Systems I: Computer Organization and Architecture

Lecture 1: Introduction

What Are Analog & Digital?

- Analog devices process time-varying signal that can take on any value in a continuous range of voltage, current or any other measure.
- Digital devices process signals that take on one of several discrete values, e.g., 0, 1, 2, 3, etc. Usually it is one of two values, 0 & 1, low & high, false & true

Analog

Digital

From Analog To Digital

- In the past 10 years, many applications that were once analog have gone digital:
  - Still pictures – From film-based to JPEG
  - Video recordings – From VHS to DVD
  - Audio recording – CDs use 16-bit samples taken every 22 msec.
  - Automobile carburetors – From mechanical linkages sensing temperature, pressures, etc., to microprocessors
  - Telephone System – Most PBXs are digital as are central offices switching systems.
  - Traffic lights – Most controllers use microprocessor to control lights where they used to use electromechanical timers.
  - Movie effects – Computer Synthesized

Advantages of Digital

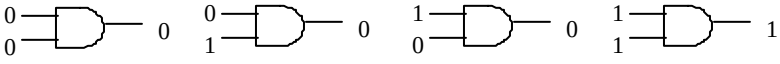
The Digital Revolution offers many advantages over the earlier generations of analog equipment:

- ***Reproducibility of results*** – the same inputs will always produce the same output. (if properly designed)
- ***Ease of design***
- ***Flexibility and Functionality*** – E.g., you could scramble your voice and unscramble it on the other end without distortion.
- ***Programmability*** -Hardware Description Languages are used to write programs for digital design
- ***Speed*** – faster than analog devices
- ***Economy*** – Can be designed and manufactured at lower cost
- ***The Technology Is Always Improving***

Logic Gates

Logic gates are the most basic digital devices, accepting one or more inputs and providing an output based on the inputs and its defining function

AND



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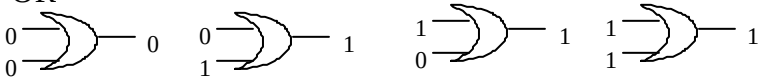
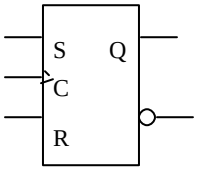


NOT

Flip-Flops

- Flip-Flops are devices that store either a 1 or 0 and can be ***set*** to 1 or ***cleared*** to 0.
- The values stored in a flip-flop can only be changed at certain times determined by the "clock" input and the new value depends on the flip-flop type, its current input and its "control" inputs.



S	R	Q(t+1)	
0	0	Q(t)	*No change*
0	1	0	*Clear to 0*
1	0	1	*Set to 1*
1	1	?	*Indeterminate*

Electronic Aspects

- In reality, digital devices do not have little 1s and 0s floating through them; they use a electrical signals which represent 1 and 0, allowing them to ignore most aspects of their analog behavior.
- A range of analog values is associated with each logic value (1 or 0). This allows for a ***noise margin*** (the difference between extremes in range for a logic value).
- It is the responsibility of the electronic circuit designer to ensure that logic gates produce the expected results. The digital designer's only responsibility is to ensure that the gates are used within its published specification.

Software Aspects

Although digital design doesn't have to involve software tools, it is considered an essential part of digital design:

- HDLs (***H***ardware ***D***escription ***L***anguages) are used to specify logic functions that will be implemented. ***HDL compilers*** translate the descriptions into a digital circuit diagram.
- Schematic Entry Tools – the digital designer's equivalent of a word processor, it allows schematic diagrams to be drawn, edited and redrawn as needed.

Software Aspects (continued)

- Simulators simulate the behavior of new chips before they are actually manufactured.
- Test benches – software environments for circuit simulation and testing
- Timing Analyzers and verifiers – automate the task of drawing timing diagrams and verifying the timing relationships between different signals.

Digital Design

In digital design, it is important to be able to simplify logical expressions that are translated into digital circuitry. This can be done using:

Boolean Algebra

- Karnaugh Maps

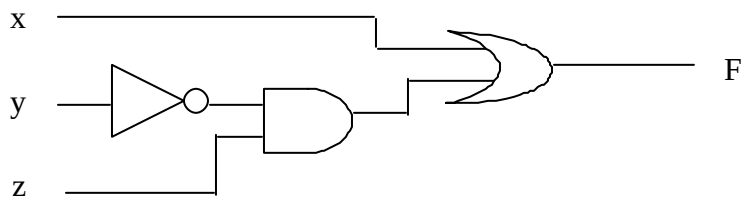
Boolean Algebra

- Boolean algebra deals with binary variables and logical operations.
- The variables are designated as A, B, x, y, etc.
- The operations are AND, OR and NOT (or complement).
- True has a value of 1 and False has a value of 0.
- In Boolean algebra, the expression F=x + y'z has a value of 1 if x is 1 or it y is 0 and z is 1.
- The laws of Boolean algebra provide rules that allow these relationships to be simplified.

Truth Table for F = x + y'z

x	y	z	F
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

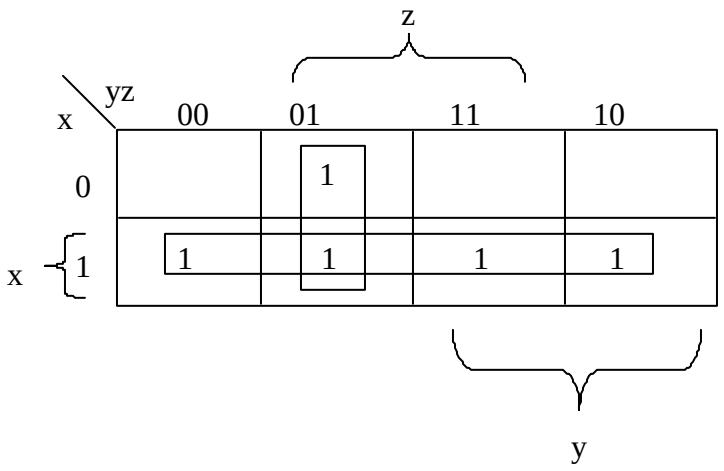
Logic Diagram for F = x + y'z



Karnaugh Maps

- Karnaugh maps provide a useful method for simplifying an expression graphically.
- This is important because more complex expressions can be much harder to simplify using the theorems of Boolean algebra.

The Karnaugh map for F = x + y'z



Combinatorial Circuits

- A ***combinatorial circuit*** is a connected arrangement of logic gates with a set of inputs and outputs, where the combination of *n* inputs will deterministically produce *m* outputs.
- A combinatorial circuit can be described by a truth table showing the relationship between the inputs and outputs.
- Examples of combinatorial circuits include adders and subtracters.

Sequential Circuits

- Sequential circuits is one whose output depends on current inputs, and the sequence of previous inputs.
- Synchronous sequential circuits, the most common type of sequential circuits, employ signals that affect storage elements only at discrete instants of time.
- Flip-flops are an example of sequential circuits.

Integrated Circuits

- An integrated circuit is a collection of one or more gates fabricated on a single silicon chip.
  - Large ICs can have millions of transistors in a ¼ square inch.
  - Small ICs may be less than 1/10 inch on a side.
- Small-scale integration (SSI) – 1-20 gates
  - ***DIP*** – ***D***ual ***I***nline ***P***in – an example of SSI ICs
- Medium-scale integration (MSI) – 20 - 300 gates
- Large-scale integration (LSI) – 200 – 200,000 gates
- Very Large-scale integration (VLSI) - > 1,000,000 gates

Programmable Logic Devices

- There are a wide variety of ICs whose logic function can be programmed (& sometimes reprogrammed).
- This allows the designer to make changes or corrections without physically rewiring or replacing the IC.
- This makes it easier and less expensive to design electronic components.

Types of PLDs

- PLAs (***P***rogrammable ***L***ogic ***A***rrays) were the first programmable logic devices, containing a two-level structure of AND and OR gates with user programmable connections.
- PAL (***P***rogrammable ***A***rray ***L***ogic) – were enhanced and less expensive versions of PLAs.
- CPLD (***C***omplex ***P***rogrammable ***L***ogic ***D***evices) – offered multiple PLDs and a programmable interconnection structure. on the same chip.
- FPGA (***F***ield-***P***rogrammable ***G***ate ***A***rrays) – a larger array of smaller logic blocks and a large distributed interconnection structure.

ASICs

- Advances in IC technology has increased opportunities for semicustom chips (also known as ***A***pplication-***S***pecific ***I***ntegrated ***C***ircuits).
- ASICs reduce the the total component and manufacturing cost of a product by reducing chip count, physical size and power consumption while providing overall higher performance.
- This is despite the fact that nonrecurring costs associated with designing an ASIC can be $5,000 or to $250,000 higher.