

# Introduction

BME208 – Logic Circuits

Yalçın İŞLER

[islerya@yahoo.com](mailto:islerya@yahoo.com)

<http://me.islerya.com>

# Lecture

- 6 ECTS course
  - Three hours theory
  - One hour laboratory
  - No other sections
- Wednesday: 13:30 – 16:15 (B2-08 for theory)
- Attendance is compulsory as usual

# Laboratory

- 9 experiments
  - Check from the CANVAS
- It is obligatory to do all the assignments
- Contact the assistants
  - Bartu and Mazlum
- If you take under 60 from laboratory, you will fail directly and it is not necessary to attend final and resit exams, etc.

# Grading

- One mid-term exam
  - Weight: 40%
- Final exam
  - Weight: 40%
- Laboratories
  - Weight: 20%
  - You need to learn VHDL

# Contact Information

- Yalçın İŞLER
- Place: Central Offices #1, 2nd Floor, Room 124
- e-mail: islerya @ yahoo.com
- Office hours:
  - Whenever you find me
  - Or by appointment via e-mail

# Course Website (theory sessions)

- You can download all presentations as PDF from

<http://me.islerya.com/bme208.php>

# Motivation

- Analysis & design of digital electronic circuits
- Why digital circuits?
  - They are everywhere and generic
  - digital computers, smart phones, data communication, digital recording, digital TV, many others
- Fundamental concepts in the design of digital systems
- Basic tools for the design of digital circuits
- Logic gates (AND, OR, NOT)
  - Boolean algebra



# What is a Digital System?

- One characteristic:
  - Ability of manipulating discrete elements of information
- A *set* that has a finite number of elements contains discrete information
- Examples for discrete sets
  - Decimal digits {0, 1, ..., 9}
  - Alphabet {A, B, ..., Y, Z}
  - Binary digits {0, 1}
- One important problem
  - how to represent the elements of physical systems?





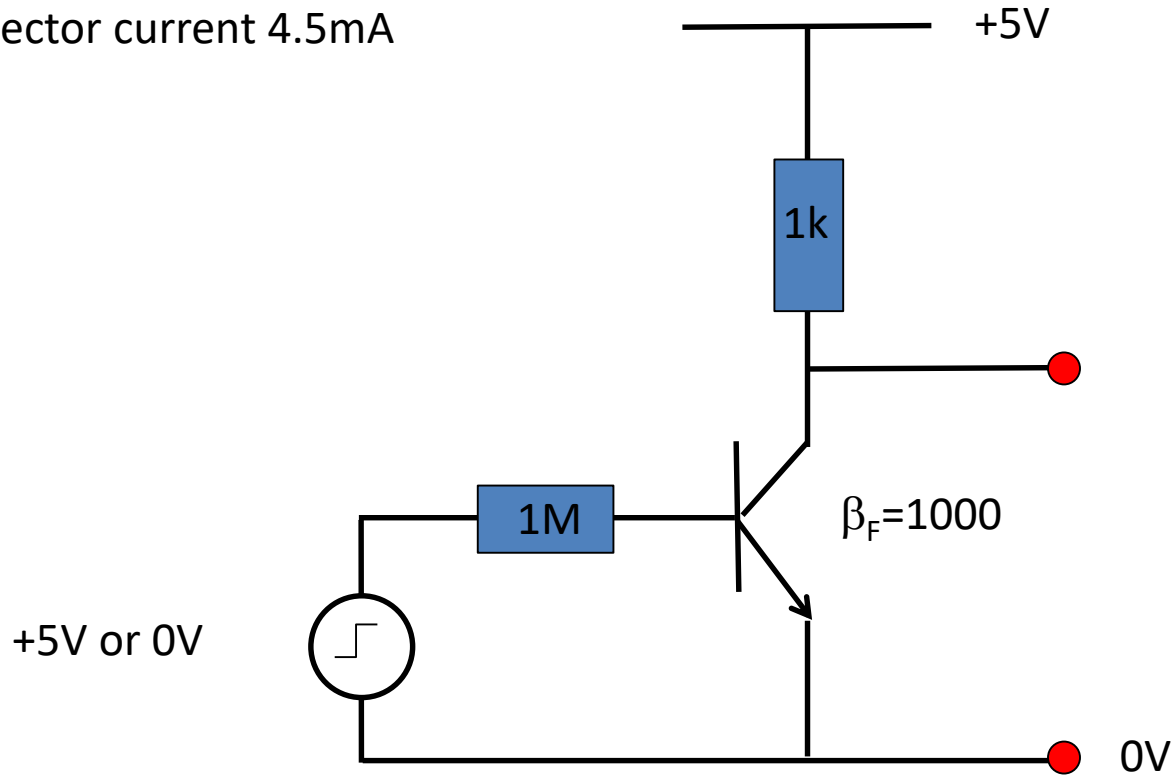
# How to Represent?

- In electronics circuits, we have electrical signals
  - voltage
  - current
- Different strengths of a physical signal can be used to represent elements of the discrete set.
- Which discrete set?
- Binary set is the easiest
  - two elements  $\{0, 1\}$
  - Just two signal levels: 0 V and 5 V
- This is why we use binary system to represent the information in digital systems.



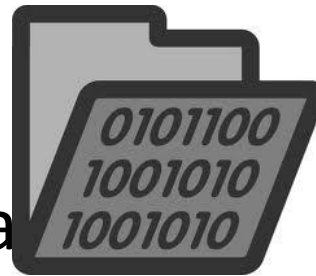
# How to Represent?

- In electronics circuits, we have electrical signals
  - voltage
  - current
  - Base current  $4.5 \mu\text{A}$
  - Collector current  $4.5\text{mA}$



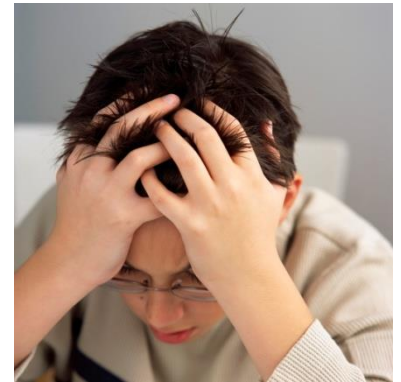
# Binary System

- Binary set  $\{0, 1\}$ 
  - The elements of binary set, 0 and 1 are called “binary digits”
  - or shortly “bits”.
- How to represent the elements of other discrete sets
  - Decimal digits  $\{0, 1, \dots, 9\}$
  - Alphabet  $\{A, B, \dots, Y, Z\}$
- Elements of any discrete set can be represented using groups of bits.
  - 9 → 1001
  - A → 1010



# How Many Bits?

- What is the formulae for number of bits to represent a discrete set of  $n$  elements
- $\{0, 1, 2, 3\}$ 
  - $00 \rightarrow 0, 01 \rightarrow 1, 10 \rightarrow 2, \text{ and } 11 \rightarrow 3.$
- $\{0, 1, 2, 3, 4, 5, 6, 7\}$ 
  - $000 \rightarrow 0, 001 \rightarrow 1, 010 \rightarrow 2, \text{ and } 011 \rightarrow$
  - $100 \rightarrow 4, 101 \rightarrow 5, 110 \rightarrow 6, \text{ and } 111 \rightarrow 7.$
- The formulae, then,
  - #of bits required =  $\lceil \log_2 \text{\#of Symbols} \rceil$
  - If  $n = 9$ , then ? bits are needed



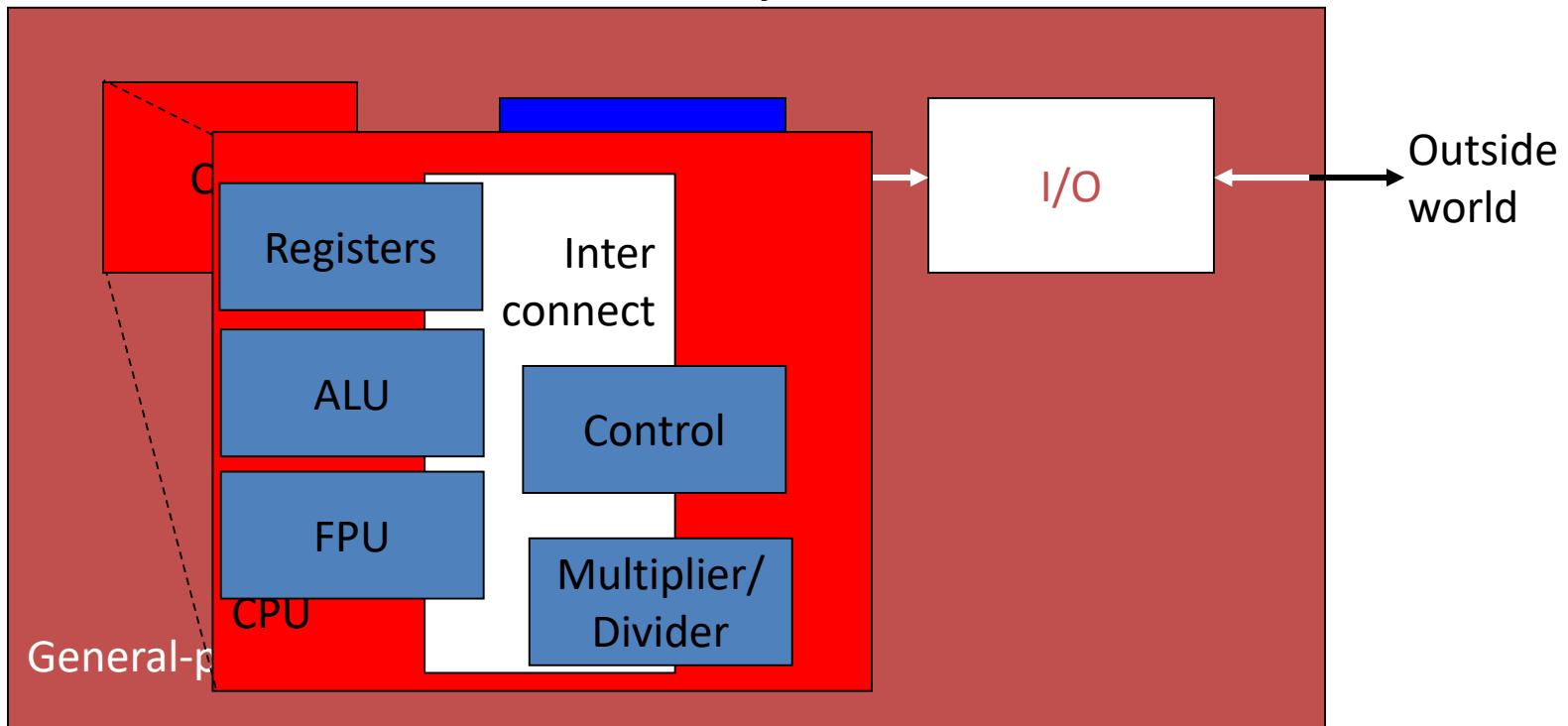
# Nature of Information



- Is information of discrete nature?
- Sometimes, but usually not.
  - Anything related to money (e.g. financial computations, accounting etc) involves discrete information
- In nature, information comes in a continuous form
  - temperature, humidity level, air pressure, etc.
- Continuous data must be converted (i.e. quantized) into discrete data
  - lost of some of the information
  - We need ADC (DAC)

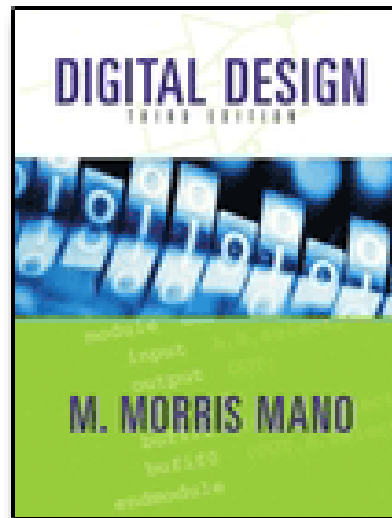
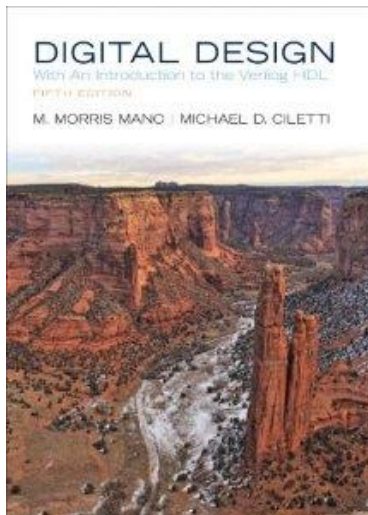
# General-Purpose Computers

- Best known example for digital systems
- Components
  - CPU, I/O units, Memory unit



# Textbook & References

- Textbook
  - M. Morris Mano Digital Design: With an Introduction to the Verilog HDL, 5th Edition, Prentice Hall, 2013.
- Other references
  - Tens of digital design books
  - Lectures from MIT Open Courseware and Stanford



# Contents

- **1 Digital Systems and Binary Numbers 1**
  - 1.1 Digital Systems *1*
  - 1.2 Binary Numbers *3*
  - 1.3 Number-Base Conversions *6*
  - 1.4 Octal and Hexadecimal Numbers *8*
  - 1.5 Complements of Numbers *10*
  - 1.6 Signed Binary Numbers *14*
  - 1.7 Binary Codes *18*
  - 1.8 Binary Storage and Registers *27*
  - 1.9 Binary Logic *30*



# Contents

- **2 Boolean Algebra and Logic Gates 38**
  - 2.1 Introduction 38
  - 2.2 Basic Definitions 38
  - 2.3 Axiomatic Definition of Boolean Algebra 40
  - 2.4 Basic Theorems and Properties of Boolean Algebra 43
  - 2.5 Boolean Functions 46
  - 2.6 Canonical and Standard Forms 51
  - 2.7 Other Logic Operations 58
  - 2.8 Digital Logic Gates 60
  - 2.9 Integrated Circuits 66

# Contents

- **3 Gate-Level Minimization 73**
  - 3.1 Introduction 73
  - 3.2 The Map Method 73
  - 3.3 Four-Variable K-Map 80
  - 3.4 Product-of-Sums Simplification 84
  - 3.5 Don't-Care Conditions 88
  - 3.6 NAND and NOR Implementation 90
  - 3.7 Other Two-Level Implementations 97
  - 3.8 Exclusive-OR Function 103
  - 3.9 Hardware Description Language 108

# Contents

- **4 Combinational Logic 125**
  - 4.1 Introduction 125
  - 4.2 Combinational Circuits 125
  - 4.3 Analysis Procedure 126
  - 4.4 Design Procedure 129
  - 4.5 Binary Adder–Subtractor 133
  - 4.6 Decimal Adder 144
  - 4.7 Binary Multiplier 146
  - 4.8 Magnitude Comparator 148
  - 4.9 Decoders 150
  - 4.10 Encoders 155
  - 4.11 Multiplexers 158
  - 4.12 HDL Models of Combinational Circuits 164

# Contents

- **5 Synchronous Sequential Logic 190**
  - 5.1 Introduction *190*
  - 5.2 Sequential Circuits *190*
  - 5.3 Storage Elements: Latches *193*
  - 5.4 Storage Elements: Flip-Flops *196*
  - 5.5 Analysis of Clocked Sequential Circuits *204*
  - 5.6 Synthesizable HDL Models of Sequential Circuits *217*
  - 5.7 State Reduction and Assignment *231*
  - 5.8 Design Procedure *236*

# Contents

- **6 Registers and Counters 255**
  - 6.1 Registers 255
  - 6.2 Shift Registers 258
  - 6.3 Ripple Counters 266
  - 6.4 Synchronous Counters 271
  - 6.5 Other Counters 278
  - 6.6 HDL for Registers and Counters 283

# Contents

- **7 Memory and Programmable Logic 299**
  - 7.1 Introduction 299
  - 7.2 Random-Access Memory 300
  - 7.3 Memory Decoding 307
  - 7.4 Error Detection and Correction 312
  - 7.5 Read-Only Memory 315
  - 7.6 Programmable Logic Array 321
  - 7.7 Programmable Array Logic 325
  - 7.8 Sequential Programmable Devices 329

# Contents (If time permits)

- **8 Design at the Register Transfer Level 351**
  - 8.1 Introduction 351
  - 8.2 Register Transfer Level Notation 351
  - 8.3 Register Transfer Level in HDL 354
  - 8.4 Algorithmic State Machines (ASMs) 363
  - 8.5 Design Example (ASMD Chart) 371
  - 8.6 HDL Description of Design Example 381
  - 8.7 Sequential Binary Multiplier 391
  - 8.8 Control Logic 396
  - 8.9 HDL Description of Binary Multiplier 402
  - 8.10 Design with Multiplexers 411
  - 8.11 Race-Free Design (Software Race Conditions) 422
  - 8.12 Latch-Free Design (Why Waste Silicon?) 425
  - 8.13 Other Language Features 426