Algorithms for VLSI Design

Chapter 1: VLSI Design Cycle

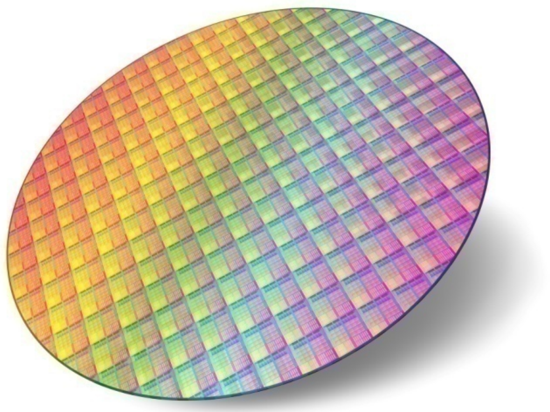
Chapter Outline

- Integrated Circuits
- Good VLSI Circuit Design
- Design Domains
- Top-down Design Methodology
- VLSI Design Actions

Integrated Circuits

- An integrated circuit (IC) is a combination of components like
  - diodes, transistors, resistors, capacitors
  - and their interconnections fabricated on the surface of a thin substrate of semiconductor material.
- Broadly classified into two types
  - monolithic
  - hybrid
- The term ‘monolithic’ is coined from two Greek words: monos mean ‘single’ and lithos mean ‘stone’.
- A hybrid IC consists of a combination of two or more IC types or an IC with some discrete elements.

Silicon Wafer



- The semiconductor substrate upon which the integrated circuits are fabricated is usually circular and flat and is referred to as ‘silicon wafer’.

  Typically a wafer has thickness less than 1mm (525μm- 775μm) and diameters in the range 100mm (4”) to 300mm (11.8”).

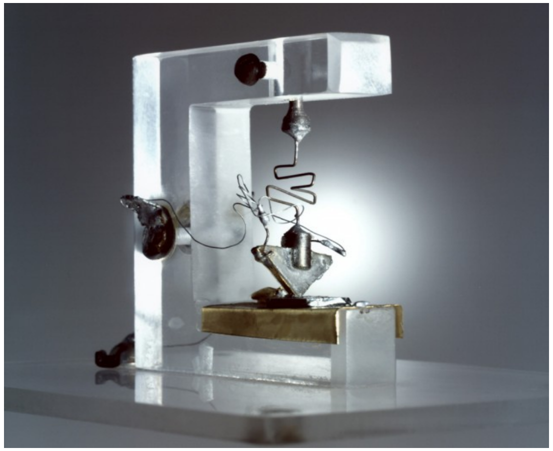
  Wafers are formed of highly pure (99.9999999% purity), nearly defect-free single crystalline material.

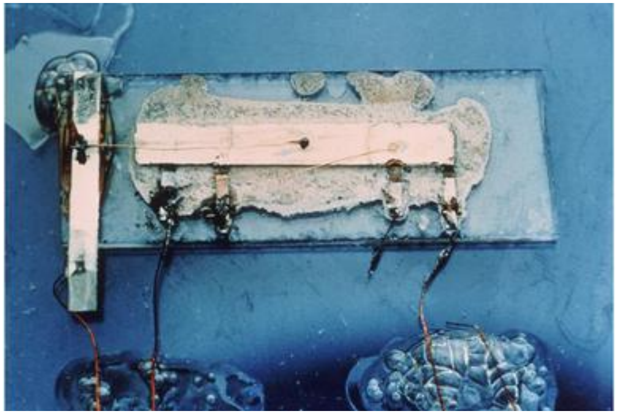
- One process for forming crystalline wafers is known as Czochralski growth

Advantages of IC

- Fabricate several hundreds of identical circuits simultaneously on a single substrate.
  - Batch fabrication
  - Reduce the cost of integrated circuits
- Much smaller compared to discrete component-based circuits.
  - small size leads to advantages in terms of high speed and low power consumption
- High frequency performance of the ICs is better compared to discrete circuits.
  - in integrated circuits, smaller components have smaller parasitic resistances, capacitances and inductances.
- Reliability of ICs is much better compared to discrete circuits.

History of IC Evolution





- First transistor invented in 1947 by Bardeen, Brattain and Schokley at the Bell Telephone Laboratory.
- Jack Kilby along with Robert Noyce at Texas Instruments first made the monolithic integrated circuit in 1958. Kilby awarded Nobel Prize in Physics in 2000.
- First commercial IC introduced by Fairchild Corporation in 1960 followed by TTL IC in 1962.
- Introduction of the first microprocessor 4004 by Intel in 1972.

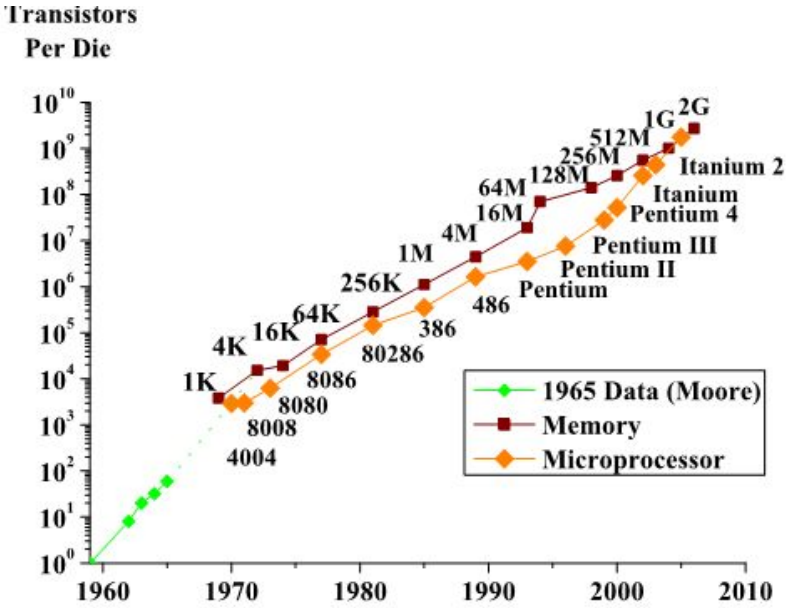
IC Evolution

Table 1.1: IC Evolution

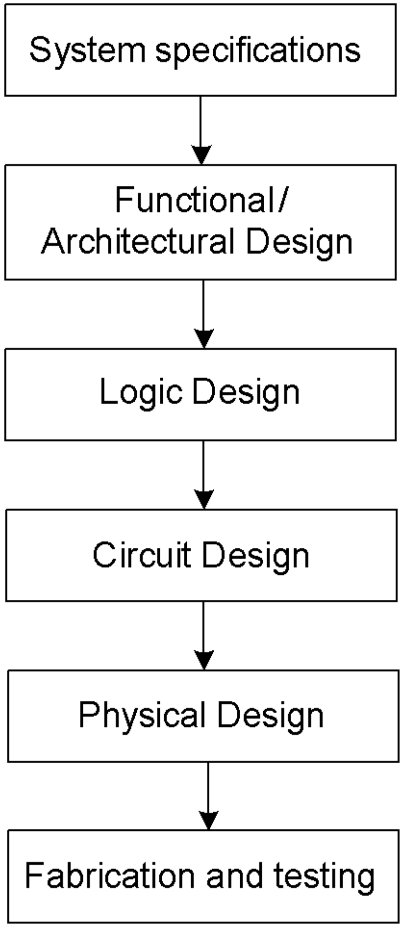
Generation	Date	Complexity
Single transistor	1958	< 1
One gate	1960	1
Single scale integration (SSI)	1964	< 20
Medium scale integration (MSI)	1967	20-200
Large scale integration (LSI)	1972	200-2,000
Very large scale integration (VLSI)	1978	2,000-20,000
Ultra large scale integration (ULSI)	1989	20,000-?

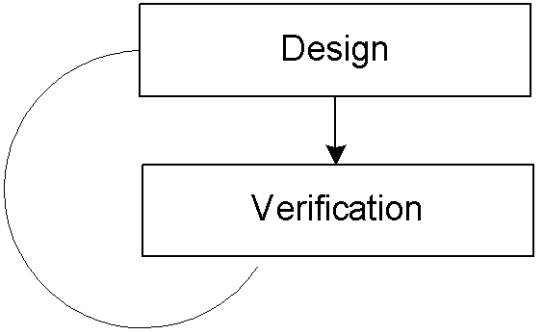
Moore’s Law (1965)

- Gordon Moore is the co-founder and chairman emeritus of Intel Corp.
- Statement: the number of transistors on a chip approximately doubles after every two years. This law is found to be valid for all technology generations.



VLSI Design Flow





- Sequence of design steps which are required to be executed to produce a packaged VLSI chip starting from a set of formal specifications of the chip.

Design Steps

- Formulation of the specifications of the system. The specifications include
  - performance, functionality and area.
  - process technology and design methodologies
- Functional/architectural design step:
  - Main functional blocks involved in the system along with the interconnects between the blocks are identified.
  - Behavioral aspects of the system are considered without considering the implementation details of the system.

Example

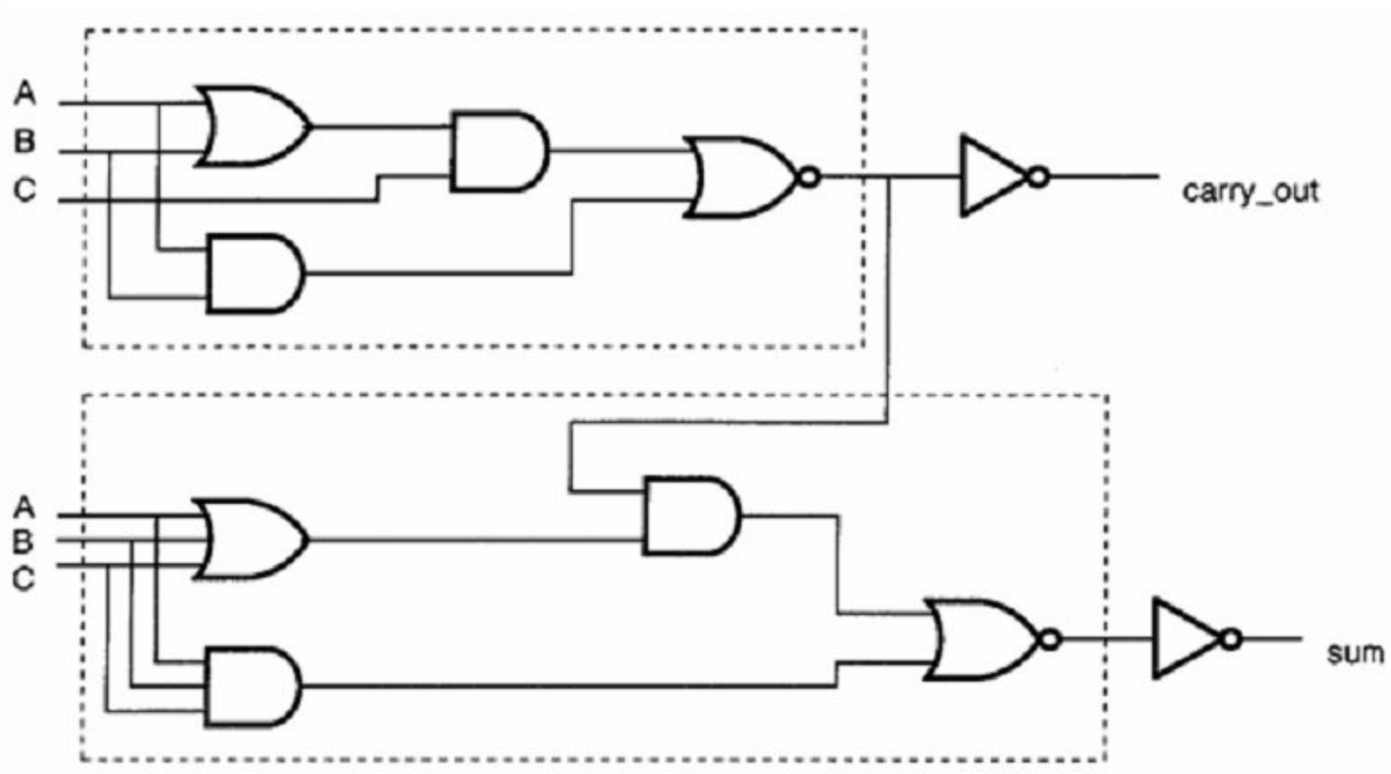
- Specifications for one-bit binary full-adder with 0.8-μm CMOS
  - Propagation delay of sum and carry_out signals < 1.2 ns (worst case)
  - Transition delay of sum and carry_out signals < 1.2 ns (worst case)
  - Circuit area < 1500 μm^2
  - Dynamic power dissipation (@ VDD = 5 V and fmax = 20 MHz) <1 mW
- Boolean description:
  - Input: A, B and C
  - Output: sum_out, carry_out

Design Steps

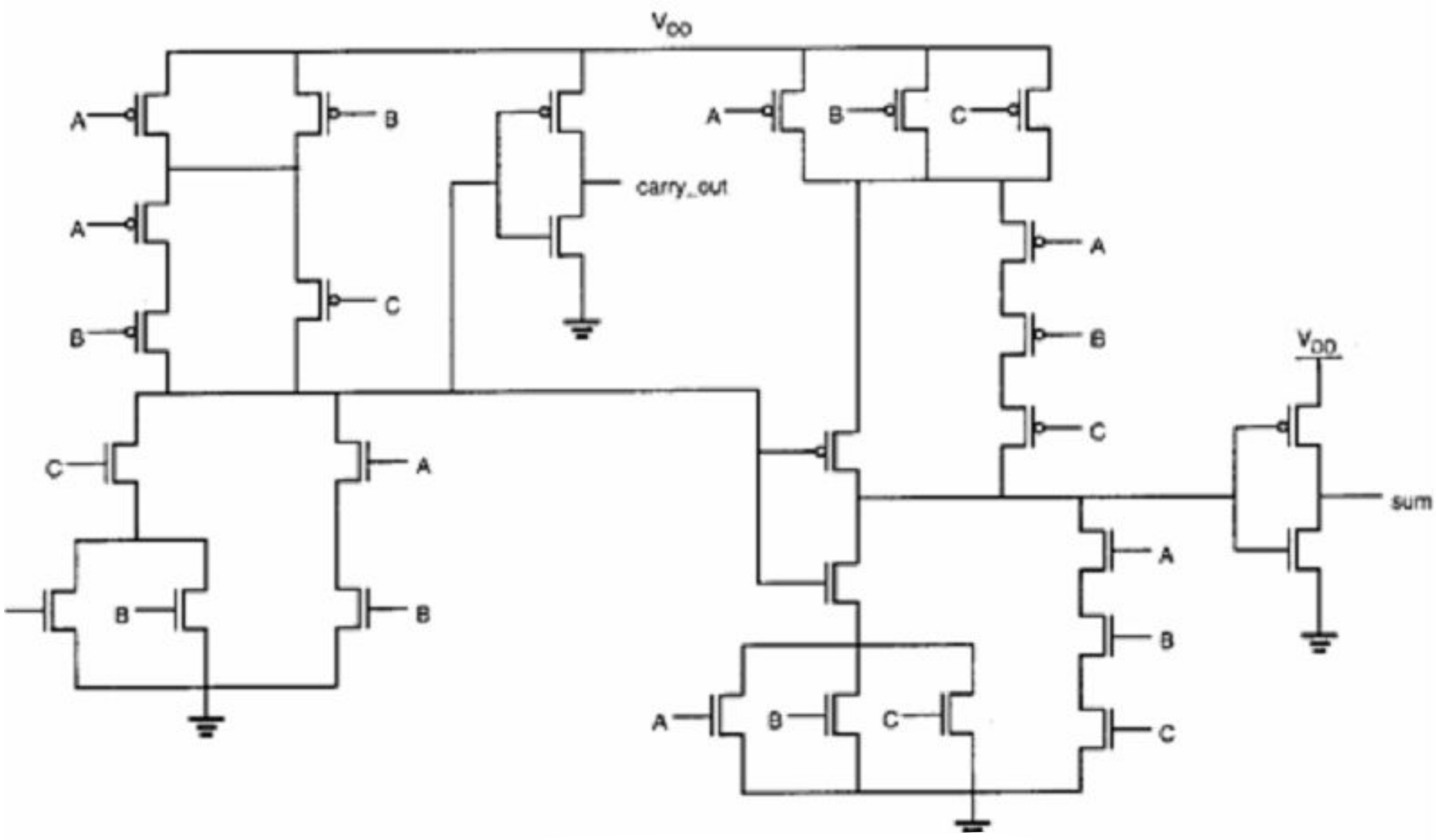
- Logic design step:
  - control flow, word widths, register allocation, arithmetic and logic operations of the design are derived.
  - The logic design deals with the gate level design.

- Circuit design step:
  - a circuit representation is developed based on transistors.
  - The Boolean expressions are converted to circuit representations by taking into consideration the speed and power requirements of the original design.

Example: Gate Level Schematic



Example: Transistor-level Schematic

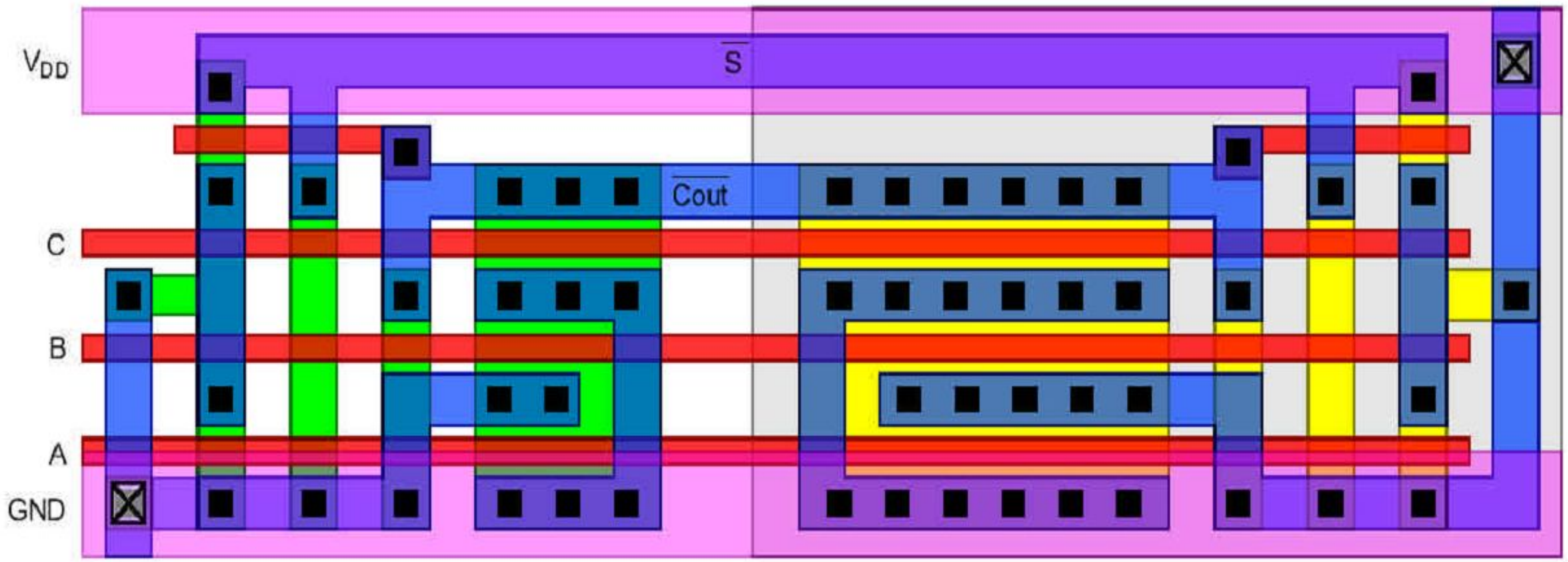


Design Steps

- Physical design:
  - the circuit representation is converted into a geometrical representation, referred to as layout.
  - sub-divided into few other steps like floor planning, placement, routing etc.

- After the physical design process, the design becomes ready for fabrication. Since the layout data (Graphics Data System-II, GDS-II) is typically sent to fabrication on a tape, the event of release of data is called tape out.

Example: Layout Design



Design Steps

- After the fabrication process, each chip is packaged and tested to ensure that it meets all design specifications and functions properly.
- After each step, the design is verified to see if the desired functionalities and specifications are satisfied at that step. Otherwise, the design step is repeated until and unless the desired goals are met.
- Verification at each of the design steps ensures that high probability of correctness of the design at the first attempt.

Good VLSI Circuit Design

- A first requirement is that the set of given specifications is realized. However, besides this, there are different entities that need to be optimized.

- Area: Minimization of the chip area is important to reduce the consumption of wafer area and to increase the yield of the design/chip.

Good VLSI Circuit Design

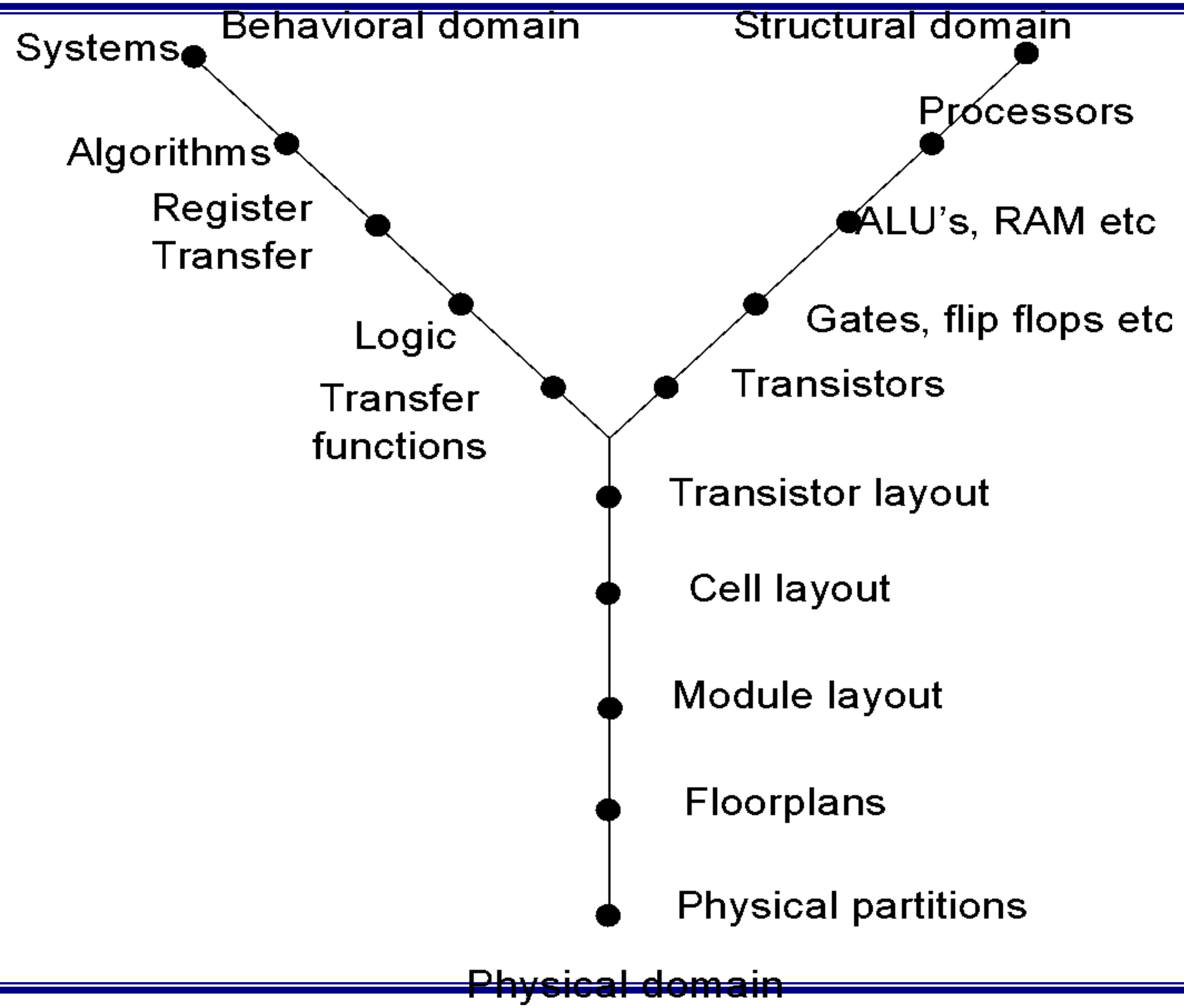
- Speed:
  - The speed of a circuit needs to be increased.
  - However, increasing the operation speed normally require a larger area.
  - The design process should therefore, always carefully consider the trade-off between the speed and the area.
- Power dissipation:
  - If a chip dissipated too much power, it either becomes too hot and ceases working or needs extra/expensive cooling mechanism.
  - In addition, for battery operated applications, medical applications etc., low power consumption is of primary importance.

Good VLSI Circuit Design

- Design time:
  - The design time of an integrated circuit needs to be small, so that it may be available in the market at the earliest for economic reasons.
  - The use of good EDA tools and design methodologies help to reduce the design time.

- Testability:
  - It is important that a chip is early testable as testing equipments as well as the testing process are expensive.
  - However, often the testability of a circuit is improved, sacrificing trivial increase in chip area.

Design Domains: Y-chart



Behavioral Domain

- A part of the design (or the whole) is seen as a black box.
- The relation between outputs and inputs are given without a reference to the implementation of these relations.
- Example: the behavioral description at the transistor level includes the mathematical equation relating the drain current with the various terminal voltages.

Structural Domain

- In this domain, a circuit is seen as the composition of sub-circuits. The structural domain description gives information of the sub-circuits used and their inter-connections.

- Each of the sub-circuits has a description in the behavioral domain or a description in the structural domain.

- Example: The schematic diagram of a NAND gate shows how transistors are interconnected to form a NAND gate.

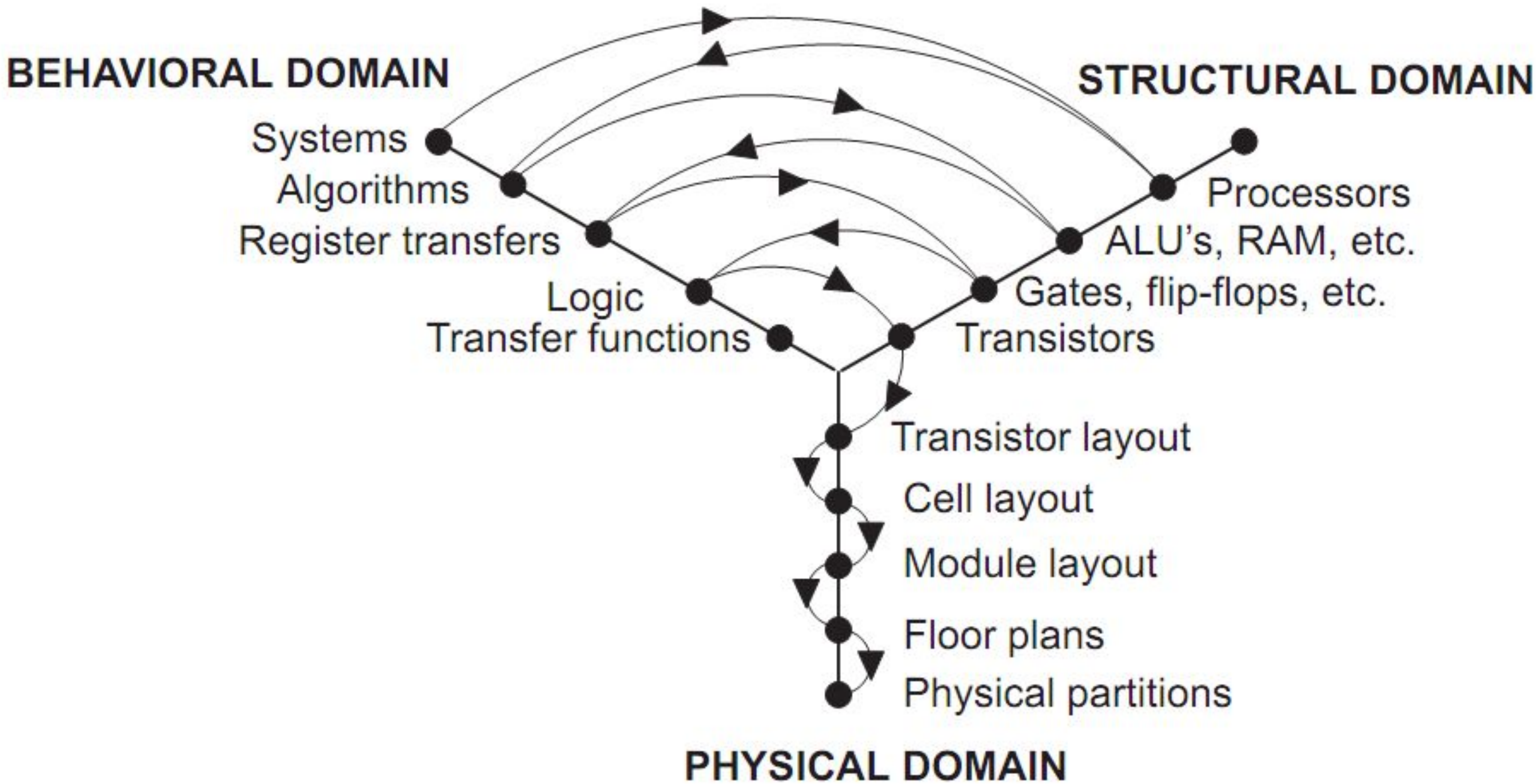
Physical Domain

- The physical domain deals with actual geometry of the circuit and describes the shape, size and location of its components.

- Gives information on how the subparts that can be seen in the structural domain, are located on the two-dimensional plane.

- Example: A cell that represents the layout of a logic gate consists of mask patterns that form the transistors of this gate and the associated interconnections.

Top-down Design Methodology



Top-down Design Methodology

- Components with know behavior are decomposed into smaller blocks with simpler behavior and an interconnection structure.
  - Corresponds to the transition from the behavioral to the structural domain.

- Each sub-component is again located on the behavioral axis and is decomposed in its own turn.
  - Continues until a sufficiently low level of abstraction is reached.

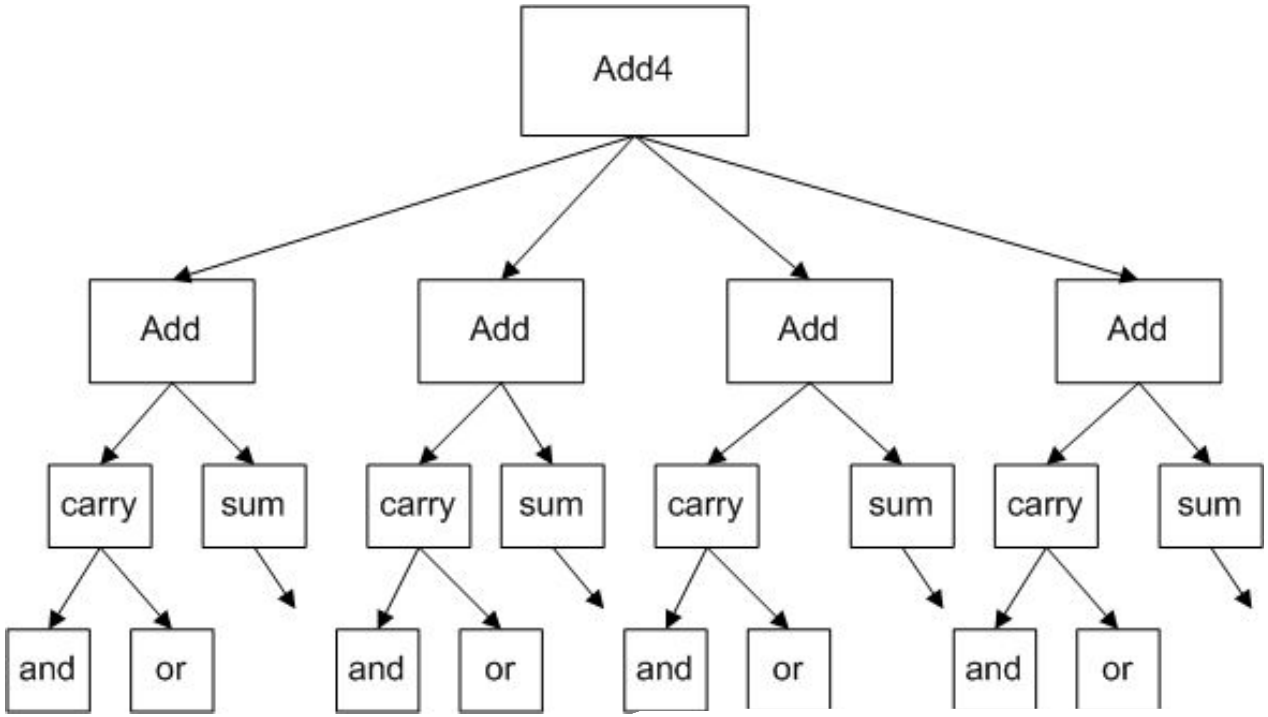
- When a circuit is fully specified down to the lowest structural level, the layout is specified in a bottom-up fashion.
  - Transistors are grouped to cells, cells are grouped to form modules etc.

VLSI Design Principle

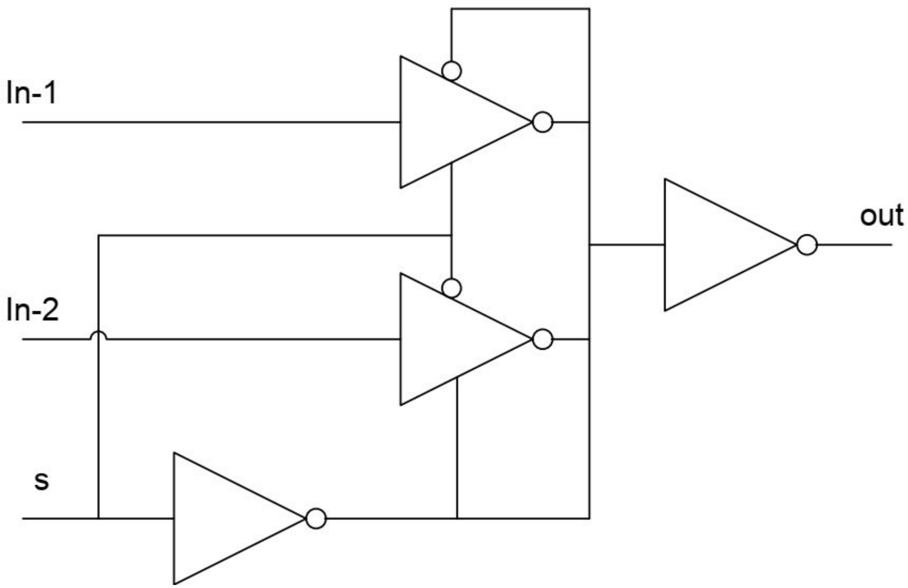
- Apart from significant development in IC fabrication technology, structured IC design principle is the key to exponential growth of integrated circuits.
- IC design principle is largely influenced by software engineering.
- Structured design technique is an engineering approach where a complex function is divided into a set of simple functions for the ease of understanding and satisfactory execution.
- The basic principle of structured design technique consists of
  - Hierarchy
  - Regularity
  - Modularity and
  - Locality

Hierarchy

- Hierarchy or ‘divide and conquer’ technique involves division of a design module into sub-modules and the repetition of this process on each of the sub-modules until the complexity of the sub-modules become manageable.



Regularity



- It is essential to divide the hierarchy into a set of similar sub-modules/building blocks.
- Regularity needs to be ensured at all steps of the design process.
- At the circuit level of design, uniformly sized transistors simplify the layout design procedure.
- During logic design, identical gate structures can be used

Modularity

- Modularity in design means that the various sub-modules and functional blocks which make up the complete design must have well-defined functions and interfaces.
- Each module or block can be designed separately and relatively independently from each other.
- The individual sub-modules are finally combined together to form the compete design.
- With the modular approach, the design procedure can be executed parallelly.
- The well-defined functionality and signal interface of the modules allow these to be reused in other designs.

Locality

- Through the well-characterized interfaces, the internal details of each module are localized and remain hidden to other modules.
- In this way, a sort of ‘information hiding’ is being performed that reduces the apparent design complexity of the module.
- Internal details are confined at the local level. The concept of locality in the design procedure ensures that connections are primarily made between neighbouring modules, avoiding long interconnects.

VLSI Design Actions

- Synthesis
  - The synthesis action increases information about the design by providing more detail.
  - Involves transition in the Y chart from one domain to another or within a single domain.
  - Synthesis action can be done in automated manner through EDA tools or manually by the designers.

- Verification
  - Ideally a synthesis step is correct-by-construction which means that the transformation leads to a new description, which satisfies the desired behavior and specifications.
  - However, if the result is not correct-by-construction, the verification action checks whether the detail design satisfies all the desired specifications and behavior.

VLSI Design Actions

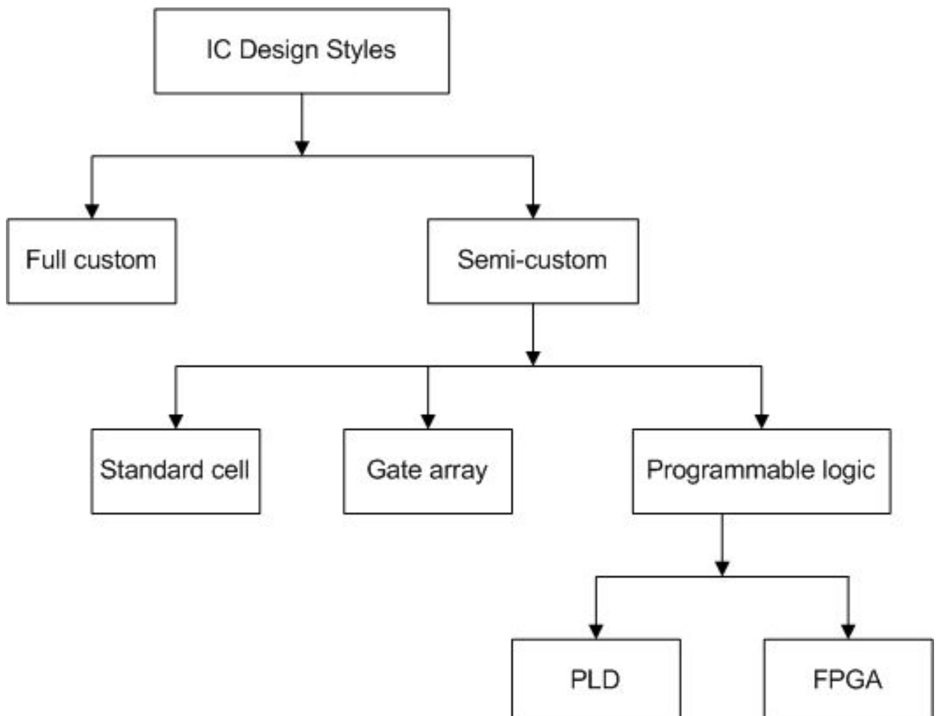
- Analysis
  - The analysis action involves collecting information on the quality of the design
  - e.g., how fast is the circuit, or how large is the area etc.

- Optimization
  - The optimization task deals with improvement of the quality of a design without necessarily making a transition to another level of abstraction or design domain.

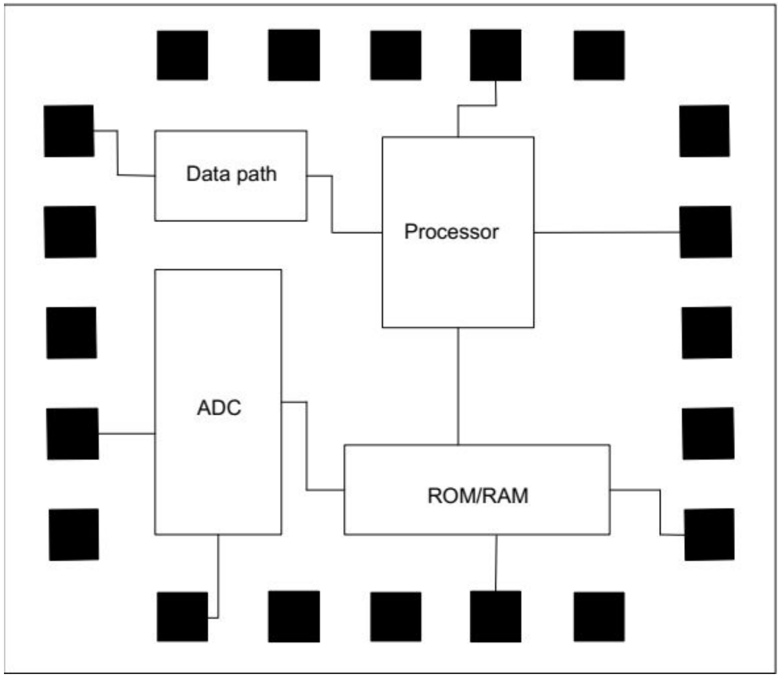
- Design Management
  - The design management tasks consist of design data storage, tool communication, invocation of tools in the right order etc.

VLSI Design Styles

- Several design styles are used in practice to reduce complexity of the design process.
- The design style is broadly classified into two types: full custom or semi custom.

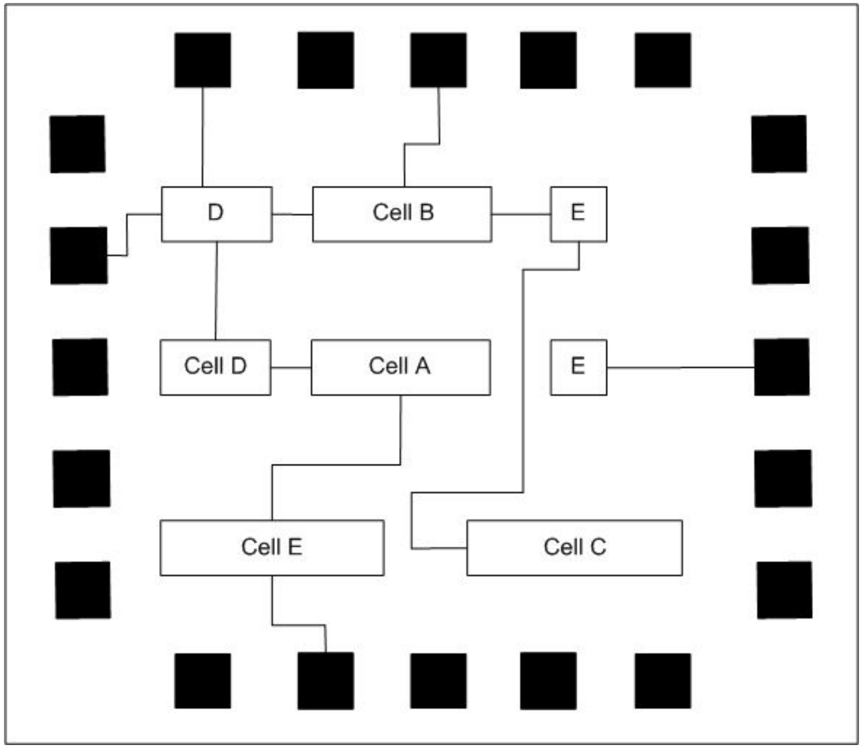


Full Custom Design Style



- Some or all of the logic cells, circuits or layouts are designed specifically for a certain application.
- This type of design style becomes essential, if the process technology is new such that well characterized technology libraries are not available or if the application is so specialized that the circuit must be entirely custom designed.
- does not impose any restriction on the sizes of the functional blocks.
- Allows very compact designs.

Standard Cell based design style



- Pre-designed logic cells (AND/OR gates, multiplexors and flip flops etc), known as standard cells are used to complete the design process.

Cells are stored in a cell library and for each functions, several alternative cells are available each with different area, speed and power characteristics.

While doing the layout of the compete circuit, the standard cells are placed in rows (like a wall built of bricks) and the space between two rows is called a channel. The empty space between the cells in a row is called feed through.