CS 31007 Autumn 2021

COMPUTER ORGANIZATION AND ARCHITECTURE

Instructors

Rajat Subhra Chakraborty (*RSC*)

Bhargab B. Bhattacharya (*BBB*)

Lecture #1, #2:

Course Overview and Evolution of Computer Design

10 August 2021

Indian Institute of Technology Kharagpur

Computer Science and Engineering

CS 31007 Autumn 2021

COMPUTER ORGANIZATION AND ARCHITECTURE

Class Schedule

Commencement: Tuesday, 10 August 2021
Closure: Thursday, 18 November 2021

Timing: 12:00-12:55 (Mon), 10:00-11:55 (Tue), and 8:00-8:55 (Thurs)

Online Classes will be held in real-time mode
or occasionally in pre-recorded mode

Tutorials and doubt-clearing sessions will be held
in real-time mode

Lab Course (39001): Computer Organization Laboratory

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COMPUTER ORGANIZATION AND ARCHITECTURE

Course Page and TAs

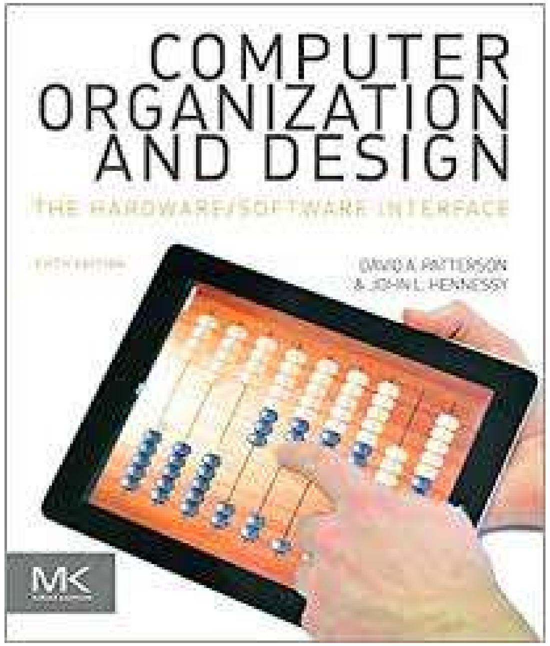
Course Page: https://moodlecse.iitkgp.ac.in/moodle/login/index.php
Moodle Student Registration Key for the Course: STU31007

Teaching Assistants: Rijoy Mukherjee (rijoy.mukherjee@gmail.com)
Akashdeep Saha (akashdeepsaha95@gmail.com)
Rajat Sadhukhan (rajatssr835@gmail.com)
Sreekanth Balija Venkata
(balijavenkatasreekanth@gmail.com)

Prerequisites

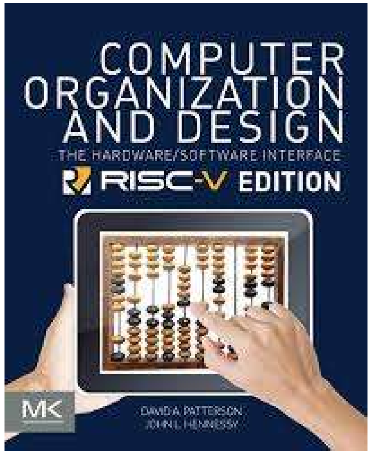
Basic logic design, combinational and sequential circuits, knowledge of high-level programming language

Textbook

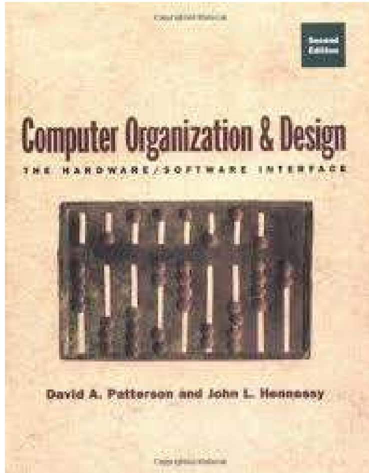


D. A. Patterson and J. L. Hennessy
Computer Organization and Design
- The Hardware Software Interface
5th Edition, Morgan Kaufmann, 2014
(MIPS Version)

2017 ACM Turing Award



RISC-V Edition 2018



Second Edition 1998

Further Reading

1. Smruti R. Sarangi, *Computer Organisation and Architecture*, McGraw Hill India, 2014

2. William Stallings, *Computer Organization and Architecture: Designing for Performance*, Eight Edition, Prentice Hall, 2010.

3. John P. Hayes, *Computer Architecture and Organization*, 3rd Edition, Tata McGraw Hill, 2012.

Grading Policy

- No Mid-Sem or End-Sem Examination
- Evaluation at regular intervals
- Homework for practicing
- Online exams/quizzes

The exams/quizzes would usually be scheduled in the regular class hours

Agenda

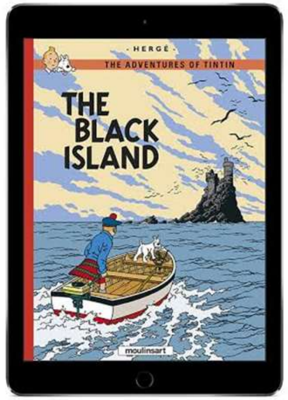
- Overview of the course
- Evolution and history of computer design
- Moore’s law
- Basic components of a computer
- Instruction Set Architecture (ISA)
- Computer organization and computer architecture: Bottom-up and Top-down view

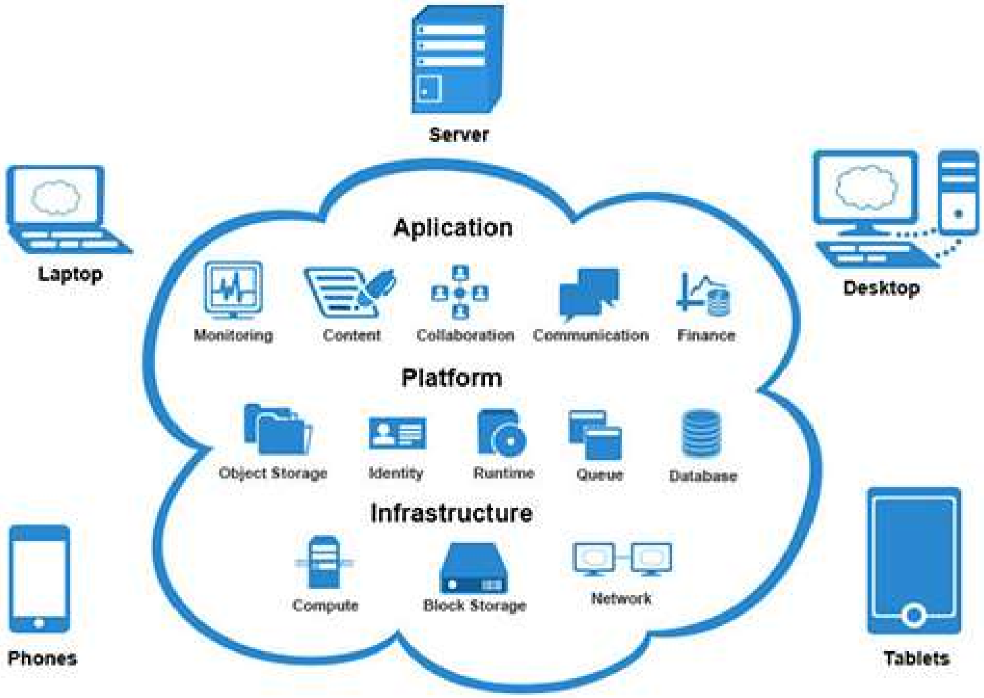
Acknowledgement: Patterson and Hennessy; V. D. Agrawal; S. R. Sarangi

Goal is to understand ….

- What are the principles of computer design?
- What is the hardware-software interface?
- Computer organization *versus* computer architecture?
- How to design the instruction set of a machine?
- How instructions are executed in a machine?
- What are the techniques for performing fast computation?
- How to design a complete processor?

What is a Computer ?





Cloud Computing

Car or Computers?

BMW
345i

- 2,000,000 lines of code
- Fiftythree 8-bit microprocessors
- Eleven 32-bit microprocessors
- Seven 16-bit microprocessors

The Computer Revolution

- Makes novel applications feasible
  - Computers in automobiles
  - Cell phones
  - Human genome project
  - World Wide Web
  - Search Engines
- Computers are all pervasive

Classes of Computers

- Personal computers
  - General purpose, variety of software
  - Subject to cost/performance tradeoff

- Server computers
  - Network based
  - High capacity, performance, reliability
  - Range from small servers to building sized
  - Cloud

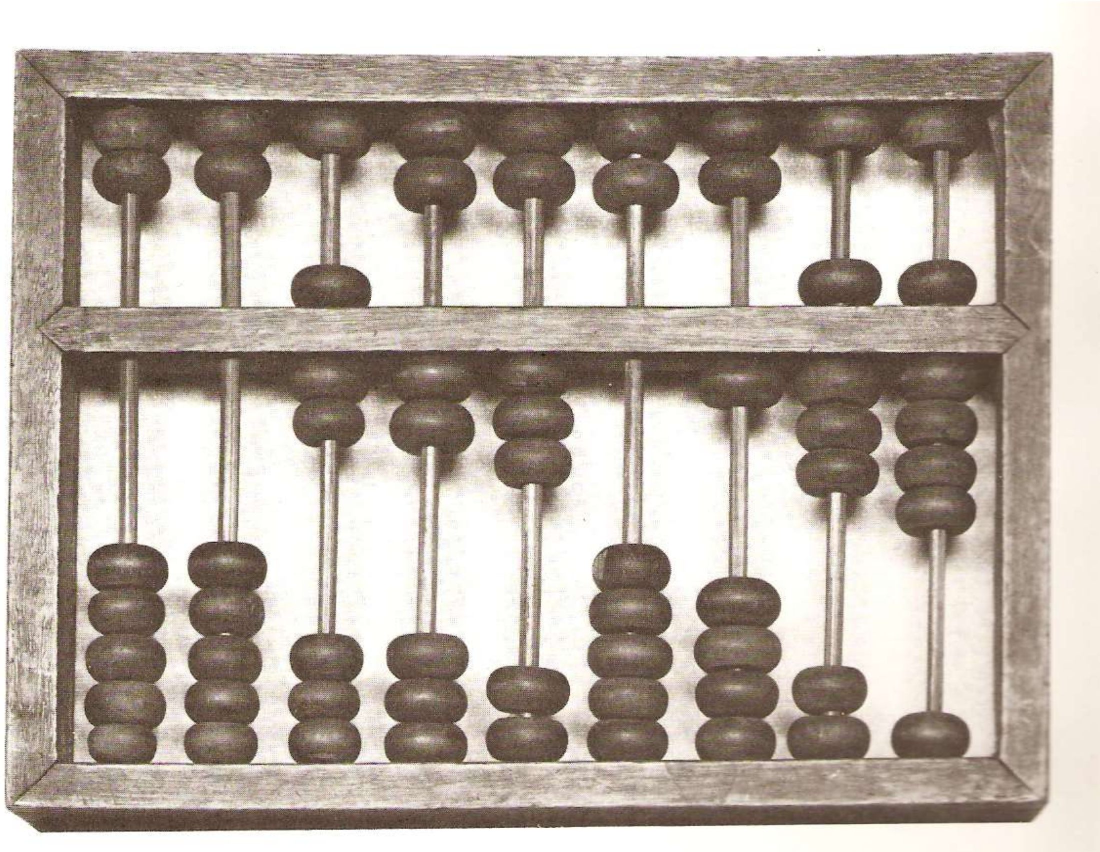
Classes of Computers

- Supercomputers
  - High-end scientific and engineering calculations
  - Highest capability but represent a small fraction of the overall computer market
- Embedded computers
  - Hidden as components of systems, IoT
  - Stringent power/performance/cost constraints
  - Autonomous vehicles, robotics

A computer is a general purpose machine which can process Information and yield results

However, centuries ago, by a computer was meant …

The First Mechanical Computing Device



The nineteenth century Chinese abacus, numbers are entered by sliding the beads towards the crossbar

First Steps in Computing

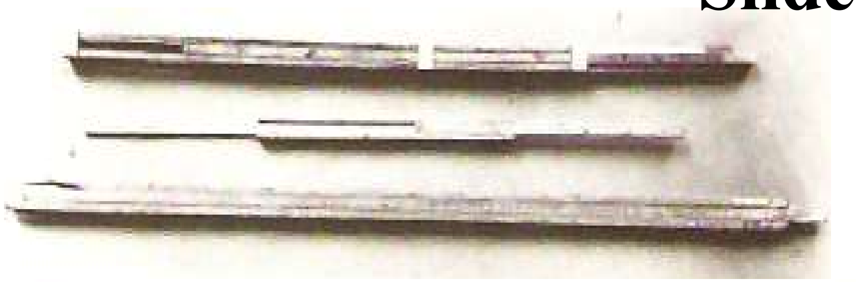
John Napier (1550-1617)

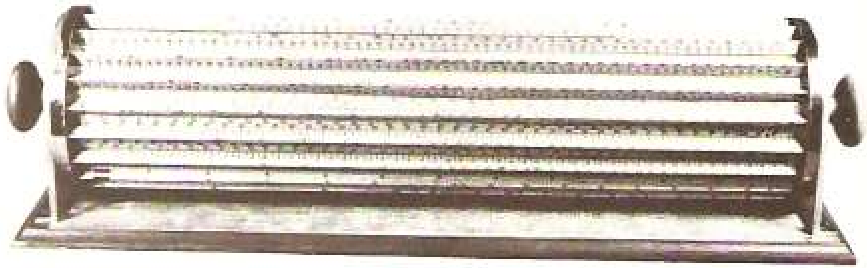
$$log\ (a \times b) = \log a + \log b$$

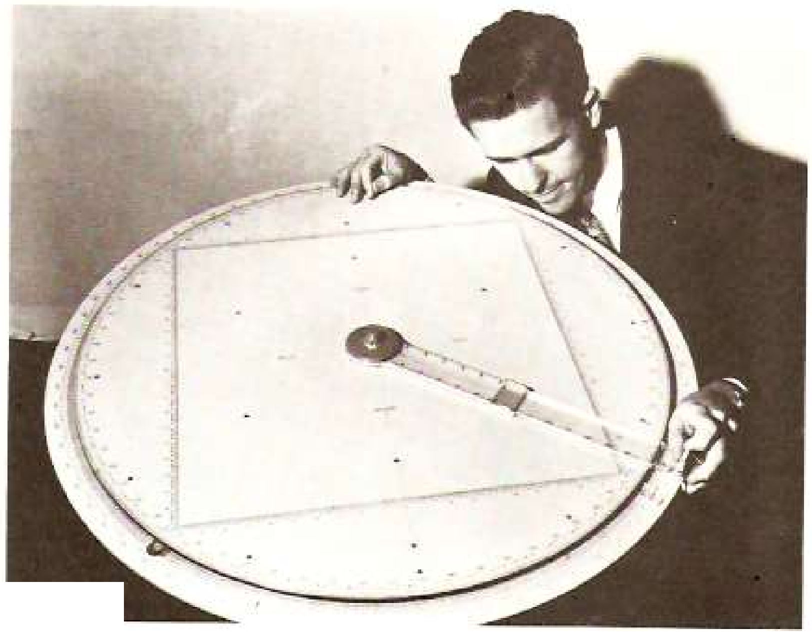
$$log\ (a / b) = \log a - \log b$$

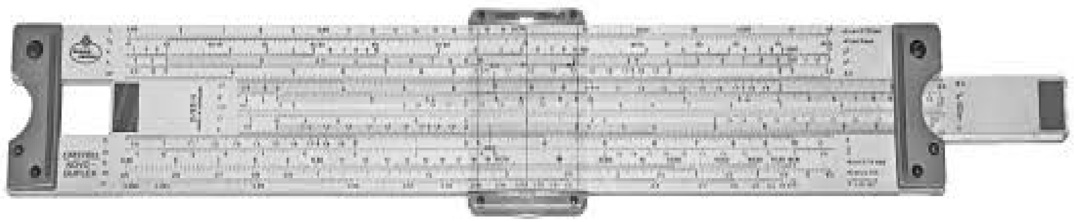
The front page of Napier's famous paper (1614) that introduced logarithm and contained ninety pages of tables.

Slide Rule





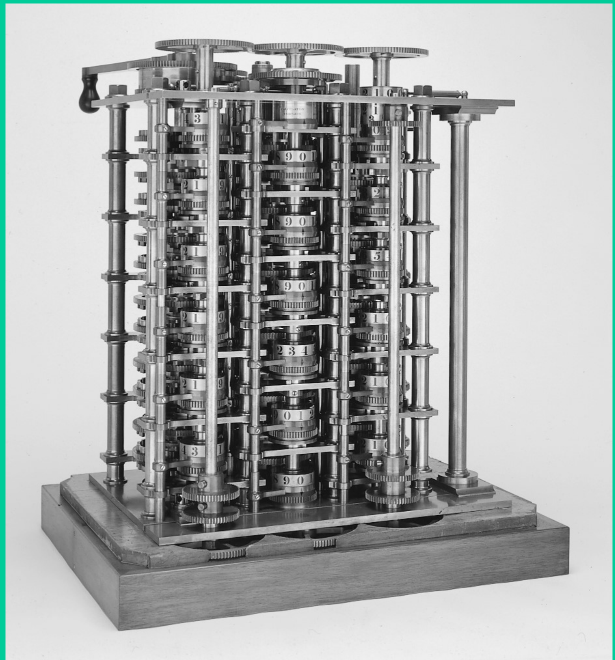




The first slide rule (top left) was made in 1654; the cylindrical slide rule (below left) and circular slide rules are useful modifications that were used for various computations; Slide rule (left-bottom) used by early generation of engineers.

Then:

The First Computer (1832)



Babbage Difference Engine (25000 parts)

Now:

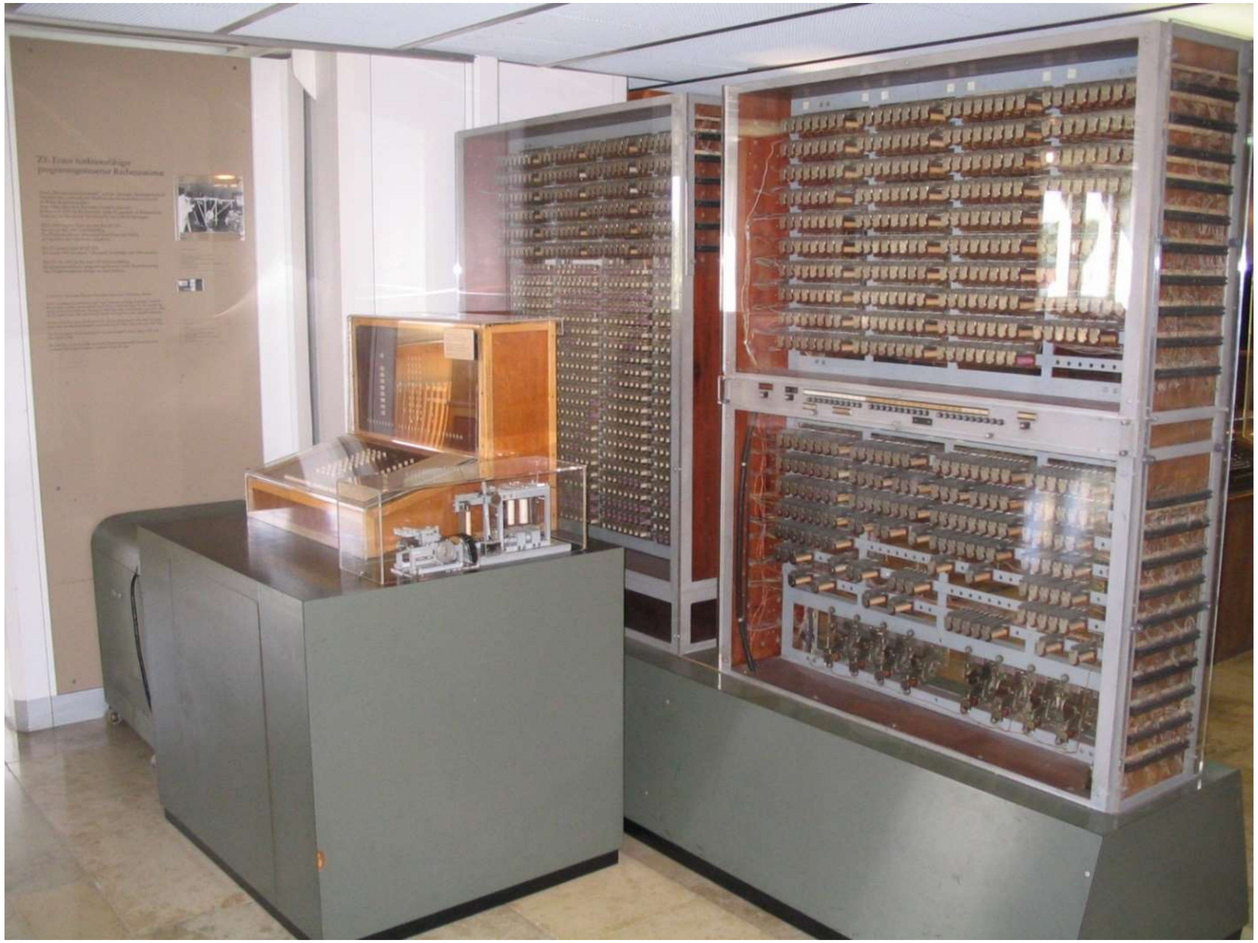
The Zuchongzhi Quantum Computer (July 2021)

China beats Google to claim the world's most powerful quantum computer. Solves a problem in around an hour that would take the world's most powerful supercomputers eight years to crack.

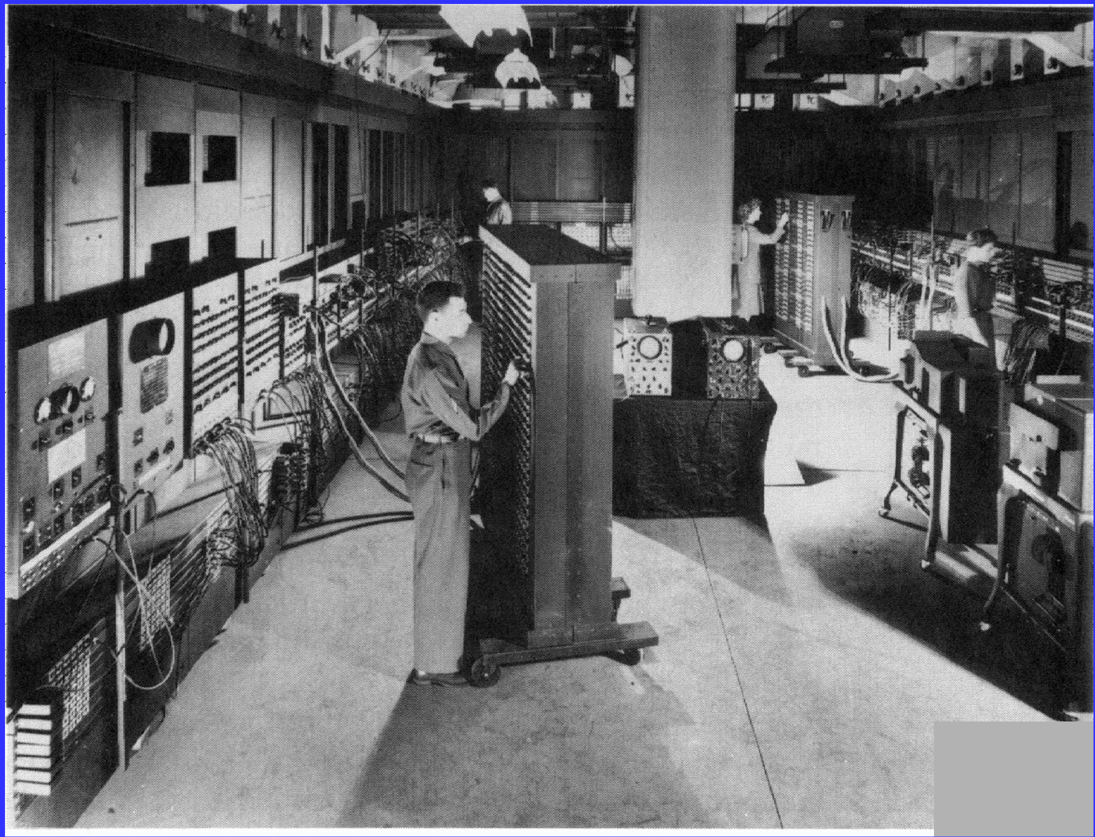
Read more:
https://www.newscientist.com/article/2282961-china-beats-google-to-claim-the-worlds-most-powerful-quantum-computer/#ixzz733bp4964

In 1941, Conrad Zuse built Z3, the first programmable computer in Germany.

Conrad Zuse
(1910-1995)



ENIAC - The First Electronic Computer (1943-1946)



Length = 80 ft

Height =8.5 ft

Floor area = 1500 sq ft

Weight = 30 tons

18000 vacuum tubes

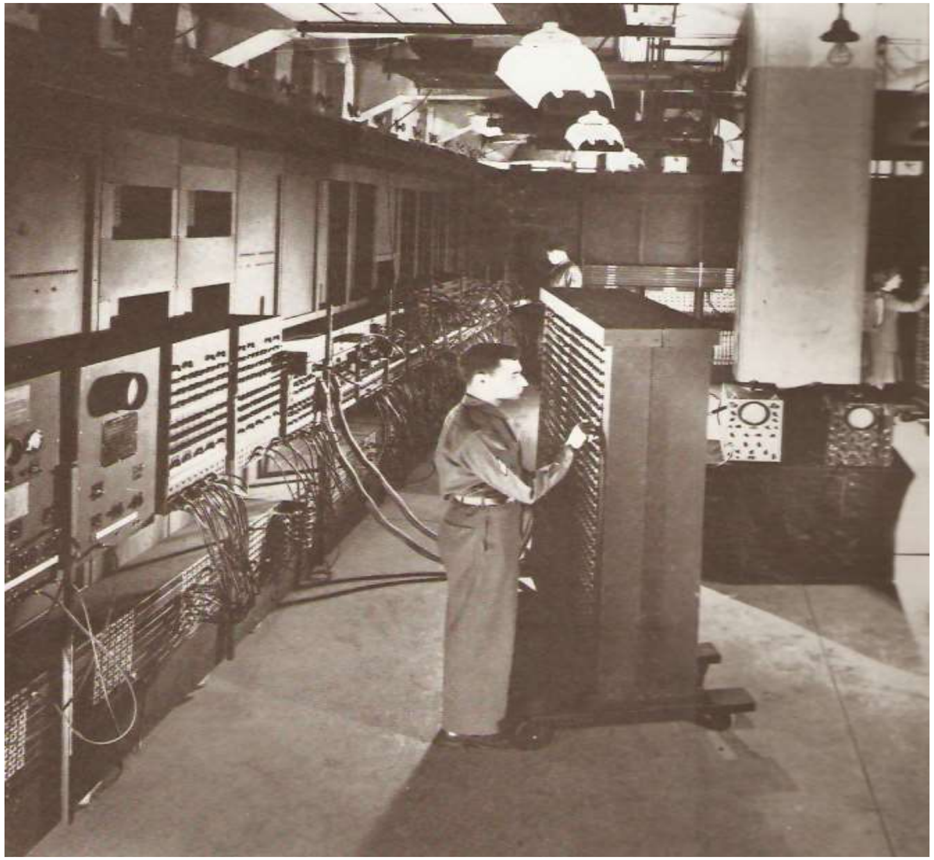
70,000 resistors

140 kw of power

John Mauchly (professor) and J. Presper Eckert (graduate student) built ENIAC at the University of Pennsylvania, Philadelphia

The Snapshots of ENIAC (1946)

This advertisement shows the amazing calculating powers of the ENIAC



A technician tracks down a misplaced cable in the ENIAC.

Courtesy: S. Augarten, Bit by Bit

First-Generation Computers

- Late 1940s and 1950s
- Stored-program computers
- Programmed in assembly language
- Used magnetic devices and earlier forms of memories
- Examples: IAS, ENIAC, EDVAC, UNIVAC, Mark I, IBM 701

Second Generation Computers

- 1955 to 1964
- Transistor replaced vacuum tubes
- Magnetic core memories
- Floating-point arithmetic
- High-level languages used: ALGOL, COBOL and FORTRAN
- System software: compilers, subroutine libraries, batch processing
- Example: IBM 7094

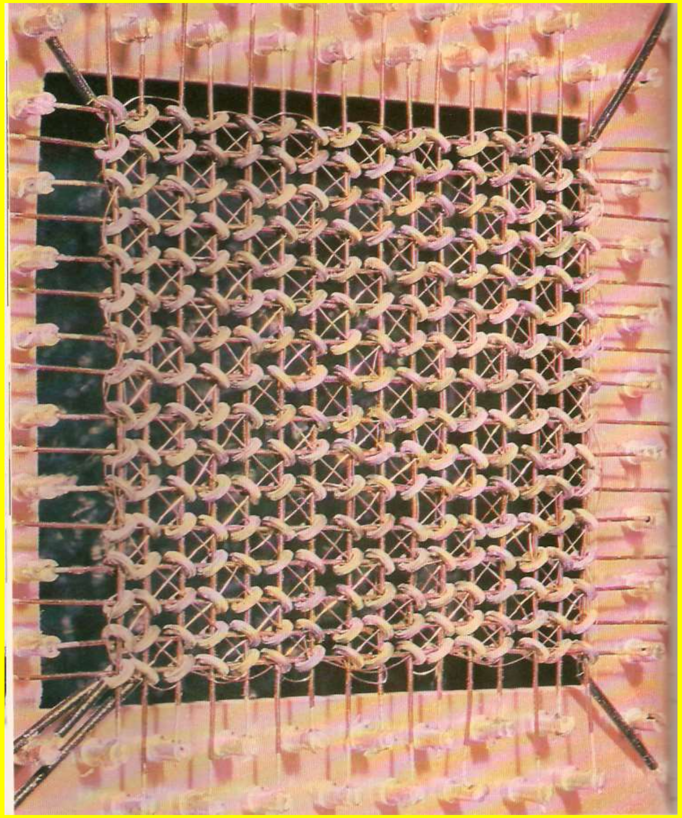
Third Generation Computers

- Beyond 1965
- Integrated circuit (IC) technology
- Semiconductor memories
- Memory hierarchy, virtual memories and caches
- Time-sharing
- Parallel processing and pipelining
- Microprogramming
- Examples: IBM 360 and 370, CYBER, ILLIAC IV, DEC PDP and VAX, Amdahl 470

The Miracle of Electronic Evolution

What is this??

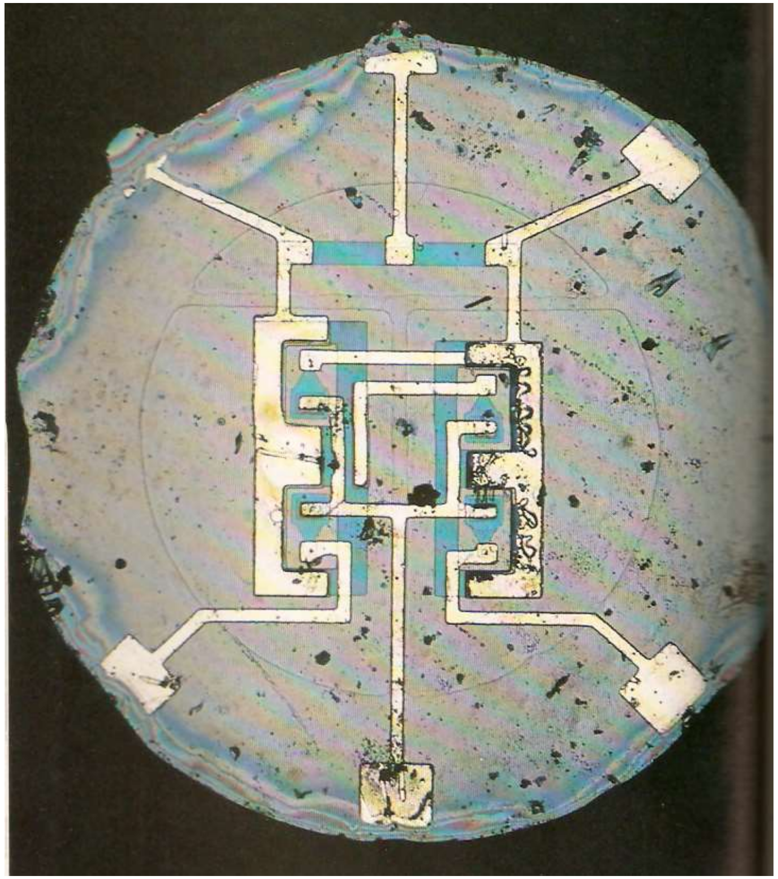
No, an early 1024-bit memory!



An early *one-bit* binary adder:
built on a kitchen table!

An electrical relay network??

The First Integrated Circuit

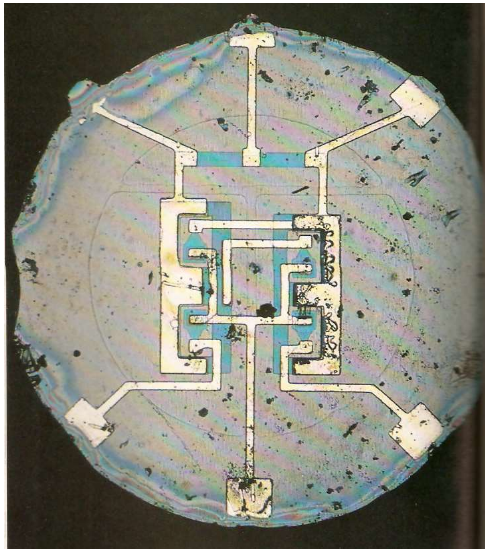


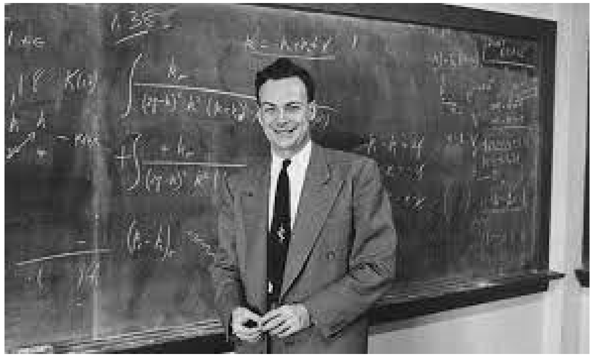
An early integrated circuit built by Fairchild Corporation in 1961. This is a logic IC with *two* flip flops, the *four* blue structures in the center are transistors, and the white lines are aluminum connecters.

"Scientists investigate that which already is; engineers create that which has never been." - *Albert Einstein*

The Miracle of Integration

An early integrated circuit (1961)





"Why can't we write the entire 24 volumes of the *Encyclopedia Britannica* on the head of a pin?" -- *Richard Feynman* (1959)

Hardware Design Creating History ……

Andy Grove, Robert Noyce, and Gordon Moore (1978)

Intel Founders

Entering the World of Microprocessors

Intel's first advertisement for the 4004 microprocessor that appeared in November 1971.

Evolution of Electronic Technology

"*Student*: Dr. Einstein, Aren't these the same question as last year's [physics] final exam?

Dr. Einstein: Yes; but this year, the answers are different." --

-- *Albert Einstein*

Evolution of Microprocessors

1970: 4004 µP

#T = 2300
Auditorium

1982: 286 µP

#T = 1,34,000
Stadium

1999: Pent III

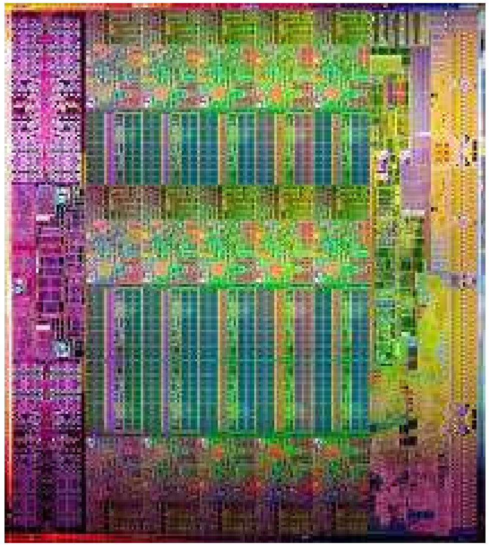
#T = 32 million
Population of
Tokyo

2008: Core i7

#T = 1.3 billion
Population of India

Number of transistors (#T)

Modern Processors



Intel 15-Core Xeon Ivy Bridge-Ex (2014)

22 *nm* technology

4.3 billion transistors

Die size ~600 mm^2

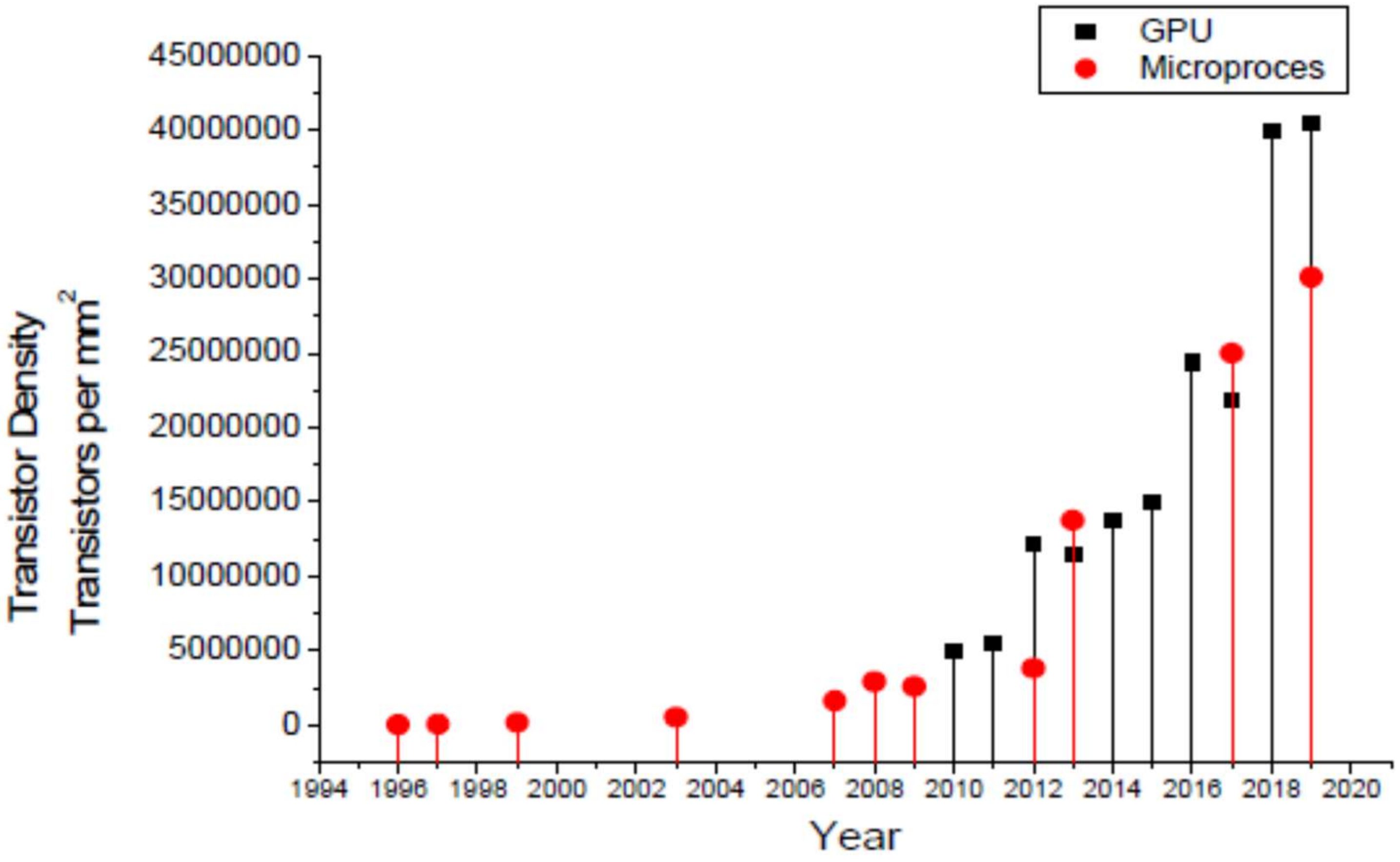
AMD Ryzen 9 5900X processor (2021); ~ 4 billion Transistors

Intel Broadwell EP Xeon SoC (2016) – 7.2 billion T; 14 *nm*

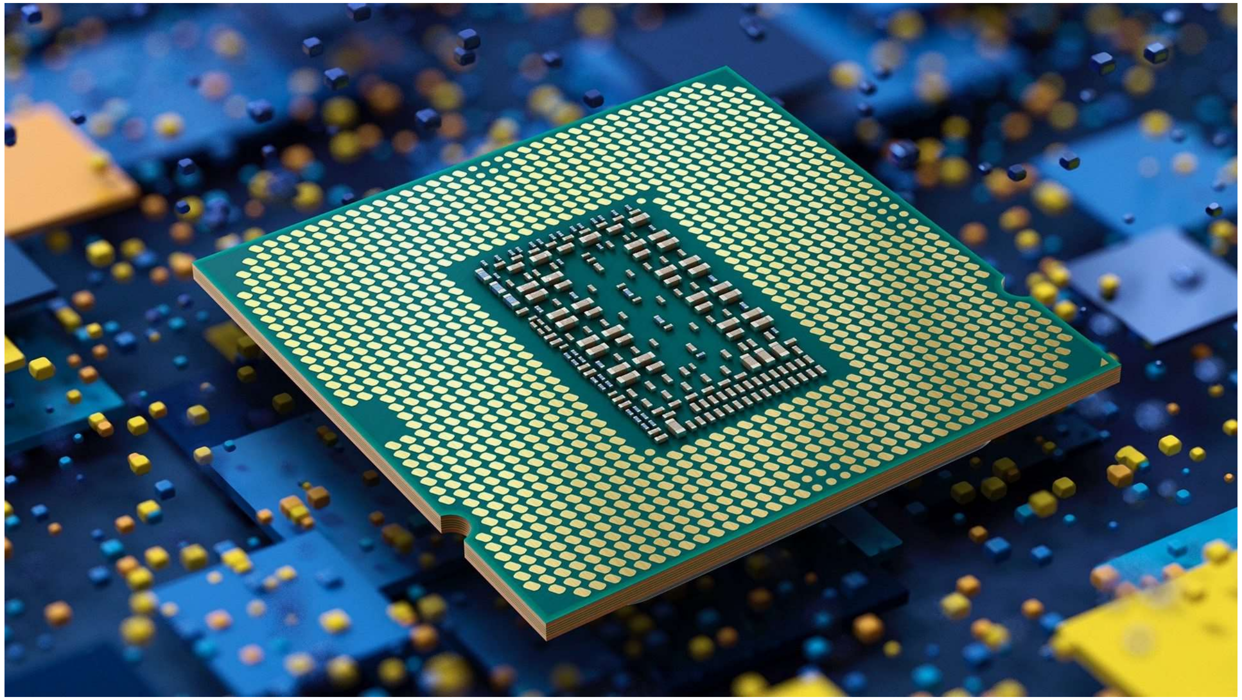
IBM Deep Blue defeated Grand Master Garry Kasparov in May 1997

"Any sufficiently developed technology is indistinguishable from magic"
– *Arthur C. Clarke* (1962)

Transistor density in AMD Processors



Intel's 7*nm* PC Chip Will Arrive in 2023 Using TSMC's Technology



Meteor Lake (for PC) and Granite Rapids (for Data Centers)
Technology: 7 *nm*; Stacking *compute tiles* one over another that include the CPU, graphics, and AI-focused processors
~ 200 million transistors per square *mm* of the chip!

Gordon Moore: 1965

Progress in computer technology underpinned by Moore’s Law

- Predicted that the number of transistors integrated on a die would grow exponentially (doubling every 12 to 18 months)
- Million transistors/chip barrier crossed in the 1980s
- Today:

  Around several billion transistors per chip

Transistor Count in a Chip

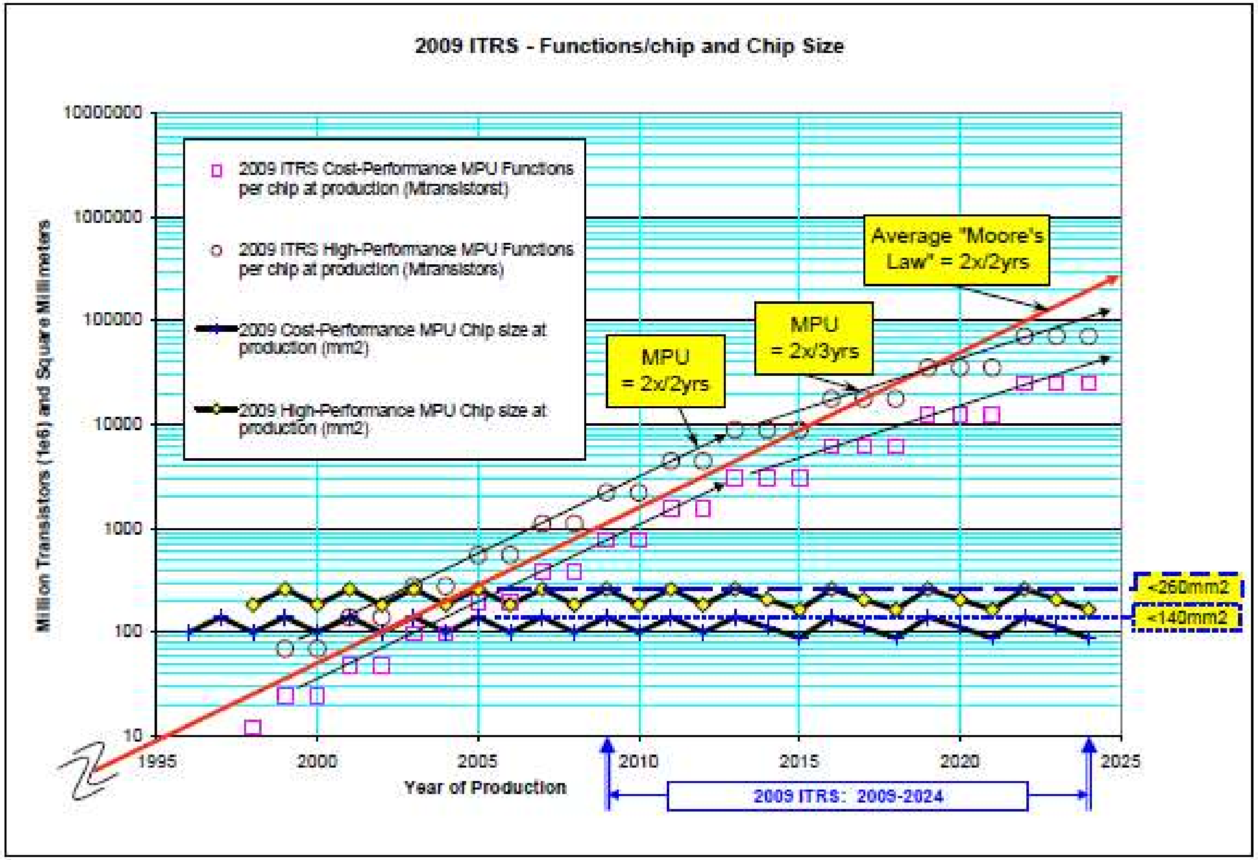
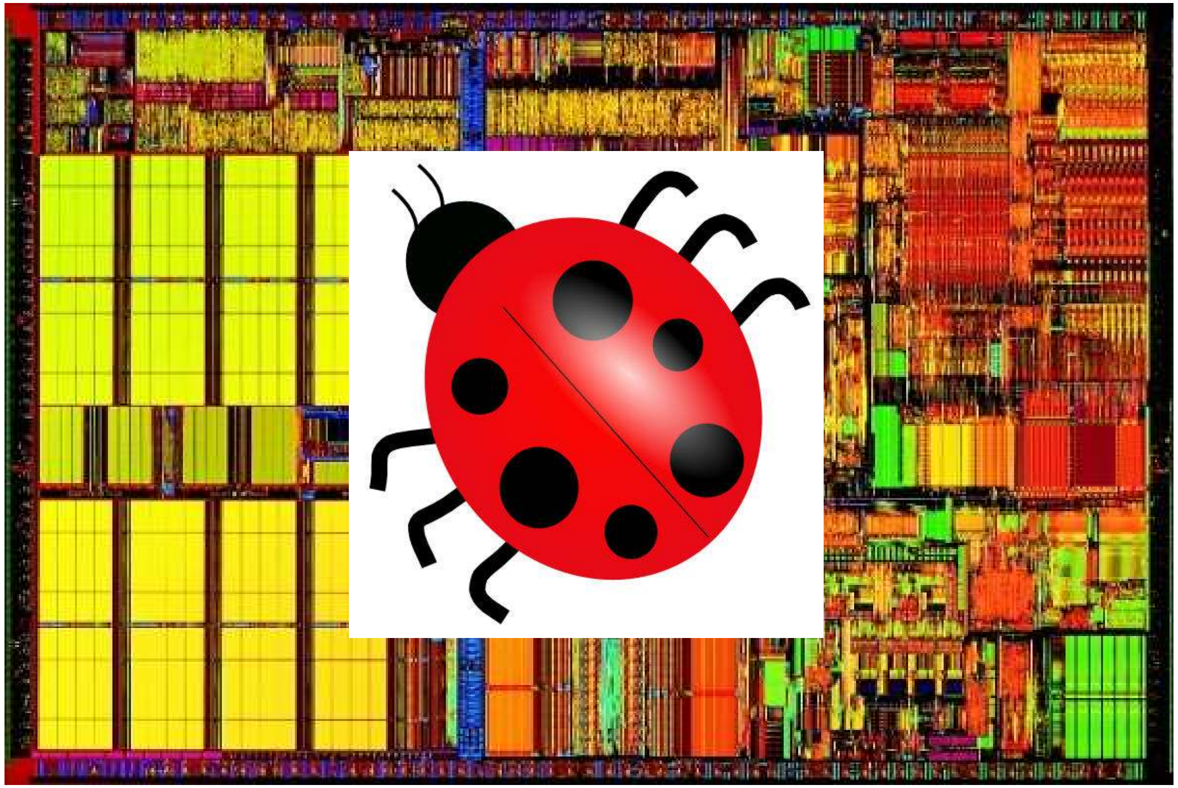


Figure 7b 2009 ITRS Product Technology Trends:
MPU Product Functions/Chip and Industry Average "Moore's Law" and Chip Size Trends

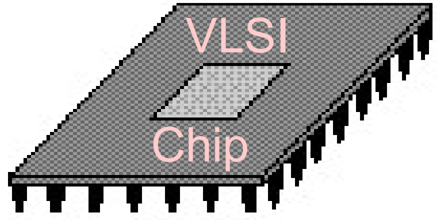
Courtesy: ITRS 2010

Today's processors encapsulate billions of transistors



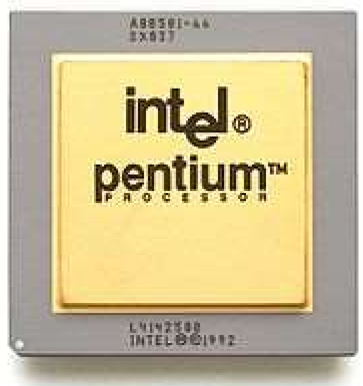
Design bugs/manufacturing defects/
field malfunctioning/aging

Reliability of Hardware Design (managing defects/hazards/errors)



US Airways jet crash landed in the Hudson river on January 16, 2009

Example: Intel Pentium Bug (1994)



66 MHz Intel Pentium

- The FDIV-bug (in floating-point division unit) was discovered in 1994 by Prof. Thomas R. Nicely at Lynchburg College, USA
- 4 to 5 million Pentium chips produced with bug
- Scientists suspected errors and posted on the Internet in September 1994
- On Nov. 22, 1994, Intel made Press release: “Can make errors in 9th digit ....”

Courtesy: D. A. Patterson and J. L. Hennessy, *Computer Organization and Design*, Morgan Kaufmann

Pentium Conclusion: Dec. 21, 1994
$ 500M write-off

"To owners of Pentium processor-based computers and the PC community:

We at Intel wish to sincerely apologize for our handling of the recently publicized Pentium processor flaw.

Intel will exchange the current version of the Pentium processor for an updated version, in which this floating-point divide flaw is corrected, for any owner who requests it, free of charge anytime during the life of their computer. Just call 1-800-628-8686."

Sincerely,

Andrew S. Grove   Craig R. Barrett   Gordon E. Moore

Computers of the Future …

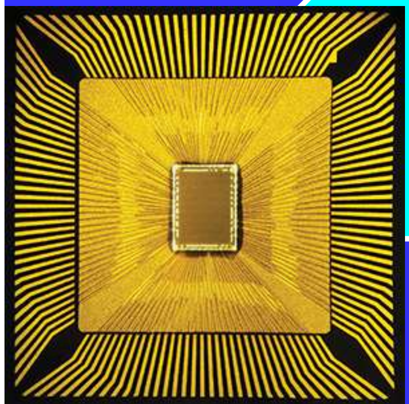
Computers – Present and Future

- Personal computers
- Laptops and Palmtops
- Networking, wireless, IoT
- SOC and MEMS technology
- Future generations
  - Biological computing
  - Neuromorphic computing
  - Molecular computing
  - Nanotechnology – Carbon Nano-tube (CNT) based CPU
  - Optical computing
  - Quantum computing

Neuromorphic Chips

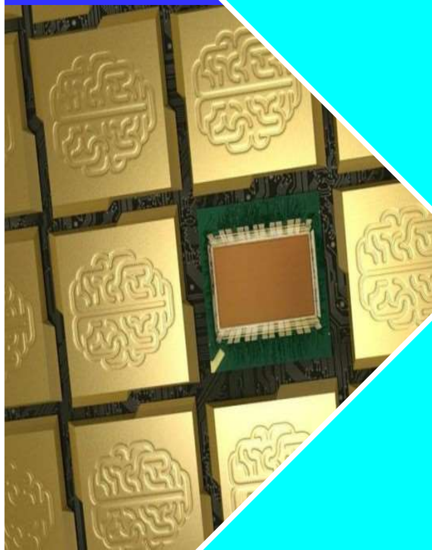
Bridging the gap between artificial and natural computation

Advances in neuroscience and chip technology now enable to process data in a similar way like brain. These “neuromorphic” chips will play chess, drive cars reliably in all conditions, and empower smartphones to act as personal assistants.



Neuromorphic Chips

Bridging the gap between artificial and natural computation



IBM TrueNorth
cores, which r
human neuron
synapses, two
biological build
up the h

This IBM chip
patterns of puls
to one of t
neuroscientis
stores i

SyNAPSE (Systems of Neur
Scalable Electronics) project

Recognizes people, cyclists, cars, buses, and trucks with about 80 percent accuracy.

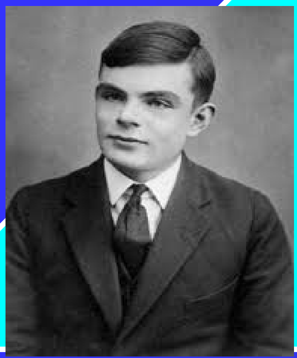
Do not separate processor & memory

Burns only 63 mW of power to process streaming video with 30 frames per sec.

Google, IBM Announce Quantum Computers (2015 - 2019)

These processors will work on sub-atomic levels based on the principles of quantum mechanics making them much faster

Technology could one day lead to intelligent machines that are capable of thinking



Alan Turing (1912-1954)

Can machines think?

China announces a very powerful QC in 2021

Computing System Hierarchy