0113611 COMPUTER HARDWARE

DIGITAL DESIGN AND CAD TOOLS

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DIGITAL HARDWARE

- Integrated circuit chips are manufactured on a silicon wafer.
- The wafer is cut to produce the individual chips, which are then placed inside a special type of chip package.

A silicon wafer
Digital Hardware

- **Moore’s Law:** Chip density—doubling the number of transistors on a chip every 1.5 to 2 years

<table>
<thead>
<tr>
<th>Table 1.1</th>
<th>A sample of the International Technology Roadmap for Semiconductors.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Year</td>
</tr>
<tr>
<td>Technology feature size</td>
<td>2006</td>
</tr>
<tr>
<td>Transistors per cm²</td>
<td>78 nm</td>
</tr>
<tr>
<td>Transistors per chip</td>
<td>283 M</td>
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<tr>
<td>Transistors per chip</td>
<td>2,430 M</td>
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</table>
Transistor Count Growth Rate

- 100 million transistors on chip by early 1990’s A.D.
- Transistor count grows much faster than clock rate
  - 40% per year, order of magnitude more contribution in 2 decades

Core 2 Duo
291 M in 2006

Intel Core i7
45nm, 781 M in 2008

Pentium 4
55M
In 2002

80486
1.18M
In 1989

Itanium 2
(1.5GHz)
221M
In 2003
Types of Chips

- **Standard Chips**
  - 7400, 7408, etc.

- **Programmable Logic Devices**
  - Programmable logic devices (PLDs)
  - Field-programmable gate array (FPGA)

- **Custom-Designed Chips**
  - Custom or semi-custom chips
  - Application-specific integrated circuits (ASICs)

A field-programmable gate array chip.
The Design Process

- Design
  - Given a specification of a problem
  - come up with a way of solving it
    - choosing appropriately from a collection of available components

- The process is to develop a product that meets certain expectations. The product must
  - function properly
  - meet an expected level of performance
  - meet some criteria for size, cost, power, etc.
The Development Process

1. Required product
2. Define specifications
3. Initial design
4. Simulation
5. Redesign
   - Design correct?
     - Yes: Prototype implementation
     - No: Redesign
6. Make corrections
   - Minor errors?
     - Yes: Prototype implementation
     - No: Redesign
7. Testing
8. Meets specifications?
   - Yes: Finished product
   - No: Redesign
Design Process

- **Define specifications:** essential features of the product are identified.
  - Specifications must be tight enough to ensure that the developed product will meet the general expectations, but not be unnecessarily constraining.

- **Initial design:** is generated from the design specifications
  - This step is usually performed by a human designer.
  - It requires considerable design experience and intuition.
Design Process

- **Simulation**: CAD tools are used to simulate the behavior of the initial design to determine whether the obtained design meets the required specifications.
  - If errors are found appropriate changes are made and verification is repeated through simulation.
  - Usually all except subtle problems are discovered in this way.

- **Prototype implementation**: When simulation indicated that the design is correct, a prototype of the product is constructed.
Design Process

- **Testing**: The prototype is thoroughly tested for conformance with the specifications.
  - Minor errors are often eliminated by making small corrections directly on the prototype.
  - In the case of large errors, it is necessary to redesign the product.
Basic Design Loop

1. Design concept
2. Initial design
3. Simulation
4. Design correct?
   - Yes
   - No, Redesign
5. Successful design
Structure of a Computer

Figure 1.5. A digital hardware system (Part a).

Figure 1.5. A digital hardware system (Part b).
A printed circuit board (PCB). NUMAachine is a multiprocessors.

Design of a Digital Hardware Unit
Logic Design

- **Logic design**
  - determining the collection of digital logic components to perform specified functions
  - which logic components to choose
    - many implementation technologies
  - Design may need to be optimized

- **Application of logic design**
  - Computer system: CPU, Register files, Busses, Peripherals
  - Embedded products: phones, cars, toys, appliances, etc.
Design flow for logic circuits
Design of digital hardware

- A common way of dealing with complexity in digital hardware is to **partition** the circuit into smaller blocks and **design** each block separately.
- Having successfully designed all blocks, the **interconnection** between blocks must be defined.
- **Functional Simulation:** The complete circuit is simulated and errors are corrected
  - Errors caused by incorrect connections: connections are redefined (path C)
  - Some blocks have not been designed correctly: erroneous blocks are redesigned (path B)
  - Some functionality missing: incorrect partitioning (path A)
Design of digital hardware

- **Physical mapping**: physical location of each chip on the board and wiring pattern
  - CAD tools are relied on
  - Does the physical layout affect the performance of the circuit (even though the functional behavior of complete system is correct)?
  - Physical wiring introduce resistance and capacitance. It may have an impact on the speed of operation.

- **Timing simulation** is used to check the performance of the circuit after wiring.
  - It is customary to use *functional* and *timing* simulation
  - A timing simulation may reveal potential performance problems.
Implementation: Having completed timing simulation a prototype of the circuit is implemented. 

- The prototype is tested.
- Minor errors are corrected on the prototype.
- Large problems require a redesign.
Completion of PCB development.

- Implementation
  - Build prototype
    - Testing
      - Correct?
        - No
          - Modify prototype
            - Yes
              - Go to A, B, C, or D in Design flow for logic circuits
            - No
        - Yes
          - Finished PCB
A CAD system has tools for performing the following tasks:

- Design entry
- Synthesis
- Functional simulation
- Logic synthesis and optimization
- Physical design
- Timing simulation
- Chip configuration
A typical CAD system.
CAD tools

- The starting point in the process of designing a digital circuit is the conception of what the circuit is supposed to do and the formulation of its general structure.
- This step is done manually. The rest is done by CAD tools.
CAD tools

- **Design entry**: A description of the circuit being designed should be entered into CAD system.

- **Schematic Capture**: The word schematic refers to a diagram of a circuit in which circuit elements, such as logic gates, are depicted as graphical symbols and connections between circuit elements are drawn as lines.

- **Hardware description languages (HDL)**: Used to describe hardware rather than a program to be executed on a computer.
  - Two HDLs are IEEE standards: VHDL (Very high speed integrated circuit HDL) and Verilog HDL.
CAD tools

- **Synthesis**: the process of generating a logic circuit
  - The process of translating, or compiling, VHDL code into a network of logic gates is part of synthesis
  - Logic synthesis and optimization produces an equivalent but better circuit
  - The measure of what makes one circuit better depends on the needs of a design project and the technology chosen for implementation

- **Step 3: Functional simulation**: is used to verify the functionality of the circuit based on input provided by the designer
  - This simulation is performed before any optimization and propagation delays are ignored.
  - **Goal**: validate the basic operations of the circuit
CAD tools

- **Physical design**: how to implement the circuit in the target technology
  - This step consists of **placement** and **routing**
    - **Placement**: where in the target device each logic function in the optimized circuit will be realized
    - **Routing**: which wires in the chip are to be used to realize the required interconnections
CAD tools

- **Timing simulation**: determines the propagation delays that are expected in the implemented circuit
- Timing simulation: ensures that the implemented circuit meets the required performance
- Some of timing errors can be corrected by using the synthesis tool
- If the logic synthesis tool cannot resolve the timing problem, it is necessary to return to the beginning of the design flow to consider other alternatives

- **Chip Configuration**: configure the target chip to implement the circuit.
- This step is called chip configuration or programming.