CS 31007 Autumn 2019

COMPUTER ORGANIZATION AND ARCHITECTURE

Instructors

Section I - Rajat Subhra Chakraborty
Class Room NR 423

Section II - Bhargab B. Bhattacharya
Class Room NR 124

Indian Institute of Technology Kharagpur
Computer Science and Engineering

Today's 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

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COMPUTER ORGANIZATION AND ARCHITECTURE

Class Schedule

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

Tutorial class will be held on **every Thursday**

Lab Course (39001): Computer Organization Laboratory

Prerequisites

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

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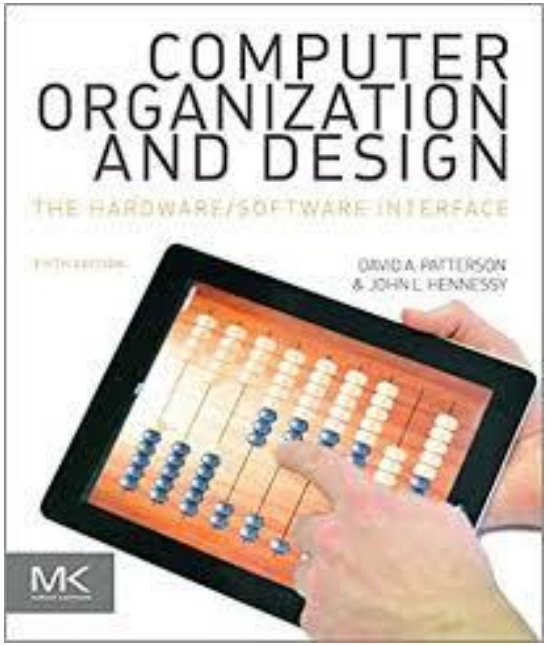
Prerequisites

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

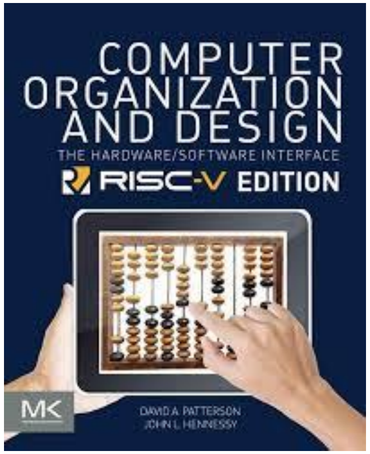
Announcement

Pre-Requisite In-Class Quiz: Monday, **22 July 2019**
12:00-12:55 (Open-Book, Open-Notes)

Textbook



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



RISC-V Edition 2018

Second Edition 1998

2017 ACM Turing Award

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.

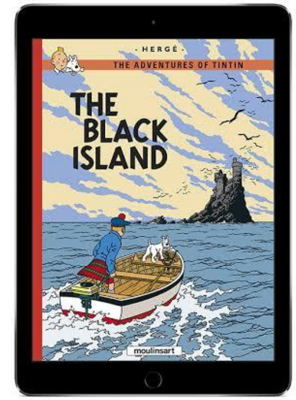
Grading Policy

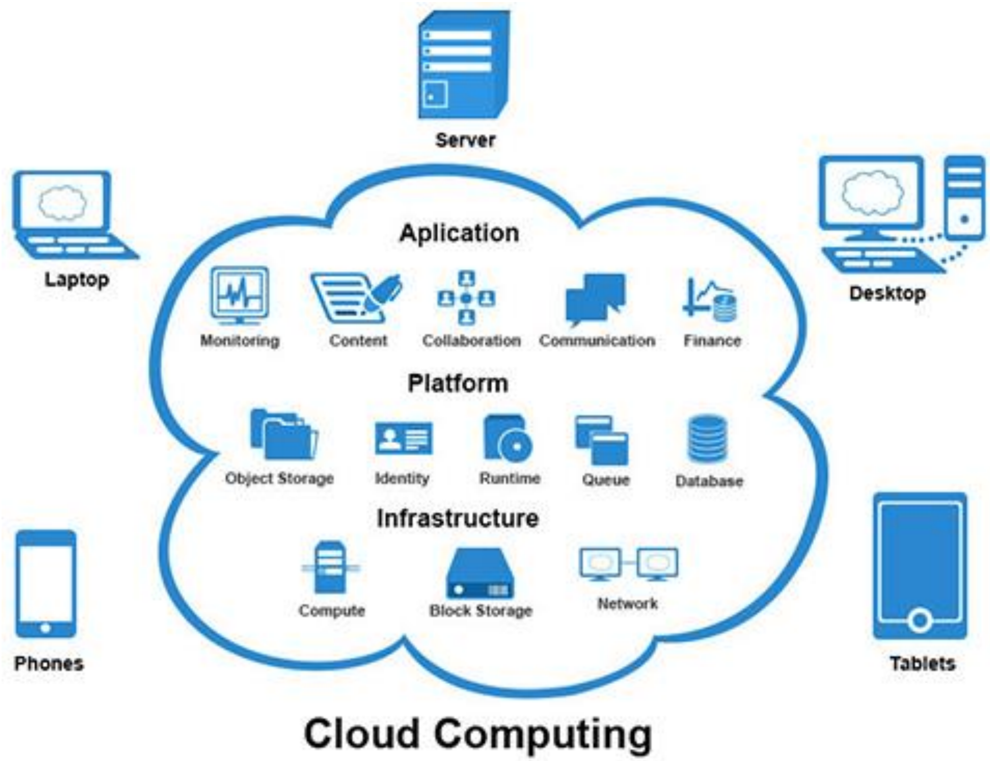
- Homework and Quiz for practicing
- In-Class Quiz on Tutorial Days: 10% (=5 × 2)
- Class-Test 1 and Class-Test 2: 10% (=2 × 5)
- Mid-Sem Exam (2 hour): 30%; 16-24 Sept. 2019
- End-Sem Exam (3 hour): 50%; 18-27 November 2019

Goal is to understand ….

- What are the principles of computer design?
- What is the hardware-software interface?
- What is computer organization and 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 a complete processor is designed?

What is a Computer ?





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 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

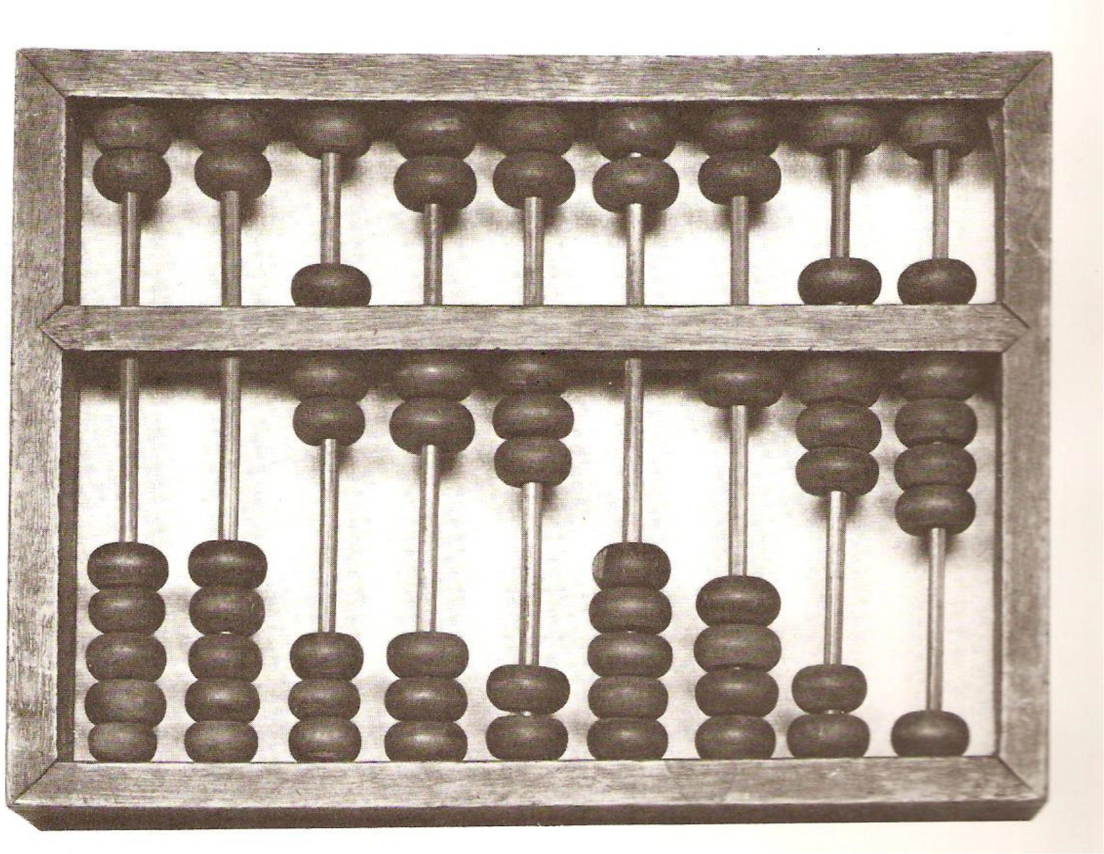
Classes of Computers

- 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
  - Stringent power/performance/cost constraints

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

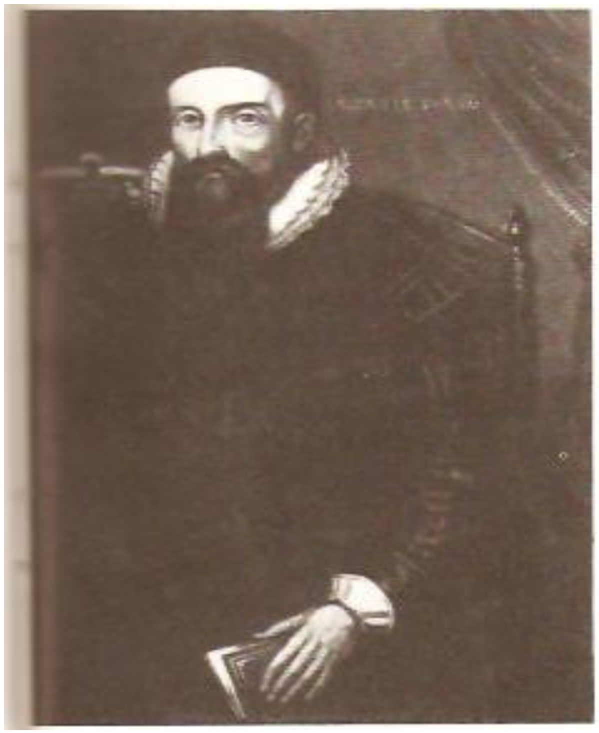
However, centuries ago, by a computer was meant …

The First Mechanical Computing Device



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

First Steps in Computing



MIRIFICI

Logarithmorum

Canonis descriptio,

Ejusque usus, in utraque

Trigonometria, ut etiam in

omni Logistica Mathematica,

Authore ac Inventore,

IOANNE NEPERO,

Barone Merchistonii,

&c. Scoto.

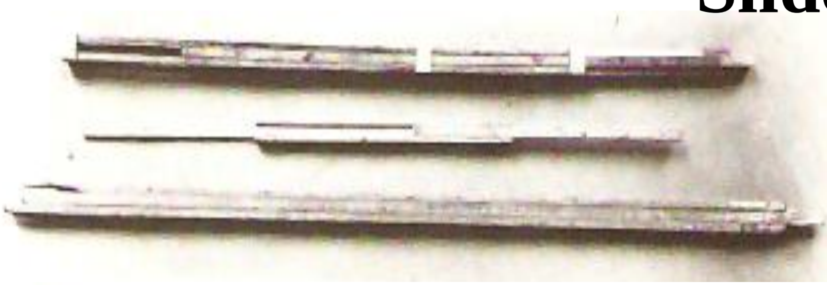
EDINBURGI,

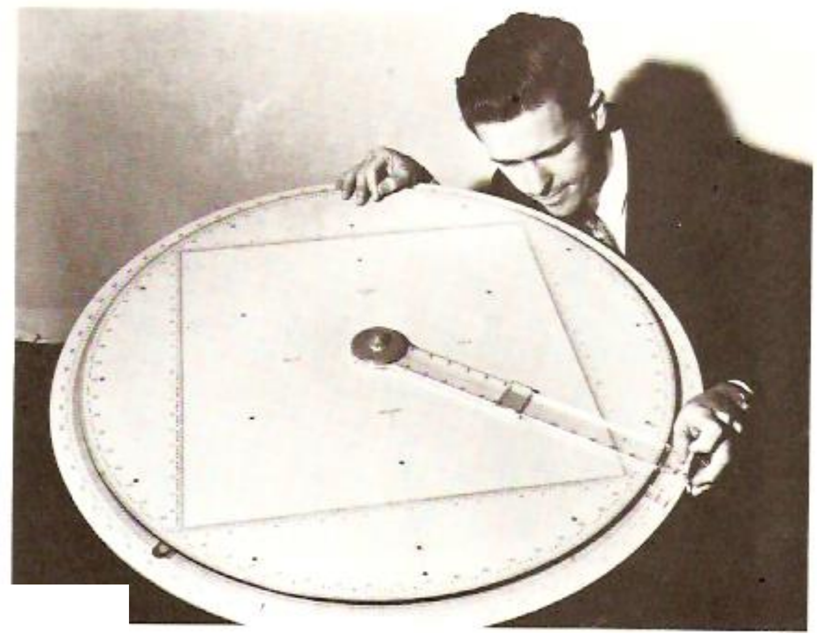
Ex officina ANDREÆ HART

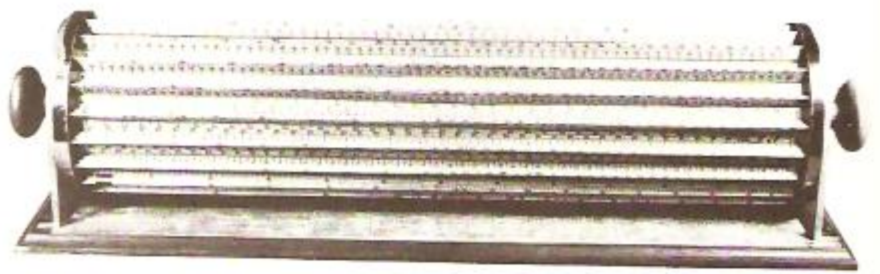
John Napier (1550-1617)

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

Slide Rule

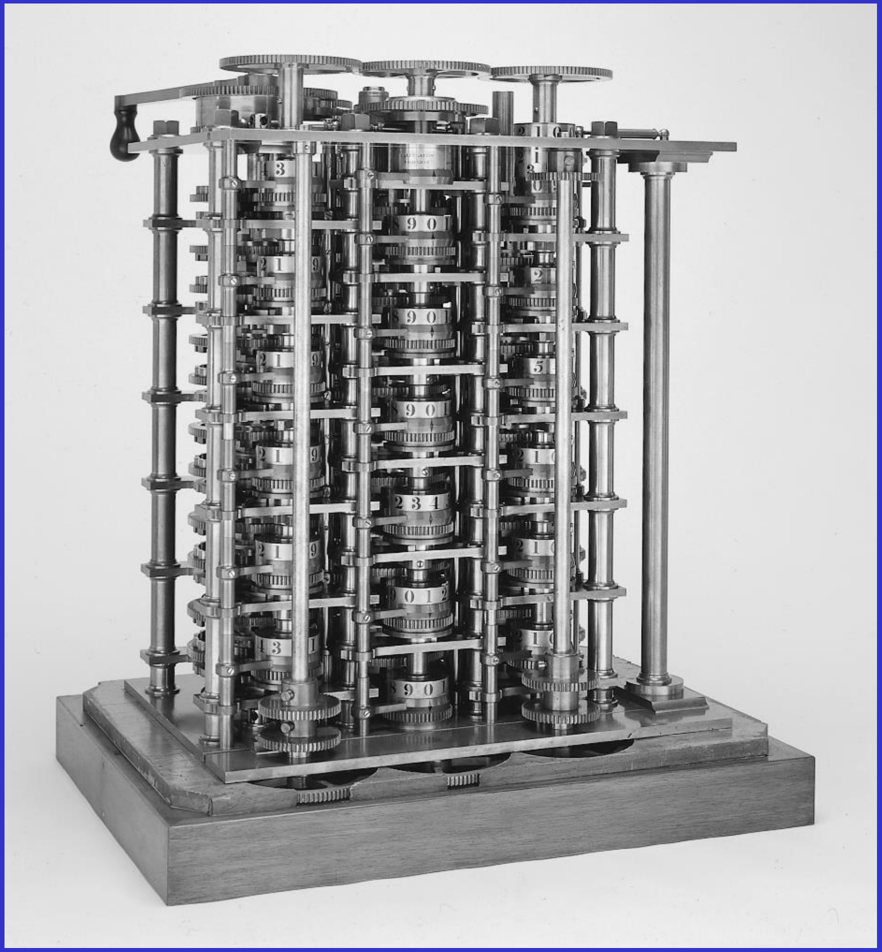






The first slide rule (top left) was made in 1654; the cylindrical slide rule (below left) and circular slide rules are useful modifications that were used for various computations; Slide rule (left-bottom) used by early generation of engineers.

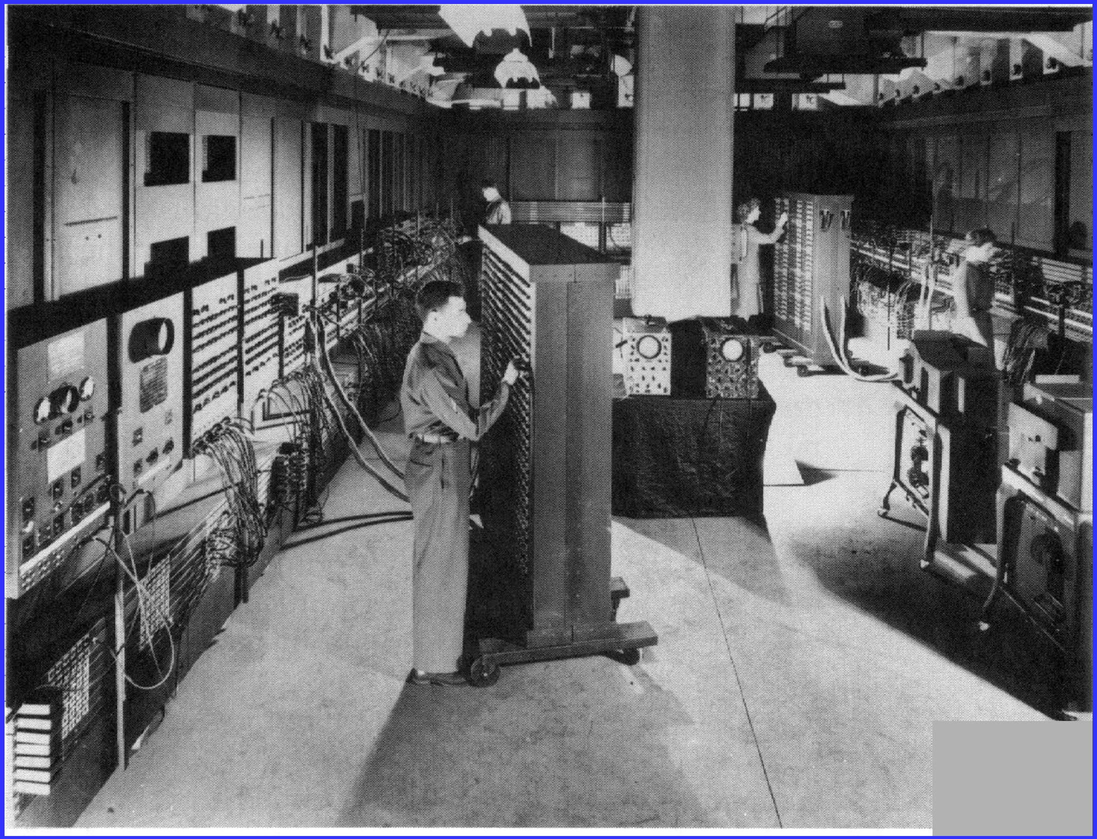
The First Computer (1832)



Babbage Difference Engine

25000 parts

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

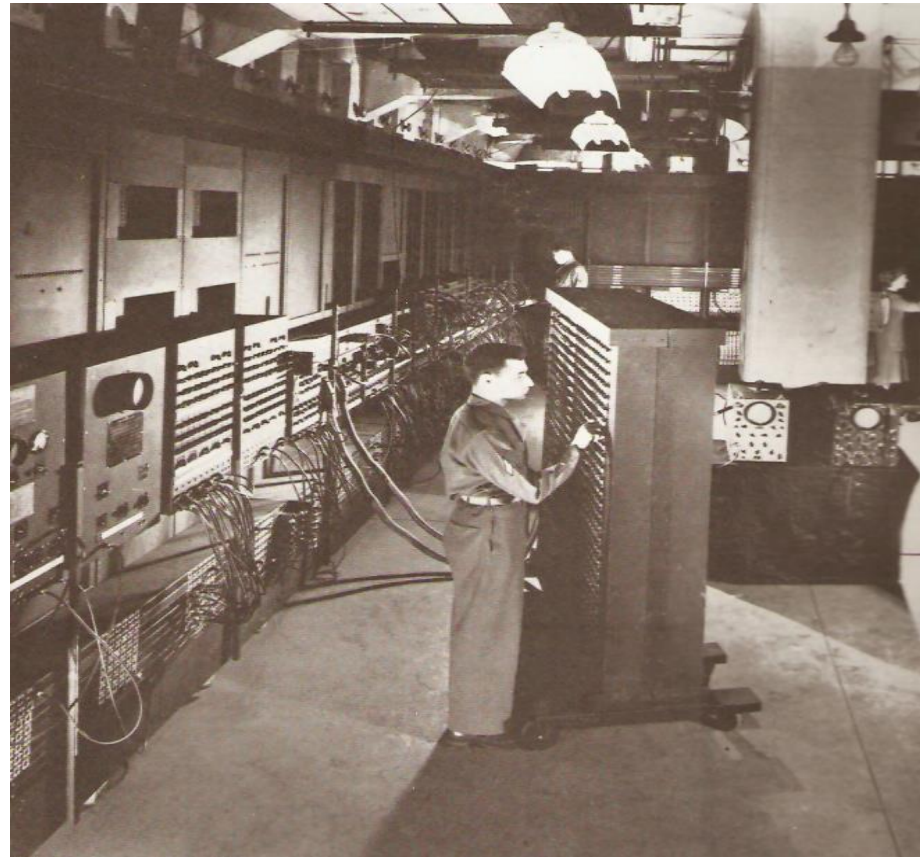
70,000 resistors

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



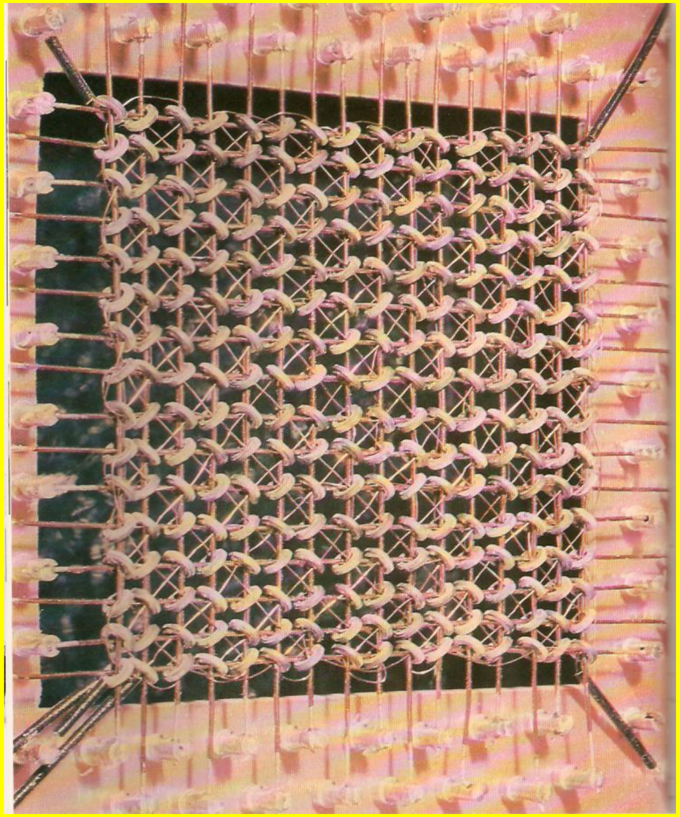
A technician tracks down a misplaced cable in the ENIAC.

Courtesy: S. Augarten, Bit by Bit

The Miracle of Electronic Evolution

Battery??

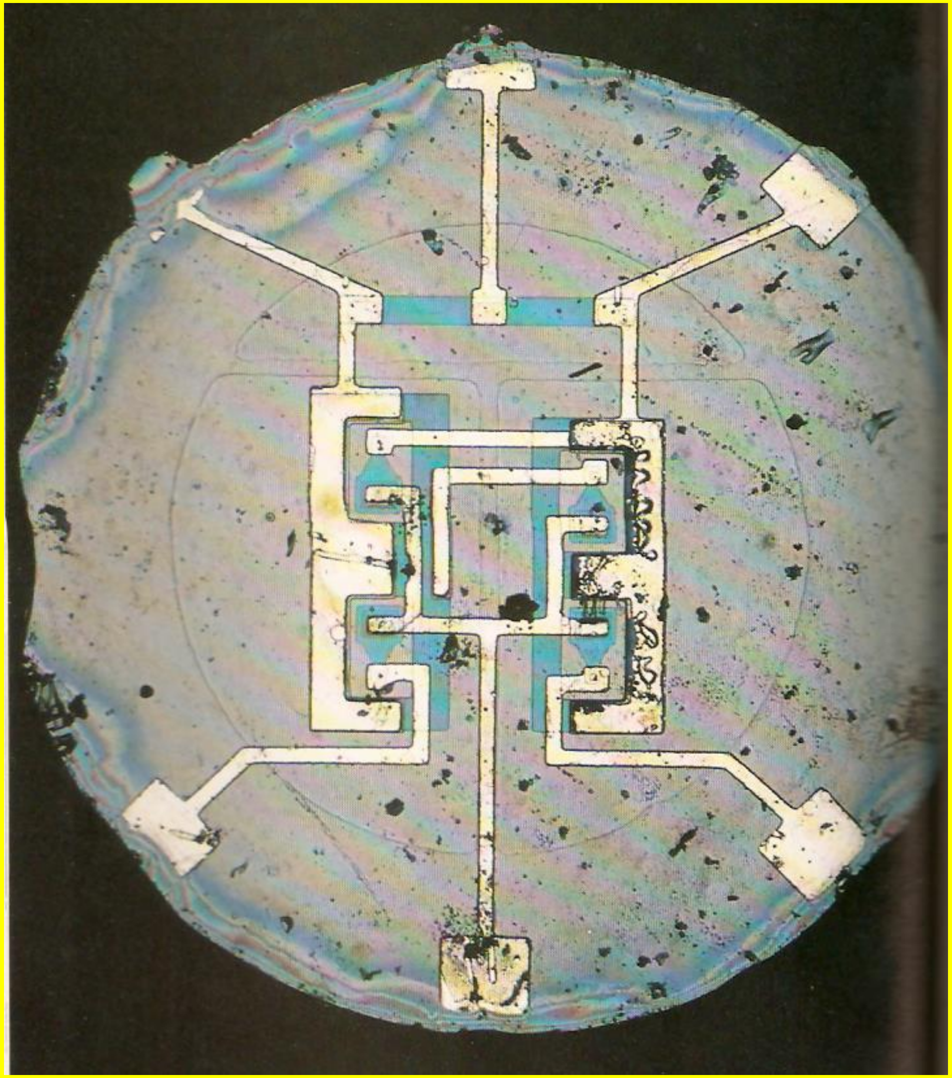
No, an early 1024-bit memory!



No, an early binary adder: built on a kitchen table!

An electrical relay network??

The First Integrated Circuit



An early integrated circuit made by Fairchild Corporation in 1961. This is a logic IC with two flip flops, the 4 blue structures in the center are transistors, and the white lines are aluminum connecters.

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 Microprocessors

1970: 4004 µP

#T = 2300
Auditorium

1982: 286 µP

#T = 1,34,000
Stadium

1999: Pent III

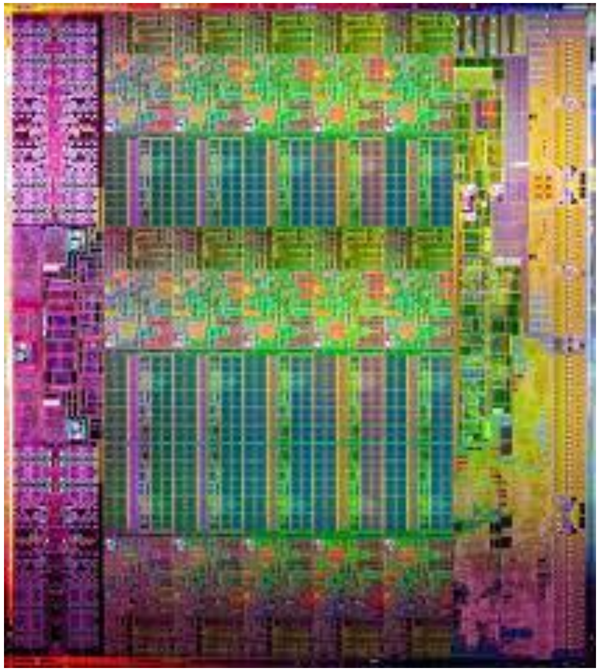
#T = 32 million
Population of
Tokyo

2008: Core i7

#T = 1.3 billion
Population of China

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

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

IBM Deep Blue defeated Grand Master Garry Kasparov in May 1997

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

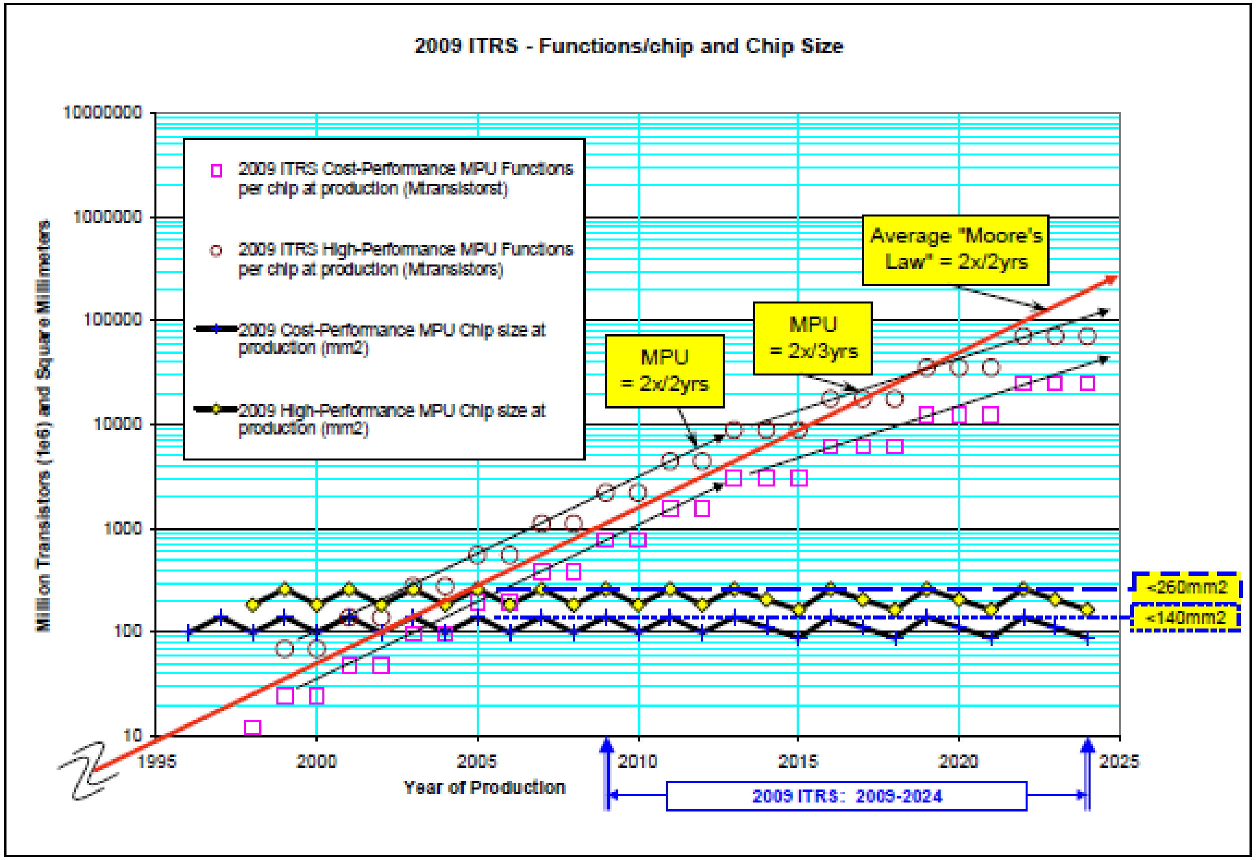
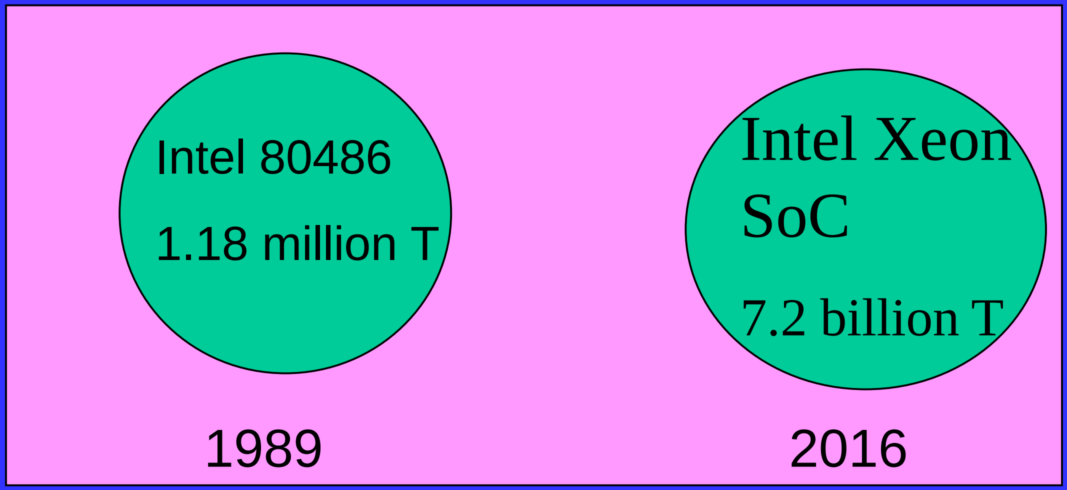
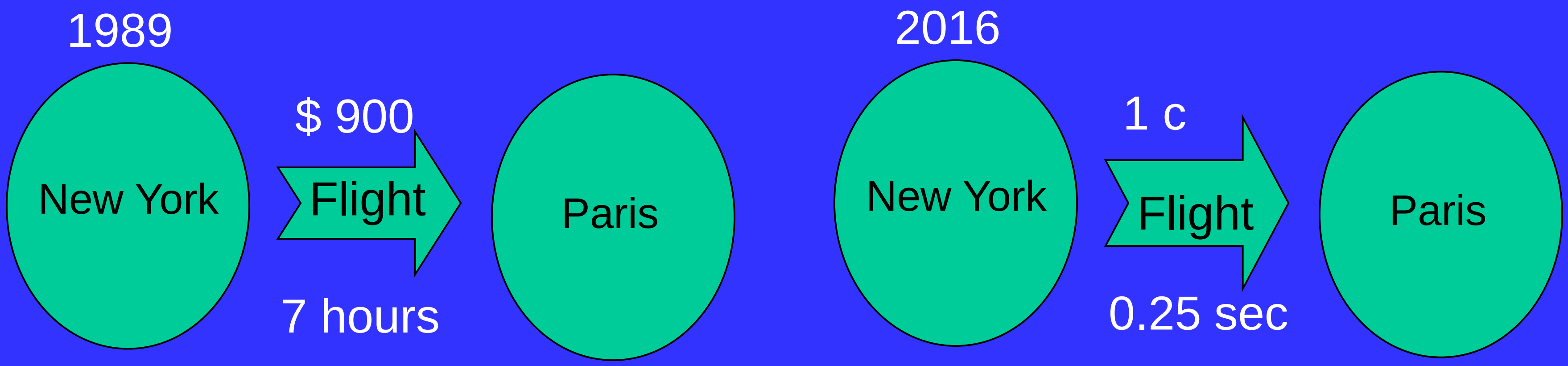


Figure 7b 2009 ITRS Product Technology Trends:
MPU Product Functions/Chip and Industry Average "Moore's Law" and Chip Size Trends

Courtesy: ITRS 2010

Example: Moore's Law



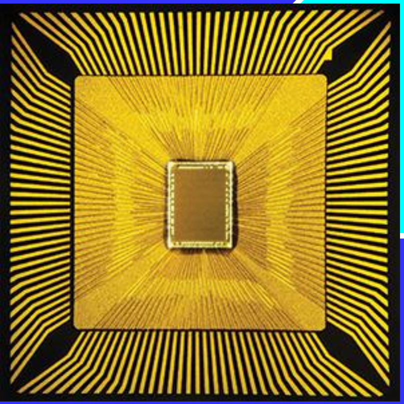


Computers of the Future …

Neuromorphic Chips

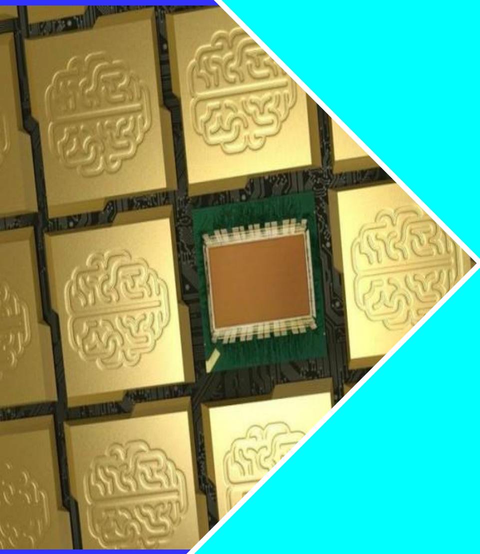
bridging the gap between artificial and natural computation

n 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
human neuro
synapses, two
biological build
up the h

This IBM chip
patterns of puls
to one of t
neuroscienti
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

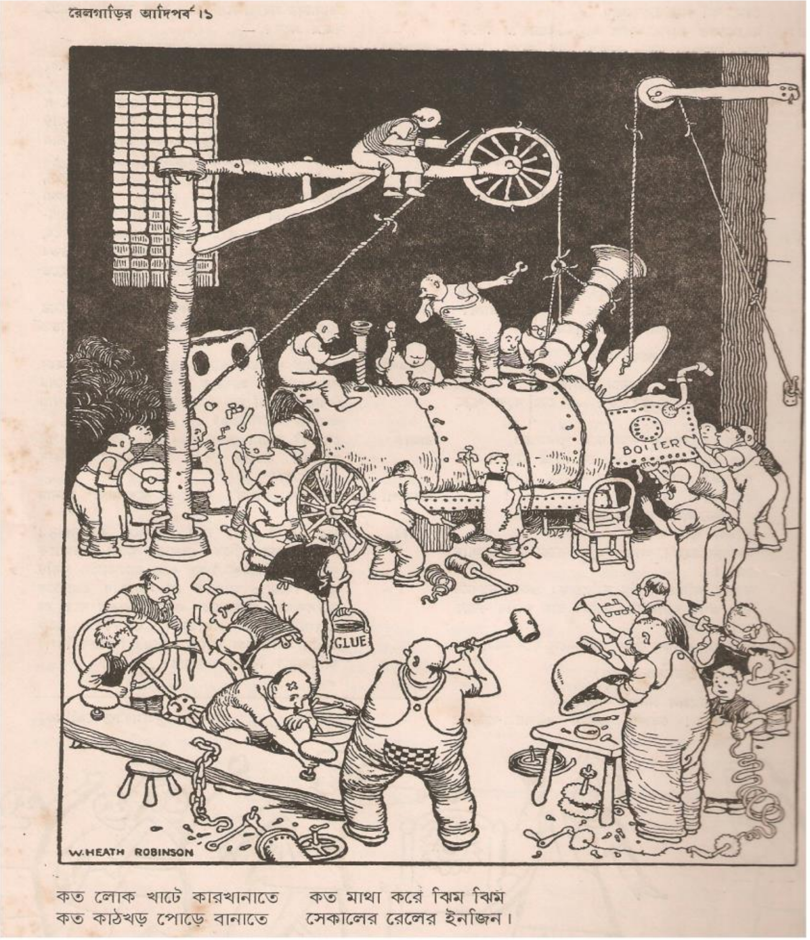
Burns only 63 mW of power to process streaming video with 30 frames per sec.

Google and 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 machines able to think for themselves

Building a Computer System ……

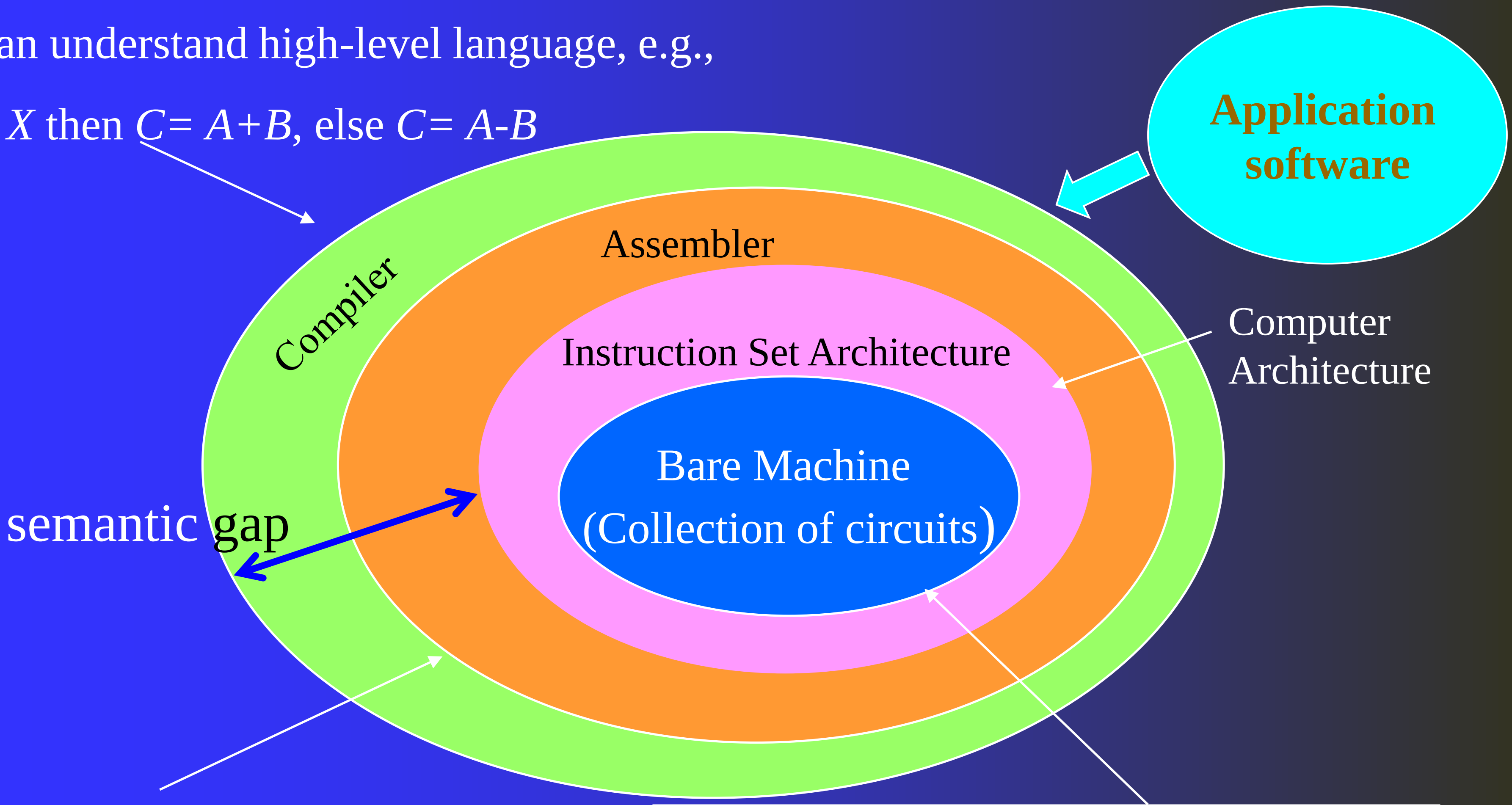


Courtesy: Satyajit Ray

Computing System Hierarchy

Can understand high-level language, e.g.,

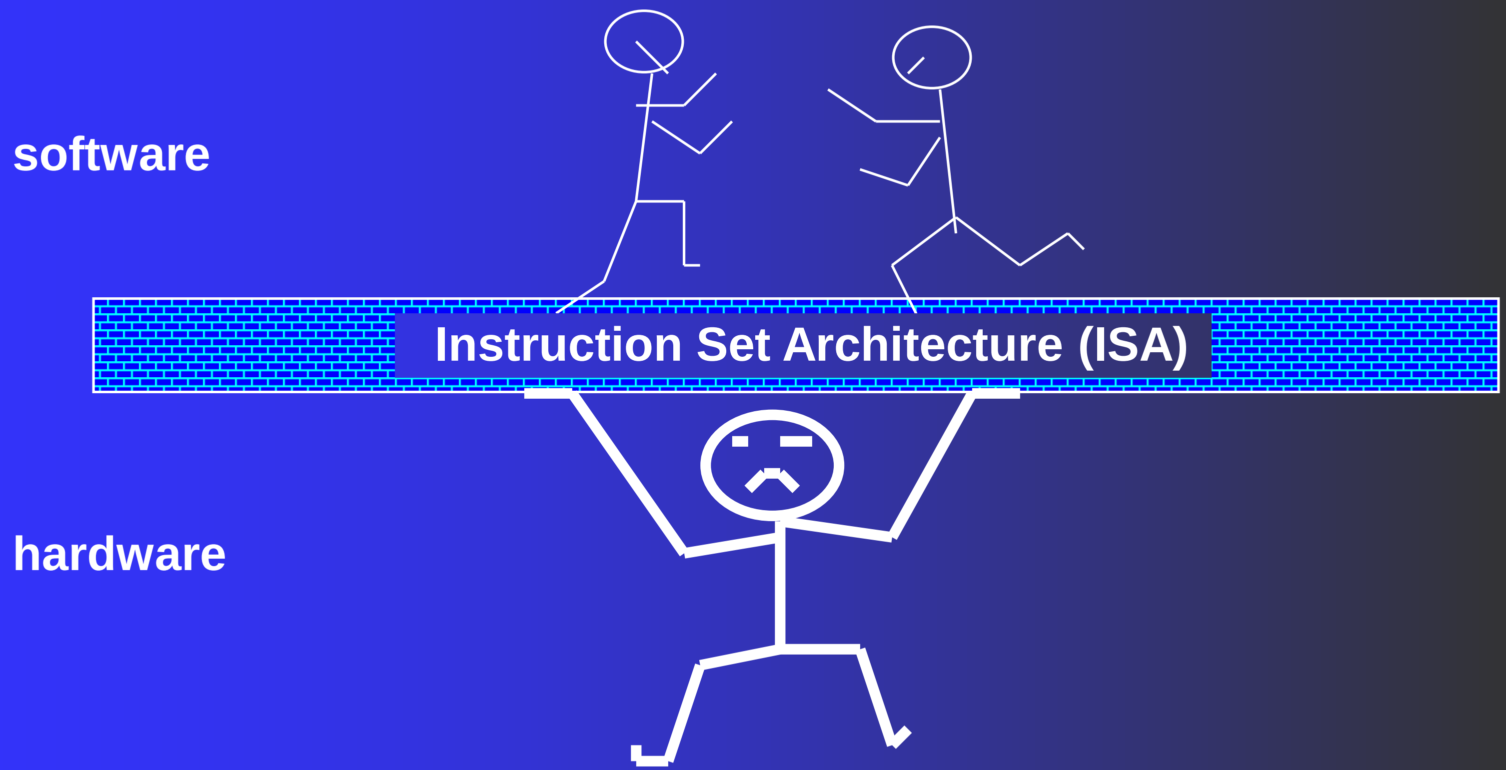
If *X* then *C*= *A*+*B*, else *C*= *A*-*B*



Can understand symbolic assembly language, e.g., add *C*, *A*, *B*

can understand only machine language – binary strings of 0's and 1's, (0101001100..) i.e., electrical *off* and *on* signals (Computer Organization)

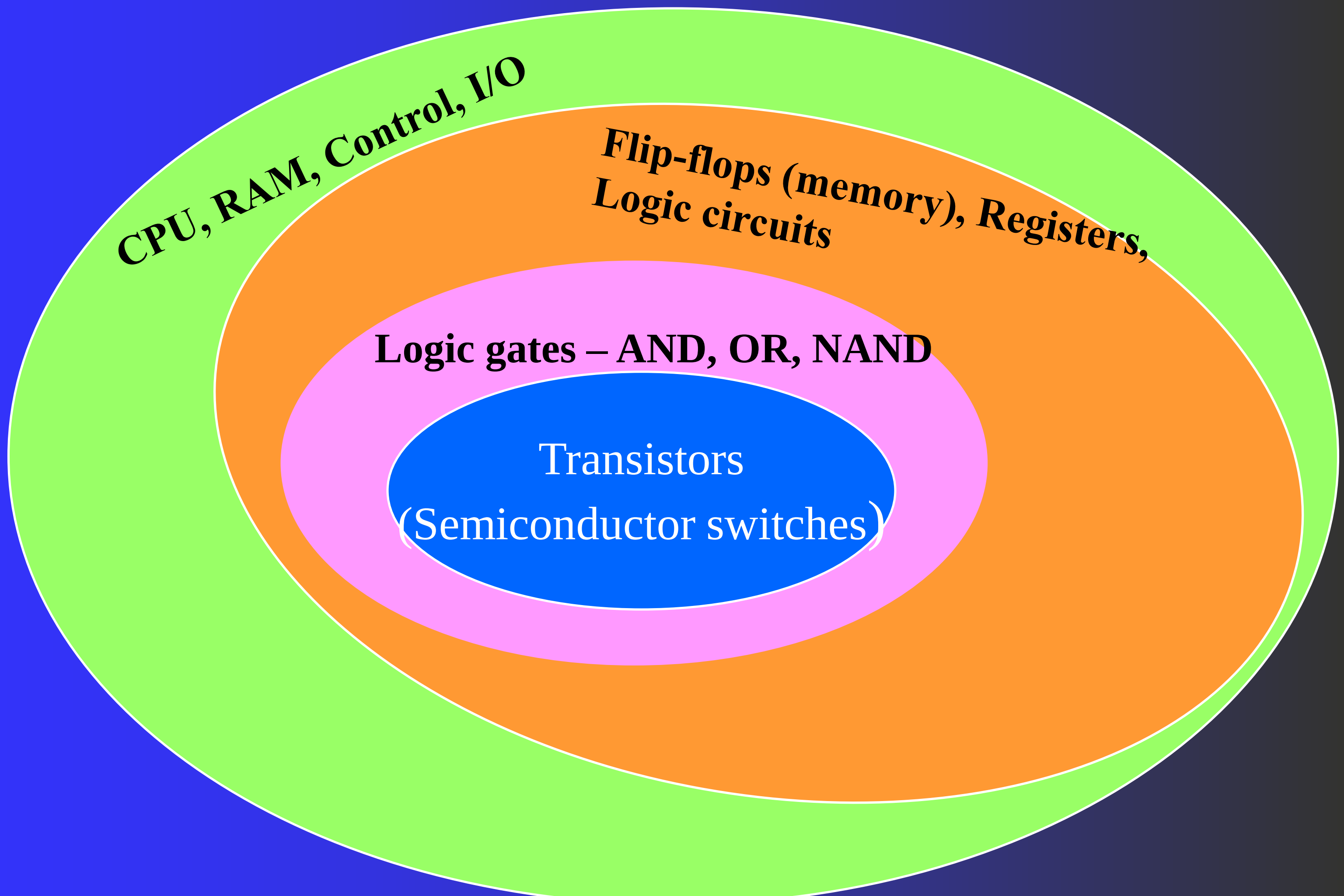
Hardware-Software Interface



ISA: Collective attributes of the machine-language instruction set

Courtesy: Patterson and Hennessy

Hardware Hierarchy



How a program is executed by a computer

Compiler →

Assembler →

Application software, a program in C:

```
swap (int  v[ ], int  k)
{int  temp;
        temp = v[k];
        v[k] = v[k+1];
        v[k+1] = temp;
}
```

Compiler translates it to assembly language program of the target machine

```
swap;
        muli    $2,     $5, 4
        add     $2,     $4, $2
        lw      $15,     0 ($2)
        lw      $16,     4 ($2)
        sw      $16,     0 ($2)
        sw      $15,     4 ($2)
        jr      $31
```

binary machine code

```
00000000101000010000000000011000
00000000000110000001100000100001
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
00000011111000000000000000001000
```

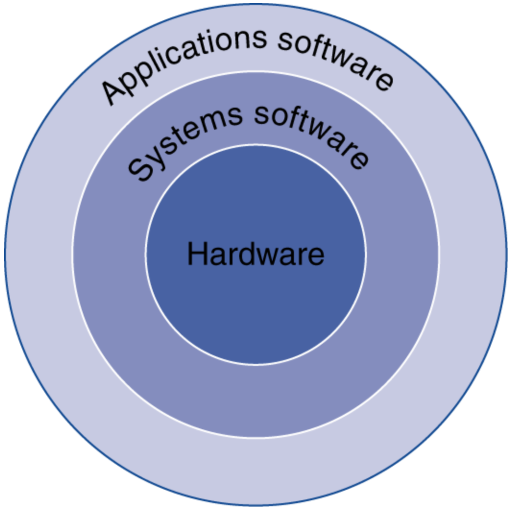
↓

Hardware

↓

output

Below Your Program



- Application software
  - Written in high-level language
- System software
  - Compiler: translates HLL code to machine code
  - Operating System: service code
    - Handling input/output
    - Managing memory and storage
    - Scheduling tasks & sharing resources
- Hardware
  - Processor, memory, I/O controllers

Levels of Program Code

- High-level language
  - Level of abstraction closer to problem domain
  - Provides for productivity and portability
- Assembly language
  - Textual representation of machine instructions
- Hardware representation
  - Binary digits (bits)
  - Encoded instructions and data

High-level language program (in C)

```
swap(int v[], int k)
{int temp;
   temp = v[k];
   v[k] = v[k+1];
   v[k+1] = temp;
}
```

Compiler

Assembly language program (for MIPS)

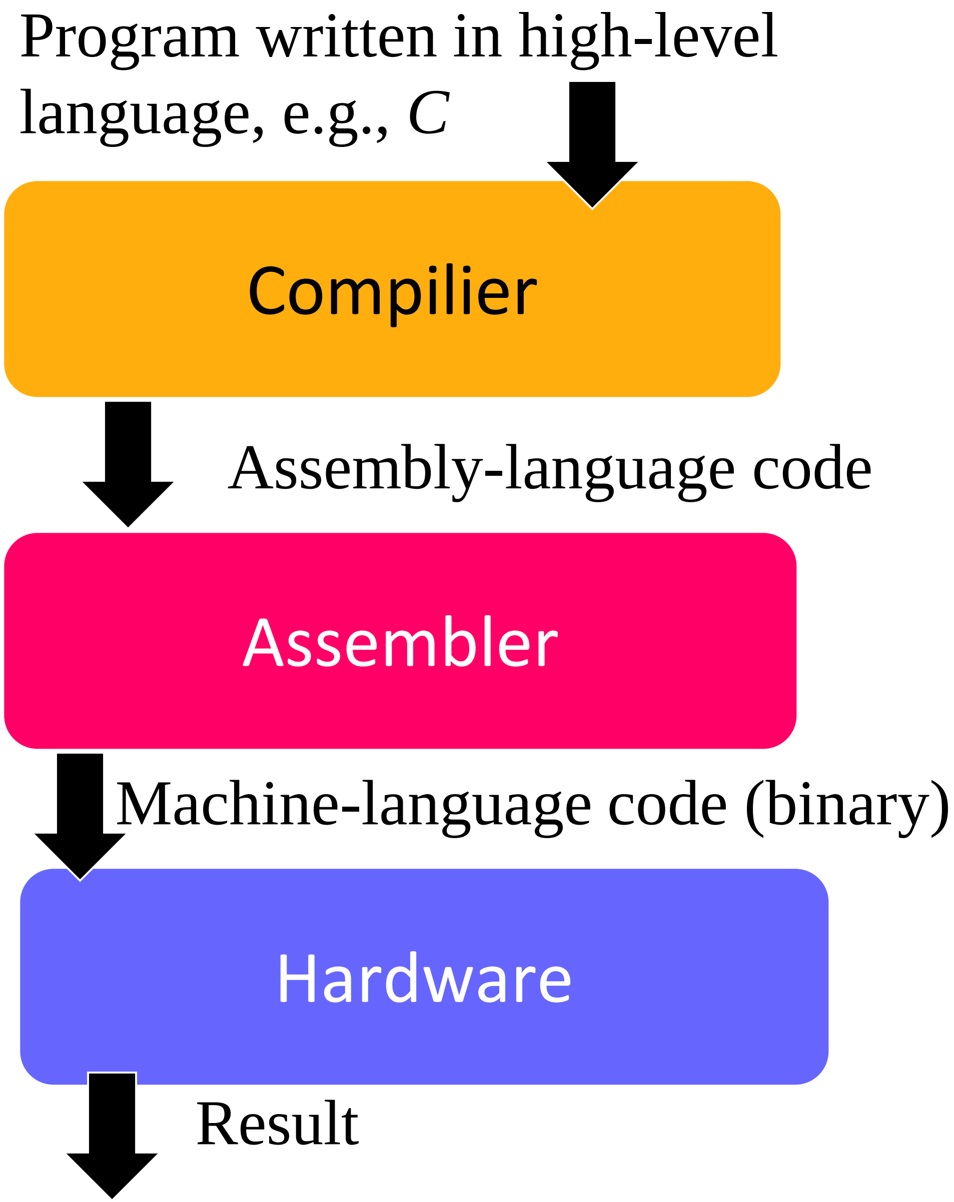
```
swap:
      muli $2, $5,4
      add  $2, $4,$2
      lw   $15, 0($2)
      lw   $16, 4($2)
      sw   $16, 0($2)
      sw   $15, 4($2)
      jr   $31
```

Assembler

Binary machine language program (for MIPS)

```
00000000101000010000000000011000
00000000000110000001100000100001
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
00000011111000000000000000001000
```

Program Execution



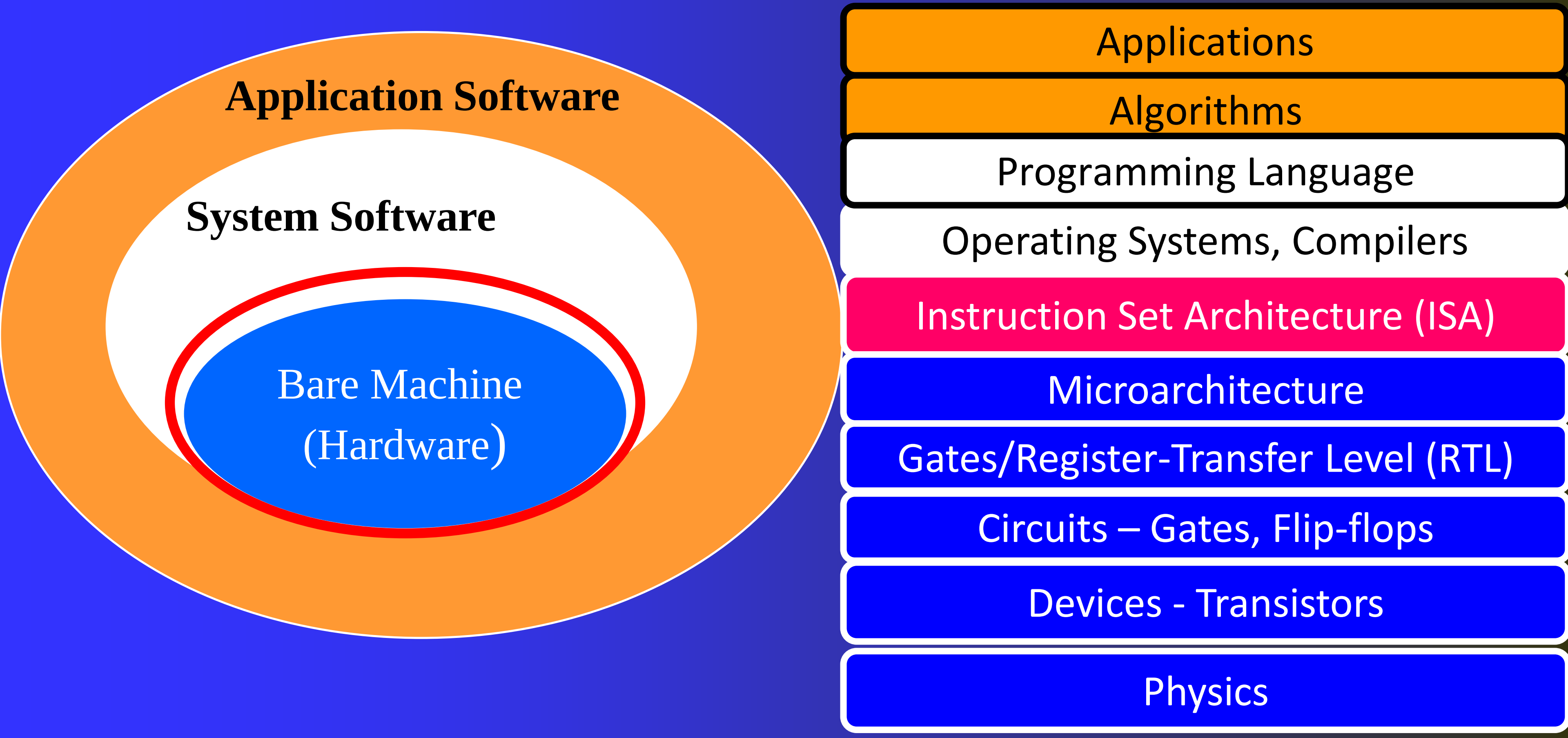
Question:

Where is the compiler running?

Who compiles the compiler?

How is the Assembler running?

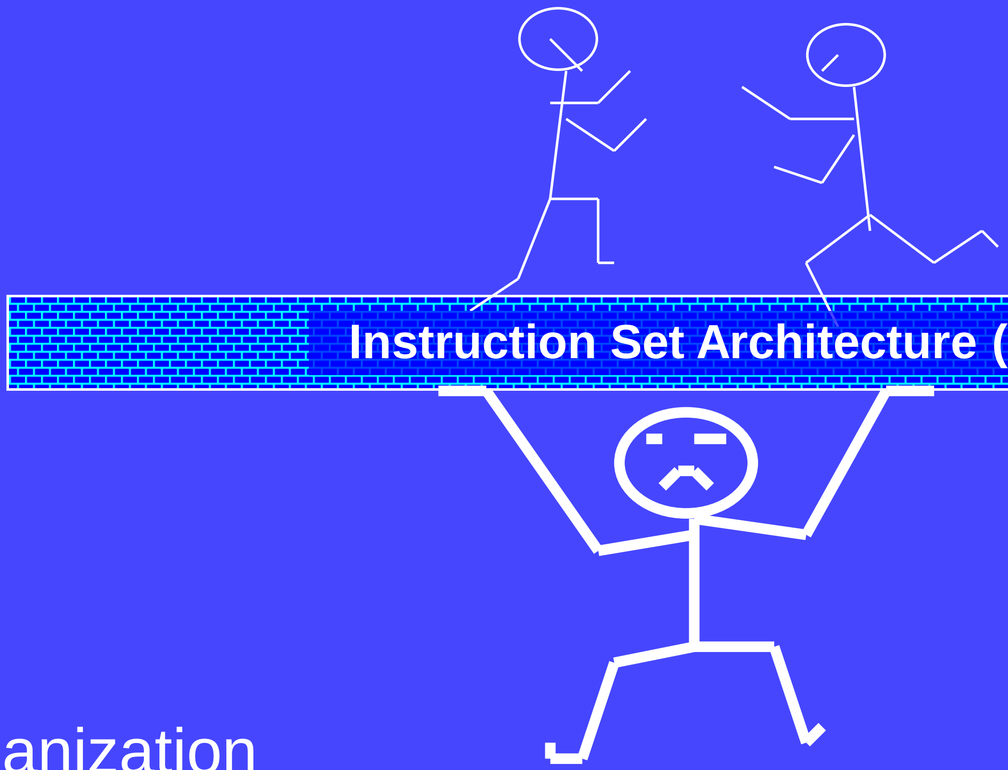
System Hierarchy



Computer Organization *versus* Computer Architecture

Computer Architecture

The view of a computer as perceived by software designers

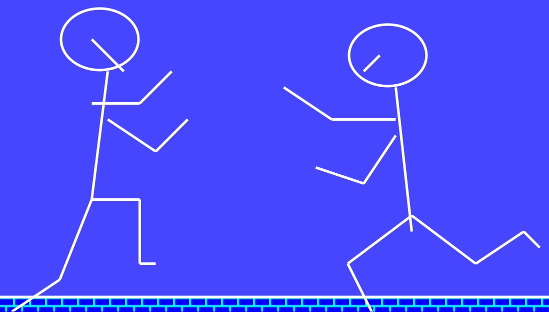


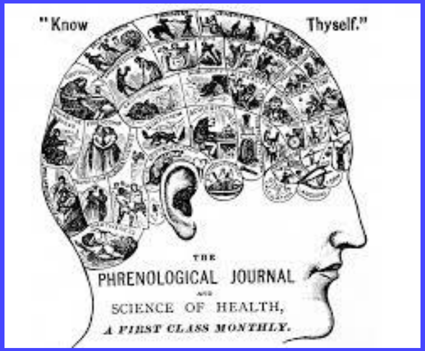
Computer Organization

The actual implementation of components in hardware

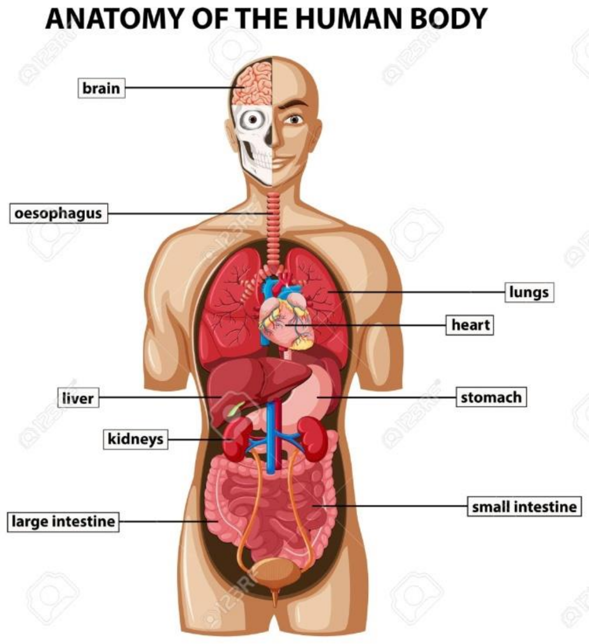
Computer Organization *versus* Computer Architecture

Computer Architecture: The personality of a machine
(behavioral view)





Instruction Set Architecture (ISA)



Computer Organization:
The anatomy of a machine
(structural view)

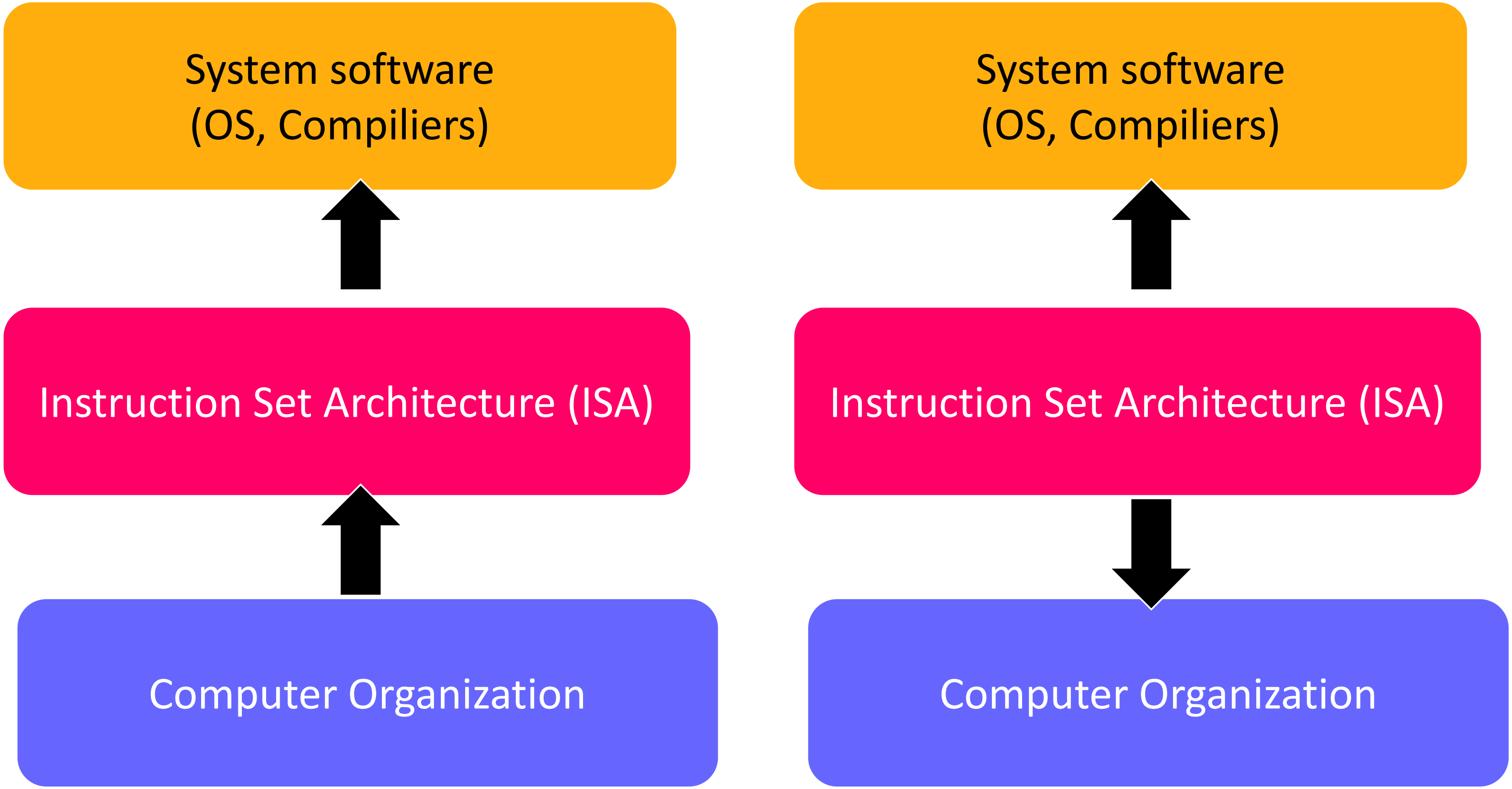
Computer Architecture

- Architecture is visible to a programmer
  - Instruction set
  - Registers
  - Data representation, addressing modes
  - I/O mechanisms
  - Virtual view of memory

Computer Organization

- Organization is visible to hardware designer
  - Hardware implementation of an instruction
  - Registers, program counter
  - Arithmetic and logical units
  - Control logic, internal states
  - Pipelining hardware
  - Cache and main memory

Computer Design Approach



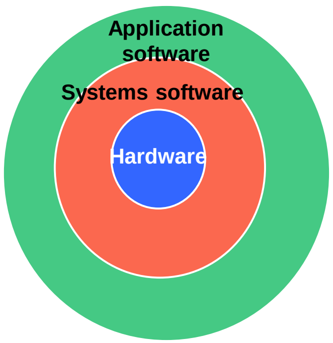
Bottom-up approach:
Hardware first, ISA later

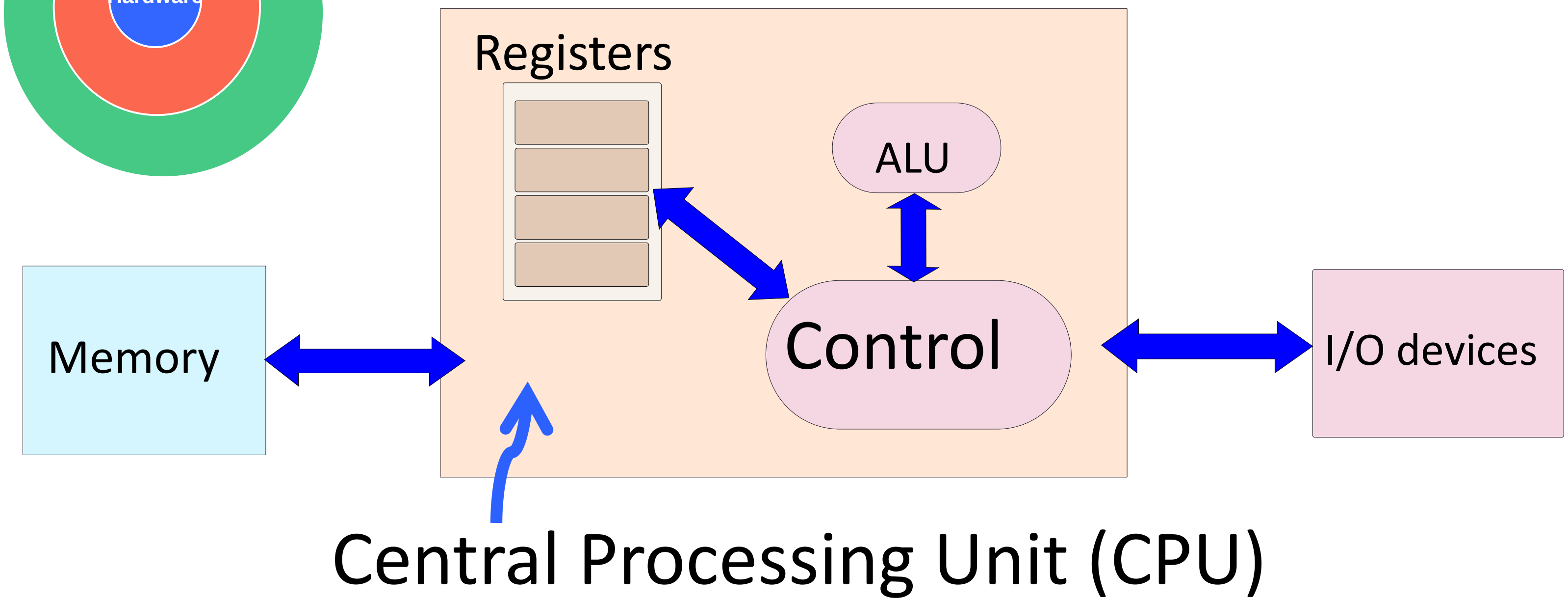
Top-down approach:
ISA first, hardware later

Instruction Set Architecture (ISA)

- A set of assembly language instructions that separates the interface between software and hardware
- In top-down design, given an ISA, an appropriate hardware platform is built to support it
- Based on ISA, OS and compilers are to be developed accordingly further going up
- Once ISA is fixed, software and hardware engineers can work independently
- ISA is designed to optimize the performance supported by the available hardware technology

The Hardware of a Computer





Five easy pieces:
Control, Arithmetic Logic Unit (ALU), Memory, Input/Output, Datapath (Bus)

Next Class

-
- Model for computation and Turing Machine
- von Neumann Architecture
- Basic Features of Instruction Set Architecture (ISA)
- CPU Performance Equation
- Amdahl's Law
- RISC *versus* CISC