VLSI MODELING AND DESIGN

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Course Staff

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- Office hours :
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- Course Webpage:
  - http://eng.alexu.edu.eg/~mmorsy/Courses/Undergraduate/EE432_VLSI_Modeling_and_Design/EE432.html

Course Text

- Textbook
  - "CMOS VLSI Design 4th ed." Harris, David, and N. Weste., (2010).
- Reference books
  - "Introduction to VLSI circuits and systems." Uyemura, John P. ,(2002).
  - "Digital integrated circuits 2nd ed." Rabaey, Jan M., Anantha P. Chandrakasan, and Borivoje Nikolic., (2002).

Course Outline

- VLSI Implementation Strategies.
- MOSFET non ideal characteristics.
- Delay models and logical effort.
- Power consumption and low-power design considerations.
- Interconnect modeling, impact, and engineering.
- Robustness: Variability, Reliability, and Scaling.
- Design Methodologies and Tools.
- Testing, Debugging, and Verification.

Course Work

- 4 Labs: 20
- 1 Project: 15
- Midterm exam: 15
- Final Exam: 75
- Tools:
  - Electric http://www.staticfreesoft.com/
  - Tanner L-edit http://www.staticfreesoft.com/

About the Lectures

- Lectures will make use of slides
  - Slides are great !
    - Nice pictures to explain concepts
    - Good addition for course text
    - I can annotate them with a tablet PC
    - I can switch to the tools and listings mid-lecture
  - Slides are horrible !
    - They make me teach 30% faster (really)
    - They give you the sense that this is all easy stuff (it's not)
    - They make you fall a sleep
    - They make me lazy
    - They make me waste time looking for clipart
  - Slides are a two-edged sword
    - I encourage you to be active and take notes
    - I may fall back to blackboard-based teaching occasionally

History of VLSI

The Integrated Circuit

- 1959: Jack Kilby, working at TI, invented a monolithic "integrated circuit"
  - Components connected by hand-soldered wires and isolated by "shaping", PN-diodes used as resistors (U.S. Patent 3,138,743)

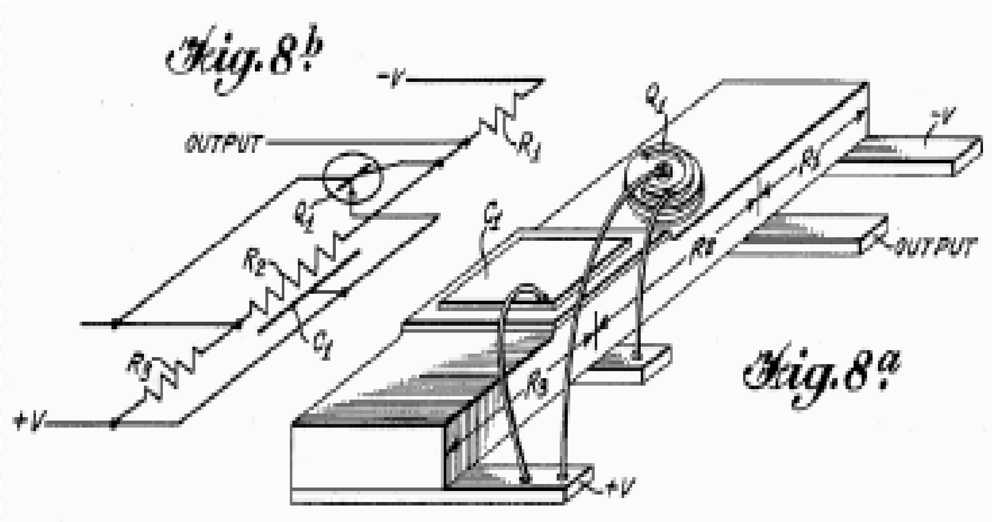


Figure 0.1 Diagram from patent application

Integrated Circuits

- 1961: TI and Fairchild introduced the first logic ICs ($50 in quantity)
- 1962: RCA developed the first MOS transistor

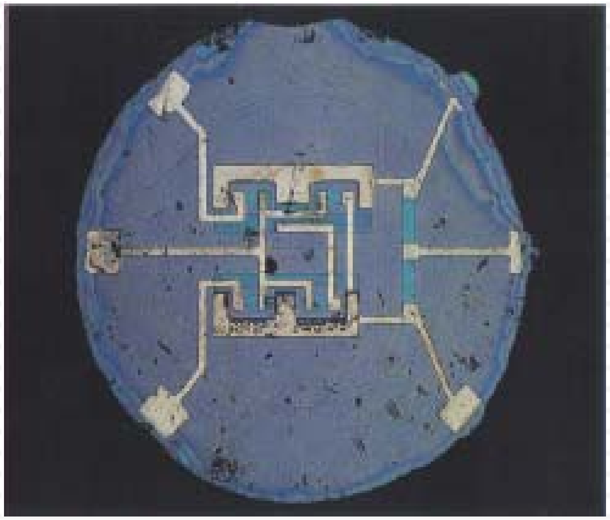


Figure 0.2 Fairchild bipolar RTL Flip-Flop

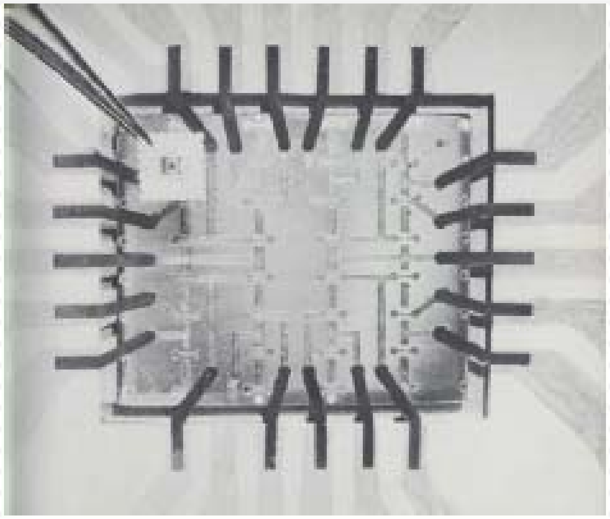
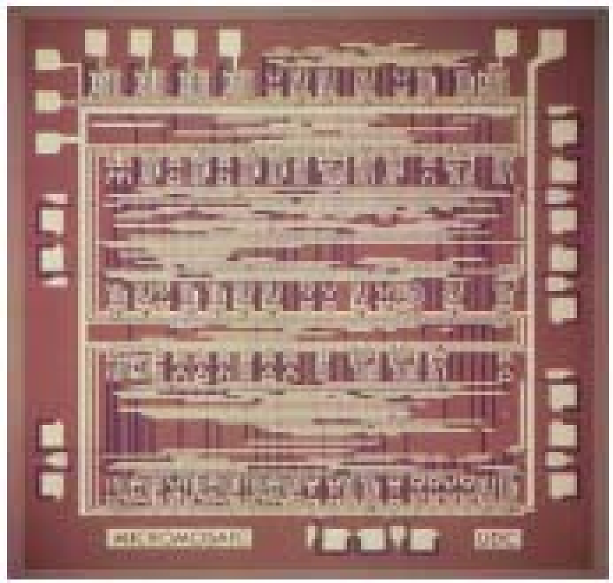


Figure 0.3 RCA 16-transistor MOSFET IC

Computer-Aided Design

- 1967: Fairchild developed the "Micromosaic" IC using CAD
  - Final layer of interconnect could be customized for different applications



- 1968: Noyce, Moore left Fairchild, started Intel

RAMs

- 1970: Fairchild introduced 256-bit Static RAMs
- 1970: Intel started selling 1K-bit Dynamic RAMs

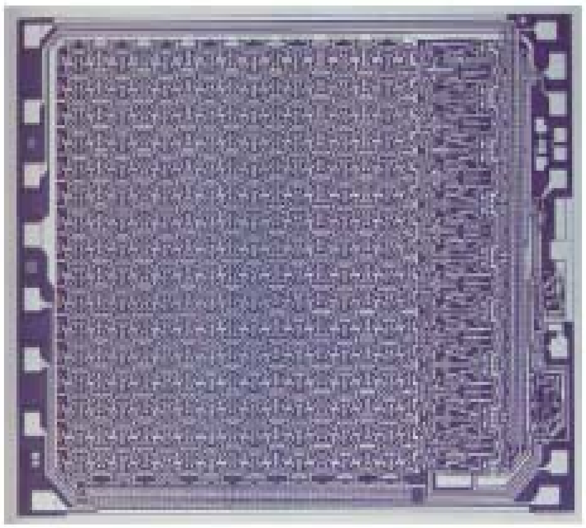


Figure 0.4 Fairchild 4100 256-bit SRAM

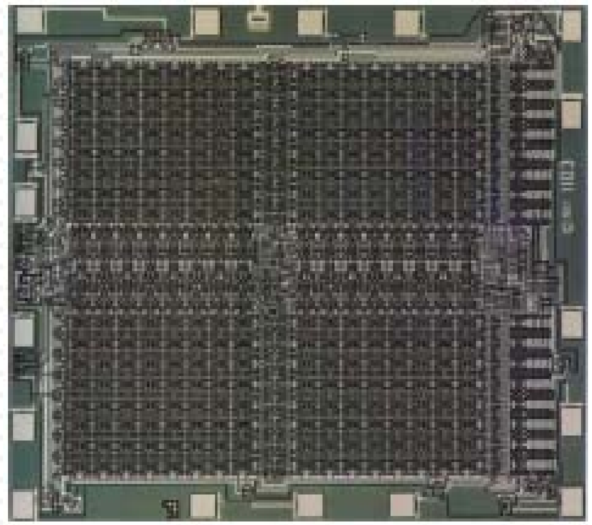


Figure 0.5 Intel 1103 1K-bit DRAM

The Microprocessor

- 1971: Intel introduced the 4004
  - General purpose programmable computer instead of a custom chip for a Japanese calculator company

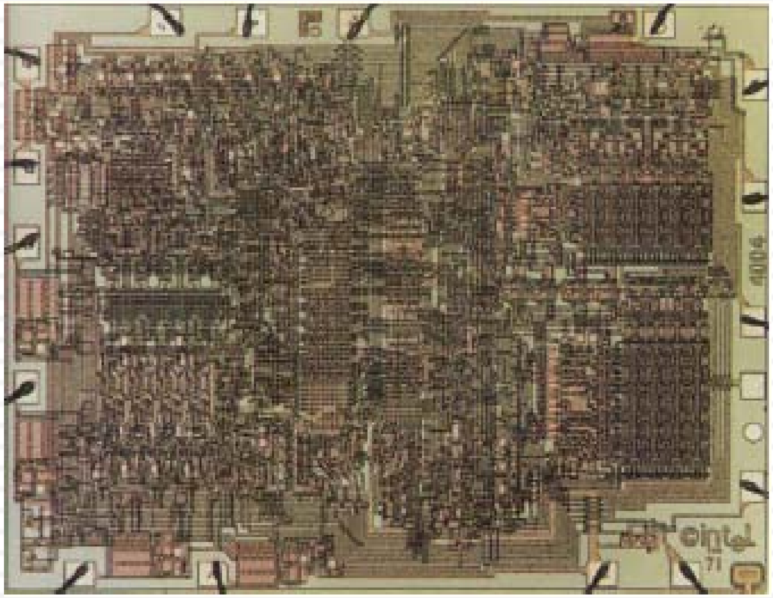
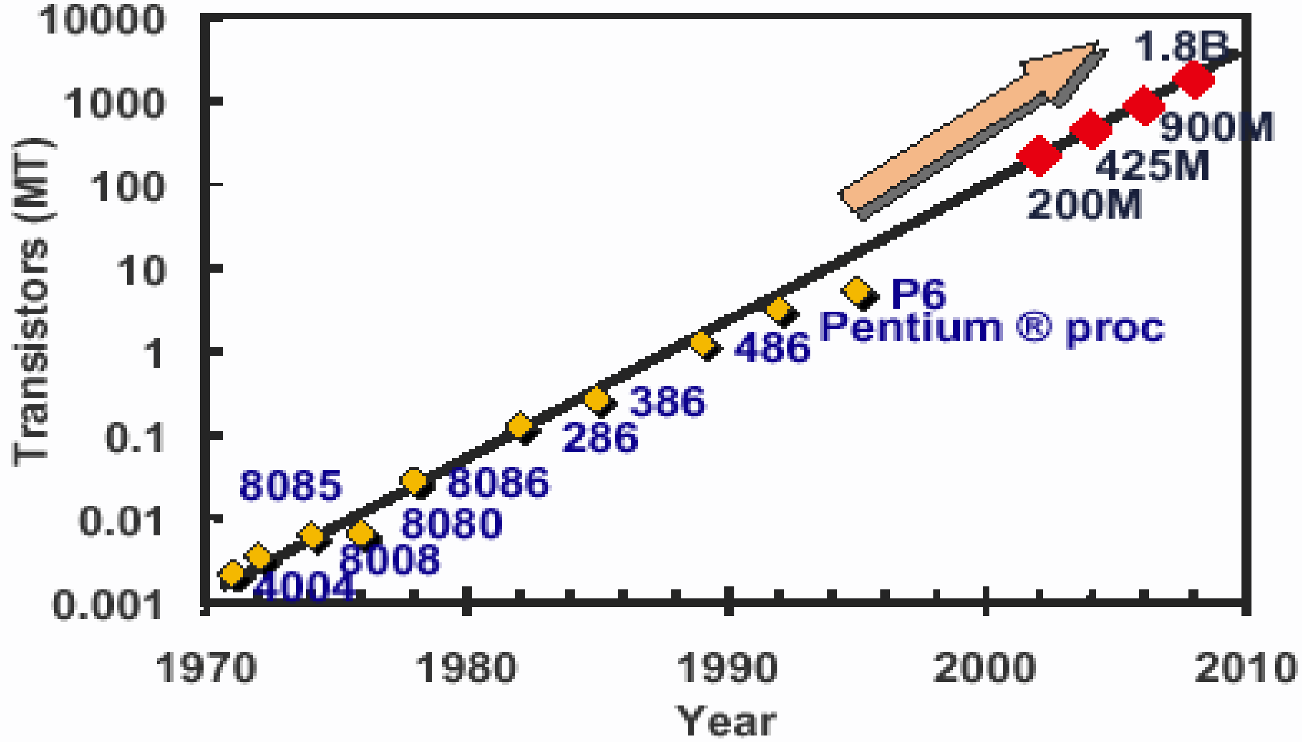


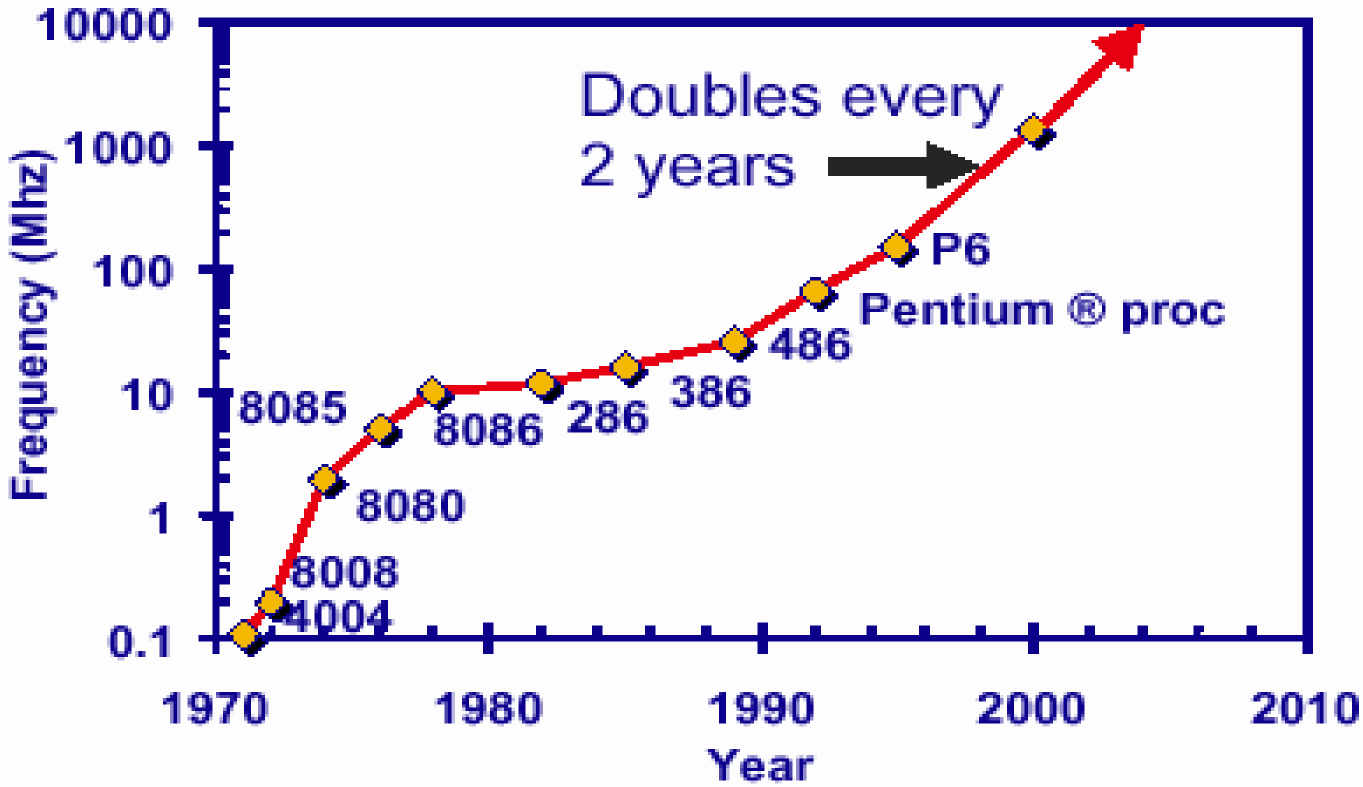
Figure 0.6 Intel 4004 Microprocessor

Moore's Law and Transistor Count



Transistors in Lead Microprocessors double every 2 years
Leads to 200M--1.8B transistors on the Lead Microprocessor

Moor's Law and Frequency



Lead Microprocessors frequency doubles every 2 years

Introduction

Outline

- Introduction
- Complexity and Design
- Basic Concepts

Introduction

- IC: Integrated Circuits, many transistors on one chip
- VLSI: Very Large Scale Integration, a modern technology of IC design flow
- MOS: Metal-Oxide-Silicon transistor (also called device)
- CMOS: Complementary Metal Oxide Semiconductor
  - Fast, cheap, low power transistors
  - High integration, low cost
  - n-type MOS (nMOS): Majority carriers are Electrons
  - p-type MOS (pMOS): Majority carriers are Holes
- First: How to build your own simple CMOS chip
  - CMOS transistors
  - Building logic gates from transistors
  - Transistor layout and fabrication
- Rest of the course: How to build a good CMOS chip!!

Introduction

- The term VLSI is used to collectively refer to many fields of electrical and computer engineering that deal with the analysis and design of very dense ICs
- A VLSI chip contains more than 10^6 switching devices or logic gates
- Early in the first decade of the 21st century, the actual number of transistors has exceeded 10^8 on a silicon die of typically 1 cm^2 area

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Complexity and Design

- Creating a design team provides a realistic approach to approaching a VLSI project, as it allows each person to study small sections of the system
  - VLSI project needs hundreds of engineers, scientists, and technicians
  - *Hierarchy design* and many different "*Level Views*" help to manage the complexity
  - Most work is conducted using computer-Aided Design (CAD) tools

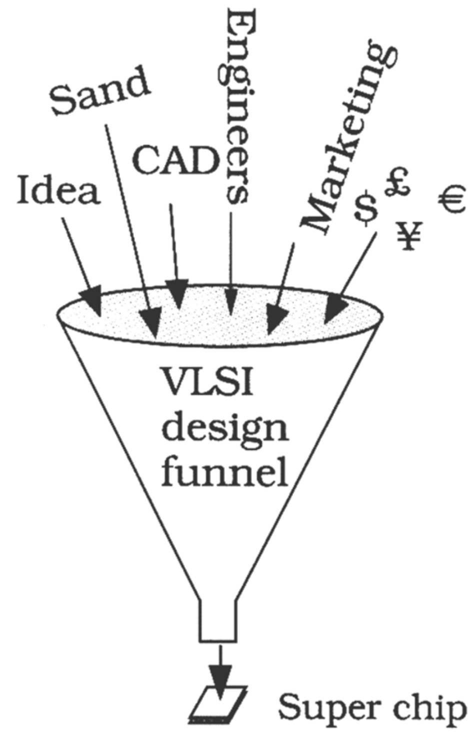

Figure 1.1 The VLSI design funnel

Complexity and Design

- Design teams provide a realistic approach to develop a VLSI chip
- The design hierarchy enables collaboration between team members and partitioning the work into a number of sub-tasks
- The chip is viewed at many abstraction levels from the system specifications to the physical implementation.

Design Hierarchy (1/2)

- System specifications: is defined in both general and specific terms, such as *functions*, *speed*, *size*, etc.
- Abstract high-level model: contains information on the behavior of each block and the interaction among the blocks in the system
- Logic synthesis: To provide the logic design of the network by specifying the primitive gates and units needed to build each unit
- Circuit design: where transistors are used as switches and Boolean variables are treated as vary voltage signal
- Physical design: the network is built on a tiny area on a slice of silicon
- Manufacturing: a completed design process is moved on to the manufacturing line

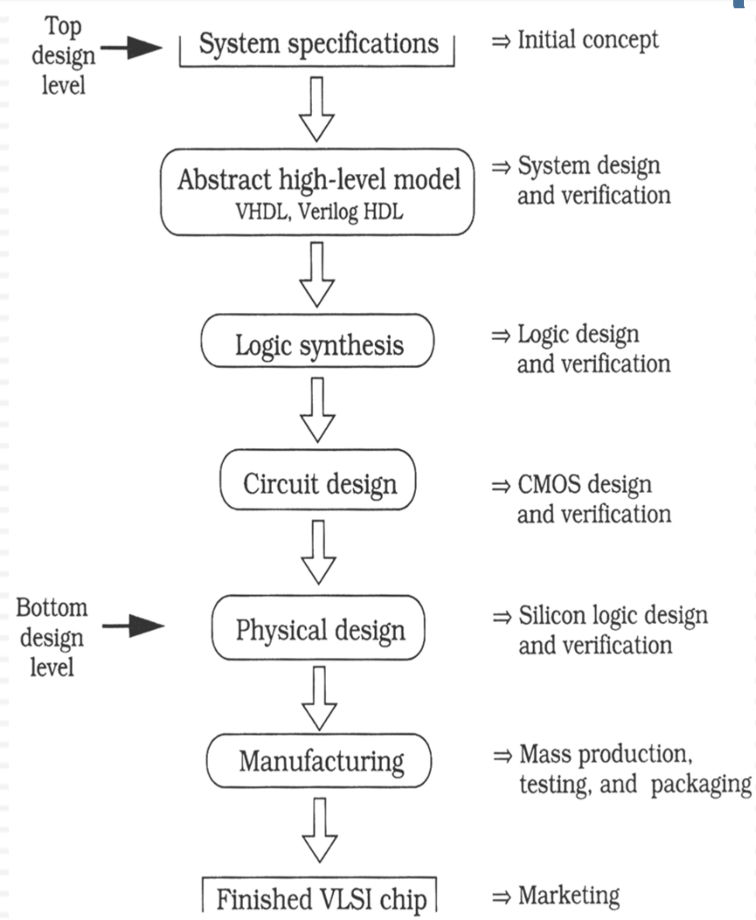

Figure 1.2 General overview of the design hierarchy

Design Hierarchy (2/2)

- Hierarchical design
  - **Top-down design**
    - The initial work is quite abstract and theoretical and there is no direct connection to silicon until many steps have been completed
    - Acceptable in modern digital system design
    - Co-design with combining HW/SW is critical
    - Similar to *Cell-based Design Flow*
  - **Bottom-up design**
    - Starts at the silicon or circuit level and builds primitive units such as logic gates, adders, and registers as the first steps
    - Acceptable for small projects
    - Similar to *Full-custom Design Flow*
- An example of a design hierarchy in Figure 1.3

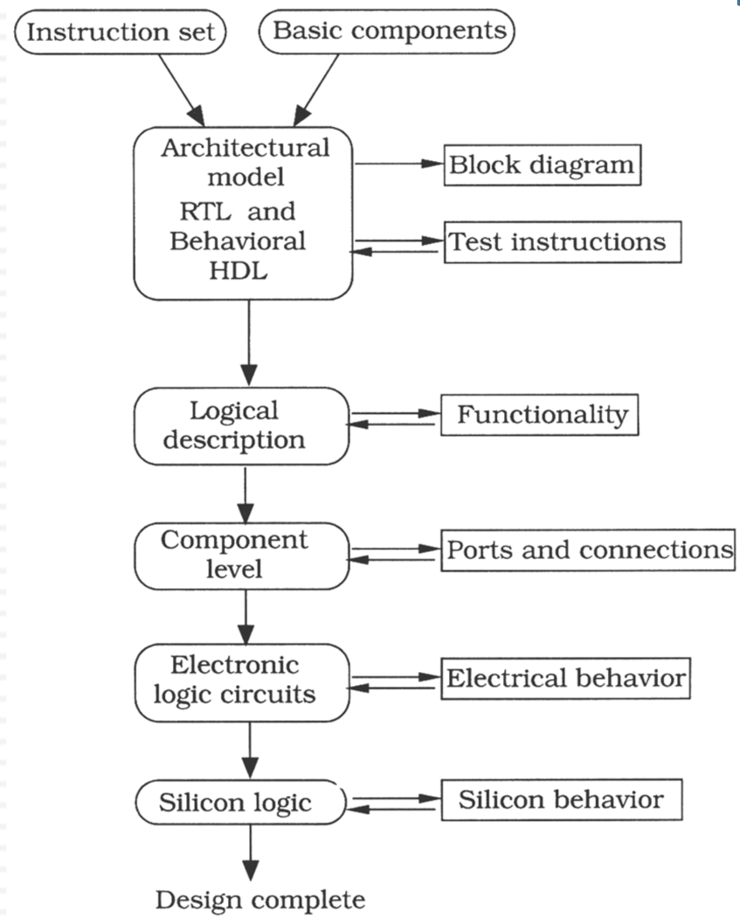

Figure 1.3 A simple design flow for a microprocessor

VLSI Chip Types

- At the engineering level, digital VLSI chips are classified by the approach used to implement and build the circuit
  - **Full-custom Design**: where every circuit is custom designed for the project
    - Extremely tedious
    - Time-consuming process
  - **Application-Specific Integrated Circuits (ASICs)**: using an extensive suite of CAD tools that portray the system design in terms of standard digital logic constructs
    - Including state diagrams, functions tables, and logic diagram
    - Designer does not need any knowledge of the underlying electronics or the physic of the silicon chip
    - Major drawback is that all characteristics are set by the architectural design
  - **Semi-custom Design**: between that of a full-custom and ASICs
    - Using a group of primitive predefined cells as building blocks, called *cell library*

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Basic Concepts

- VLSI Design is a system design discipline
- Many aspects can be taught without any reference to the underlying silicon circuits
- System solutions can be generated using CAD tools
- Such an approach hides many details from the designer
- However, many of the most powerful techniques and ideas of VLSI reside at lower levels
- VLSI should be thought as a single discipline that deals with the conception, design, and manufacture of complex ICs

Basic Concepts: Geometrical Patterns

- Carver Mead of Caltech pioneered the field in the 1970's, a topic that *the electronic integrated circuits could be viewed as a set of geometrical patterns on the surface of a silicon chip*
  - Can achieve signal flow and data movement by tracing the paths of the metallic "lines" that carried electricity
  - Using the repeated patterns and ordered placement of rectangular lines, polygons, and groups of geometric patterns
  - Most modern VLSI technology is based on this important field
- Today, the most powerful topic is System-on-Chip (SoC) that using *bonding pad* technology as Figure 1.5 shows

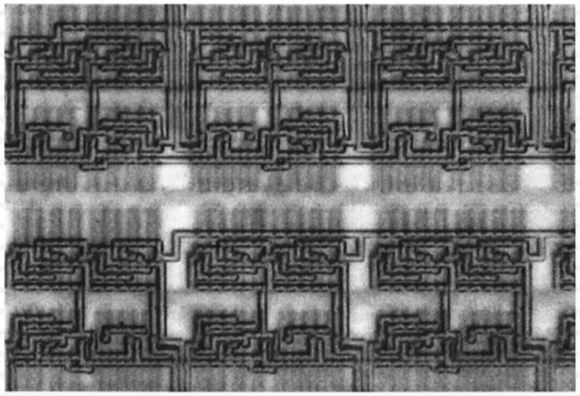

Figure 1.4 Micrograph of a section of a digital CMOS integrated circuit

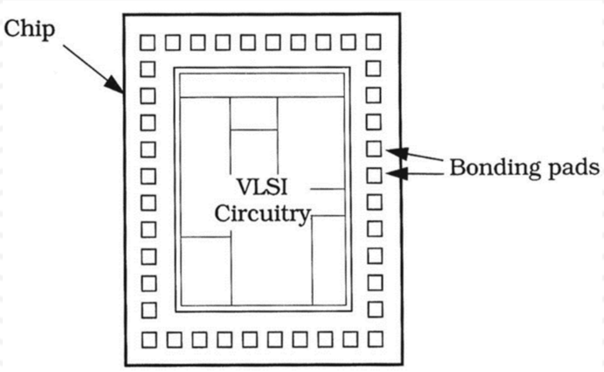

Figure 1.5 Bonding pad frame for interfacing