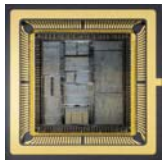
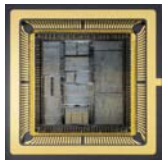


Lecture 2: Introduction

CSCI 5330
Digital CMOS VLSI Design

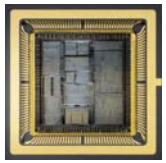
Instructor: Saraju P. Mohanty, Ph. D.

NOTE: The figures, text etc included in slides are borrowed from various books, websites, authors pages, and other sources for academic purpose only. The instructor does not claim any originality.



Lecture Outline

- Historical development of computers
- Introduction to a basic digital computer
- Five classic components of a computer
- Microprocessor
- IC design abstraction level
- Intel processor family
- Developmental trends of ICs
- Moore's Law

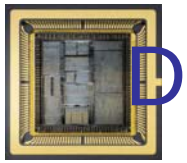


What is a digital Computer ?

A fast electronic machine that accepts digitized input information, processes it according to a list of internally stored instruction, and produces the resulting output information.

List of instructions → Computer program

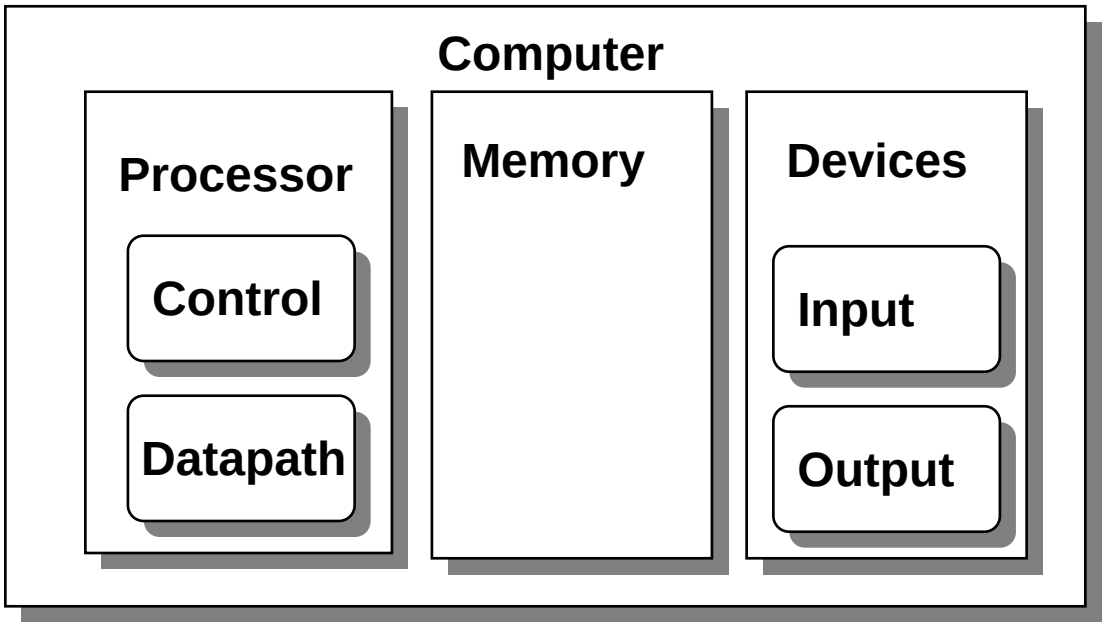
Internal storage → Memory



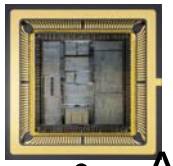
Different Types and Forms of Computer

- Personal Computers (Desktop PCs)
- Notebook computers (Laptop computers)
- Handheld PCs
- Pocket PCs
- Workstations (SGI, HP, IBM, SUN)
- ATM (Embedded systems)
- Supercomputers

Five classic components of a Computer



(1) Input, (2) Output, (3) Datapath, (4) Controller, and (5) Memory



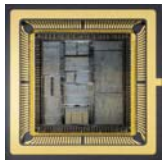
What is a microprocessor ?

- A microprocessor is an integrated circuit (IC) built on a tiny piece of silicon. It contains thousands, or even millions, of transistors, which are interconnected via superfine traces of aluminum. The transistors work together to store and manipulate data so that the microprocessor can perform a wide variety of useful functions. The particular functions a microprocessor performs are dictated by software. (source : Intel)

- Simply speaking, microprocessor is the CPU on a single chip. CPU stands for “central processing unit” also known as processor.

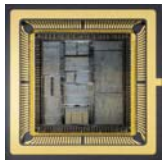
- Processor can be “general purpose” or “special purpose”. A special purpose processor is also known as “application specific integrated circuit” (ASIC).

The terms have become more or less fuzzy at present.

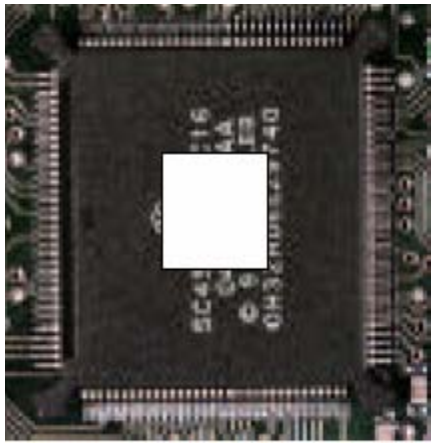


What is an Integrated Circuit ?

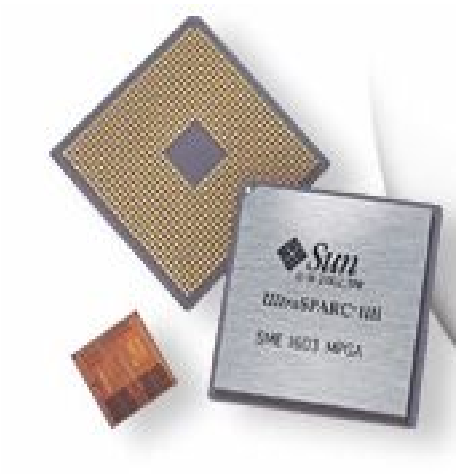
- An integrated circuits is a silicon semiconductor crystal containing the electronic components for digital gates.
- Integrated Circuit is abbreviated as IC.
- The digital gates are interconnected to implement a Boolean function in a IC .
- The crystal is mounted in a ceramic/plastic material and external connections called “pins” are made available.
- ICs are informally called chips.



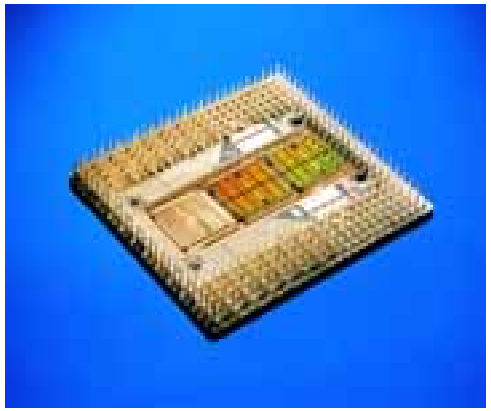
How does a microprocessor look?



(1) ASIC

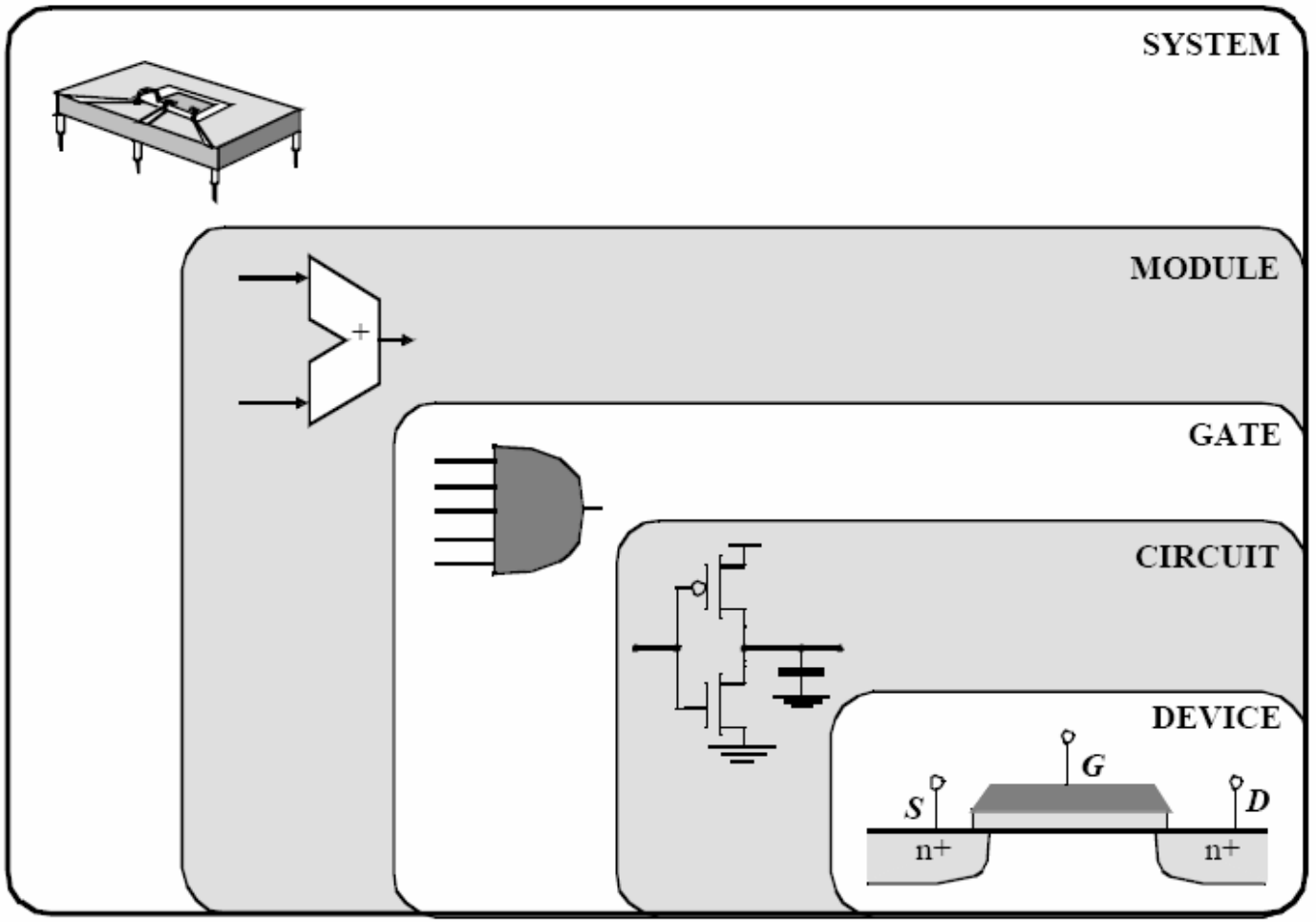


(2) Sun UltraSparc



(3) PentiumPro

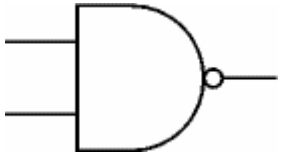
Circuits Design : Abstraction Levels



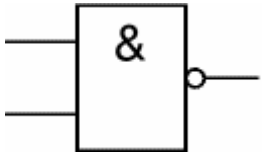
In this Course

In this Course

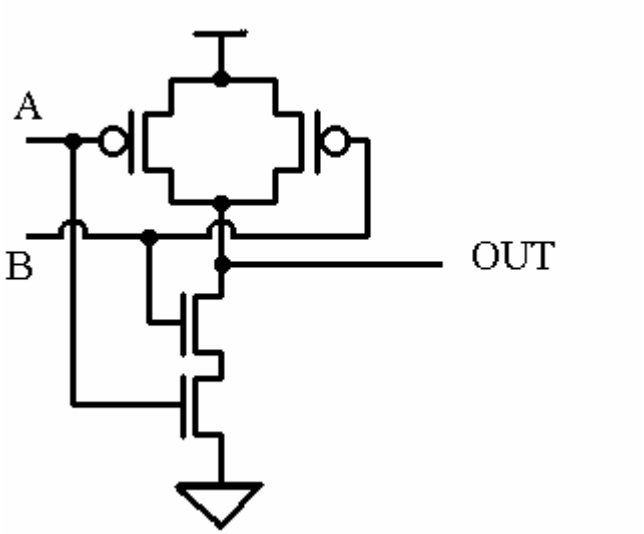
Digital Circuits : Logic to Device



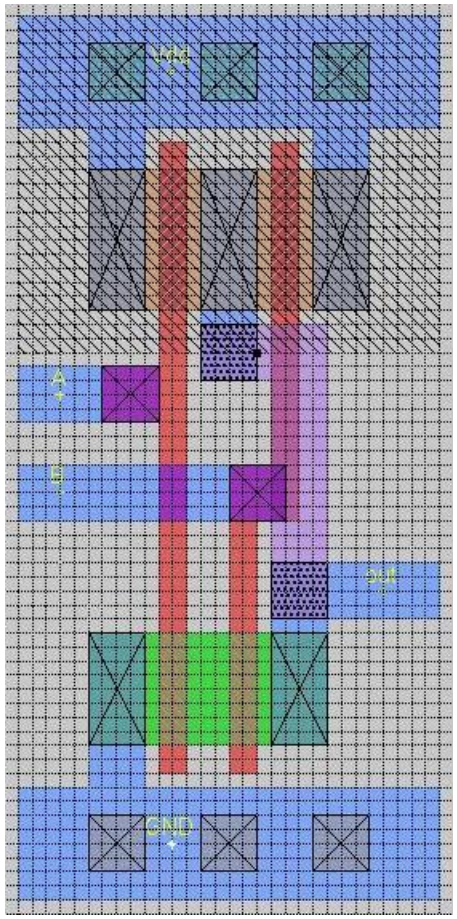
(NAND Gate)



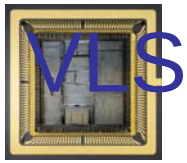
(IEC Symbol)



(Transistor Diagram)

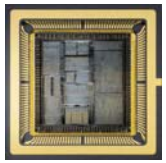


(Layout Diagram)



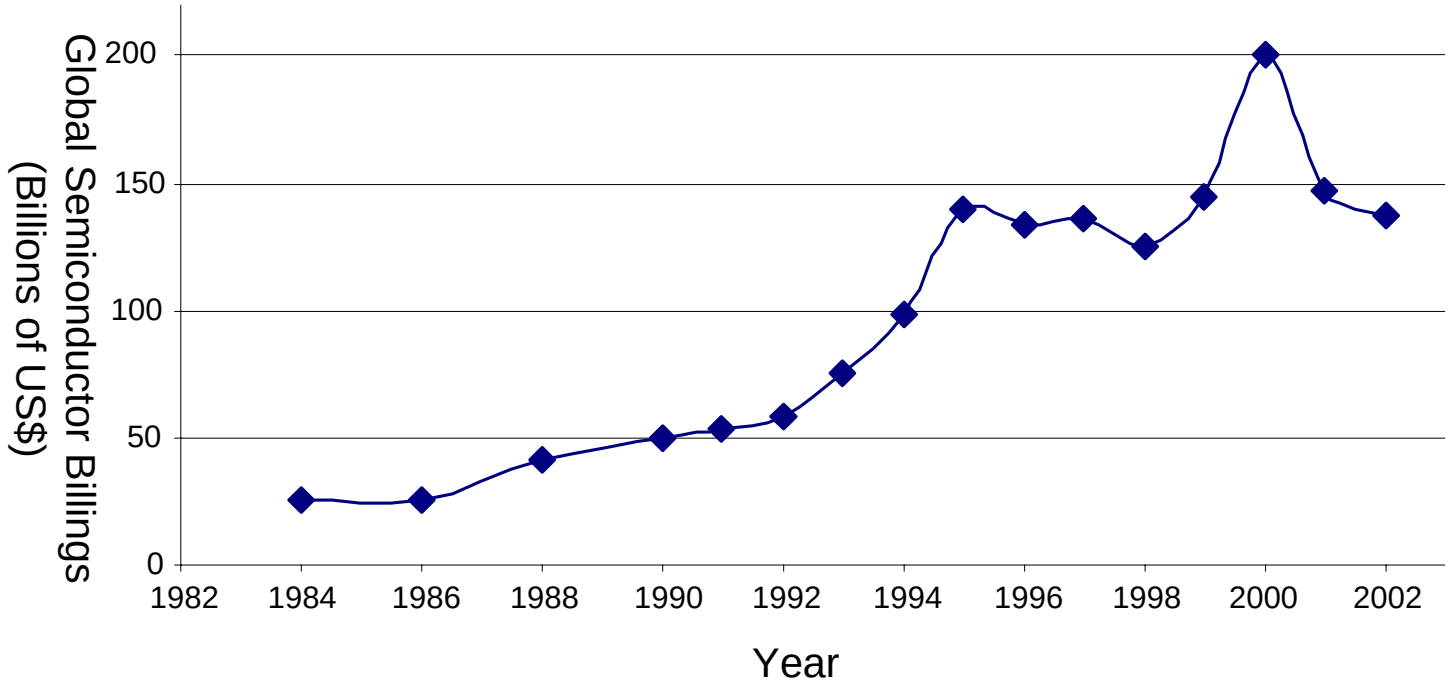
VLSI Technology: Highest Growth in History

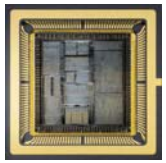
- 1958: First integrated circuit
  - Flip-flop using two transistors
  - Built by Jack Kilby at Texas Instruments
- 2003
  - Intel Pentium 4 μprocessor (55 million transistors)
  - 512 Mbit DRAM (> 0.5 billion transistors)
- 53% compound annual growth rate over 45 years
  - No other technology has grown so fast so long
- Driven by miniaturization of transistors
  - Smaller is cheaper, faster, lower in power!
  - Revolutionary effects on society



VLSI Industry : Annual Sales

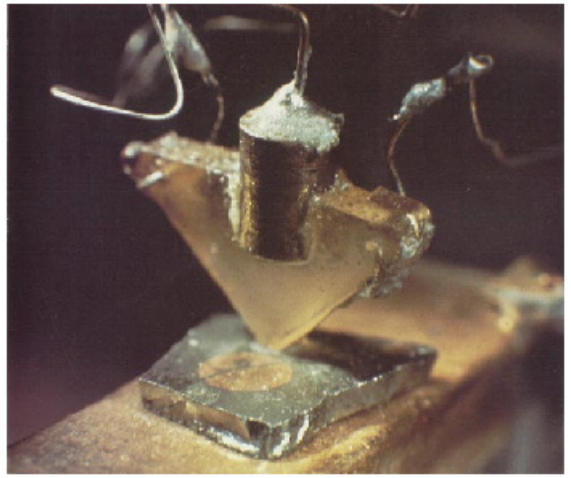
- 10^{18} transistors manufactured in 2003
  - 100 million for every human on the planet

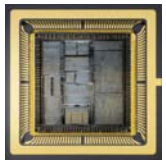




Invention of the Transistor

- Invention of transistor is the driving factor of growth of the VLSI technology
- Vacuum tubes ruled in first half of 20th century Large, expensive, power-hungry, unreliable
- 1947: first point contact transistor
  - John Bardeen and Walter Brattain at Bell Labs
  - Earned Nobel prize in 1956

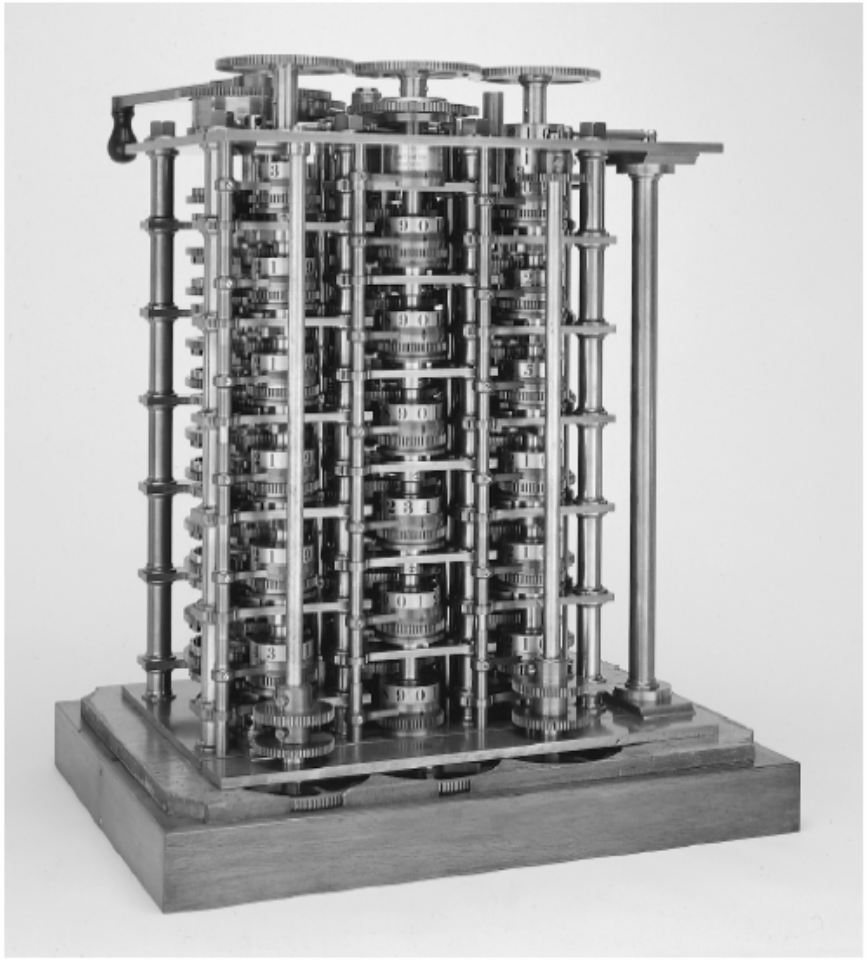




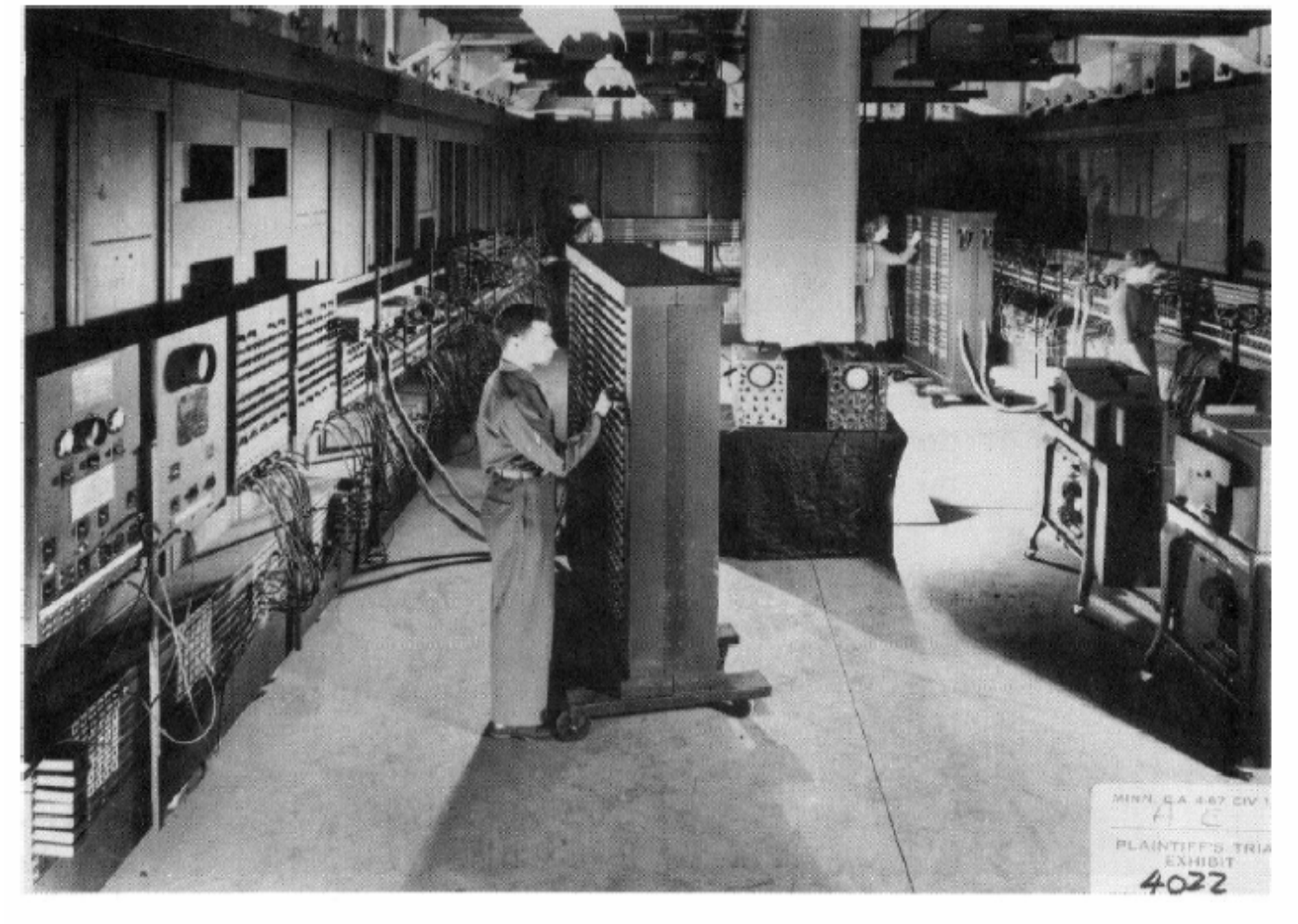
Transistor Types

- Bipolar transistors
  - n-p-n or p-n-p silicon structure
  - Small current into very thin base layer controls large currents between emitter and collector
  - Base currents limit integration density
- Metal Oxide Semiconductor Field Effect Transistors (MOSFET)
  - nMOS and pMOS MOSFETS
  - Voltage applied to insulated gate controls current between source and drain
  - Low power allows very high integration

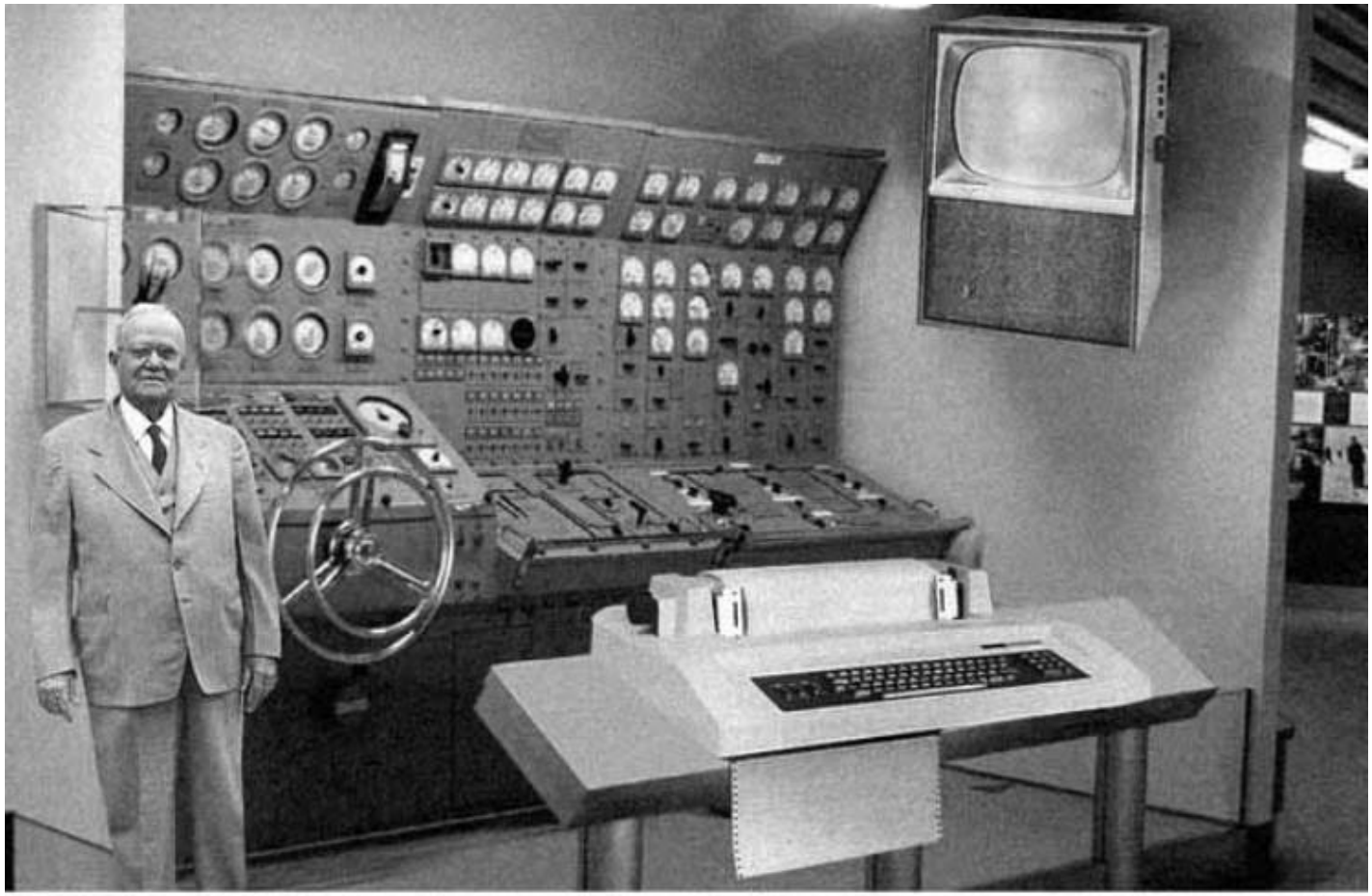
The Babbage Difference Machine in 1832



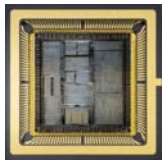
The First Electronic Computer in 1946 (ENIAC)



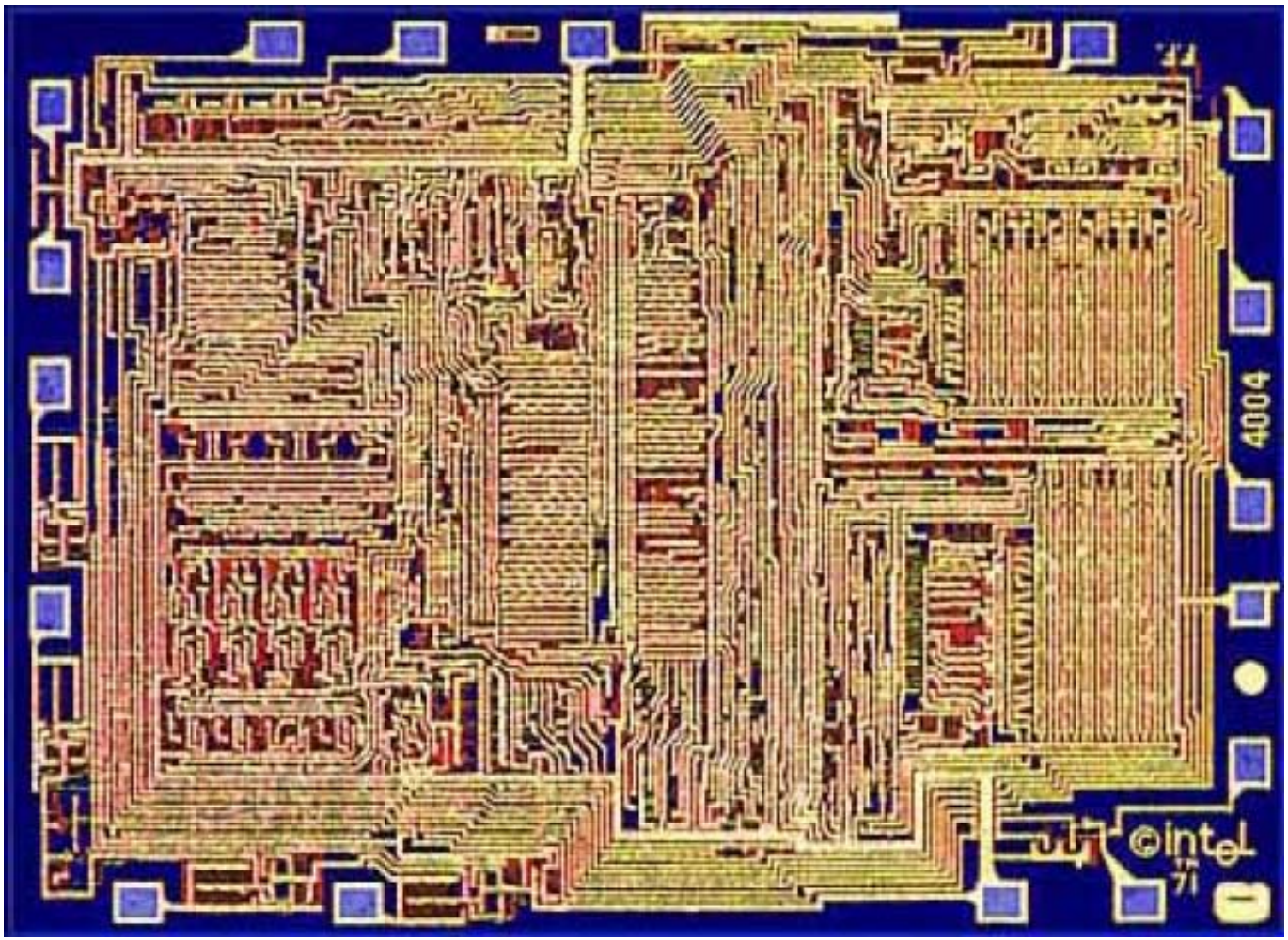
Prediction about Home PC in 1954

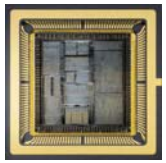


Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology 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.

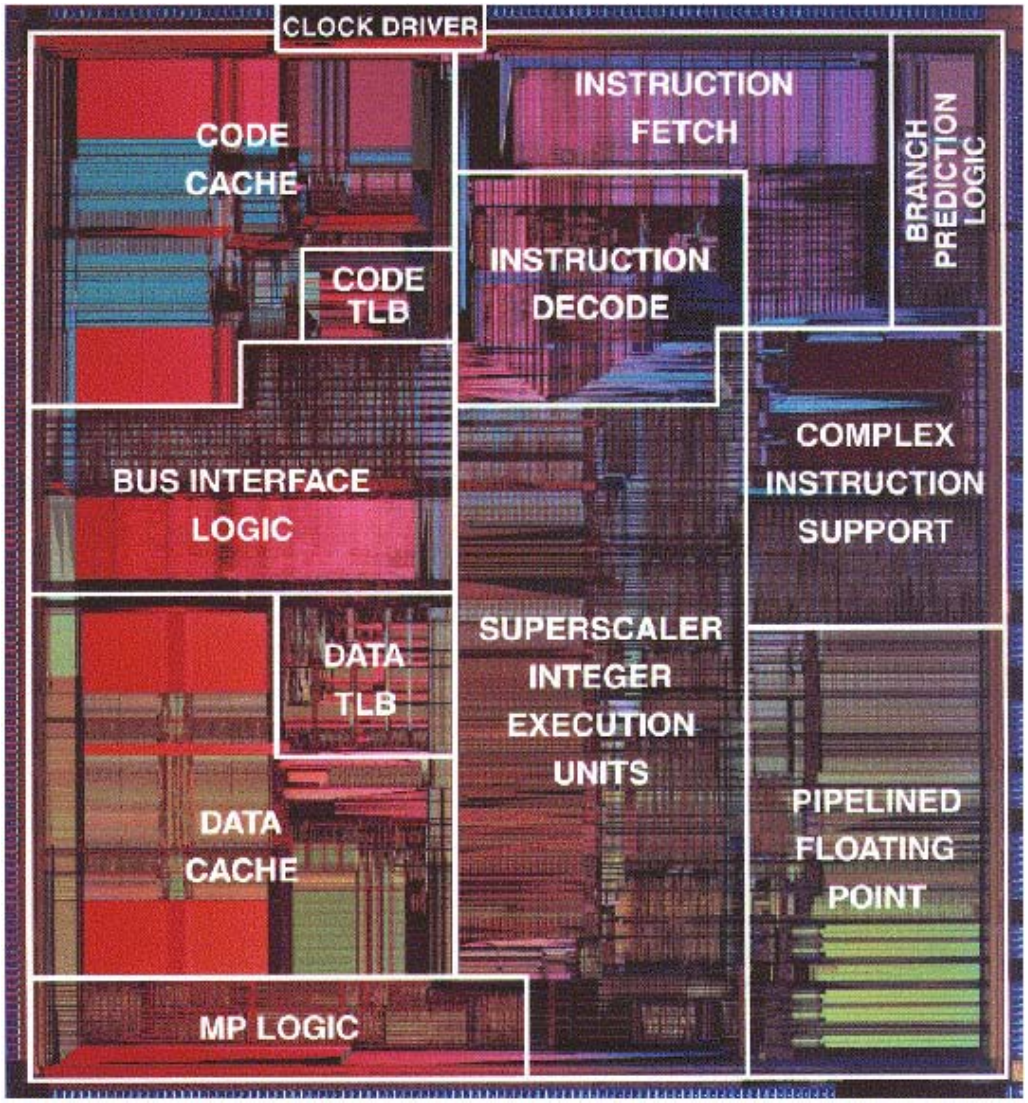


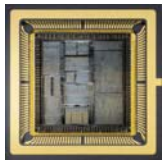
Intel 4004 : 2.3K Transistors (1971)



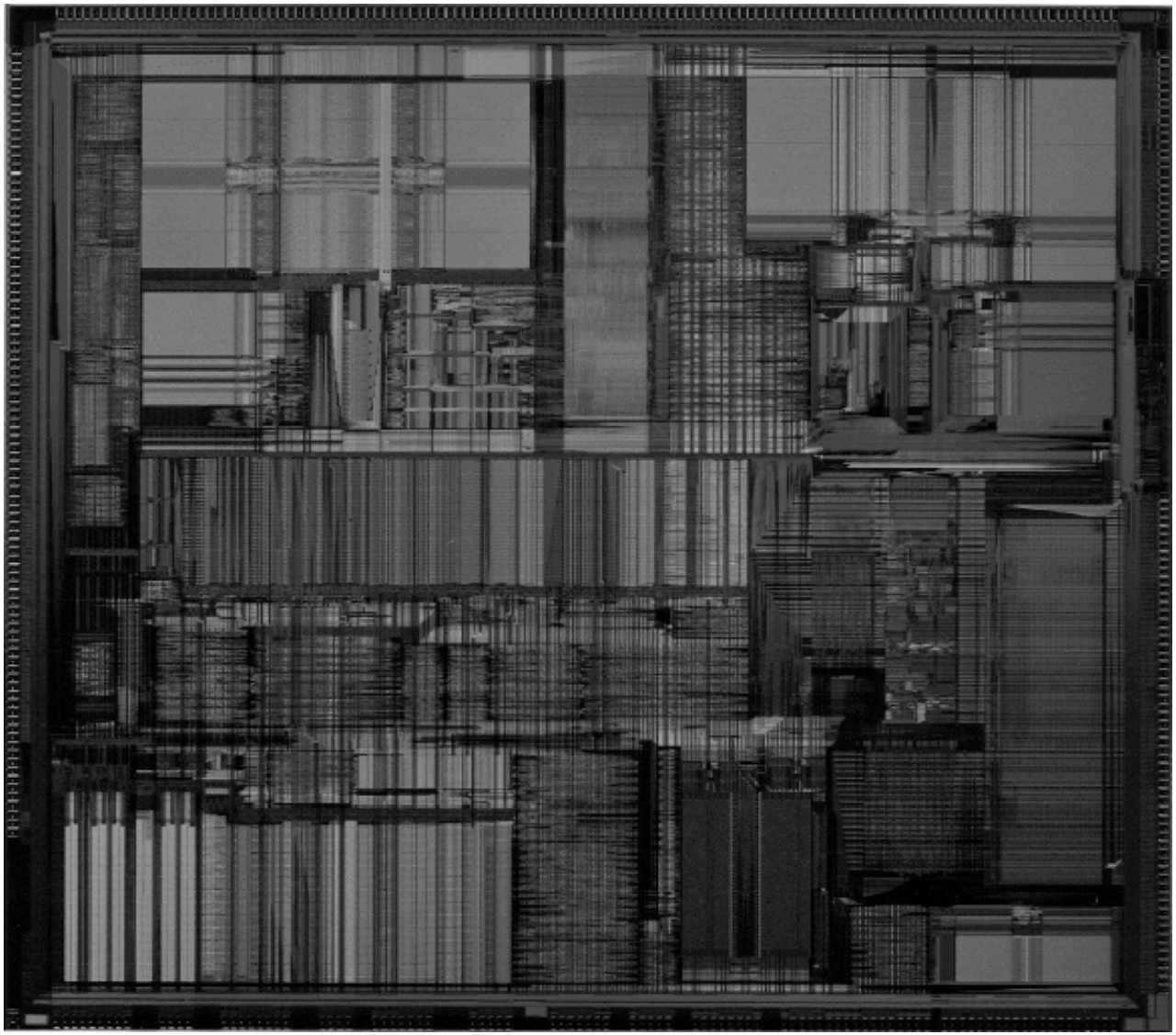


Pentium : 3.1 M Transistors (1993)

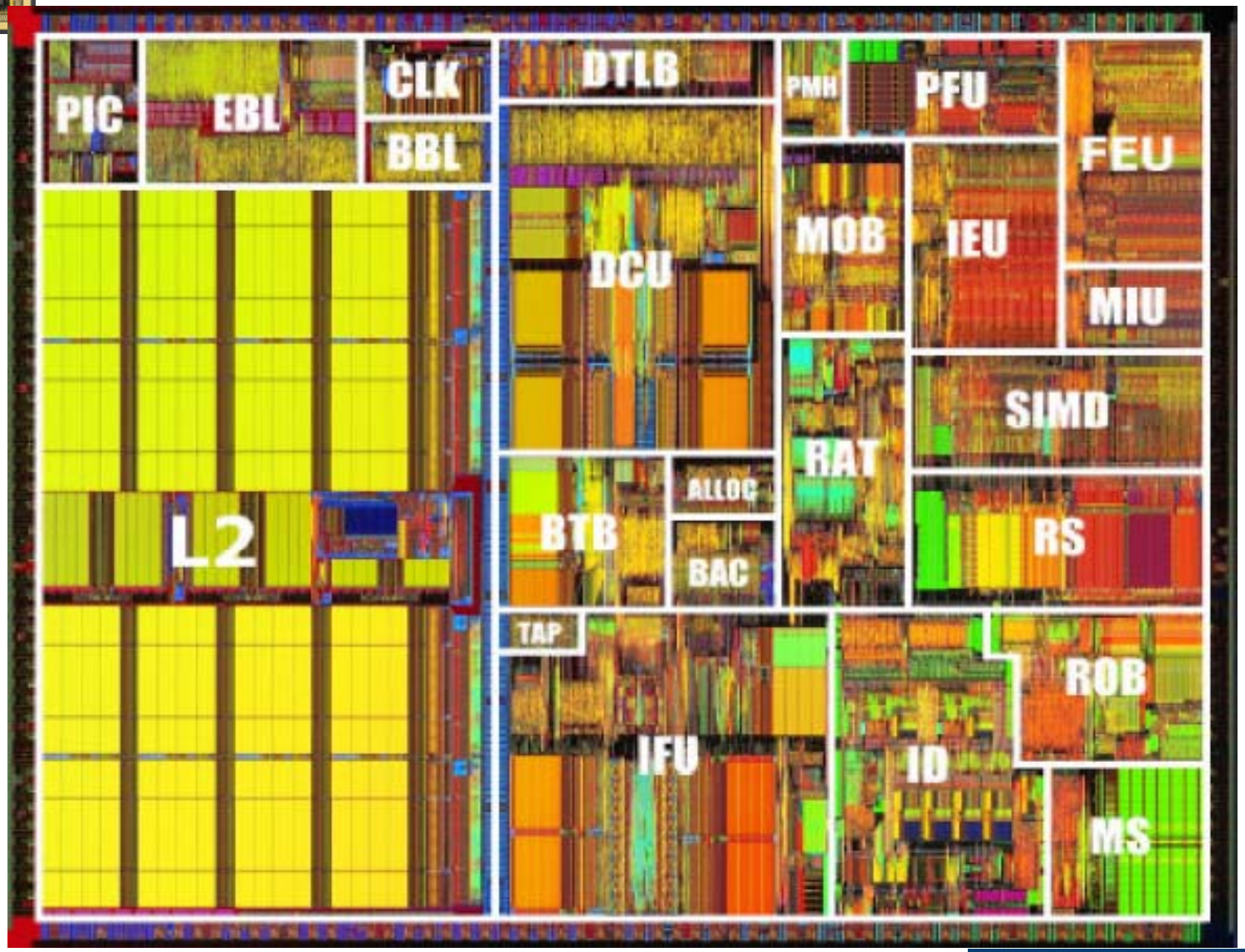


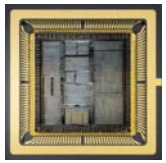


Pentium II : 7.5 M Transistors (1997)



Pentium III : 28.1 M Transistors (1999)



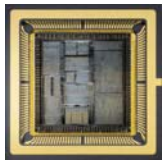


Different Attributes of an IC or chip

We will briefly discuss the VLSI technological growth based on these attributes.

- Gate count of a chip
- Transistor count of a chip
- Operating frequency of a chip
- Power consumption of a chip
- Power density in a chip
- Size of a device used in chip

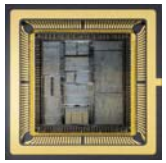
NOTE: Chip is informal name for IC.



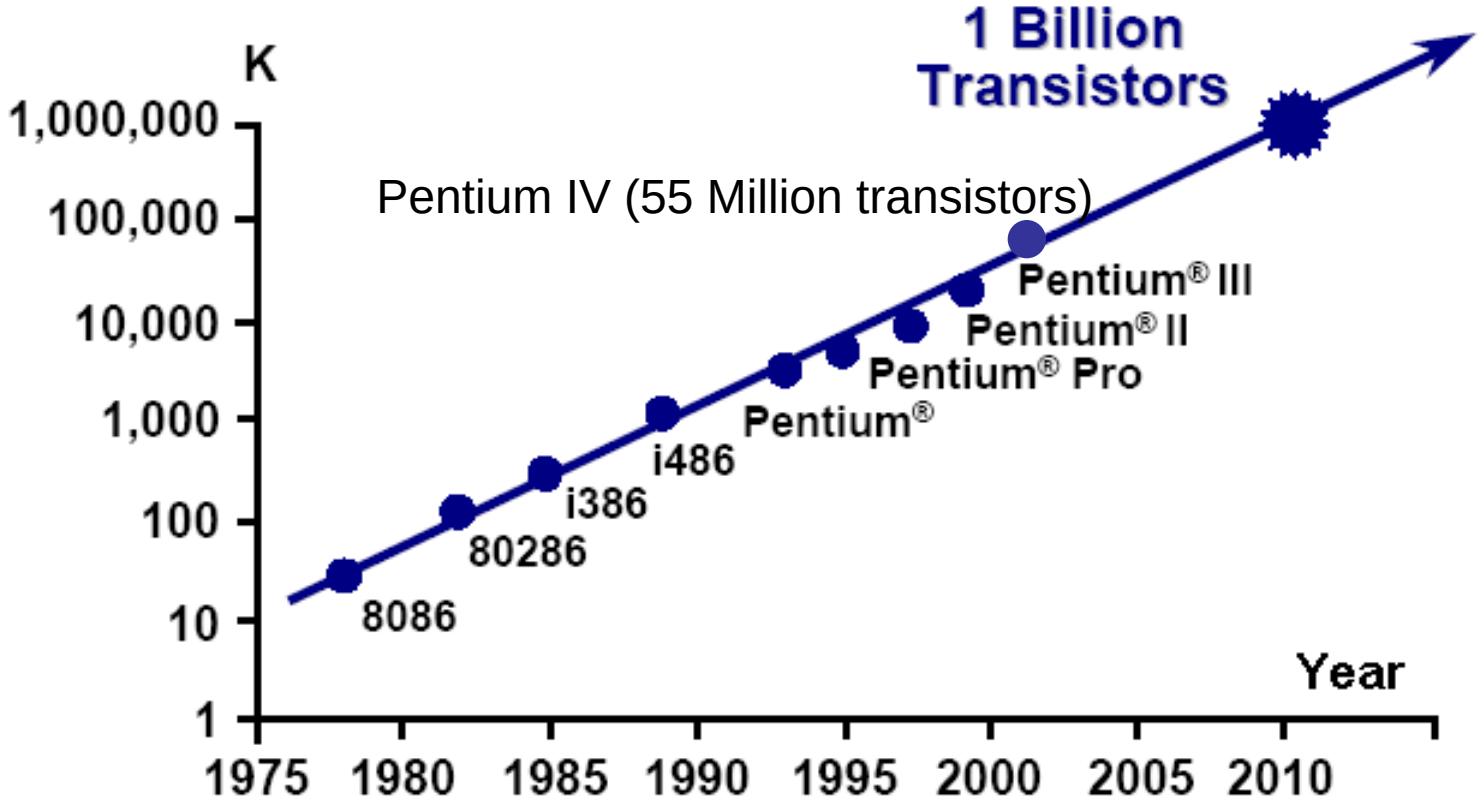
Moore's Law

- 1965: Gordon Moore plotted transistor on each chip
  - Transistor counts have doubled every 26 months

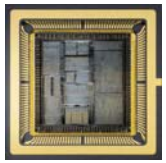
- Many other factors grow exponentially
  - clock frequency
  - processor performance



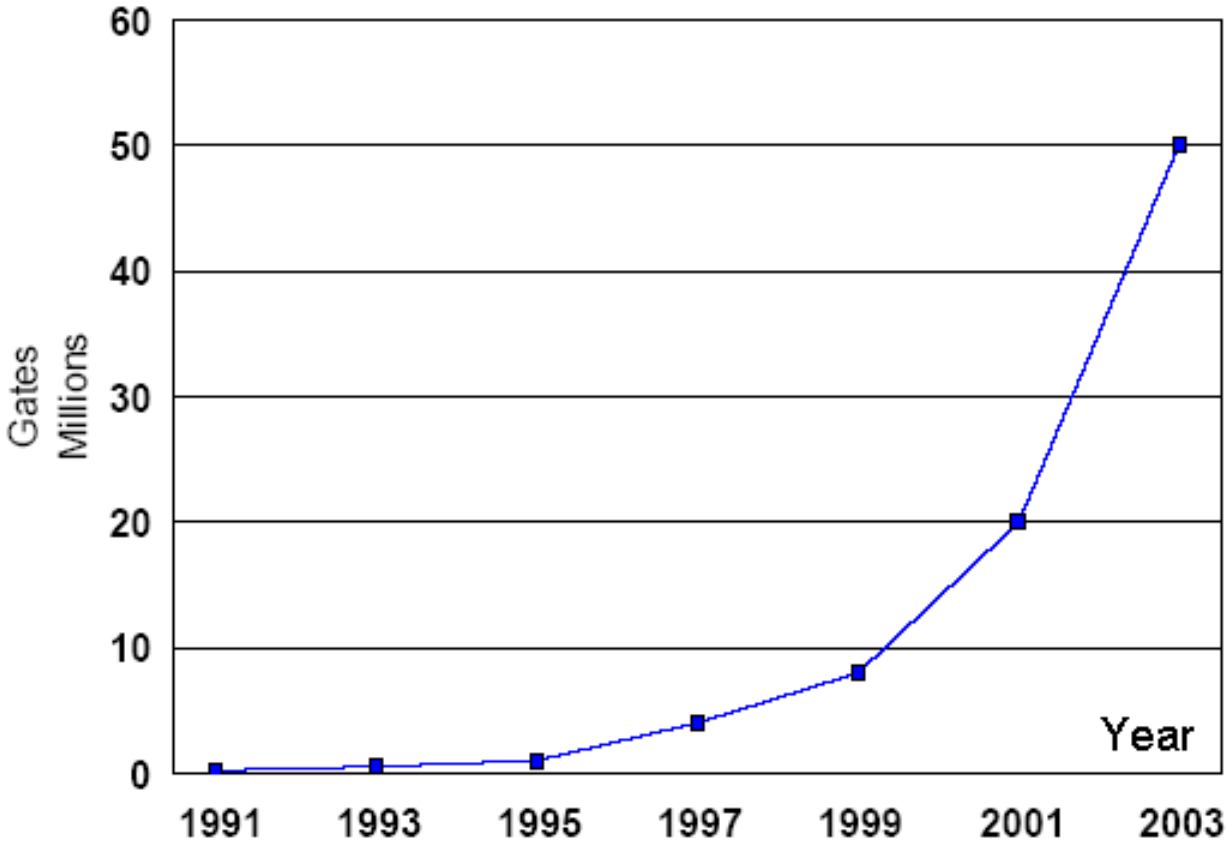
Increase in Transistor Count



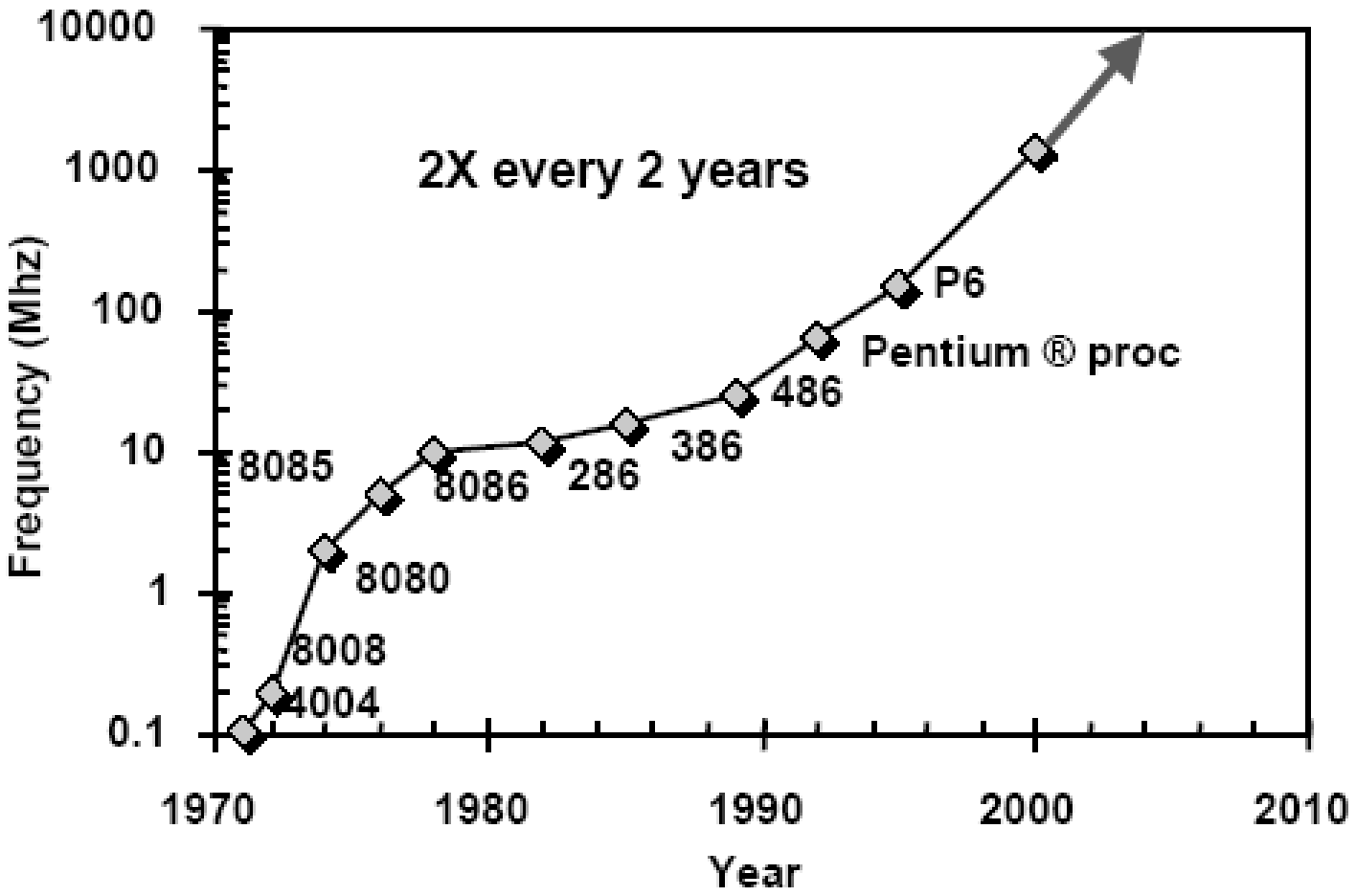
Moore's Law: Number of transistors of a chip doubles every 1.5 to 2 years.



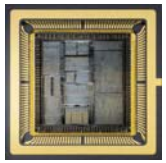
Increase in Gate Count



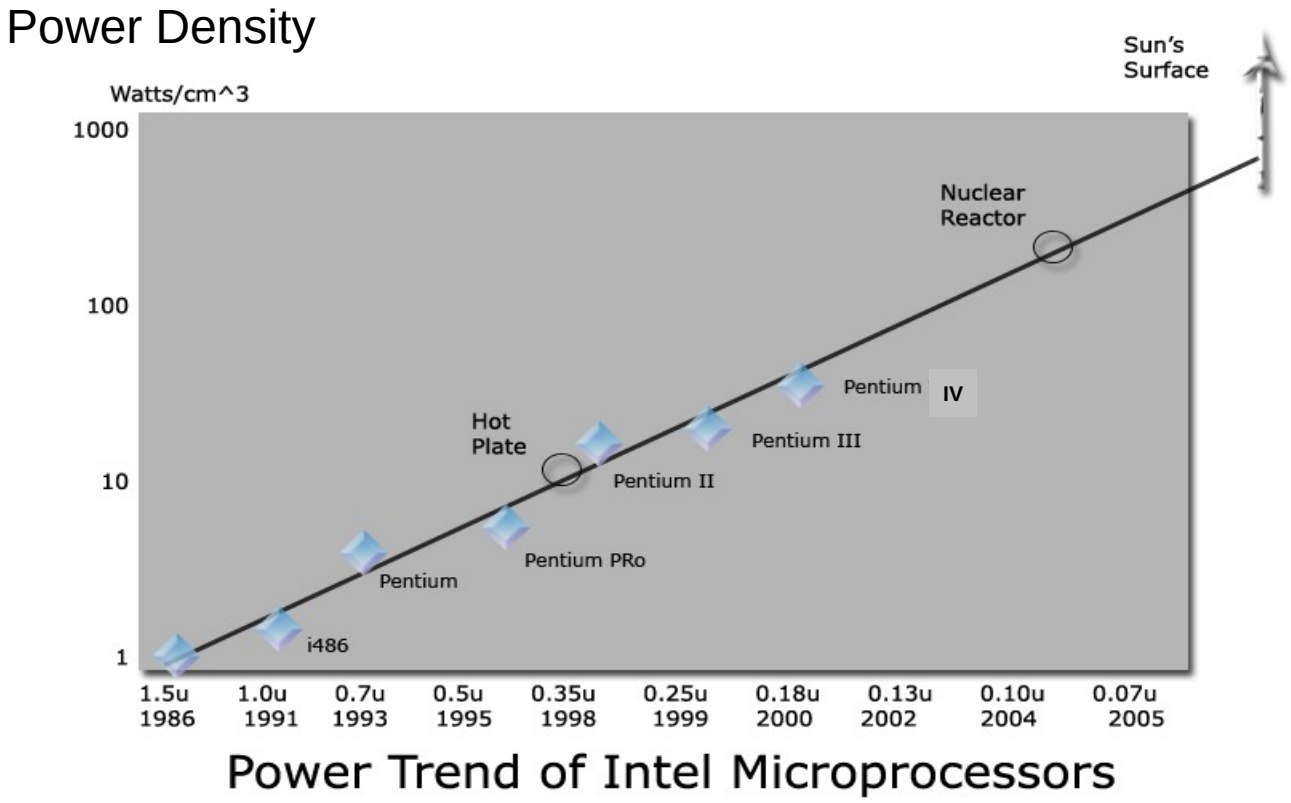
Increase in Operating Frequency



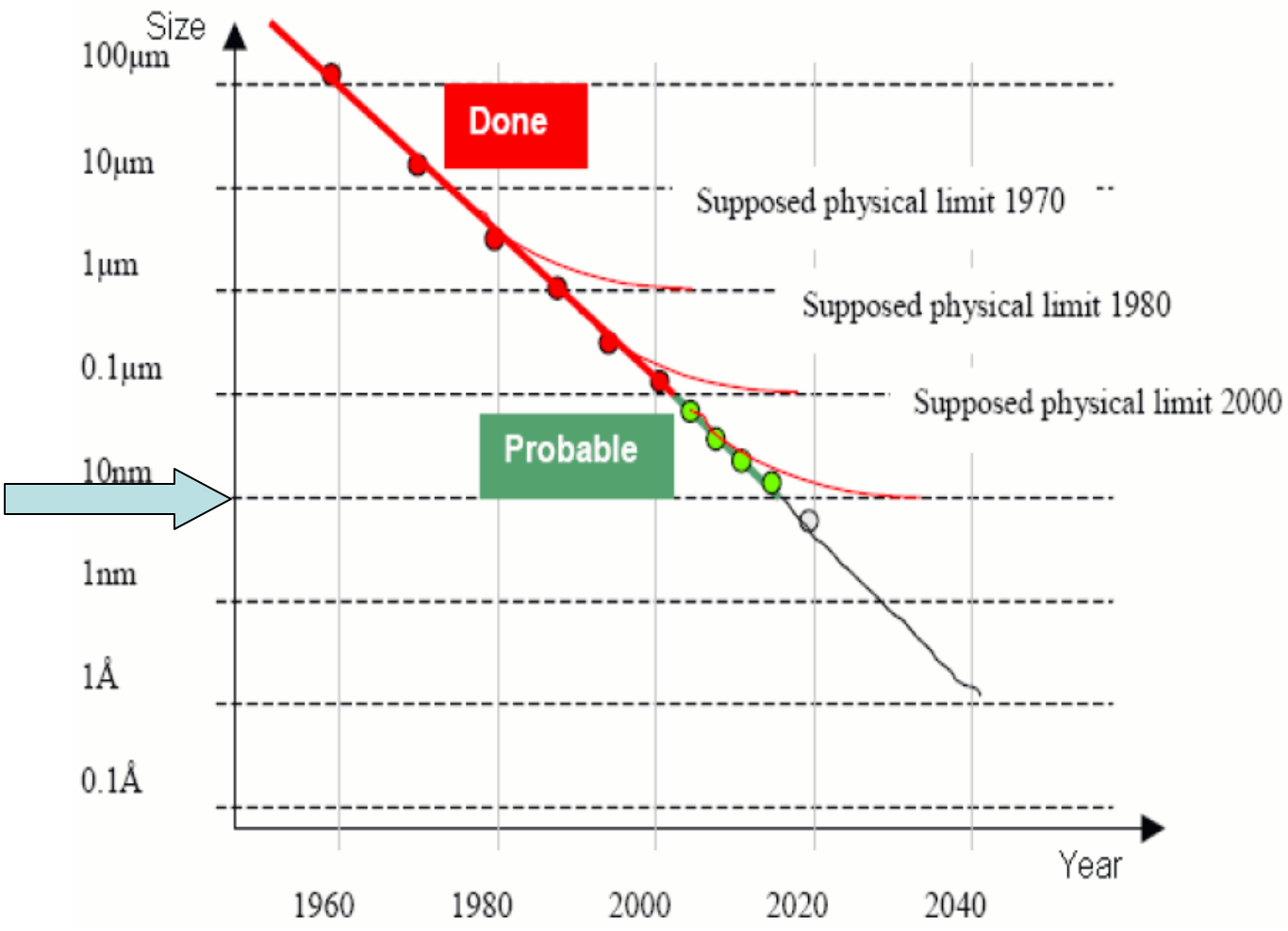
Operating frequency doubles every two years.



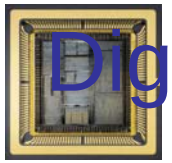
Increase in Power Density



Technology Scaling Trend

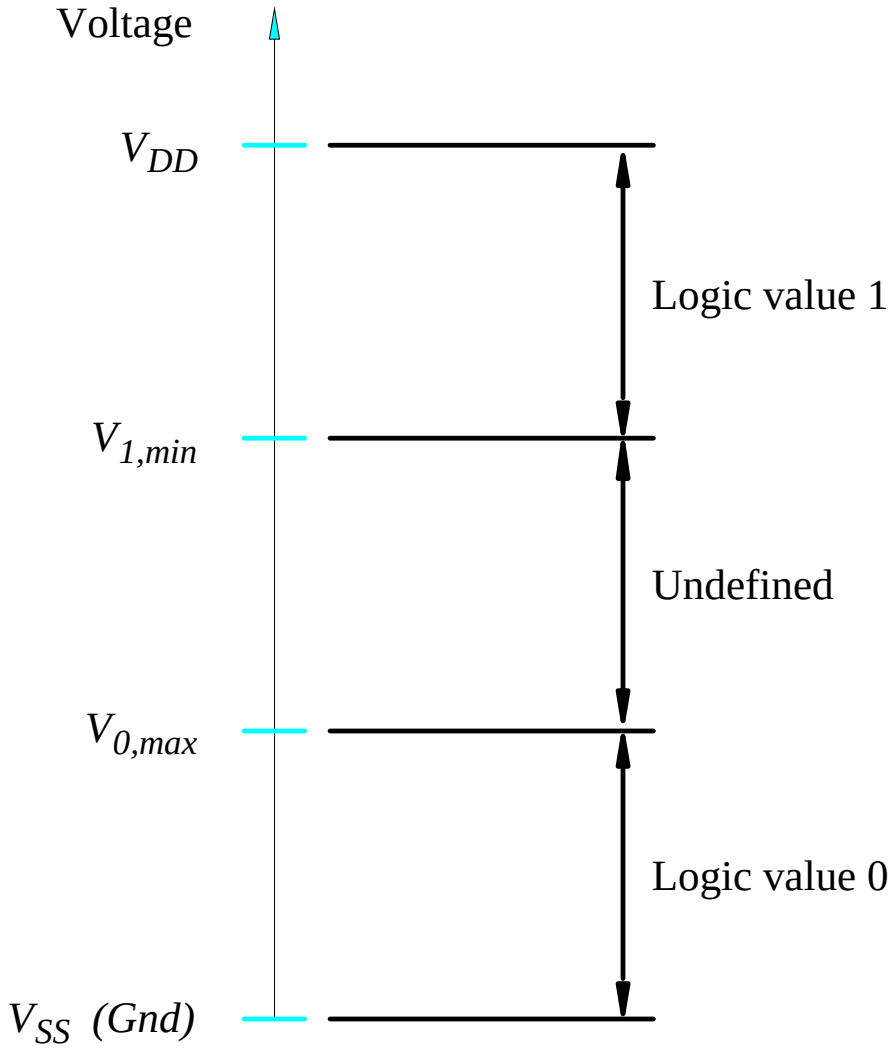


Source: Bendhia 2003

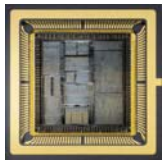


Digital Systems: Information Representation

Digital system → manipulates *discrete elements of information* represented by physical quantities called signals (voltages, currents), mostly using two discrete values – binary signals. (HIGH – LOW, TRUE-FALSE, 1-0, positive / negative logic).

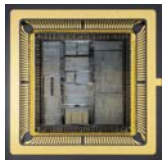


Logic values as voltage levels.



Why is Binary Used ??

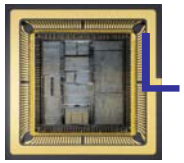
- It is easy to distinguish between two states: high or low voltage, presence or absence of electric charge or a switch in the on or off position of a transistor.
- To reduce cost of electronic circuits.
- High noise margin compared to the multi-valued logic circuits.



Integrated Circuits Categories

There are many different types of ICs as listed below.

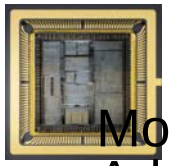
IC Categories	**Functions**
Analog ICs	Amplifiers
	Filters
Digital ICs	Boolean Gates
	Encoders/Decoders
	Multiplexers / Demultiplexers
	Flip-flops
	Counters
	Shift Registers
Hybrid ICs	Mixed Signal Processors
Interface ICs	Analog-Digital Converters
	Digital-Analog Converters



Levels of Integration (Chip Complexity)

Categorized by the number of gates contained in the chip.

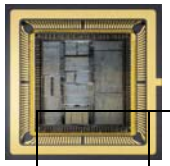
IC Complexity	Number of Gates	Functional Complexity	Examples
SSI	<10	Basic gates	Inverters, AND gates, OR gates, NAND gates, NOR gates
MSI	10-100	Basic gates	Exclusive OR/NOR
		Sub-modules	Adders, subtractors, encoders, decoders, multiplexers, demultiplexers, counters, flip-flops
LSI	100-1000s	Functional modules	Shift registers, stacks
VLSI	1000s-100,000	Major building blocks	Microprocessors, memories
ULSI	>100,000	Complete systems	Single chip computers, digital signal processors
WSI	>10,000,000	Distributed systems	Microprocessor systems



IC Nomenclature

Most chips are identified in a similar way regardless of vendors. Adoption of this notation allows user to select chips with similar functions from a variety of vendors.

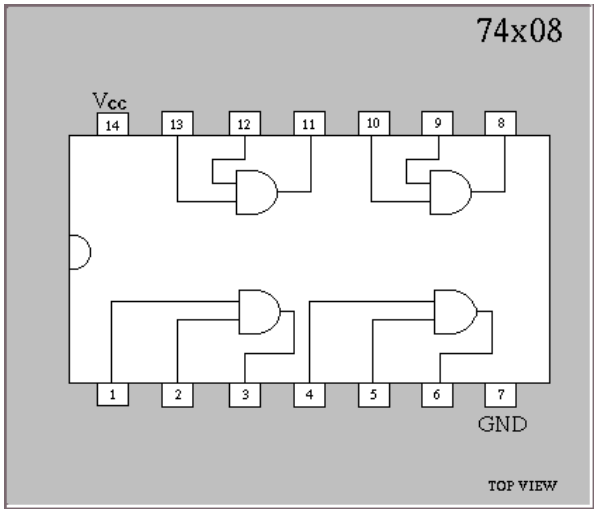
- Manufacturer Code:
  (i) SN - Texas Instruments, (ii) DM - National Semiconductor, (iii) MC – Motorola, (iv) MM - Monolithic Memories
- Product Line:
  (i) 5 - Military grade TTL products (40C to 100C)
  (ii) 7 - Commercial grade TTL products (0C to 70C), ….., and so on.
- Performance:
  (i) (blank) - Regular, (ii) H - High-speed, (iii) L - Low-power, (iii) S –Schottky, (iv) LS - Low-power Schottky, (v) AS - Advanced Schottky, (vi) ALS - Advanced low-power Schottky
- Logic Family:
  (i) 00 - Quad 2-input positive NAND, (ii) 02 - Quad 2-input positive NOR
  (iii) 0 - Hex inverters, (iv) 08 - Quad 2-input positive AND
- Package Type:
  (i) J - Ceramic Dual-In-Line (DIP), (ii) N - Plastic DIP, (iii) T -Tin can, (iv) W - Ceramic flat package



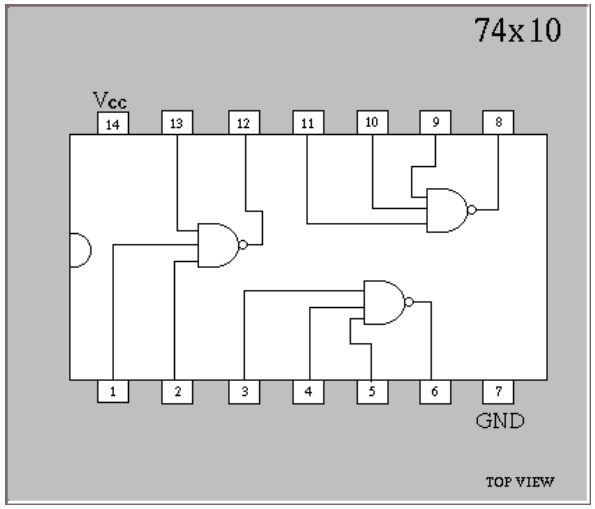
IC Nomenclature : Example ….

	Manufacturer Code	Product Line	Performance Class	Logic Family	Package Type
1	SN	74	LS	00	N
2	MC	54	S	190	T

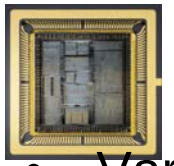
Chip 1: Texas Instruments, Low-power Schottky, Quad 2-input positive NAND, Plastic DIP, and Chip 2: Motorola, Schottky, Tin can



Qaud 2-input Positive AND Gates



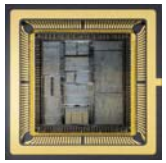
Triple 3-input Positive NAND Gates



Digital Logic Families

- Various circuit technology used to implement an IC at lower level of abstraction.
- The circuit technology is referred to as a digital logic family.

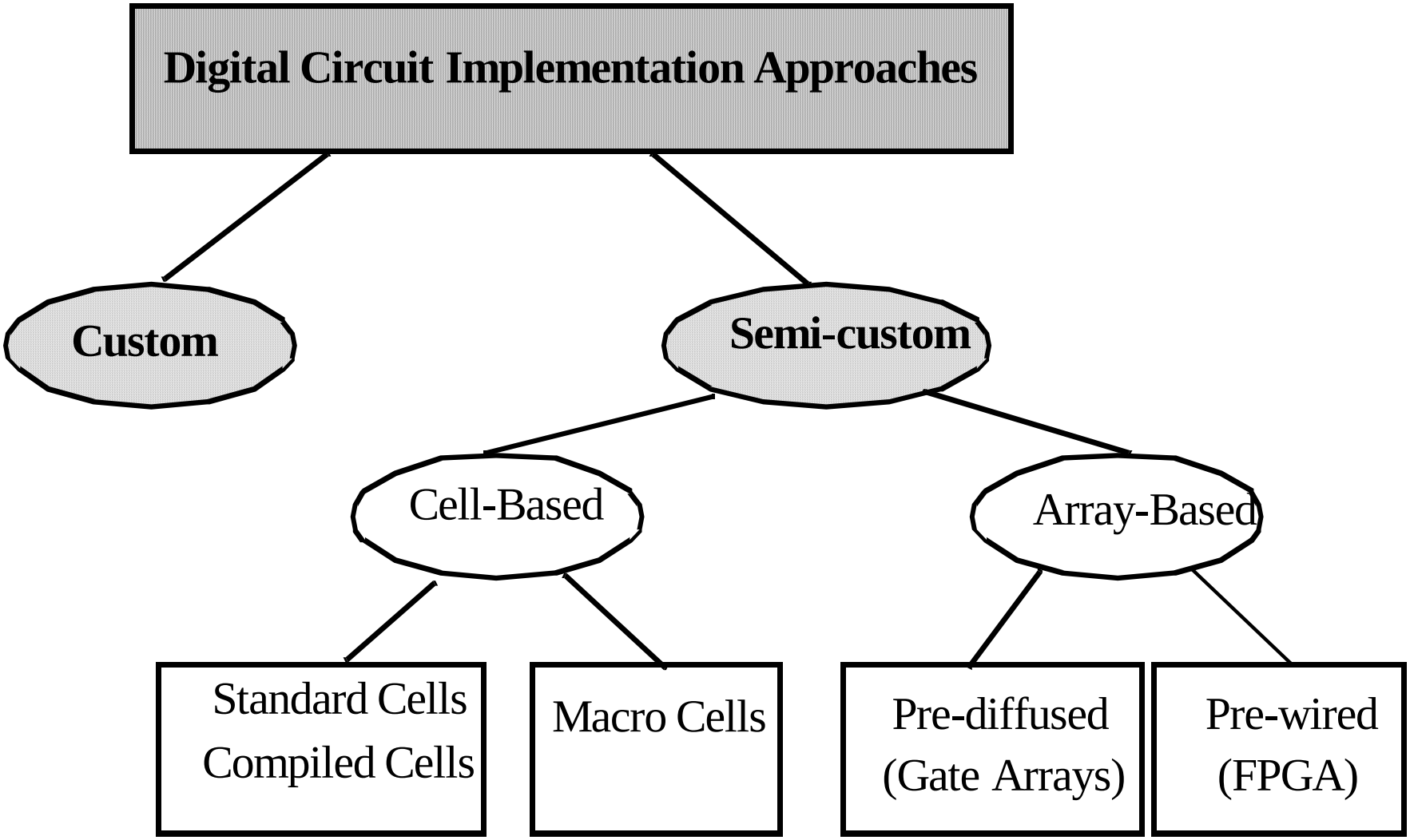
RTL	Resistor-transistor Logic
DTL	Diode-transistor logic
TTL	Transistor-transistor logic
ECL	Emitter-coupled logic
MOS	Metal-oxide semiconductor
CMOS	Complementary Metal-oxide semiconductor
BiCMOS	Bipolar Complementary Metal-oxide semiconductor
GaAs	Gallium-Arsenide

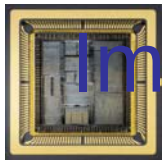


Digital Logic Families …….

- RTL, DTL, and obsolete.
- TTL are not much used now-a-days.
- ECL can provide high-speed ICs.
- MOS is suitable for high-component density.
- CMOS is preferred for low-power high-performance and high-packing density IC implementation.
- CMOS is widely used technology at present.
- BiCMOS is used where high current and high-speed is necessary.
- GaAs is used for very high speed circuits.

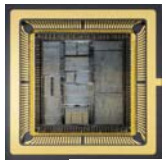
Implementation Approaches for Digital ICs



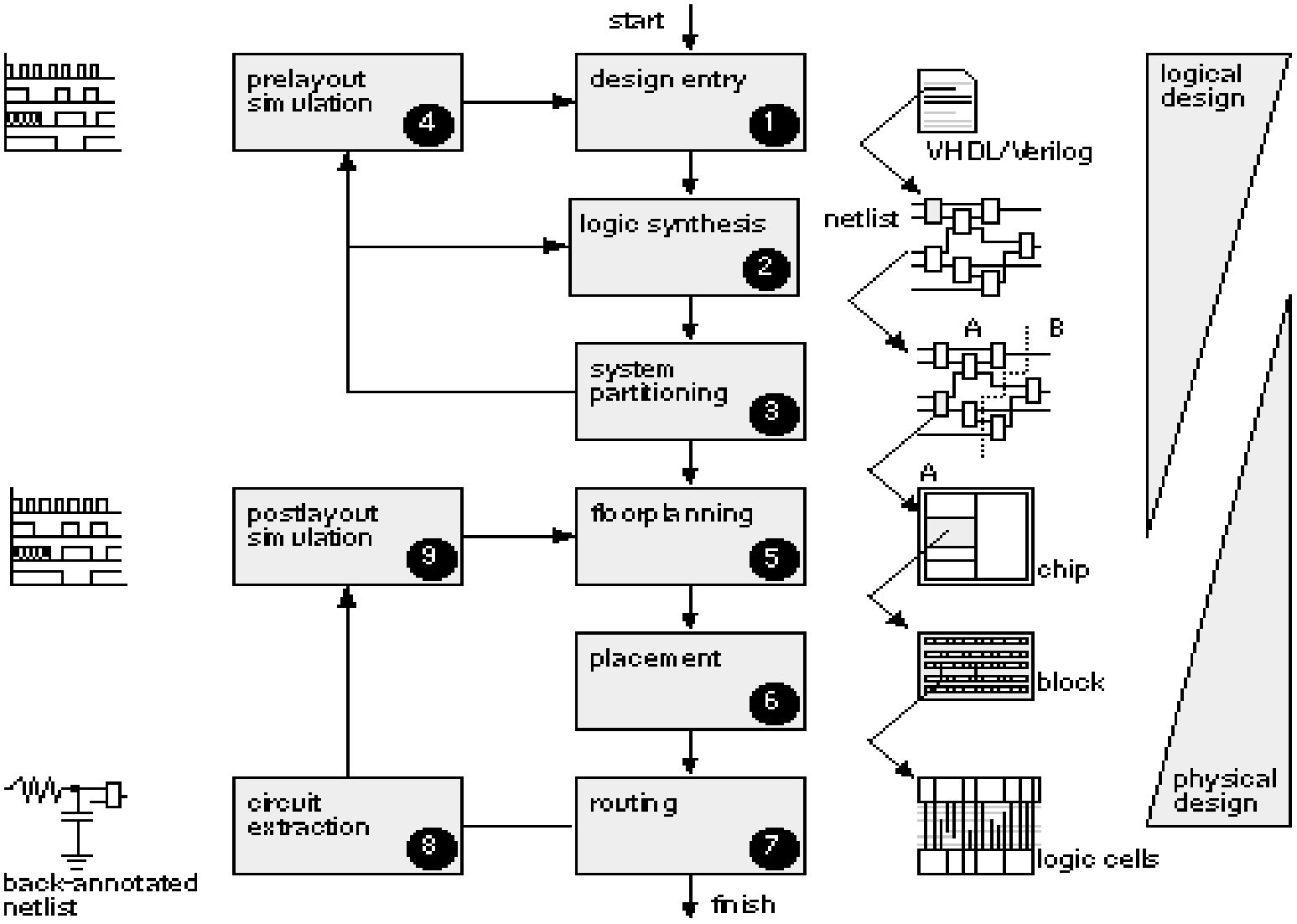


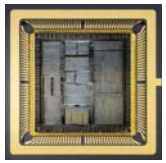
Implementation Approaches for Digital ICs

- Full-custom: all logic cells are customized. A general purpose microprocessor is designed this way.
- Semi-custom: all of the logic cells are from predesigned cell libraries (reduces the manufacture lead time of the IC)
- Standard-cell based IC uses predesigned logic cells such as AND gates, OR gates, MUXs, FFs,.., etc.
- Macrocells (also called megacells) are larger predesigned cells, such as microcontrollers, even microprocessors, etc.
- Gate-Array, Sea-of-Gates or prediffused arrays contains array of transistors or gates which can be connected by wires to implement the chip.
- Programmable-Logic-Array (PLA) is an example of fuse-based FPGA design. (NOTE: Fuse-based, nonvolatile and volatile are three types of FPGAs)



Digital IC Design Flow





Digital IC Design Flow

- Design entry : Enter the design into an ASIC design system, either using a hardware description language (HDL) or schematic entry .
- Logic synthesis : Use an HDL (VHDL or Verilog) and a logic synthesis tool to produce a netlist—a description of the logic cells and their connections.
- System partitioning : Divide a large system into ASIC-sized pieces.
- Prelayout simulation : Check to see if the design functions correctly.
- Floorplanning : Arrange the blocks of the netlist on the chip.
- Placement : Decide the locations of cells in a block.
- Routing : Make the connections between cells and blocks.
- Extraction : Determine the resistance and capacitance of the interconnect.
- Postlayout simulation : Check to see the design still works with the added loads of the interconnect.