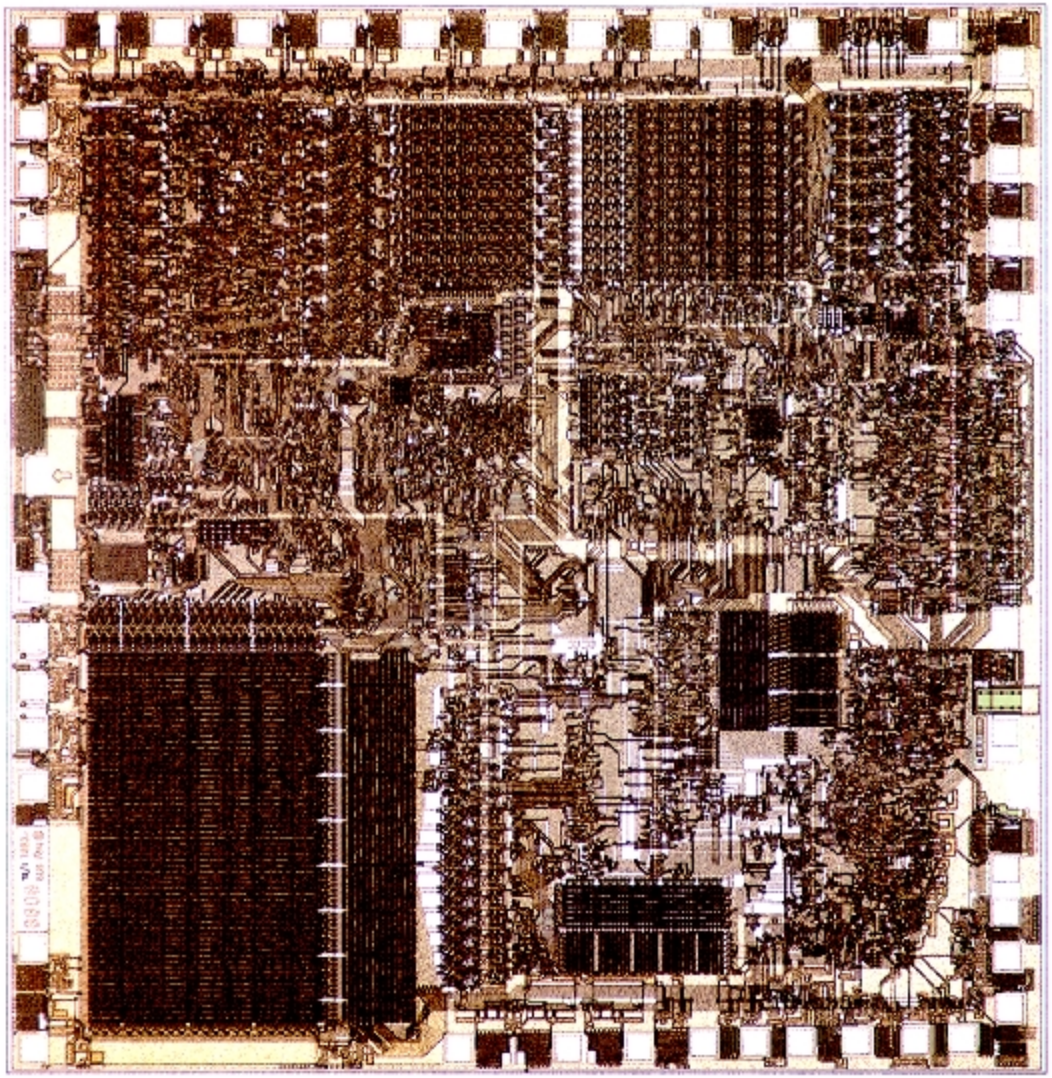


8008

1972

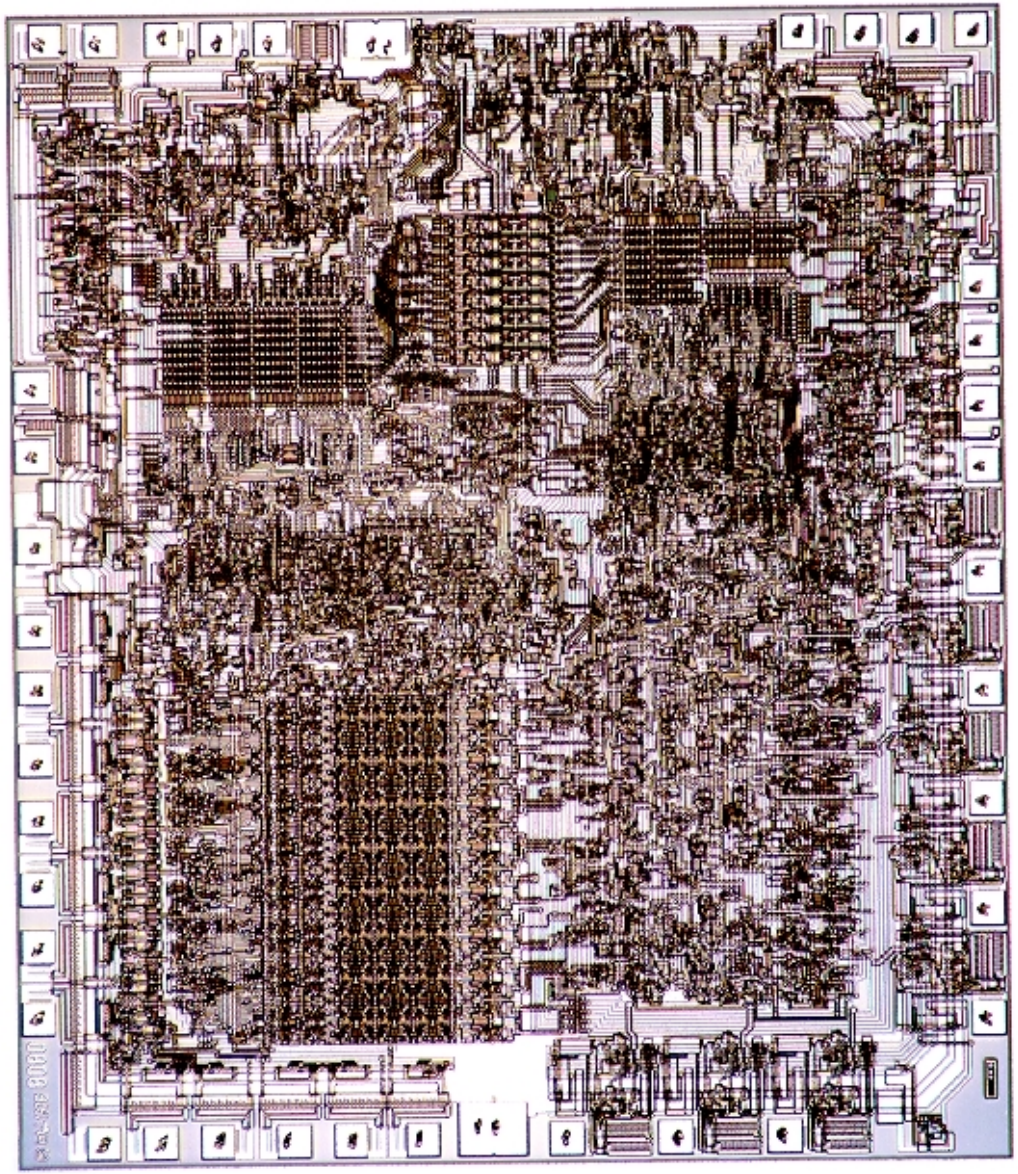
3,500

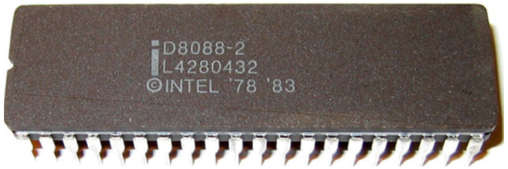
Transistors



8080
1974

6,000
Transistors



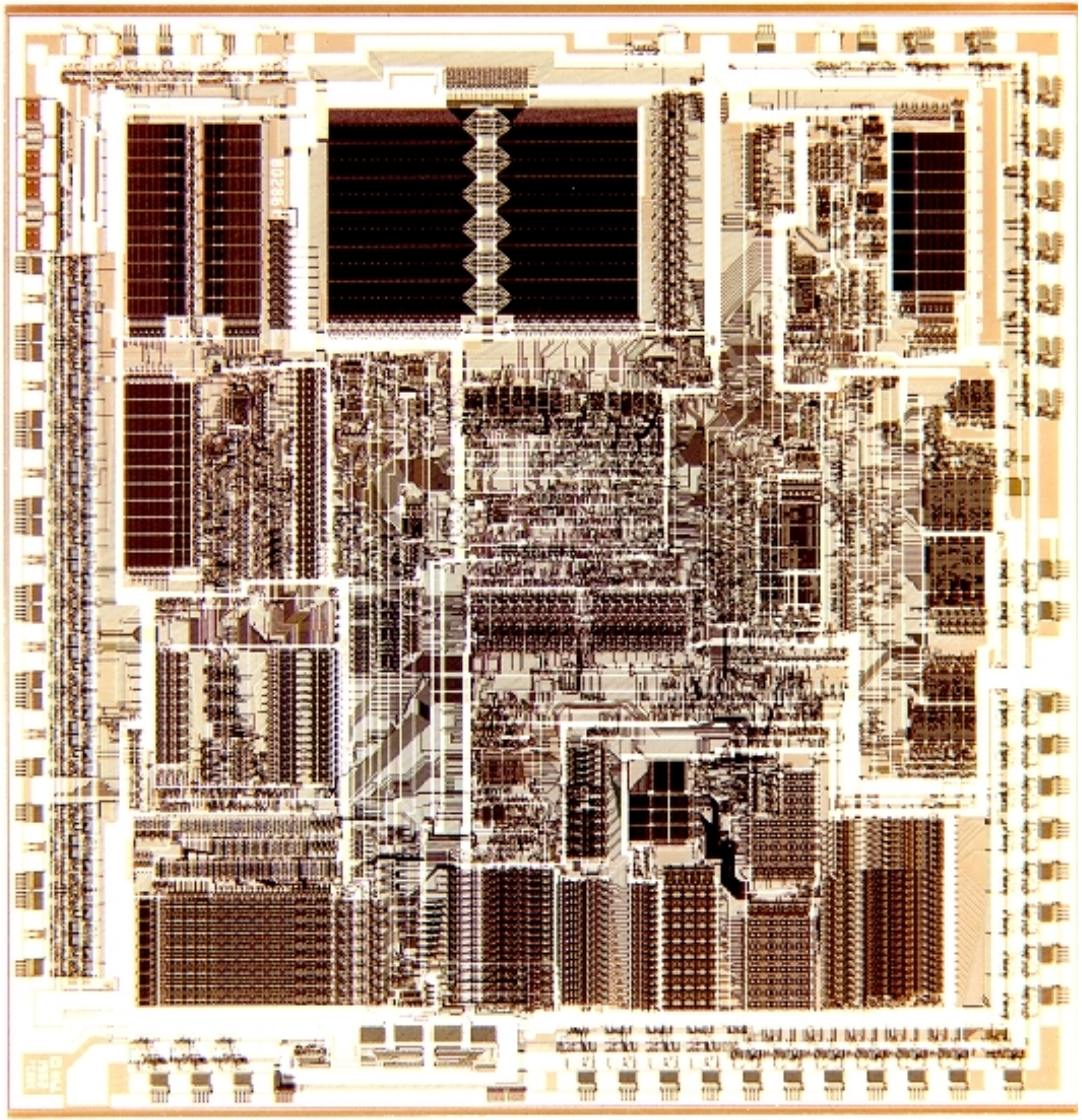


8088

1979

29,000

Transistors



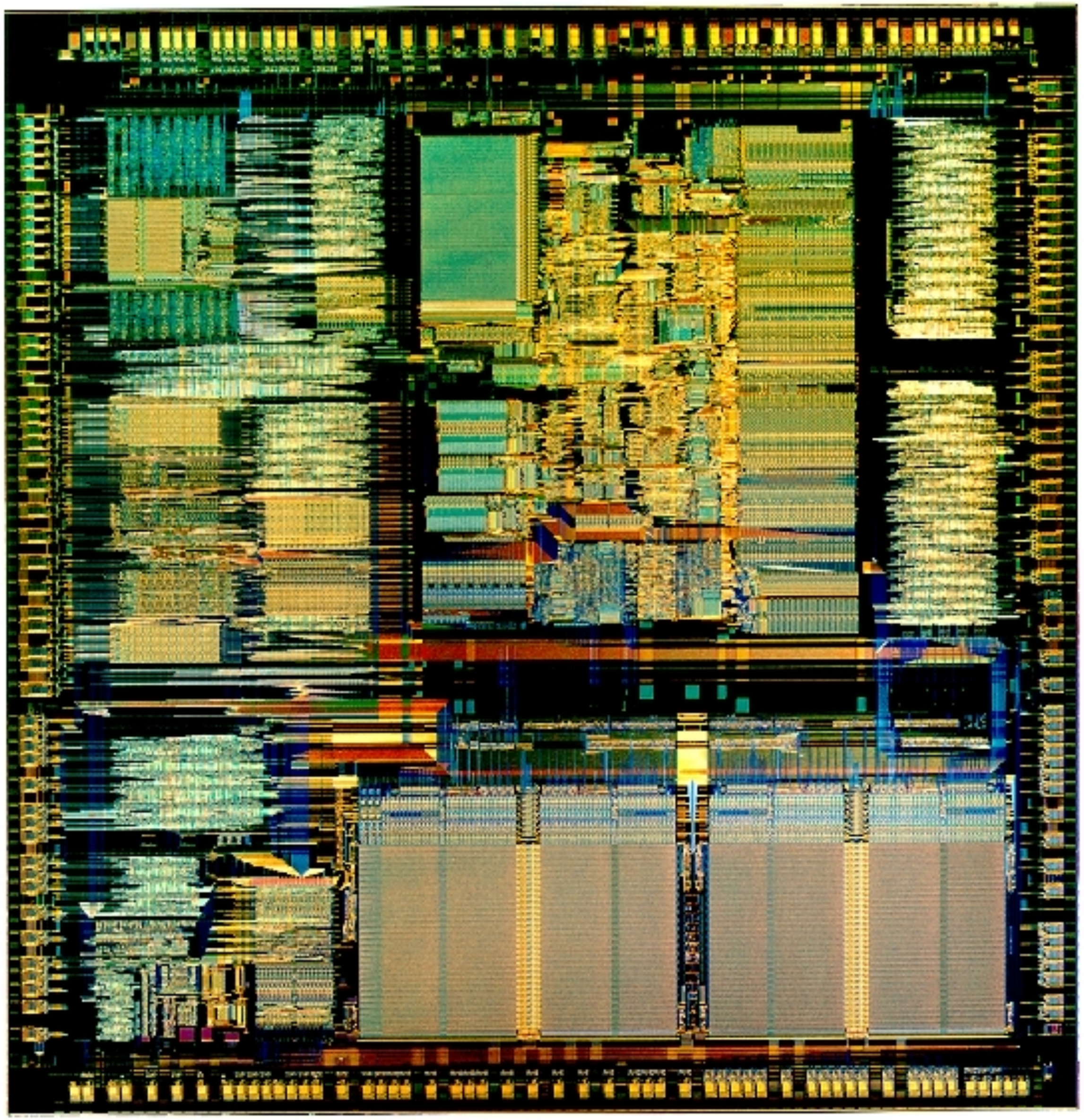
Sold in over 15 Million PCs

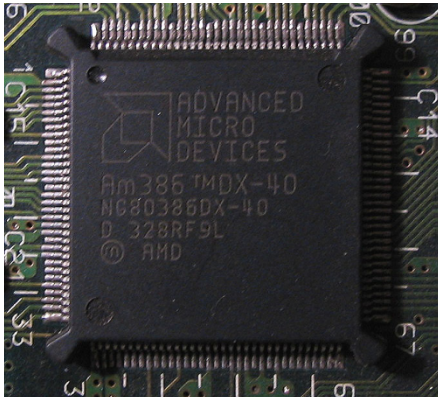
Backward compatible

80286

1982

134,000 Transistors



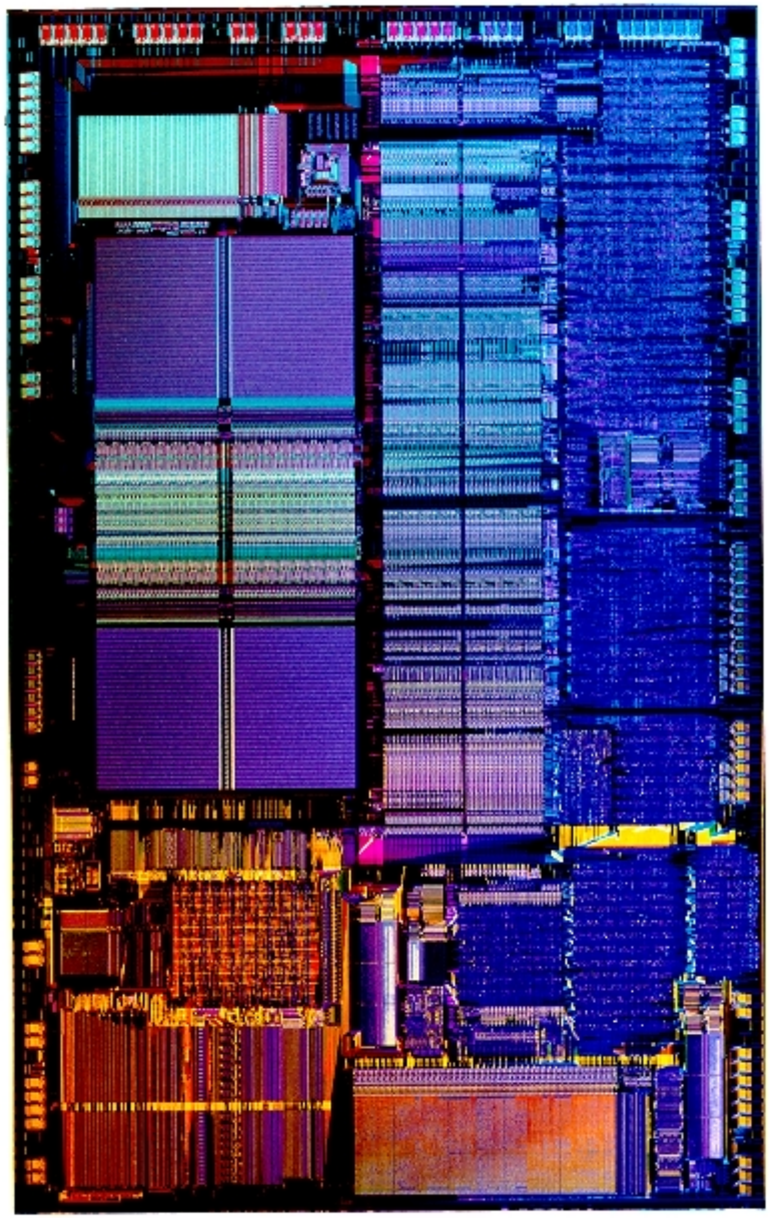


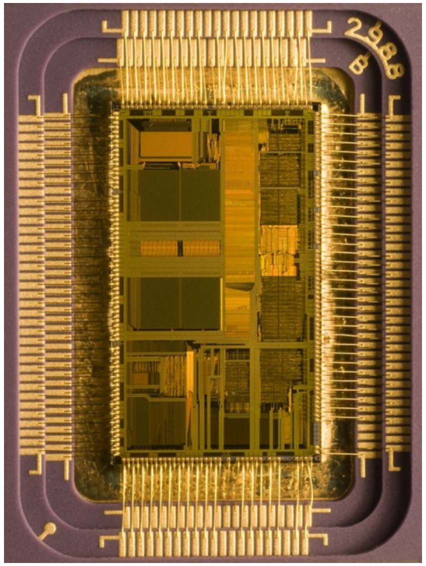
AMD's compatible processor 1991

80386

1985

275,000 Transistors

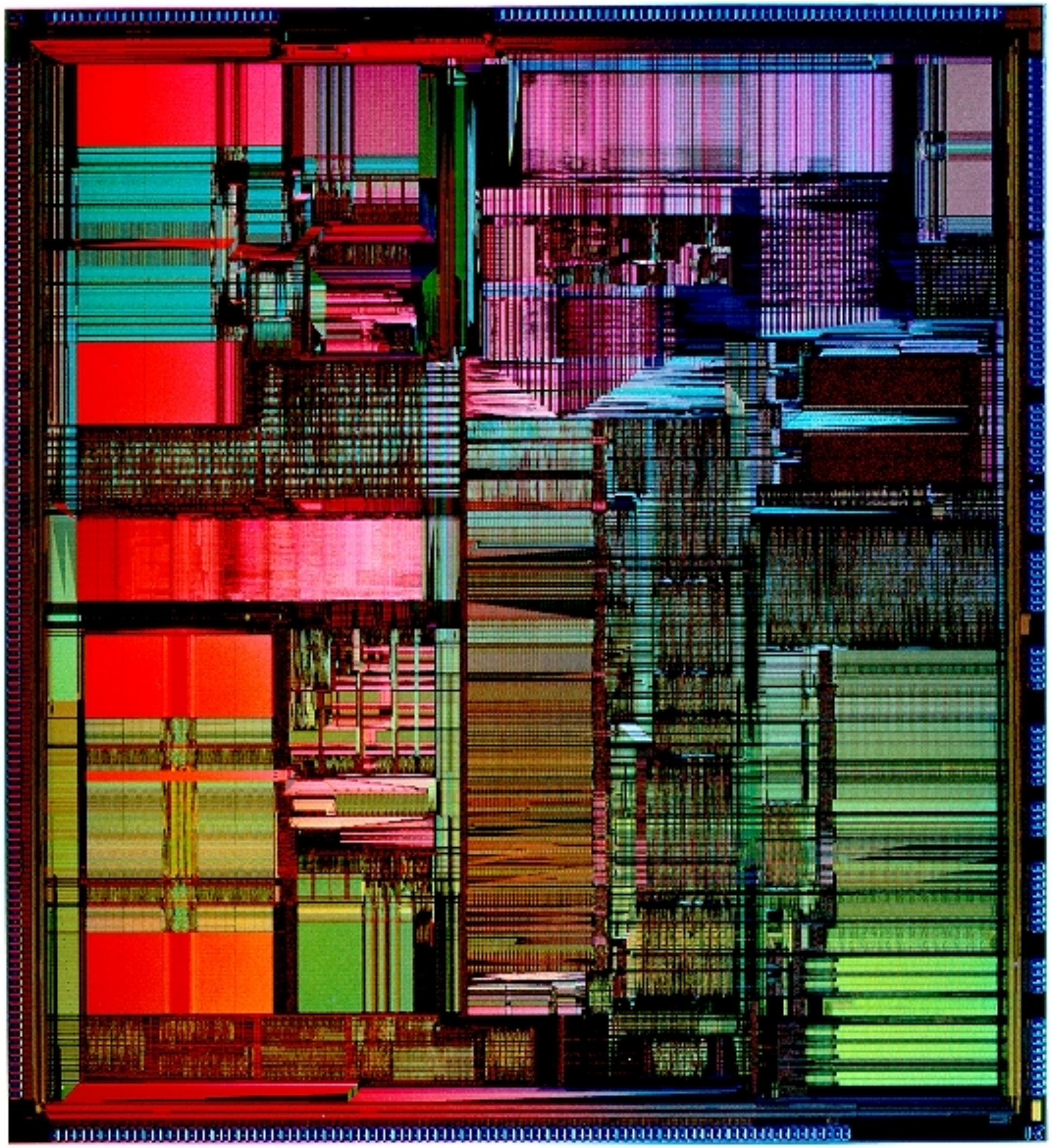


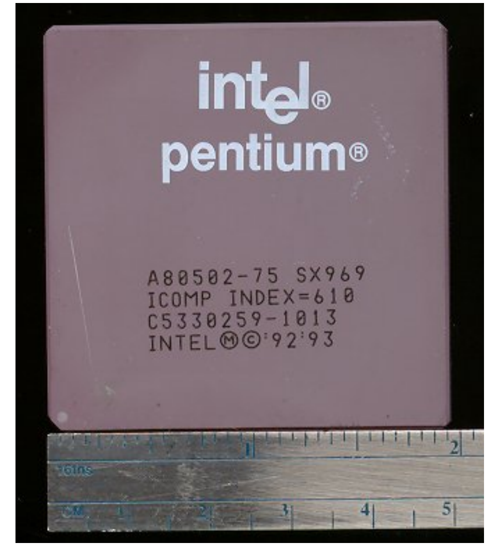


80486

1989

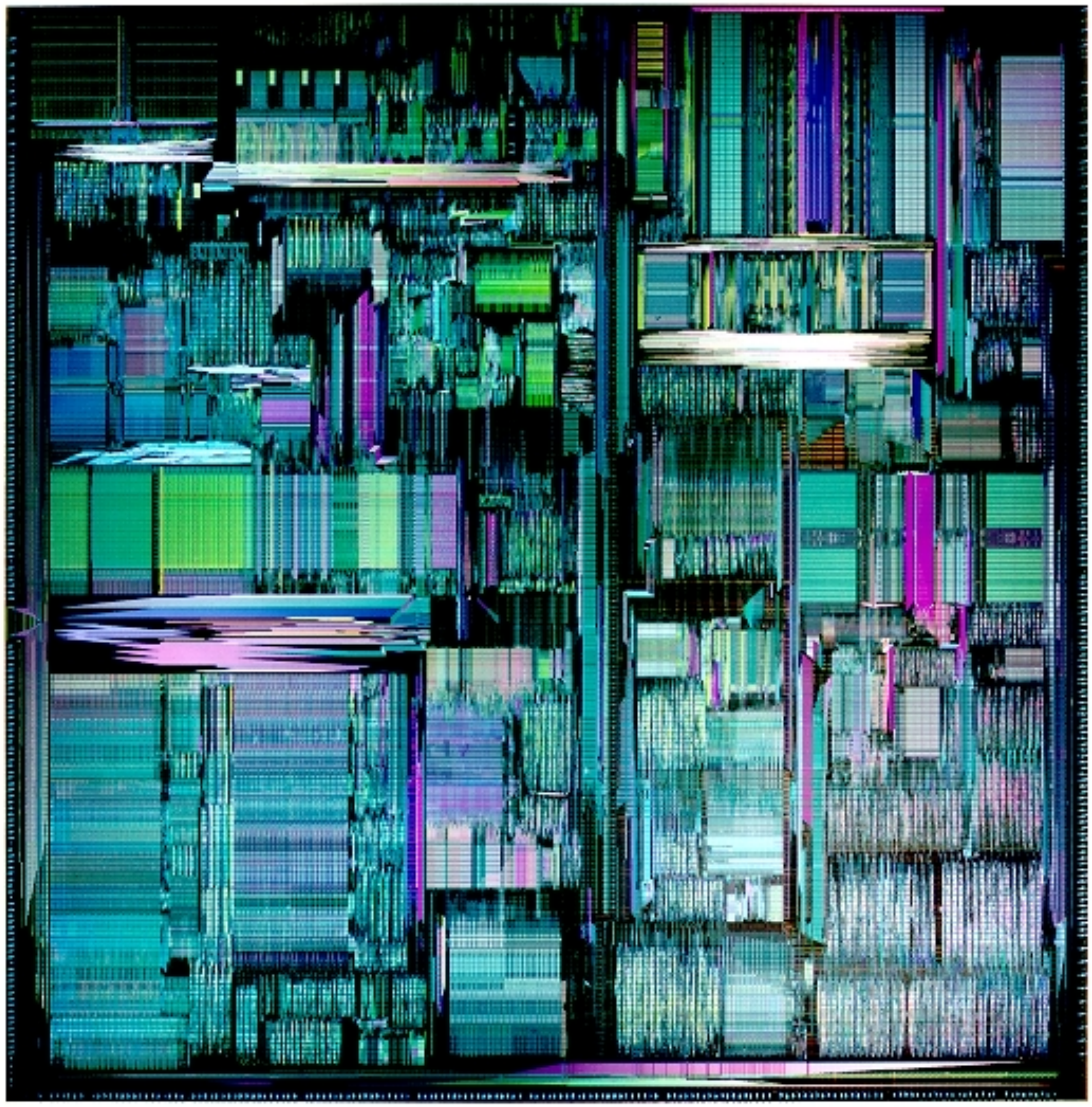
1.2 Million Transistors





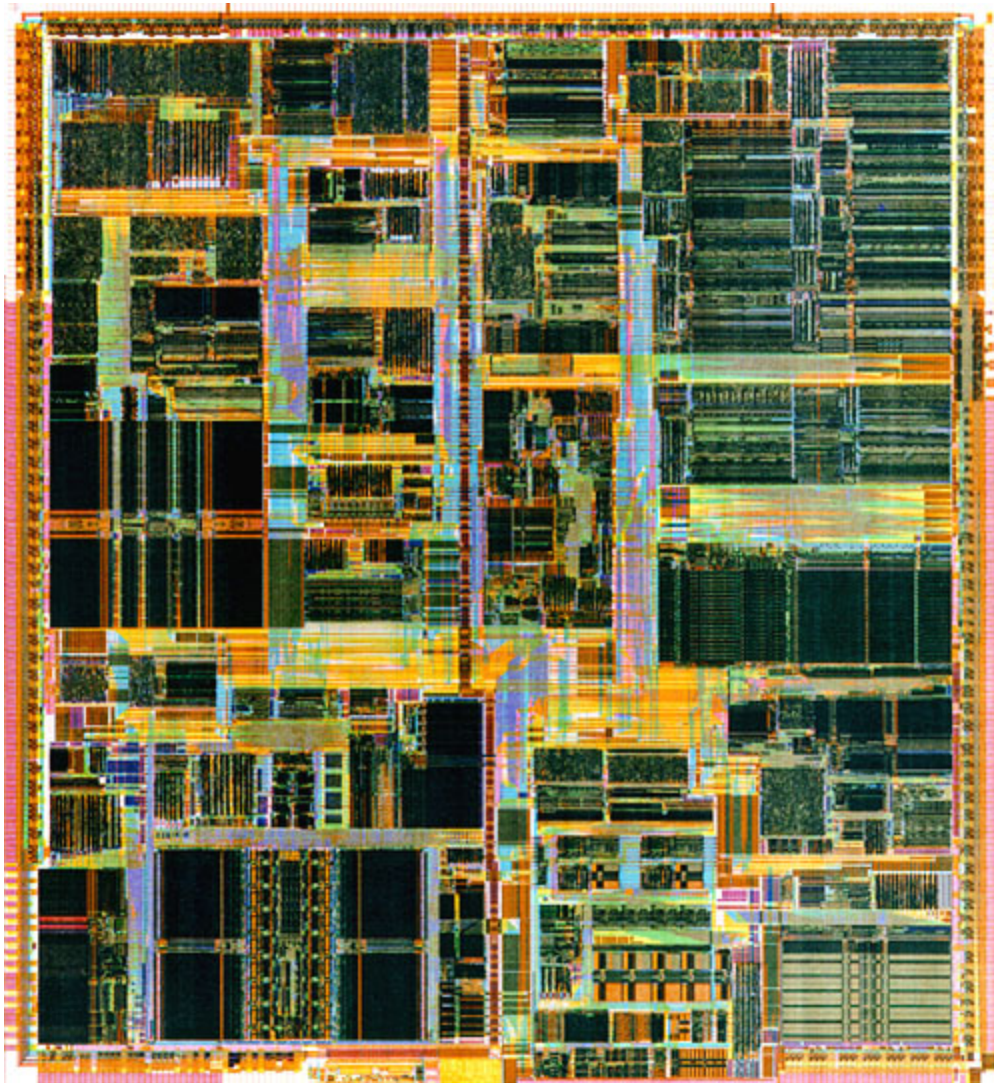
Pentium
1993

3.1 Million
Transistors



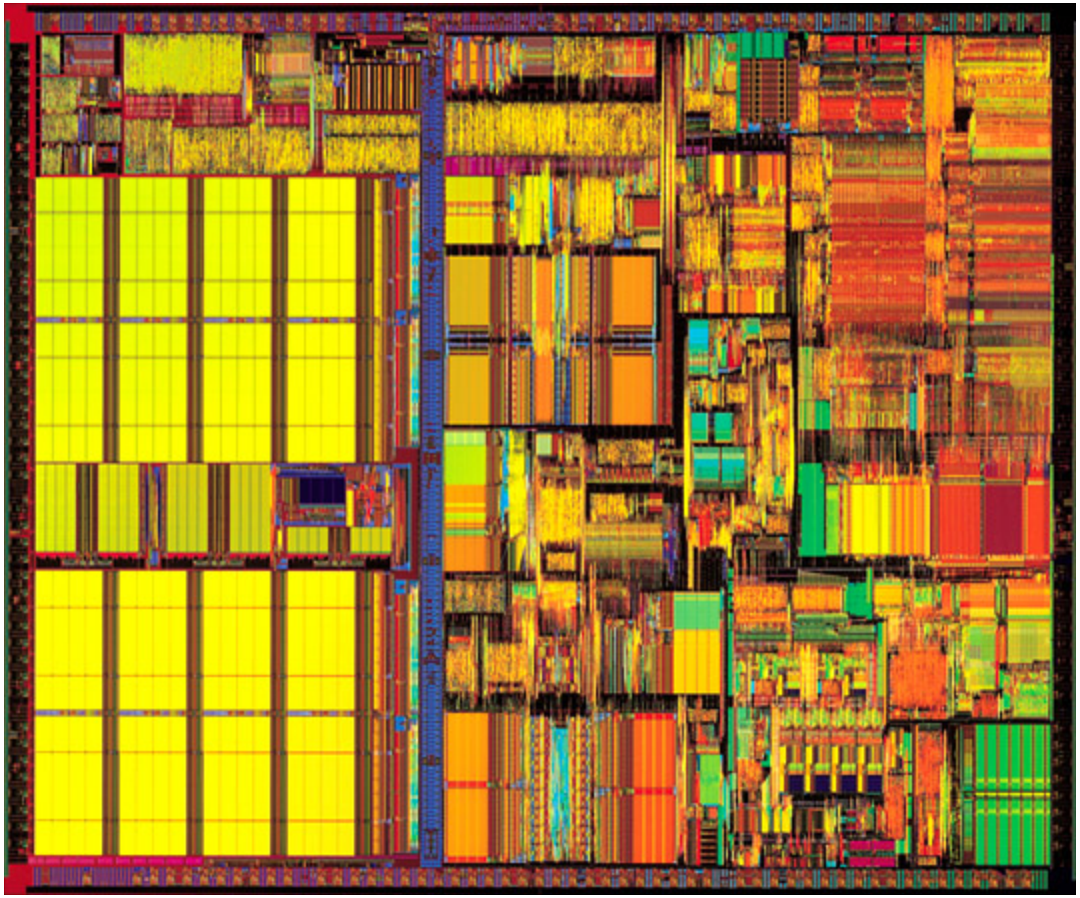
Pentium Pro
1995

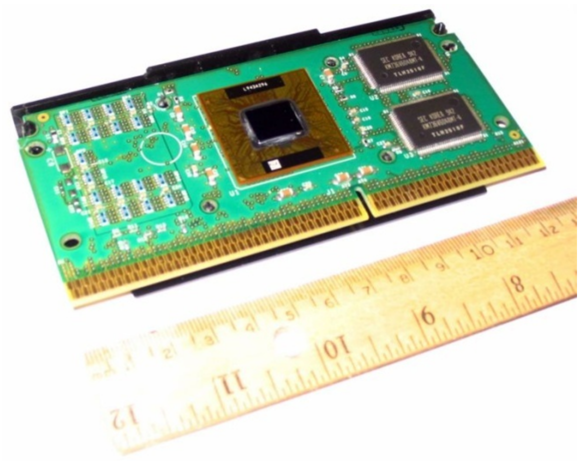
5.5 Million
Transistors



Pentium II
1997

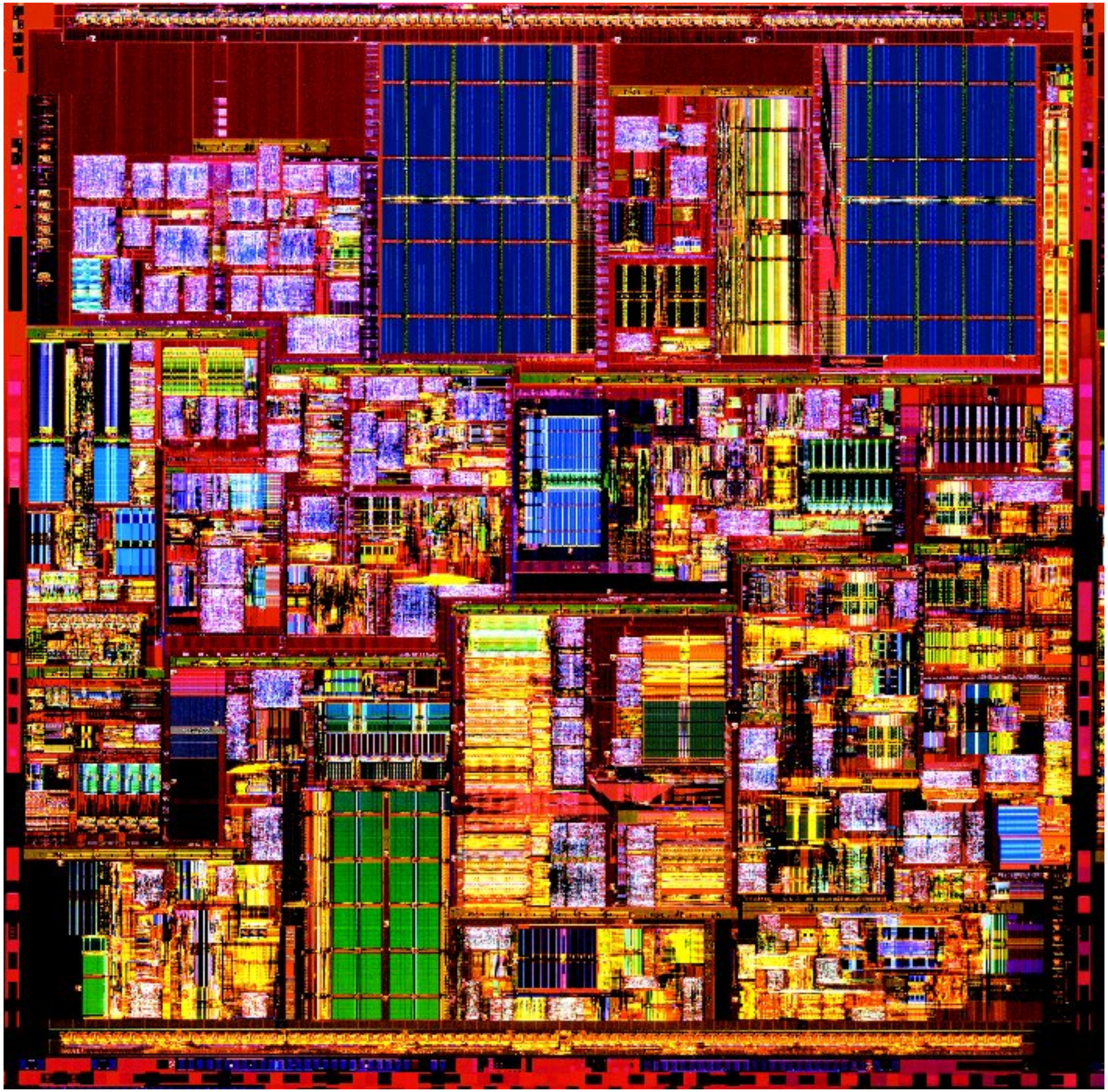
7.5 Million
Transistors





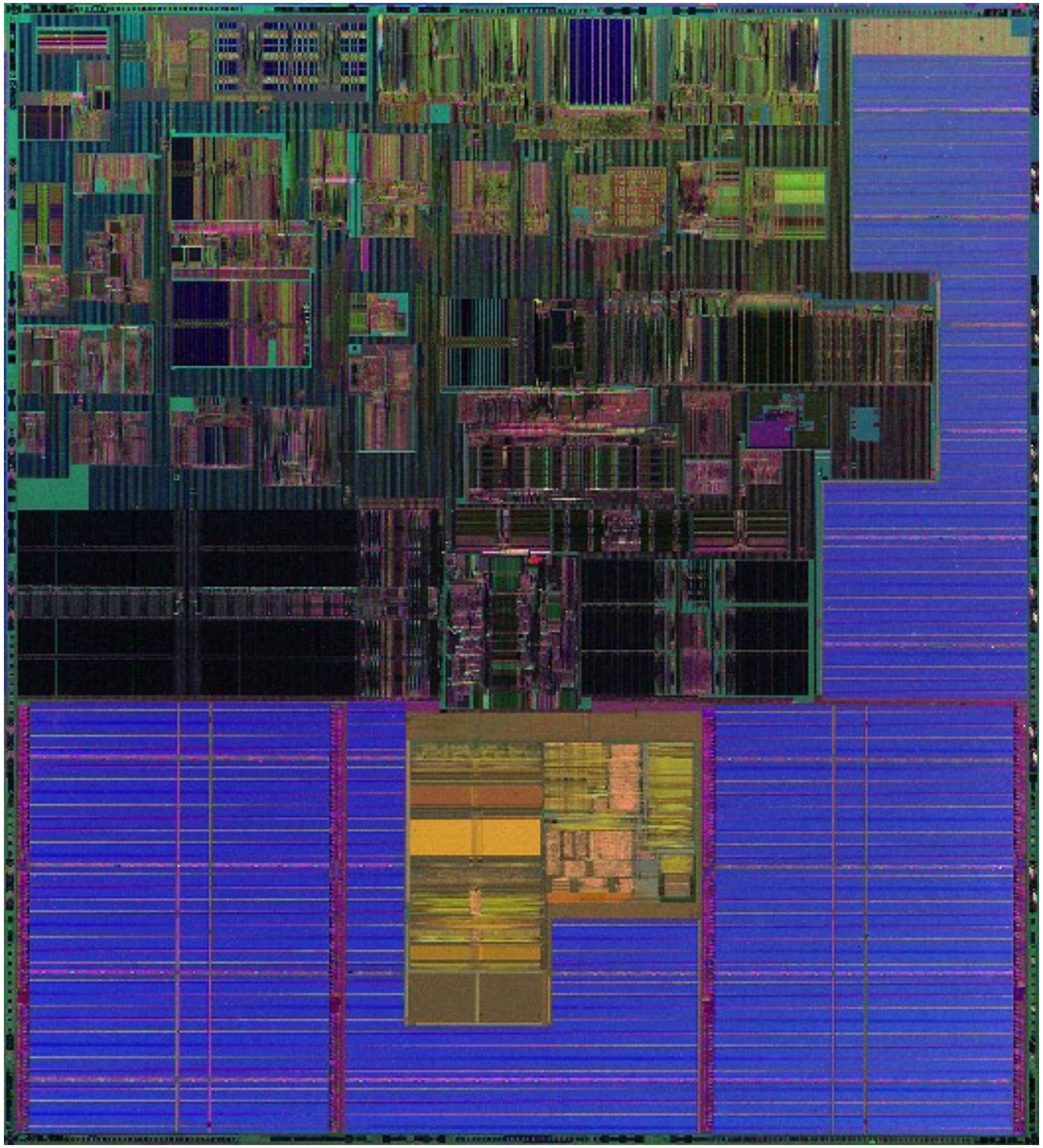
Pentium III
1999

9.5 Million Transistors



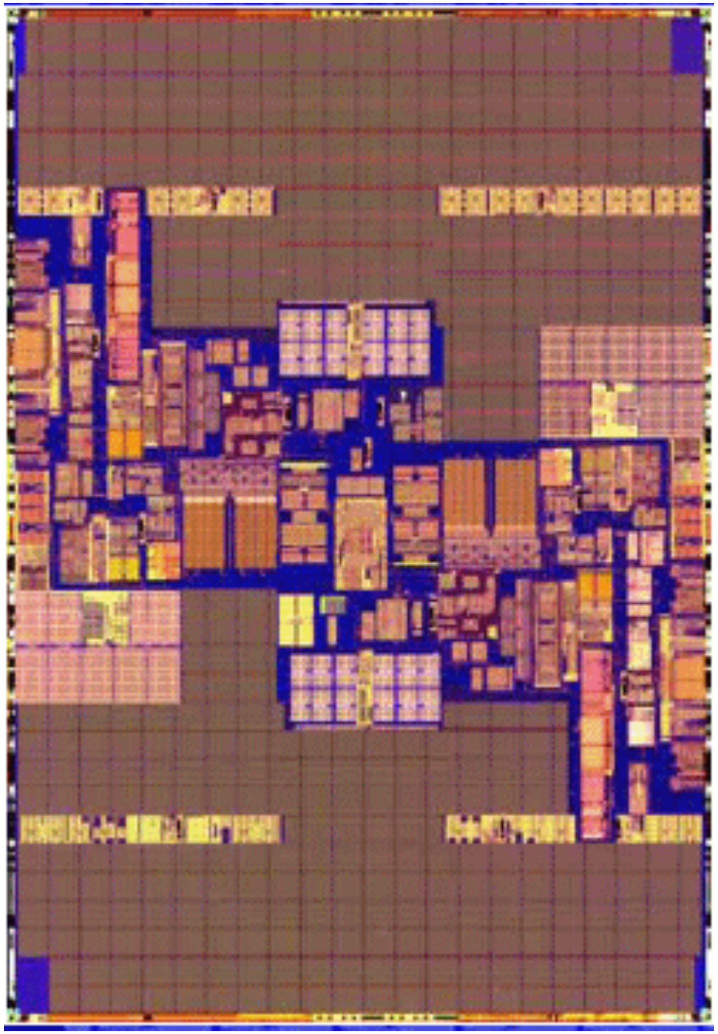
Pentium 4
2000

42 Million
Transistors



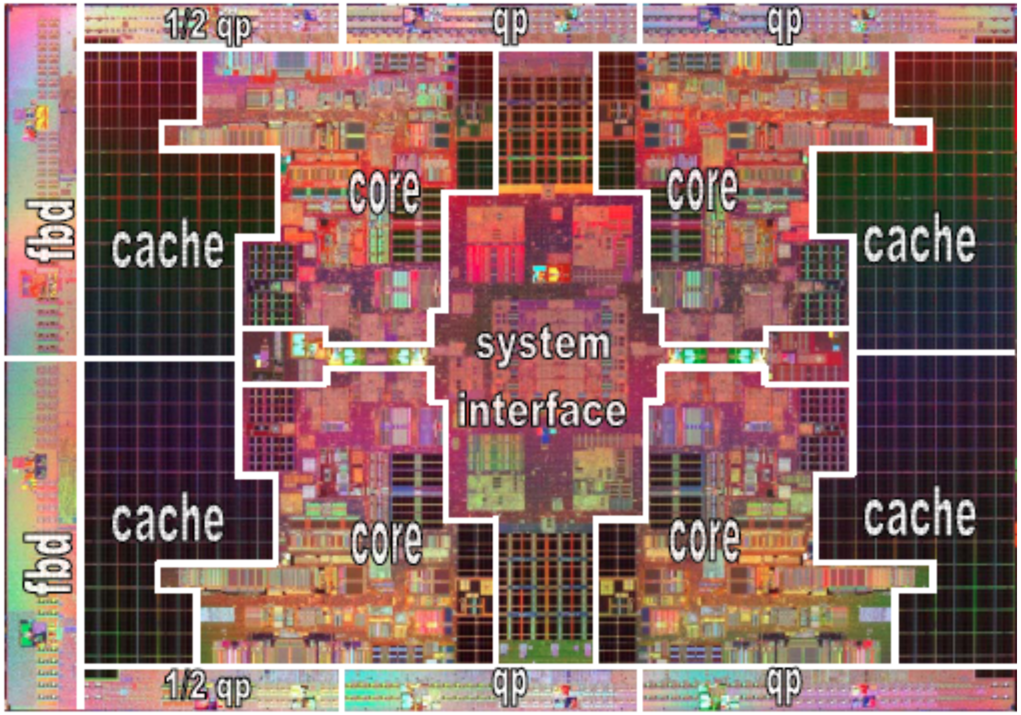
Itanium 2 (with 9MB cache)
2004

592 Million Transistors



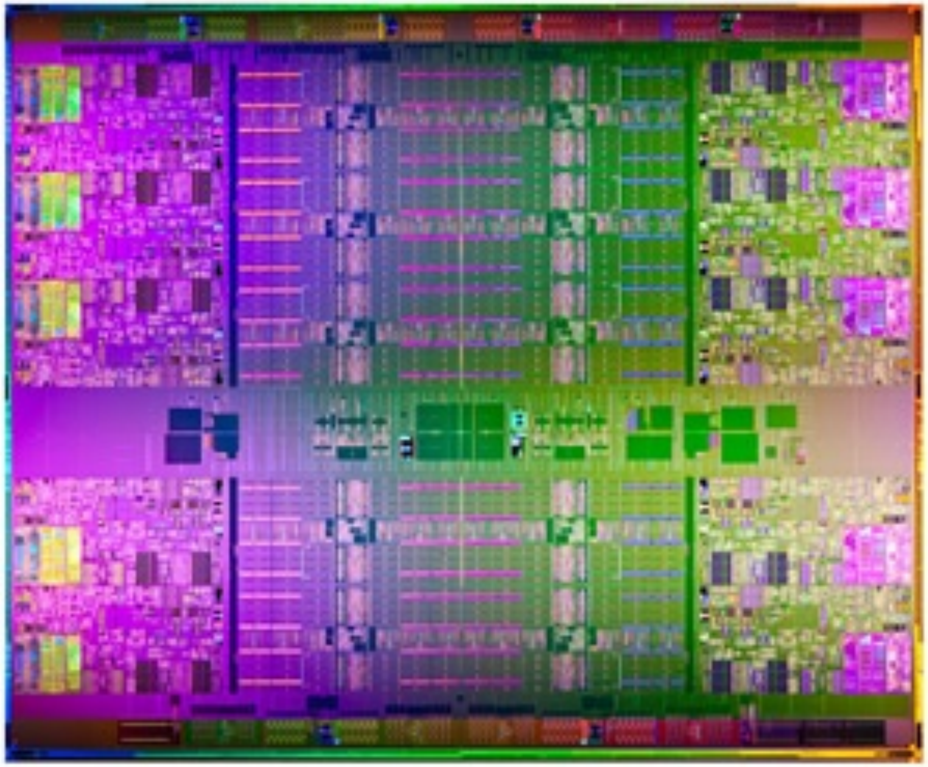
Dual Core
Itanium 2
2006

1.7 Billion
Transistors



Quad-Core Itanium Tukwila
2010

2.0 Billion Transistors



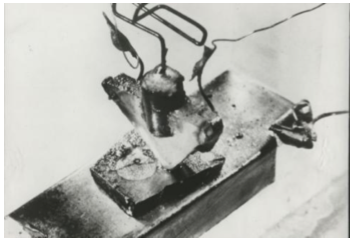
10-Core Xeon Westmere-Ex
2011

2.6 Billion Transistors

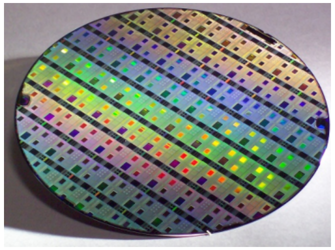
Moore’s Law

Gordon Moore 1965 –

“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. I believe that such a large circuit can be built on a single wafer.”

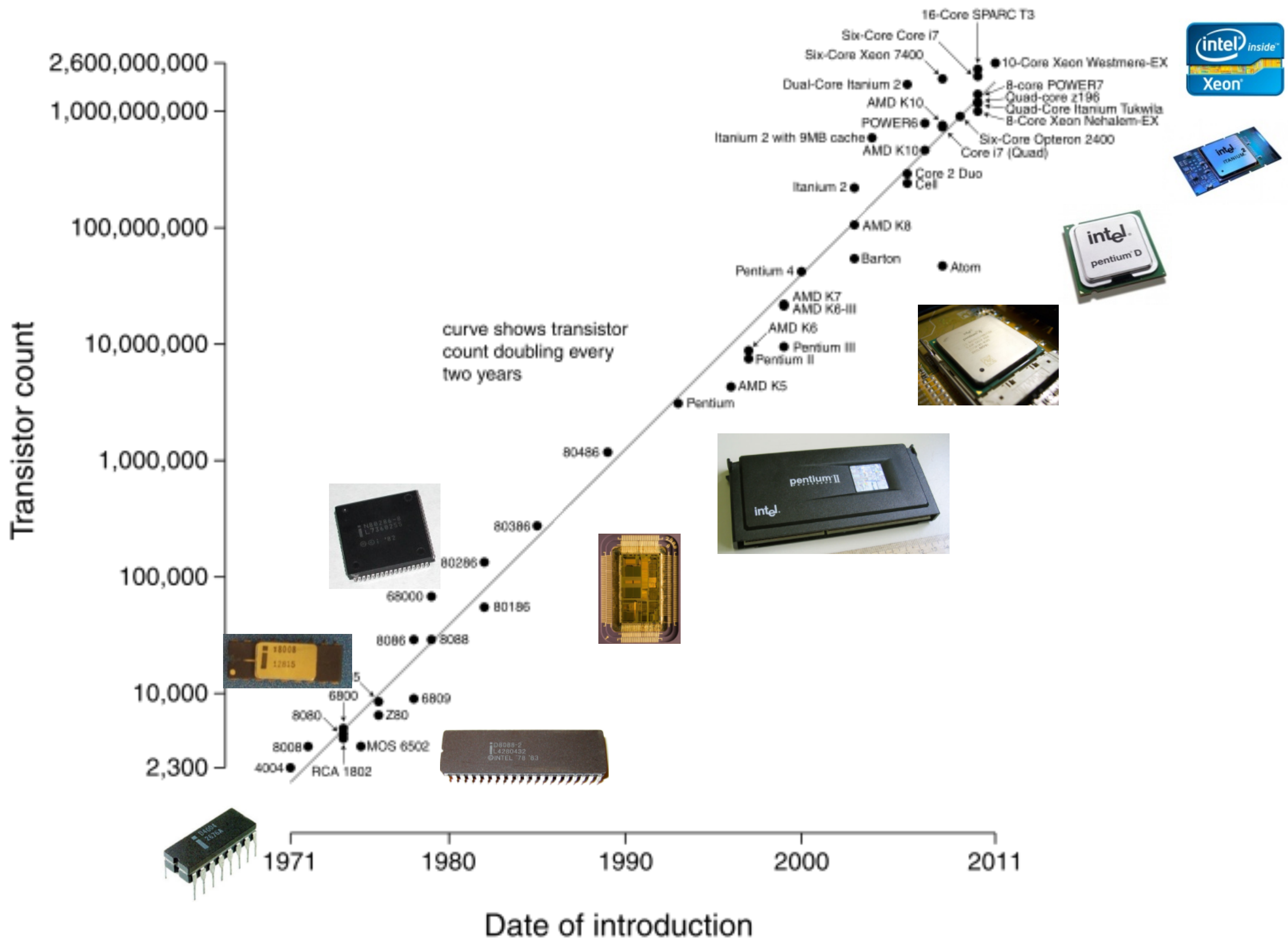


1949, the 1st Transistor



2012 TSMC 28nm wafer

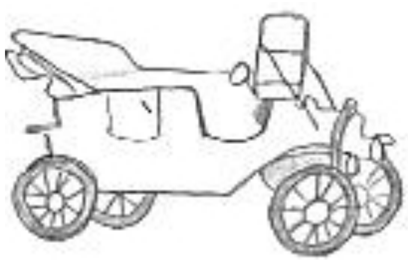
Microprocessor Transistor Counts 1971-2011 & Moore's Law



Moore's Law at CES2015: http://youtu.be/iPUKqhCZzi0

Moore's Law

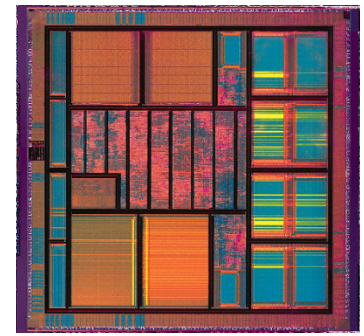
"If GM had kept up with technology like the computer industry has, we would all be driving $25 cars that got 1,000 miles per gallon…"



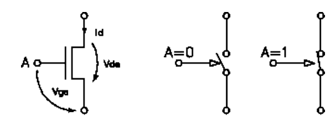
– Bill Gates, *COMDEX* keynote

Technology Scaling

What Made of Digital ICs



- Sea of transistors
- Each or a group of transistors act as switches (called logic gates)
- Design goals
  - – Minimize number of transistors used (size and cost)
  - – Shortest propagation delay of signal pass (speed and performance)



What Will We Learn?

- The Fundamentals of Digital Circuits
  - Building blocks
  - Operation principles
  - Design methodologies

... From Gate to System...

- Aims of Module:
  - To enable the student understand how digtial systems work and what they are built from
  - To enable the student to analyse digital circuits and design small digital building blocks and subsystems
  - To give an understanding of how digital systems communicate with each other and with their external environment
  - To give an understanding of the factors that limit performance

Course Outline

- Introduction
  - Digital Electronics Overview
  - Binary Systems
- Boolean Algebra
  - Digital Logic Gates
  - Karnaugh Maps
- Combinational Logic
  - Binary Arithmetic
  - Decoders and Multiplexors

Course Outline

- Sequential Logic
  - Flip Flops
  - Registers
  - Counters
  - Synchronous Machines
  - Memory Circuits
- Logic Design Procedures
  - Implemention
- Transistor Logic
  - Logic Families
  - Performance Metrics
  - CMOS Logic

How Will We Learn?

- Lectures 30 x 1 hour
  - Tuesdays 09:00 -- 09:50 Room 326
  - Wednesdays 14:00 -- 14:50 Room 326
  - Thursdays 09:00 -- 09:50 Room 326
- Laboratory/Tutorials 10 x 3 hours
  - Mondays 15.00 – 18:00 Room 329
  - Tutorials help preparing lab and homework.
  - Lab running on two shifts (due to a large number of class).
  - Detailed arrangment will follow.
- Autonomous Student Learning 60 hours
  - Review lectures, solve sample exercises
  - Homework
  - Text book: Morris Mano, "*Digital Design*", 4th Edition, Prentice Hall.

Total: 120 hours

How Will You Be Assessed?

• Laboratory work	20%
• Mid-term Test	10%
• Homework	10%
• End of Semester Exam	60%