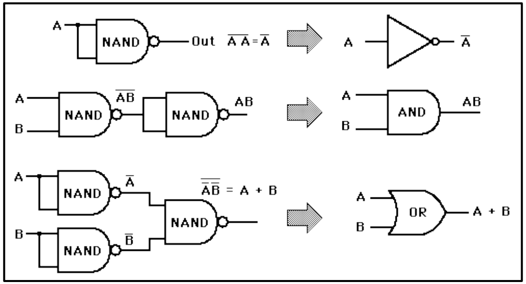
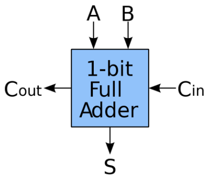
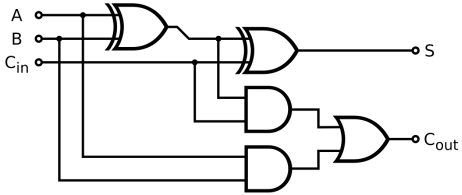
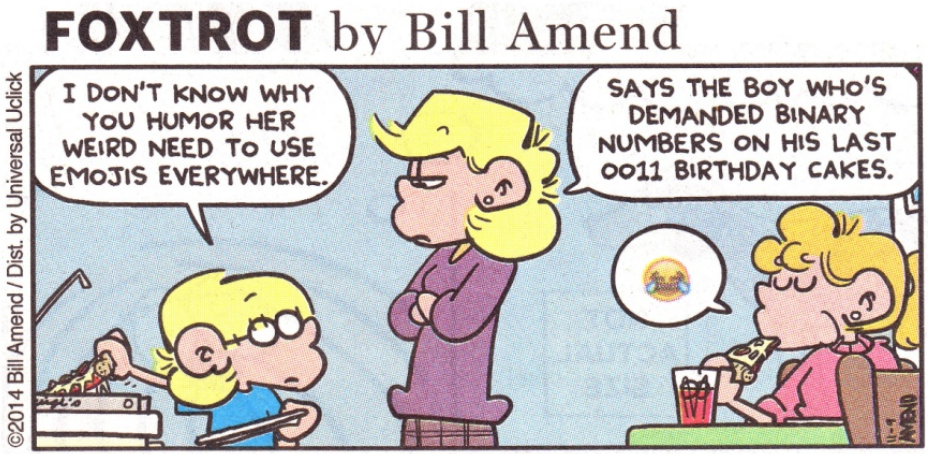
Review Digital Basics

- **Logic Gates**
  - *AND, OR, NOT*
  - *NOR (NOT+OR)*
  - *XOR (eXclusive OR)*
  - *XNOR*
- ***NAND : NOT+AND***
  Make any gate with NANDS
  Least amount of transistors (cost/size)
- ***Half-Adder***
  Adds two binary digits
- ***Full- Adder***
  Half-adder, but includes carry bits








FOXTROT by Bill Amend
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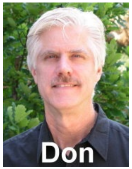
I DON'T KNOW WHY YOU HUMOR HER WEIRD NEED TO USE EMOJIS EVERYWHERE.
SAYS THE BOY WHO'S DEMANDED BINARY NUMBERS ON HIS LAST 0011 BIRTHDAY CAKES.



Calendar of Topics Covered

Physics PHYS 2371/2372, Electronics for Scientists

Don Heiman and Hari Kumarakuru
Northeastern University, Fall 2020

Also see **Course Description** and **Syllabus**

This is a schedule of the topics covered, but it may be modified occasionally (10/22/2020).

Week #	**Lectures**	**Weekly Topics** (Chs.)	**Homework** (Ch-Problem)	**Lab Experiments** (always look for latest version)
VIII Oct 28-30	**Wed Lecture** Optoelectronics Optoele Lecture	*Photodiode, LED, laser*	none	**Lab-7, *Optoelectronics*** (coupled LED-photodiode) Lab-7 Optoele video
IX Nov 2, 4-6 **MON/WED**	**Mon/Wed Lectures** MON Digital-1 Digital-1 Lecture WED Digital-2 Digital-2 Lecture	Digital Logic (Ch-19,22), Binary Numbers (Ch-54) Logical Networks (Ch-20)	19-all, 20-all	**Lab-8a, *Digital Circuits*** (truth table, 4-bit decoder) Lab-8a Digital video
X Nov 11-13	**Wed Lecture** Pulsed ICs Pulsed Lecture	Lecture: Pulsed ICs Digital Summary	21-1/2	**Lab-8b, *Pulsed Digital*** (Flip-flops, counter, displays) Lab-8b Pulsed video
XI Nov 18-20 **WED EXAM**	**EXAM-II - Wed** Final Project	**EXAM-II: Magnetoelectronics, Optoelectronics, Digital/Pulsed**		***Final Project***
XII Nov 25-27	No Lecture	**Thanksgiving**		No Lab
XIII Dec 2	**Wed Lecture**	Future Electronics		***Project PowerPoint*** **due Monday Dec 2** (EG361 or email file)
XIV Dec 7-9	**No Classes**			

Digital Circuits

- **Logic NETWORKS, Ch-20**
  - design a circuit
  - miniterms
- **Karnaugh Map**
  - simplifies miniterms
- **Lab-8a**
  - Digital Circuits

Gates → modular Circuits → do Math, Store information

Minecraft Computers

Minecraft computer "BlueStone“, 2012

- Describes various parts of a computer

16 Bit Minecraft Computer, 2012 (0-2:00)

- Two 16 bit Input Registers.
- 11 function - NOT A, NOT B, AND, OR, XOR, ADD, Cin ON, Shift Right, NOT Out. Zero A, Zero B

32 Bit Calculator in Minecraft, 2014 (0-1:00)

- 32 Bit Minecraft-Redstone-Calculator
- It took me about **800 hours** to accomplish this gigantic project.

64 Bit Minecraft Computer, 2018

Inside Computers

The word "computer" refers to an object that can ***accept some input*** *and* ***produce some output****.*

See How Computers Add Numbers in One Lesson
(14:27, simple , 6:42->, 11:10->)
See How the CPU Works in One Lesson
(20:42, bus/registers details)

How a CPU is made (10:16, 2013)
Sand to Silicon - the Making of a Chip **(2:21, music)
How Microchips are made (8:53)
The Fabrication of Integrated Circuits (10:42, 2010)
Inside a Computer *How Stuff Works* (ad+3:24)

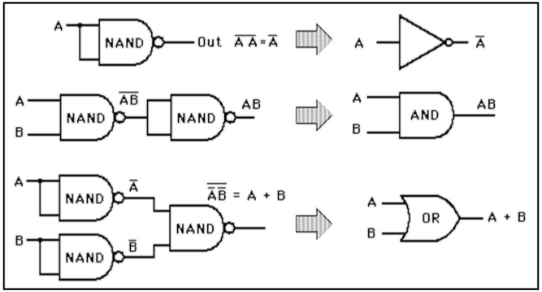
Inside a Google data center ** (0-1:01, 2:49-4:55)

Questions?

Designing Digital Circuits, Ch-20

Now that we have digital gates,
what do we do with them?

- Build digital circuits to do things -



Why NAND Gates?

NAND/NOR **4** MOSFETs, AND/OR **6** MOSFETs

NAND gates are smaller and cheaper than NOR.

Thus, are faster because of less delay time.

Binary Addition and Multiplication

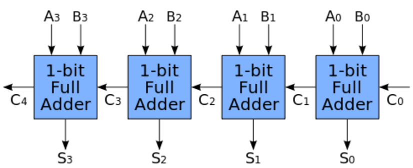
Binary ADDITION : A + B = S

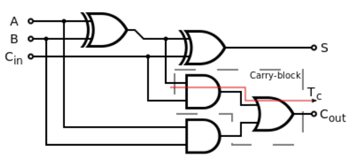
An **adder** is a digital circuit that performs addition of numbers. In many computers and other kinds of processors adders are used in the arithmetic logic units or ALU. They are also utilized in other parts of the processor, where they are used to calculate addresses, table indices, increment and decrement operators, and similar operations. (Wiki)

Same method as digital MULTIPLICATION (Wiki)

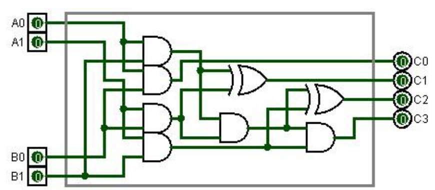
```
   1011 (this is 11 in decimal)
 x 1110 (this is 14 in decimal)
 ======
   0000 (this is 1011 x 0)
  1011 (this is 1011 x 1, shifted one position to the left)
 1011 (this is 1011 x 1, shifted two positions to the left)
+ 1011 (this is 1011 x 1, shifted three positions to the left)
=========
10011010 (this is 154 in decimal)
```

$$\begin{array}{r} A_3\ A_2\ A_1\ A_0 \\ +\ B_3\ B_2\ \ B_1\ B_0 \\ S_3\ S_2\ \ S_1\ S_0 \end{array}$$





1-bit Full Adder



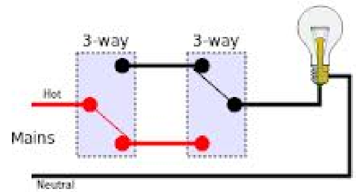
2-bit by 2-bit Multiplier

Designing Digital Circuits - Miniterms

Two-way Light

- 1 light bulb
- 2 3-way light switches

Either switch turns on or off the light

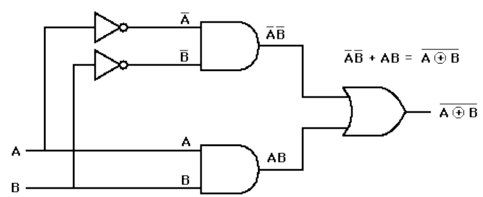


RULE: for every "1" answer, then that is a miniterm

A	B	Light
dn ↓	dn	on
up ↑	dn	off
dn ↓	up	off
up ↑	up	on

Row	A	B	Light	XNOR
1	0	0	1	1
2	1	0	0	0
3	0	1	0	0
4	1	1	1	1

Write down the Boolean expression for each miniterm.
Only Rows 1 and 4 are miniterms.
Row-1, $(\underline{A}\cdot\underline{B})$
Row-4, $(A\cdot B)$
Out = $(\underline{A}\cdot\underline{B}) + (A\cdot B)$



More Complex Digital Circuits

Example
Three inputs – **A, B, C**

Given the truth table
Miniterms in rows 2, 4, 8

row-2 row-4 row-8

$$\text{Out} = A\cdot B\cdot \underline{C} + A\cdot \underline{B}\cdot \underline{C} + \underline{A}\cdot \underline{B}\cdot \underline{C}$$

$$\text{Out} = A\cdot B\cdot \underline{C} + (A+\underline{A}) \cdot (\underline{B}\cdot \underline{C})$$

but $A+\underline{A}=1$

$$\textbf{Out} = A\cdot B\cdot \underline{C} + \underline{B}\cdot \underline{C}$$

Distributive property

Truth Table

Row	Inputs			Out
	A	B	C	
1	1	1	1	0
2	1	1	0	1
3	1	0	1	0
4	1	0	0	1
5	0	1	1	0
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1

Simplify equation ** (4:56)

Karnaugh Maps

Truth Table

Row	A	B	C	D	Out
1	1	1	1	1	0
2	1	1	1	0	0
3	1	1	0	1	1
4	1	1	0	0	0
5	1	0	1	1	0
6	1	0	1	0	1
7	1	0	0	1	1
8	1	0	0	0	0
9	0	1	1	1	0
10	0	1	1	0	0
11	0	1	0	1	0
12	0	1	0	0	0
13	0	0	1	1	0
14	0	0	1	0	0
15	0	0	0	1	0
16	0	0	0	0	1

Karnaugh Maps (K-maps) are graphical solutions that greatly simplify truth tables.

Compress into matrix →

How do we compress the truth table into matrix?

Truth Table

CD \ AB	00	01	11	10
00	1	0	0	0
01	0	0	1	1
11	0	0	0	0
10	0	0	0	1

Karnaugh Map - *Example*

Truth Table 20-3

Row	A	B	C	D	Out
1	1	1	1	1	0
2	1	1	1	0	0
3	1	1	0	1	1
4	1	1	0	0	0
5	1	0	1	1	0
6	1	0	1	0	1
7	1	0	0	1	1
8	1	0	0	0	0
9	0	1	1	1	0
10	0	1	1	0	0
11	0	1	0	1	0
12	0	1	0	0	0
13	0	0	1	1	0
14	0	0	1	0	0
15	0	0	0	1	0
16	0	0	0	0	1

Truth Table

AB / CD	00	01	11	10
00	1	0	0	0
01	0	0	1	1
11	0	0	0	0
10	0	0	0	1

MATRIX RULE

Order top/side axes
- **vary only one bit**
when moving to next cell

Four inputs – A, B, C, D

Four miniterms (Out=1)

$\text{Out} = (A\cdot\mathbf{B}\cdot\underline{C}\cdot D) + (A\cdot\underline{B}\cdot C\cdot\underline{D})$
$\quad + (A\cdot\underline{\mathbf{B}}\cdot\underline{C}\cdot D) + (\underline{A}\cdot\underline{B}\cdot\underline{C}\cdot\underline{D})$ [$B+\underline{B}=1$, drops out]

Out = $(A\cdot\underline{C}\cdot D) + (A\cdot\underline{B}\cdot C\cdot\underline{D}) + (\underline{A}\cdot\underline{B}\cdot\underline{C}\cdot\underline{D})$

Same

← →

COMBINE ADJACENT ELEMENTS

In second row of adjacent "**1**"
it does not matter what B is
so B drops out

Out = $(A\cdot\underline{C}\cdot D) + (A\cdot\underline{B}\cdot C\cdot\underline{D}) + (\underline{A}\cdot\underline{B}\cdot\underline{C}\cdot\underline{D})$

Rules for Karnaugh Map Solutions

RULE-1: Order top/side table axes,
vary only **one** bit
when moving to next cell

RULE-2: Group **even numbers** of "1"s that are **adjacent**

You can wrap around the cylinder, as in AB=10 → CD=00

Truth Table

AB / CD	00	01	11	10	00
00	1	0	0	1	1
01	0	0	0	0	0
11	1	0	0	0	1
10	1	0	1	0	1

Rules for Karnaugh Map Solutions

RULE-1: Order top/side table axes,
vary only one bit
when moving to next cell

RULE-2: group **even numbers** of
"1"s that are **adjacent**
You can wrap around the cylinder,
as in AB=10 → CD=00

RULE-3: Each group is one miniterm

RULE-4: If input is both "0" and "1"
you don't need that input.

RULE-5: You can use a miniterm
more than once.

Truth Table

AB / CD	00	01	11	10	00
00	1	0	0	1	1
01	0	0	0	0	0
11	1	0	0	0	1
10	1	0	1	0	1

(1) In the first column of adjacent of "1"s
it does not matter what **D** is
and thus **D** drops out **($\underline{A}\cdot\underline{B}\cdot C$).**

(2) In the top row of ~adjacent of "1"s
it does not matter what **A** is
and thus **A** drops out **($\underline{B}\cdot\underline{C}\cdot\underline{D}$).**

Out = ($\underline{A}\cdot\underline{B}\cdot C$) + ($\underline{B}\cdot\underline{C}\cdot\underline{D}$) + ($A\cdot B\cdot C\cdot\underline{D}$) 3 terms

The Karnaugh Map - Rules of Simplification (8:38)

Karnaugh Map Tutorial 4 Variable (K-map) (7:54)

Problem 20-1, solve for Y

Row	A	B	C	Y
1	1	1	1	0
2	1	1	0	1
3	1	0	1	1
4	1	0	0	0
5	0	1	1	0
6	0	1	0	0
7	0	0	1	1
8	0	0	0	1

Truth Table

AB / C	00	01	11	10
0	1	0	1	0
1	1	0	0	1

In first **column** of adjacent "1"
it does not matter what **C** is,
so C drops out.
($\underline{A}\cdot\underline{B}$)

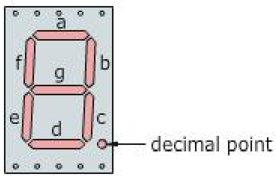
In second **row** of ~adjacent "1"
wrapped around,
it does not matter what **A** is,
so A drops out.
($\underline{B}\cdot C$)

Out = ($\underline{A}\cdot\underline{B}$) + ($\underline{B}\cdot C$) + ($A\cdot B\cdot\underline{C}$)

Problem 20-1, solve for "f" segment

7-segment LED for digits 0-9

Segments a-f



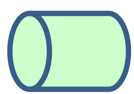
"BCD"
Binary-Coded Decimal

Conversion
$\text{digital}_{10} \leftrightarrow \text{binary}_2$
$0\text{-}9_{10} \leftrightarrow ABCD_2$

Digit	A	B	C	D	"f"
0	0	0	0	0	1
4	0	1	0	0	1
5	0	1	0	1	1
6	0	1	1	0	1
8	1	0	0	0	1
9	1	0	0	1	1

The digits_{10} =0, 4, 5, 6, 8, 9
$ABCD_2$=0000, 0100, 0101, 0110…

light up the "f" segment



Truth Table for the "f" segment

AB / CD	00	01	11	10
00	1	1	0	1
01	0	1	0	1
11	0	0	0	0
10	0	1	0	0

Out = $(\underline{A}\cdot\underline{C}\cdot\underline{D}) + (\underline{A}\cdot B\cdot\underline{C}) + (A\cdot\underline{B}\cdot\underline{C}) + (\underline{A}\cdot B\cdot\underline{D})$

Problem 20-3, solve for AB < CD

$\#_{10}$	$\#_2$	AB	CD
0	0000	00	00
1	0001	01	01
3	0011	11	11
2	0010	10	10

AB < CD
Decimal numbers
For AB=0, CD=1,2,3
For AB=1, CD=2,3
For AB=2, CD=3

Truth Table for AB<CD

AB / CD	00	01	11	10
00	0	0	0	0
01	1	0	0	0
11	1	1	0	1
10	1	1	0	0

Block of 4 "1"s
It does not matter what **B** and **D** are
so B and D drop out = **$(\underline{A}\cdot C)$**

Combine 2 top "1"s in first column = **$(\underline{A}\cdot\underline{B}\cdot D)$**

Combine 2 "1"s in third row = **$(\underline{B}\cdot C\cdot D)$**

Out = $(\underline{A}\cdot C) + (\underline{A}\cdot\underline{B}\cdot D) + (\underline{B}\cdot C\cdot D)$

Lab-8a, Digital Circuits

I. Test digital logic gates using inputs of **0** or **+5 V**.
Determine output using **LED** and current-limiting resistor.

II. Measure the truth table of a various gate.
Construct an XOR gate using a 4-gate 7400 NAND chips.

III. Design and construct a 4-bit decoder

Lab-8a, 4-bit Decoder

Design a 4-bit (ABCD) decoder circuit that lights an LED when the inputs correspond to the decimal numbers **3, 9** and **11.**

Truth Table for 3

#	A	B	C	D	Out
0	0	0	0	0	0
1	0	0	0	1	0
2	0	0	1	0	0
3	0	0	1	1	1
4					

Truth Table for 3, 9, 11

AB CD	00	01	11	10
00				
01				
11	1			
10				

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