Controlling The Real World With Computers

::. Control And Embedded Systems .::

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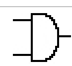
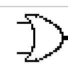
Boolean Logic

As I indicated in the previous section, a bit is the smallest piece of information most computers can work with. Control and embedded systems frequently deal with individual or groups of bits in order to control specific operations or to determine the condition of part of a system. For example, a bit might be turned on to light a lamp or activate a relay, or a bit might be off to indicate a switch is on (off meaning on is very common due to the nature of hardware).

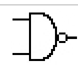
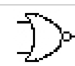
Boolean logic, developed by George Boole (1815-1864), is often used to refine the determination of system status or to set or clear specific bits. Boolean logic is simply a way of comparing individual bits. It uses what are called **operators** to determine how the bits are compared. They simulate the **gates** seen in hardware.

Think of operators as boxes with multiple inputs and one output. Feed in various combinations of bit values, and the output will be high or low depending on the type of operation. The examples that follow show 2 inputs, although gates can have more. Also, gates are often combined to form more complex logic. A modern microprocessor contains huge numbers of them with many inputs and many varying combinations. Please note that the terms **on**, **high** and **1** will be considered the same logical state, and **off**, **low** and **0** will be considered the same logical state in the discussions that follow.

The operators used most often are **AND** and **OR**. The **AND** operation says if and only if **all** inputs are on, the output will be on. The output will be off if any of the inputs are off. The **OR** operation says if **any** input is on, the output will be on. It's easy to see all of the combinations by using what are called **truth tables**, illustrated below. At the bottom of each table is shown the schematic symbol found in circuit diagrams:

AND (all high = high, else low)				**OR** (any high = high, else low)		
Input 1	Input 2	Output		Input 1	Input 2	Output
0	0	0		0	0	0
0	1	0		0	1	1
1	0	0		1	0	1
1	1	1		1	1	1
						

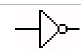
There are two operations that have the same logic as on the previous page, but with an inverted output. High outputs in the previous tables are low in these operations. The **NAND** operation says if and only if all inputs are on, the output will be **off**. The output will be on if any of the inputs are off. The **NOR** operation says if any input is on, the output will be **off**. Notice the bubble on the output of the schematic symbol used to indicate an inversion:

NAND (all high = low, else high)				**NOR** (any high = low, else high)		
Input 1	Input 2	Output		Input 1	Input 2	Output
0	0	1		0	0	1
0	1	1		0	1	0
1	0	1		1	0	0
1	1	0		1	1	0
						

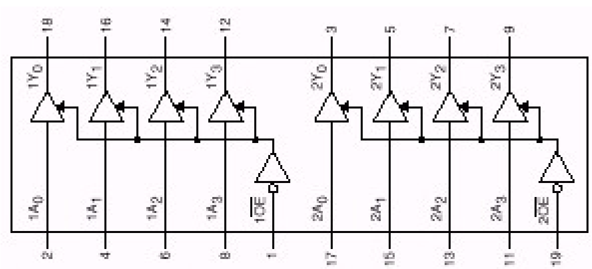
There is a variation on the OR logic called **Exclusive OR** or **XOR**. Exclusive OR says simply that the output will be **on** (or off with **NXOR**) if the inputs are **different**:

XOR (different = high, same = low)		
Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	0
		

Another one, the **inverter** or **NOT** operation, says that the output will be opposite in state to the input. It obviously has only one input and one output. Note that it will change an AND to a NAND, an OR to a NOR and an XOR to a NXOR if connected to their outputs. It simply changes 1s to 0s and 0s to 1s:

NOT (inverter)	
Input = 1	Output = 0
Input = 0	Output = 1
	

One other basic digital device is on a lot of boards. It actually performs no logic. It looks like an inverter without the bubble, and is called a buffer. It's a triangle with a single input and output. It is not used for logic, but to increase the output drive capability of a line, or to lighten the load seen by off-board circuits. This is sometimes called repowering. Some buffers have a third line entering the side of the triangle. When it is not activated, the output of the buffer is removed from the circuit to keep it from interfering with other devices. The 74LS244 is an example:



Symbols are substituted for the full description or abbreviation of a Boolean operation in the C programming language. They are as follows for the operations covered so far:

Logical Operation	Abbreviation	Symbol
And	AND	**&**
Or	OR	|
Exclusive OR	XOR	^
Inversion	NOT	~

It is common in the C language to perform logical operations on bytes or words. As noted in the previous section, a byte is a group of eight bits. A word is commonly considered to be sixteen bits in embedded and control systems. Combinations of on and off conditions are often important determinants of condition, and the use of logical combinations as outputs can be used to cause complex actions. To determine the result when logical operations are applied to larger variable types, simply work with one bit at a time. Some examples follow. The numbers are presented in both hexadecimal and binary form. The top line shows an equation illustrating the operation in hexadecimal notation and the symbol used in C. It is not a C statement, but simply an illustration of the action taken. The three lines following it show the numbers used in the operation and the result in both HEX and binary. The first example is expanded to show how the result is determined one bit at a time.

```
0xC1 & 0xEA = 0xC0 (this says 0xC1 AND 0xEA = 0xC0)
0xC1 11000001 (the two nibbles are 1100 = 12 = 0xC and 0001 = 1 = 0x1)
0xEA 11101010
0xC0 11000000
     ||||||||_ 1 AND 0 = 0
     |||||||__ 0 AND 1 = 0
     ||||||___ 0 AND 0 = 0
     |||||____ 0 AND 1 = 0
     ||||_____ 0 AND 0 = 0
     |||______ 0 AND 1 = 0
     ||_______ 1 AND 1 = 1
     |________ 1 AND 1 = 1

0x00 & 0x86 = 0x00 (this says 0x00 AND 0x86 = 0x00)
0x00 00000000
0x86 10000110
0x00 00000000 (Think, "This bit will be on
only if both of the ones above it are on.")
0x88 & 0xE0 = 0x80 (this says 0x88 AND 0xE0 = 0x80)
0x88 10001000
0xE0 11100000
0x80 10000000
```

```
0xC0 | 0xAD = 0xED (this says 0xC0 OR 0xAD = 0xED)
0xC0 11000000
0xAD 10101101
0xED 11101101 (Think, "If either one of the bits above is on,
 this one will be on.")
0xAD | 0xEF = 0xEF (this says 0xAD OR 0xEF = 0xEF)
0xAD 10101101
0xEF 11101111
0xEF 11101111
0xC4 | 0x84 = 0xC4 (this says 0xC4 OR 0x84 = 0xC4)
0xC4 11000100
0x84 10000100
0xC4 11000100
```

```
0xD4 ^ 0x8D = 0x59 (this says 0xD4 XOR 0x8D = 0x59)
0xD4 11010100
0x8D 10001101
0x59 01011001 (Think, "This bit will be on only if the two above it are
 not the same.")
0xDA ^ 0x87 = 0x5D (this says 0xDA XOR 0x87 = 0x5D)
0xDA 11011010
0x87 10000111
0x5D 01011101
0xAB ^ 0xFC = 0x57 (this says 0xAB XOR 0xFC = 0x57)
0xAB 10101011
0xFC 11111100
0x57 01010111
```

```
~0x86 = 0x79 (this says 0x86 inverted = 0x79)
0x86 10000110
0x79 01111001 (Think, "This is all of the bits above reversed.")
~0xC1 = 0x3E (this says 0xC1 inverted = 0x3E)
0xC1 11000001
0x3E 00111110
~0xEA = 0x15 (this says 0xEA inverted = 0x15)
0xEA 11101010
0x15 00010101
```

The following is a self-test over this section. It would be a very good idea to make sure you know the answers to all of the questions since sections that follow will build on this one.

1) It was developed by George Boole, and is often used to refine the determination of system status or to set or clear specific bits.

A) On B) NXOR C) Boolean Logic D) AND

2) Boolean Logic uses ____ to determine how bits are compared and simulates ____ .

A) Operators B) NOR C) NAND D) Truth Tables
E) Buffers F) AND G) Gates H) Off

3) The _____ operation says if and only if all inputs are on, the output will be on. The output will be off if any of the inputs are off.

A) OR B) NAND C) NOR D) AND

4) The _____ operation says if any input is on then the output will be on.

A) NOT B) OR C) NOR D) XOR

5) If and only if all of the inputs are on, the output will be off. This is called _____ .

A) NAND B) NOR C) Truth Tables D) On

6) This operation says that if any input is on, the output will be off. What operation is this?

A) Boolean Logic B) XOR C) NOR D) AND

7) _____ says that if the inputs are different then the output will be on.

A) Gates B) Low C) NXOR D) XOR

8) _____ simply changes the input to the opposite (0 to 1 or 1 to 0).

A) Operator B) NOT C) AND D) OR

9) 0xB0 & 0xD9
Operator: ___________
Binary for 0xB0: ___________ ___________
Binary for 0xD9: ___________ ___________
Binary Result of Operation: ___________ ___________
HEX Result of Operation: ___________ ___________

10) 0xAF | 0x9C
Operator: ___________
Binary for 0xAF: ___________ ___________
Binary for 0x9C: ___________ ___________
Binary Result of Operation: ___________ ___________
HEX Result of Operation: ___________ ___________

11) 0xC3 ^ 0x7C
Operator: ___________
Binary for 0xC3: ___________ ___________
Binary for 0x7C: ___________ ___________
Binary Result of Operation: ___________ ___________
HEX Result of Operation: ___________ ___________

12) ~0x85
Operator: ___________
Binary for 0x85: ___________ ___________
Binary Result of Operation: ___________ ___________
HEX Result of Operation: ___________ ___________

Answers To Above Test

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