CS M51A/ EE M16 LOGIC DESIGN OF DIGITAL SYSTEMS

- INSTRUCTOR: Prof. Miloš Ercegovac
- TAs: Dis 2A Gurupavan Mazumdar, Dis 2B Sonali Garg, Dis 2C Arulsaravana Jeyaraj
- TEXTBOOK: *Introduction to Digital Systems* by Ercegovac, Lang and Moreno, Wiley 1999. Available as Reader in UCLA Bookstore and on the Web
- GRADING
  - Homeworks: 10%
  - Quizzes (4): 20% (in Discussions)
  - Midterm: 30% ; Final: 40%

- IT HELPS TO READ THE TEXTBOOK BEFORE LECTURES, IDENTIFY KEY CONCEPTS and THINK OF QUESTIONS

- LECTURES VIEWGRAPHS AUGMENTED WITH NOTES AND EXAMPLES

- QUESTIONS DURING LECTURES ARE WELCOME; YOU CAN ALSO POST THEM ON CLASS FORUM OR E-MAIL THEM TO ME

- COME TO OFFICE HOURS - WITH SPECIFIC QUESTIONS

- DISCUSSION SECTIONS FOCUS ON : HOMEWORKS, PROBLEM SOLVING, LogiSim DESIGNS, Q & A, QUIZZES

- MIDTERM and FINAL EXAMS are closed book and notes; 4 cheat sheets OK.

- CHECK REGULARLY THE CLASS WEB SITE FOR UPDATES
  Lecture viewgraphs, homeworks/solutions, solutions to all odd-numbered exercises from the book, sample exams, announcements, and more ...

- WE USE A SIMPLE LOGIC DESIGN ENTRY AND SIMULATION TOOL LogiSim (free download); VHDL WILL NOT BE COVERED;

- SOLUTIONS TO ODD-NUMBERED EXERCISES POSTED ON THE CLASS WEB PAGE. WORK IN GROUPS ON THESE PROBLEMS.
- WORK INDEPENDENTLY ON THE GRADED MATERIAL: YOUR HIGHEST ETHICAL CONDUCT IS EXPECTED.

INTRODUCTION TO DIGITAL SYSTEMS

- DESCRIPTION AND DESIGN OF DIGITAL SYSTEMS
- FORMAL BASIS: SWITCHING ALGEBRA
- IMPLEMENTATION: MODULES (ICs) AND NETWORKS
- IMPLEMENTATION OF ALGORITHMS IN “HARDWARE”
- COURSE EMPHASIS: CONCEPTS, ANALYSIS AND DESIGN
- Follow-on courses:
  - Computer Architecture CS M151B;
  - Introductory Digital Design Lab CS M152A;
  - Digital Design Project Lab CS 152B

OVERVIEW

- WHAT IS A DIGITAL SYSTEM?
- HOW IT DIFFERS FROM AN ANALOG SYSTEM?
- WHY ARE DIGITAL SYSTEMS IMPORTANT?
- BASIC TYPES OF DIGITAL SYSTEMS: COMBINATIONAL AND SEQUENTIAL
- SPECIFICATION AND IMPLEMENTATION OF DIGITAL SYSTEMS
- ANALYSIS AND DESIGN OF DIGITAL SYSTEMS
- DESIGN PROCESS AND CAD TOOLS

WHAT IS DIGITAL?

DIGITAL SYSTEMS

– inputs and outputs:

finite number of discrete values

ANALOG SYSTEMS

– inputs and output values:

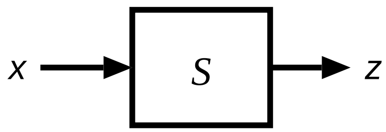
from a continuous (infinite) set

Example: digital vs. analog scale for measuring weights

MAIN USES OF DIGITAL SYSTEMS:

- INFORMATION PROCESSING (text, audio, visual, video)
- TRANSMISSION (communication)
- STORAGE

SYSTEM AND SIGNALS



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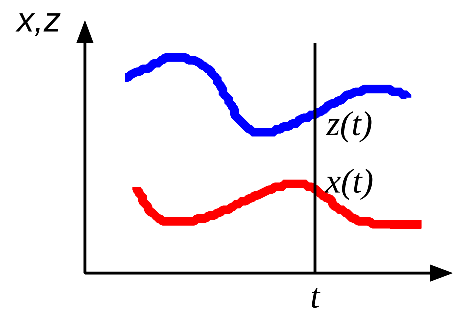

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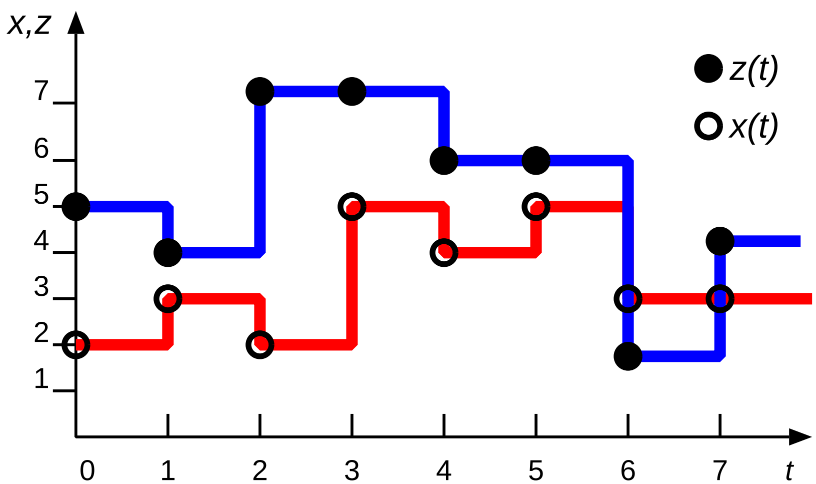


(c)

t	0	1	2	3	4	5	6	7
$x(t)$	2	3	2	5	4	5	3	3
$z(t)$	5	4	7	7	6	6	2	4

(d)

Figure 1.1: System S: a) Block diagram. b) Analog I/O signals. c) Digital I/O signals. d) I/O sequence pair.

WHY DIGITAL

1. FOR BOTH NUMERICAL AND NONNUMERICAL INFORMATION PROCESSING
2. INFORMATION PROCESSING CAN USE A GENERAL-PURPOSE SYSTEM (a *computer*)
3. DIGITAL REPRESENTATION:

– vector of signals with just two values (*binary signals*)

Example:

digit	0	1	2	3	4	5	6	7	8	9
vector	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001

– All signals binary

– Simple devices to process binary signals:

(SWITCHES with two STATES: open and closed).

WHY DIGITAL (cont.)

4. DIGITAL SIGNALS INSENSITIVE TO VARIATIONS OF COMPONENT PARAMETER VALUES

Figure 1.2: Separation of digital signal values.

WHY DIGITAL (cont.)

5. Numerical digital systems can be made MORE ACCURATE by simply increasing the number of digits used in the representation.

6. PHENOMENAL ADVANCES OF MICROELECTRONICS TECHNOLOGY:

   - Possible to fabricate extremely complex digital systems, which are small, fast, and cheap

   - Digital systems built as *integrated circuits* composed of a large number of very simple devices

7. DIFFERENT IMPLEMENTATIONS OF SYSTEMS WHICH TRADE-OFF SPEED AND AMOUNT OF HARDWARE (COST)

Example:

– add two integers represented by six decimal digits

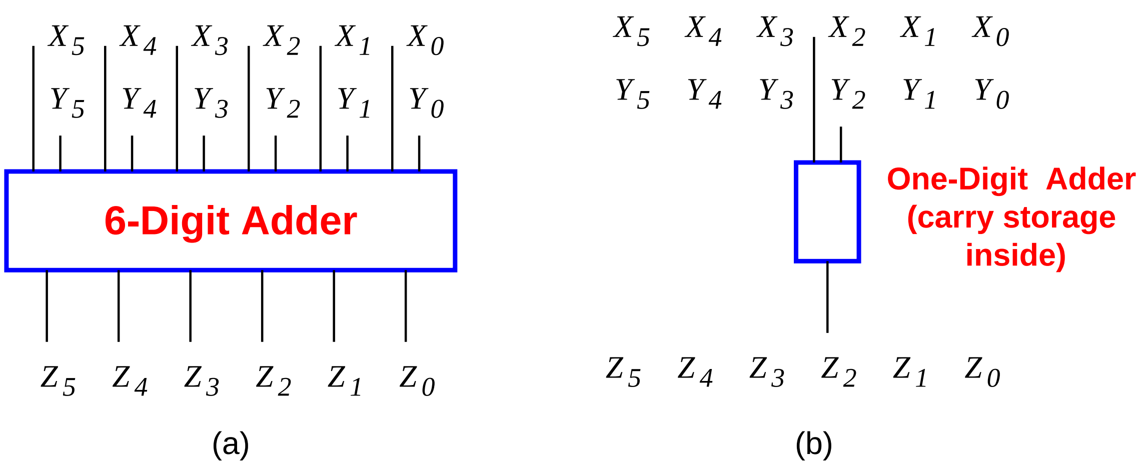
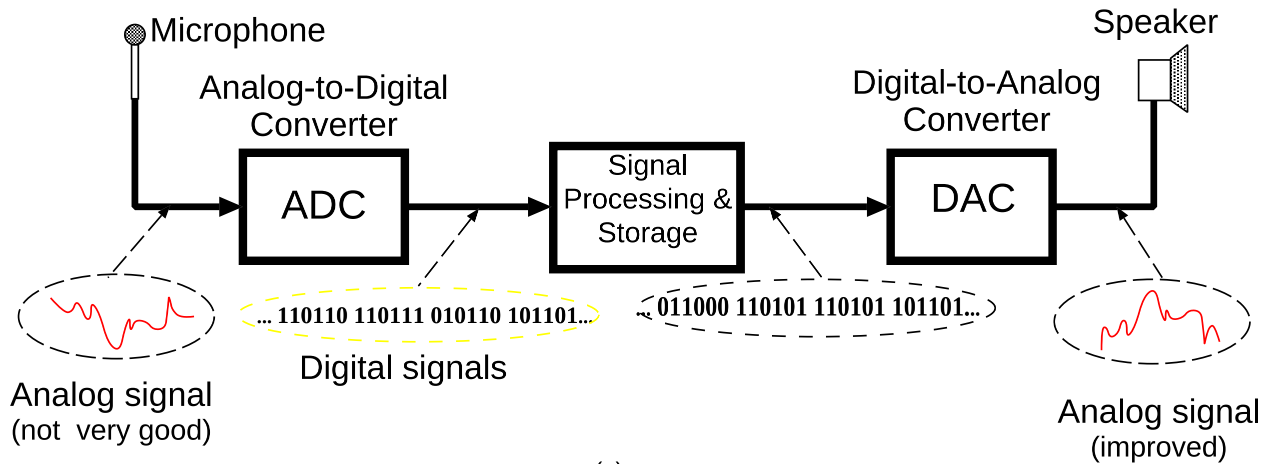


Figure 1.3: Six-digit adder: a) Parallel implementation. b) Serial implementation.

SUMMARY

- DIGITAL REPRESENTATION AND PROCESSING METHODS WIDELY USED
- EXTRAORDINARY PROGRESS IN DIGITAL TECHNOLOGY AND USE
- INDISPENSABLE IN MODERN SOCIETY
- NEW APPLICATIONS FUELED BY THE DEVELOPMENT OF COMPUTER TECHNOLOGY
- KNOWLEDGE ABOUT THE DESIGN AND USE OF DIGITAL SYSTEMS REQUIRED IN A LARGE VARIETY OF HUMAN ACTIVITIES



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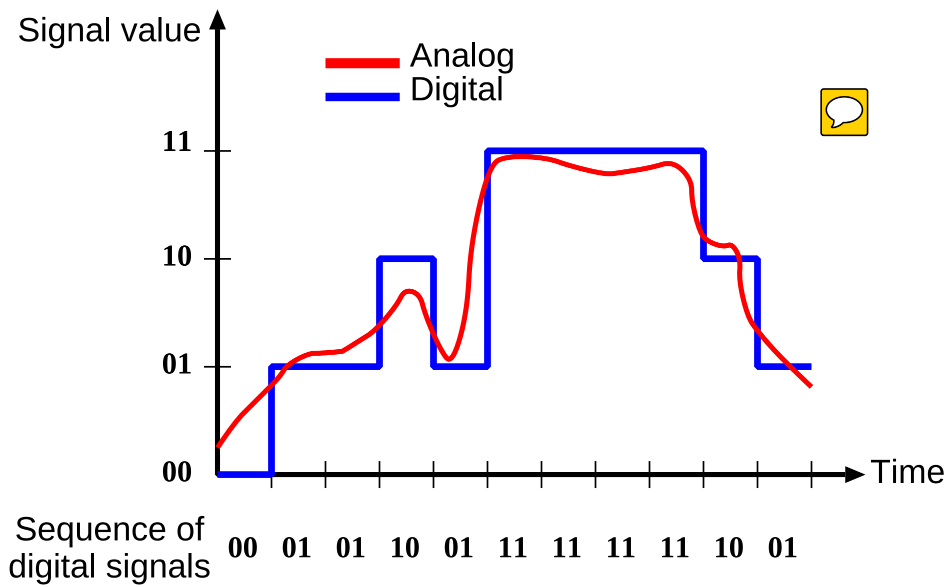

(b)

Figure 1.4: a) A system with analog and digital signals. b) Analog-to-digital conversion.

COMBINATIONAL AND SEQUENTIAL SYSTEMS

- DIGITAL SYSTEMS - TWO CLASSES:
- *COMBINATIONAL SYSTEMS*

$$z(t) = F(x(t))$$

– no memory, the output does not depend on previous inputs

- *SEQUENTIAL SYSTEMS*

$$z(t) = F(x(0,t))$$

$x(0,t)$: input sequence from time 0 to time t

– $z(t)$ depends also on previous inputs - the system has MEMORY

COMBINATIONAL AND SEQUENTIAL SYSTEMS (cont.)

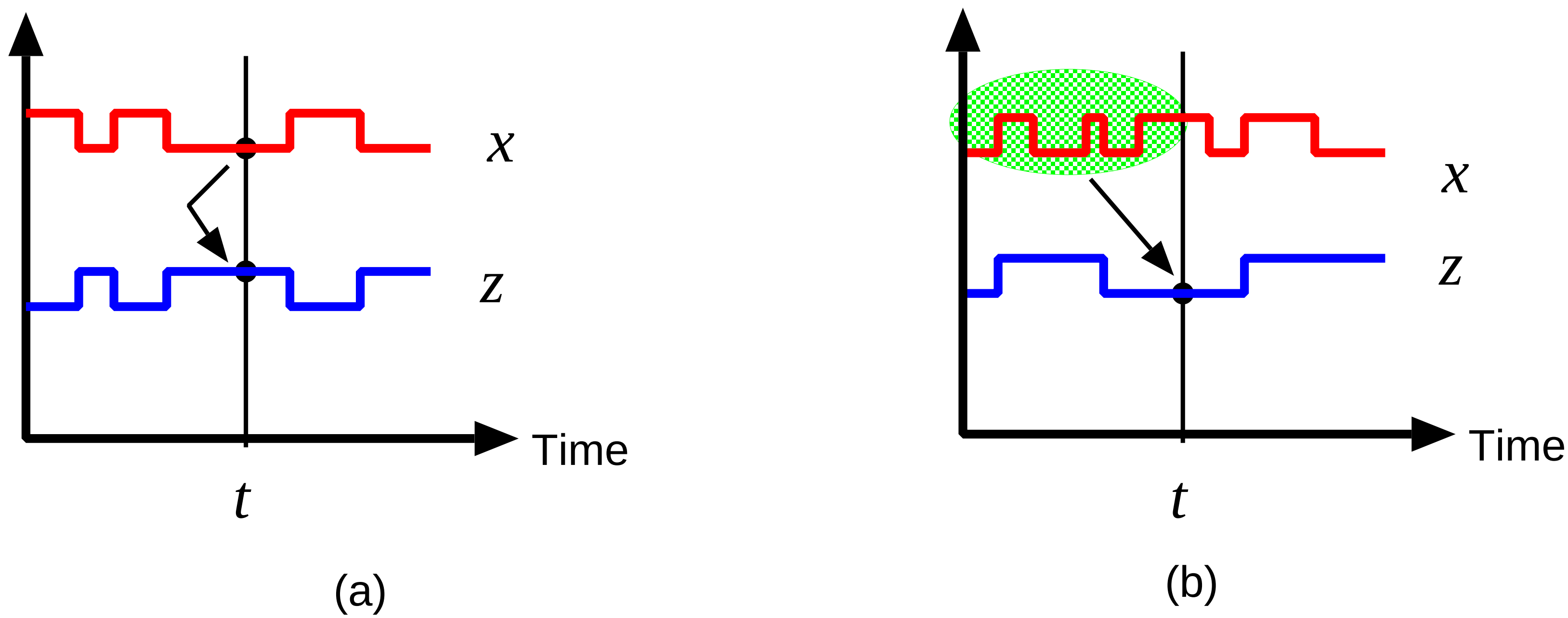

Figure 1.5: Input-output functions for: a) Combinational system; b) Sequential system.

EXAMPLE 1.1: SEQUENTIAL SYSTEM

- INPUT x with VALUES 0,1, or 2
- OUTPUT z with VALUES 0 or 1
- FUNCTION:

$$z(t) = \begin{cases} 1 & \textbf{if} \quad (x(0), x(1), \ldots, x(t)) \text{ has} \\ & \qquad \text{even } 2's \text{ and odd } 1's \\ 0 & \textbf{otherwise} \end{cases}$$

- AN INPUT-OUTPUT PAIR:

t	0	1	2	3	4	5	6	7	8	9	10	11
x	1	2	2	0	1	2	0	0	0	2	1	1
z	1	0	1	1	0	0	0	0	0	0	1	0

EXAMPLE 1.2: COMBINATIONAL SYSTEM

- INPUT $x(t)$ with values from the set of letters (upper and lower case)
- INPUT $y(t)$ with values 0 and 1
- FUNCTION:
  - change $x(t)$ to opposite case when $y(t) = 1$
  - leave it unchanged when $y(t) = 0$
- AN INPUT-OUTPUT PAIR:

t	0	1	2	3	4	5	6
x	E	X	A	M	P	L	E
y	0	1	0	0	0	1	0
z	E	x	A	M	P	l	E

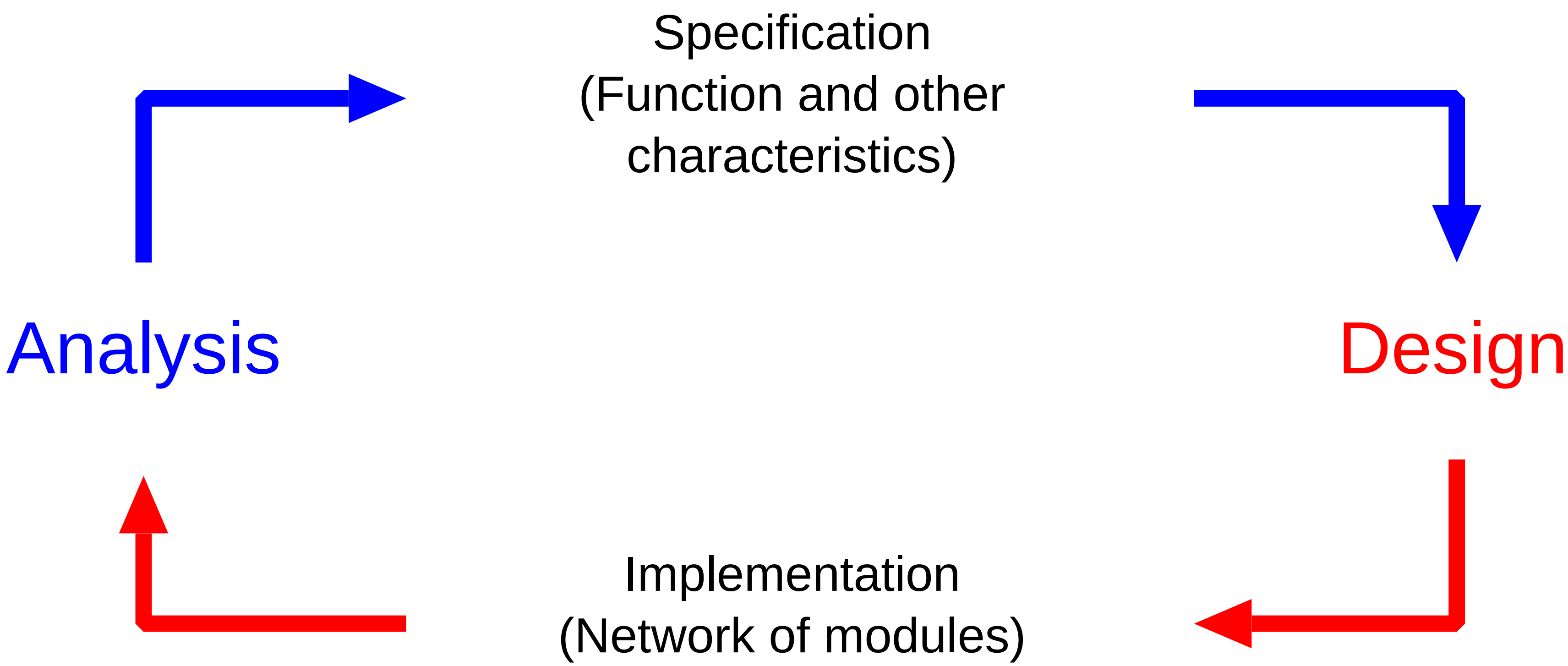

Figure 1.6: Relationship among system specification and implementation.

SPECIFICATION AND IMPLEMENTATION (cont.)

SPECIFICATION of a system describes its function.

Objective:

- to use the system as a component in more complex systems; and
- to serve as the basis for the implementation of the system by a network of simpler components.

SPECIFICATION LEVELS

- HIGH-LEVEL
- BINARY-LEVEL
- ALGORITHMIC-LEVEL
- Spec. of combinational systems: Chapter 2
- Spec. of sequential systems: Chapter 7
- Spec. of algorithmic systems: Chapter 13

IMPLEMENTATION

As a *DIGITAL NETWORK* – interconnection of modules

- SEVERAL LEVELS depending on the complexity of the primitive modules
  - from very simple *gates* to complex *processors*
- Need for *HIERARCHICAL IMPLEMENTATION*
- PHYSICAL LEVEL: interconnection of electronic elements such as transistors, resistors, and so on (Chapter 3).

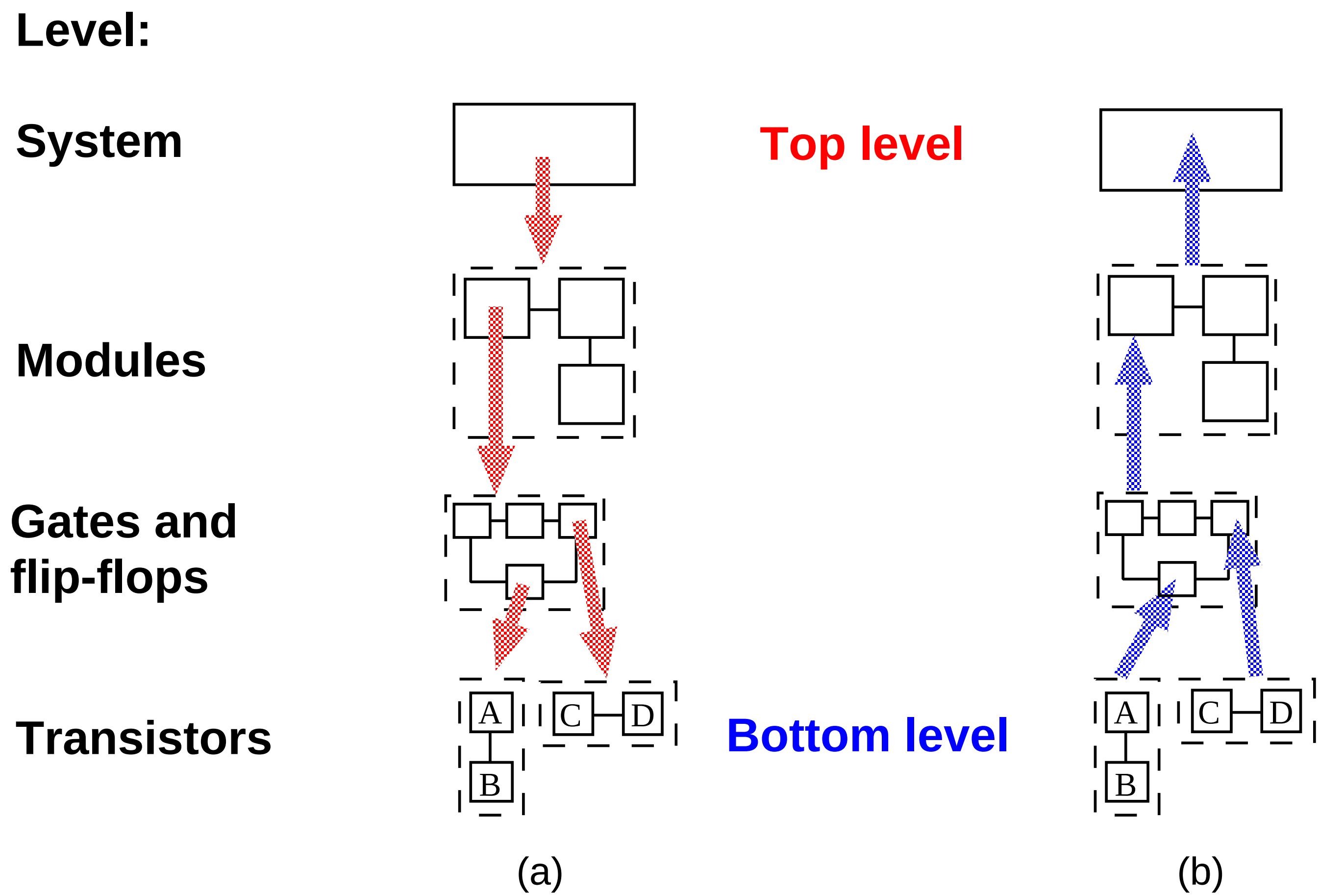

Figure 1.7: Hierarchical implementation: a) Top-down approach. b) Bottom-up approach.

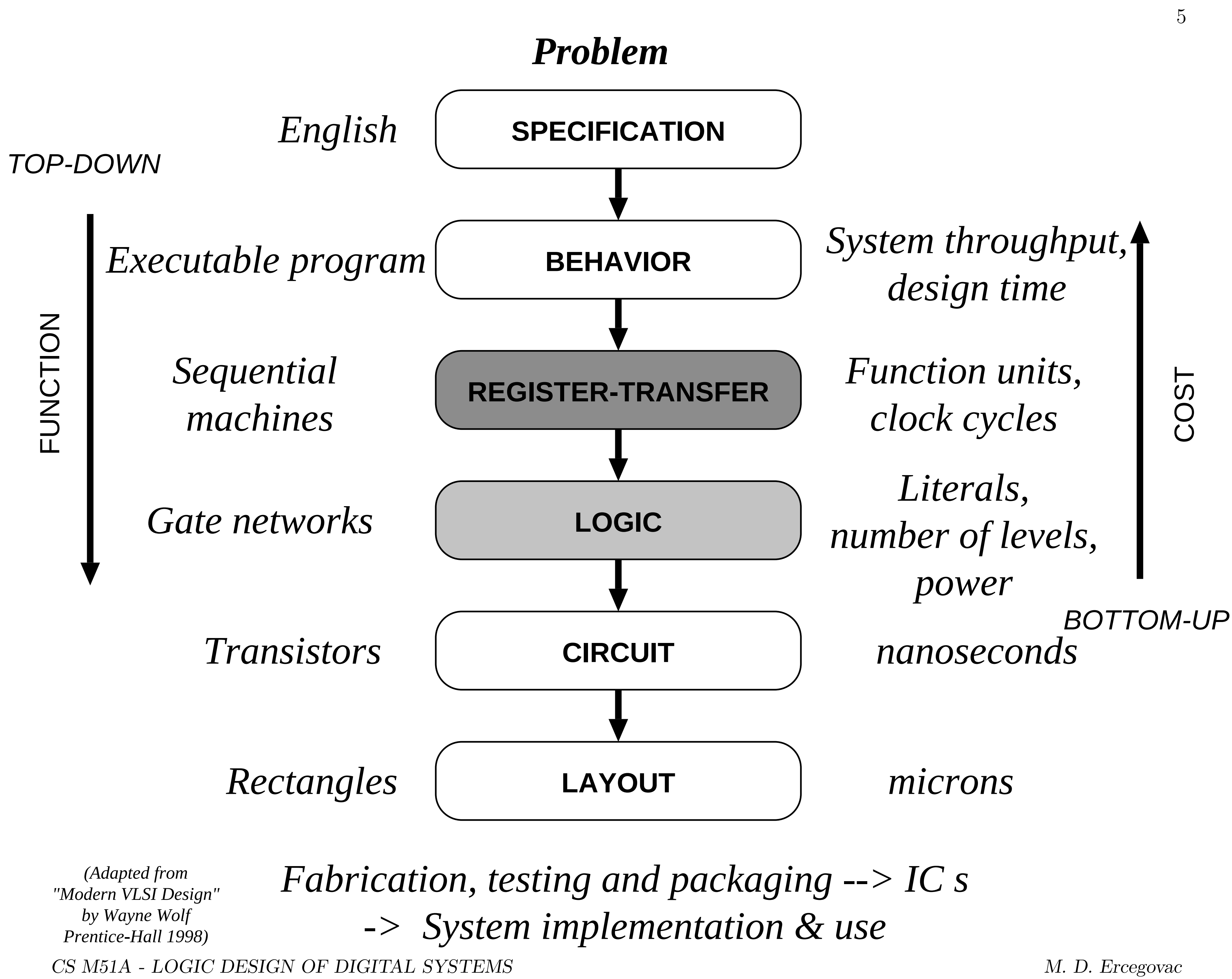

Figure 1: Big picture.

COMMENTS ON IMPLEMENTATION

- Modules as conceptual entities
  – to simplify description of an implementation
- Standard modules of several levels of complexity
  – to facilitate design of large numbers of different systems
- Rules for interconnection of modules
- Why separation of the specification of a system from its implementation?
  – to shield the description from irrelevant implementation details;
  – to allow choosing an implementation from different alternatives,

- IMPLEMENTATION OF COMBINATIONAL SYSTEMS
  - at the gate level: Chapter 5 (and 6 - not covered in this course)
  - at the module level: Chapters 9, 10, and 12
- IMPLEMENTATION OF SEQUENTIAL SYSTEMS
  - elementary: Chapter 8
  - more complex: Chapters 11 and 12
- IMPLEMENTATION OF ALGORITHMIC SYSTEMS: Chapters 13-15

LEVELS OF AN IMPLEMENTATION: MODULE, LOGICAL, PHYSICAL

Problem: Compute sum $Z(t)$ of $t+1$ inputs $X(i)$

$$Z(t) = \sum_{i=0}^{t} X(i) \quad (function)$$

$$Z(i) = Z(i-1) + X(i) \quad (algorithm)$$

$$Z(-1) = 0$$

- Sequential algorithm – sequential implementation of *datapath*
- One input and one output per cycle
- One operation: addition (operator: ADD); *control* not shown
- Two variables: input $X(i)$ and running sum $Z(i)$ (Registers: RX and RY)

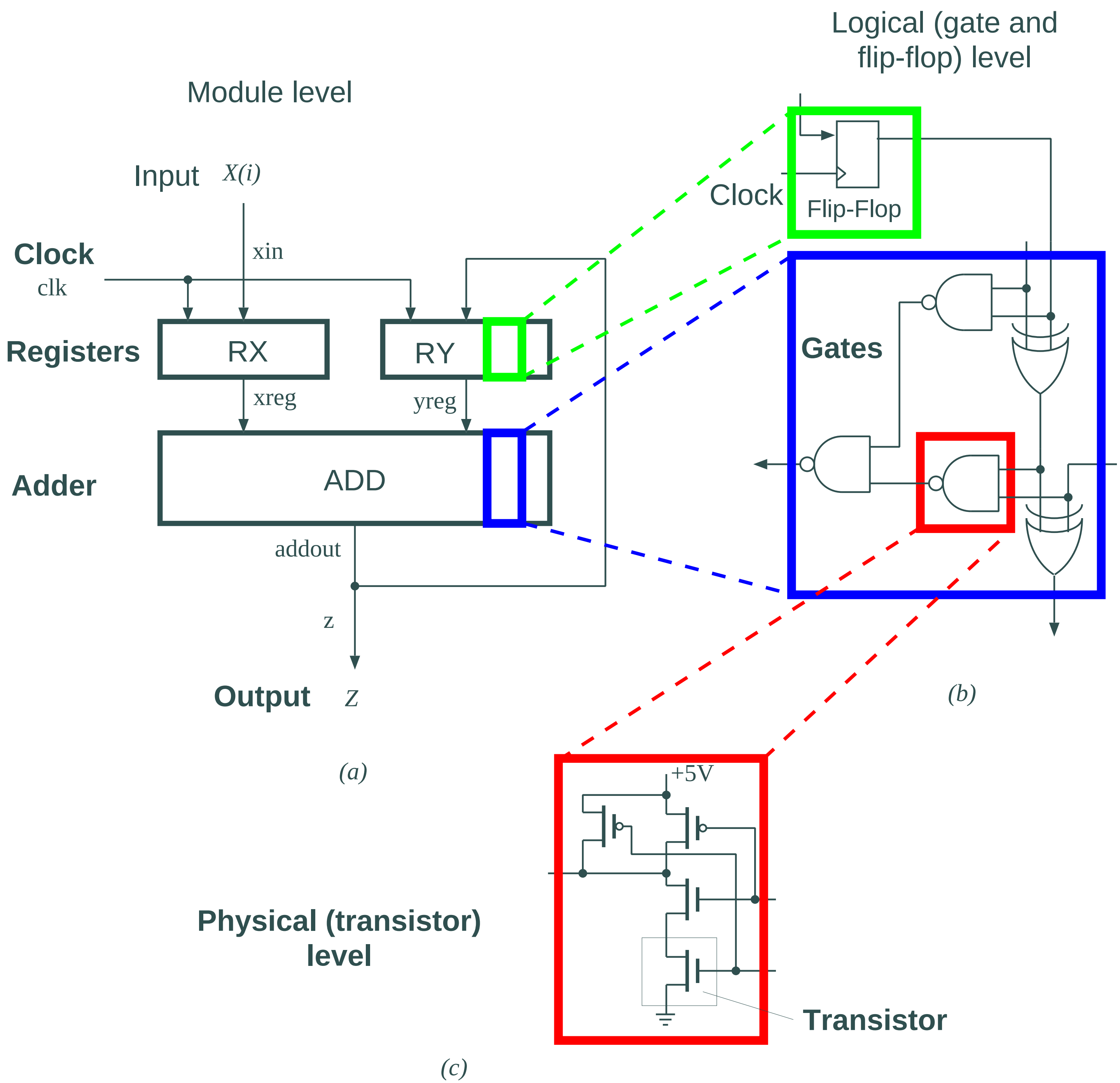

Figure 1.8: Digital system: a) module level; b) logical level; and c) physical level.

COMPUTER-AIDED DESIGN TOOLS

- Design of digital systems an involved and laborious process
- Various computer-aided design (CAD) tools available
- Main types of CAD tools support the main phases of digital design:

  (i) description (specification),

  (ii) design (synthesis) including various optimizations to reduce cost and improve performance, and

  (iii) checking of the design with respect to its specification.
- The design phases typically require several passes