# An Introduction to Microprocessors



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# Outline:

- Numerical representations
- Registers and Adders
- ATmega103 architecture
- AVR assembly language
- Elementary example program
- STUDIO7
- AVR Assembler
- Downloading with PonyProg

# Numbers in a computer:

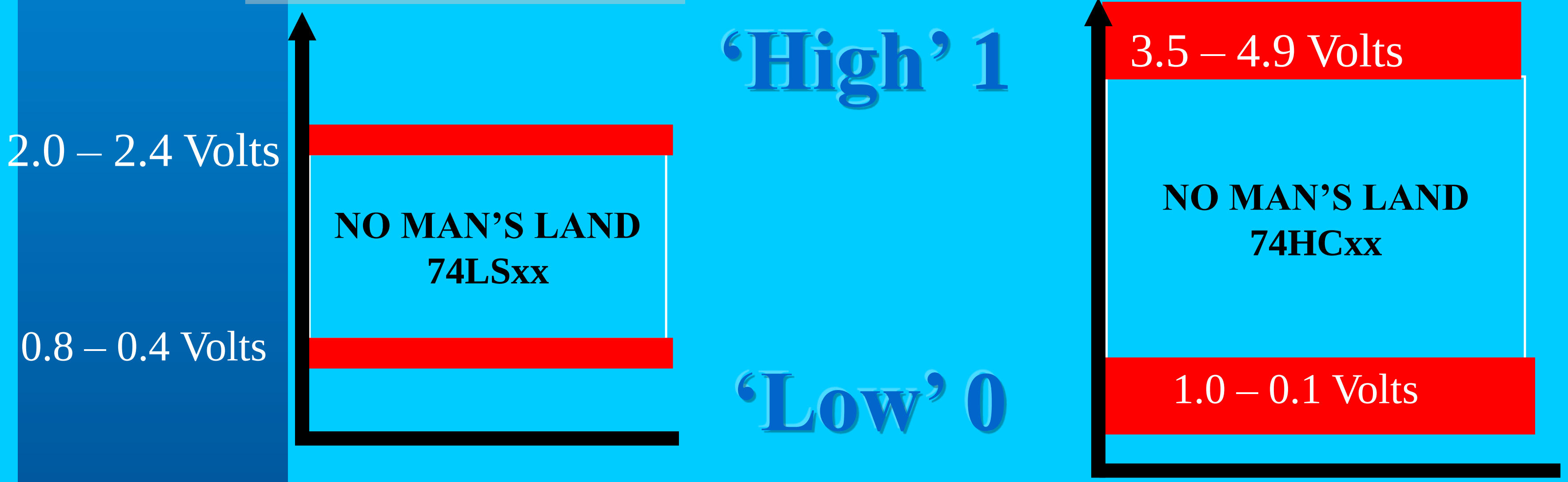
- **Computers store arithmetic units called *bits.***
- **Each bit is represented by an electrical signal which is either *high* or *low* (voltage levels).**
- ***high*** $\Rightarrow$ **1 and *low*** $\Rightarrow$ **0** — **Normal Logic**
- **Often *high*** $\Rightarrow$ **0 and *low*** $\Rightarrow$ **1** — **Inverse Logic**

# High and Low

## In this course we use TTL or TTL-like  (CMOS) technology :

**Transistor Transistor Logic (TTL)**

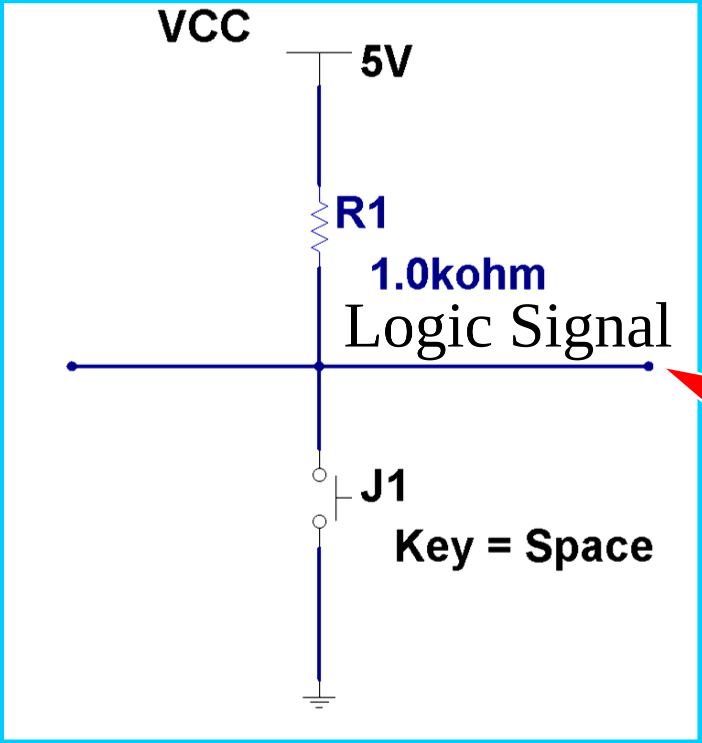
**CMOS**




It is actually a bit more complicated than this since there are actually different thresholds for inputs and outputs and noise margins (indicated here in RED) but this may be  addressed later If time permits.

# Making a Zero or and One

- **How do you actually make a 0 or 1 ?**




It is clear that depending upon the switch position the line will be either '0' or '1'

# Storing 0 and 1 : Registers

- **Registers** are electronic devices capable of storing 0 or 1
- **D-FLIP-FLOPs** are the most elementary registers which can store one bit
- **8 DFFs** clocked together make an one byte register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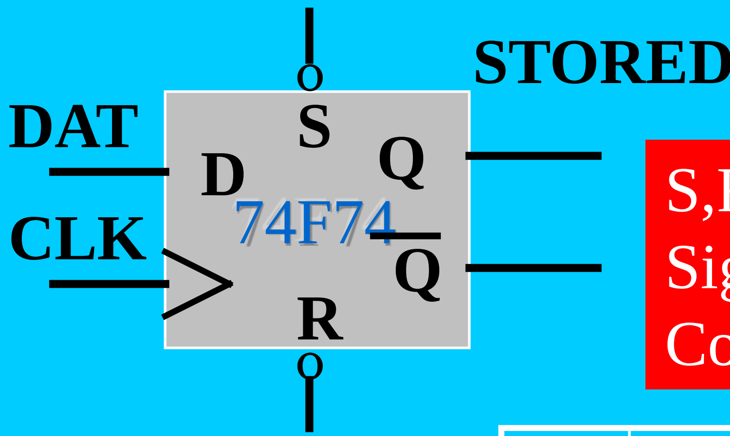
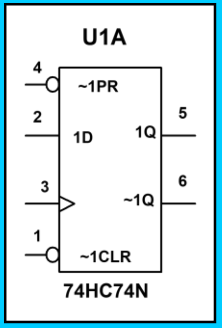
# The D-Flip-Flop (DFF)




S,R, Q-bar are Signals with Complement Logic




One can Set or Reset (Clear) the DFF using S or R

On the rising edge of the clock the data are transferred and stored in Q.

| CLK | D | S | R | Q | !Q |
|---|---|---|---|---|---|
| X | X | L | H | H | L |
| X | X | H | L | L | H |
| ↑ | H | H | H | H | L |
| ↑ | L | H | H | L | H |
| X | X | L | L | H | H |



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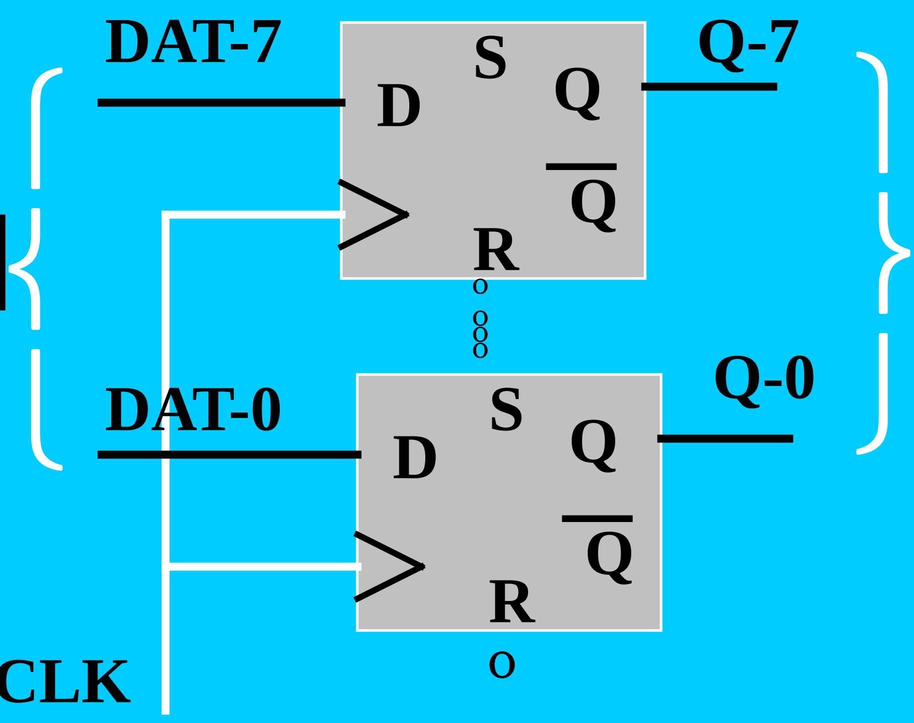
# Byte Register I

## Byte register that stores a byte

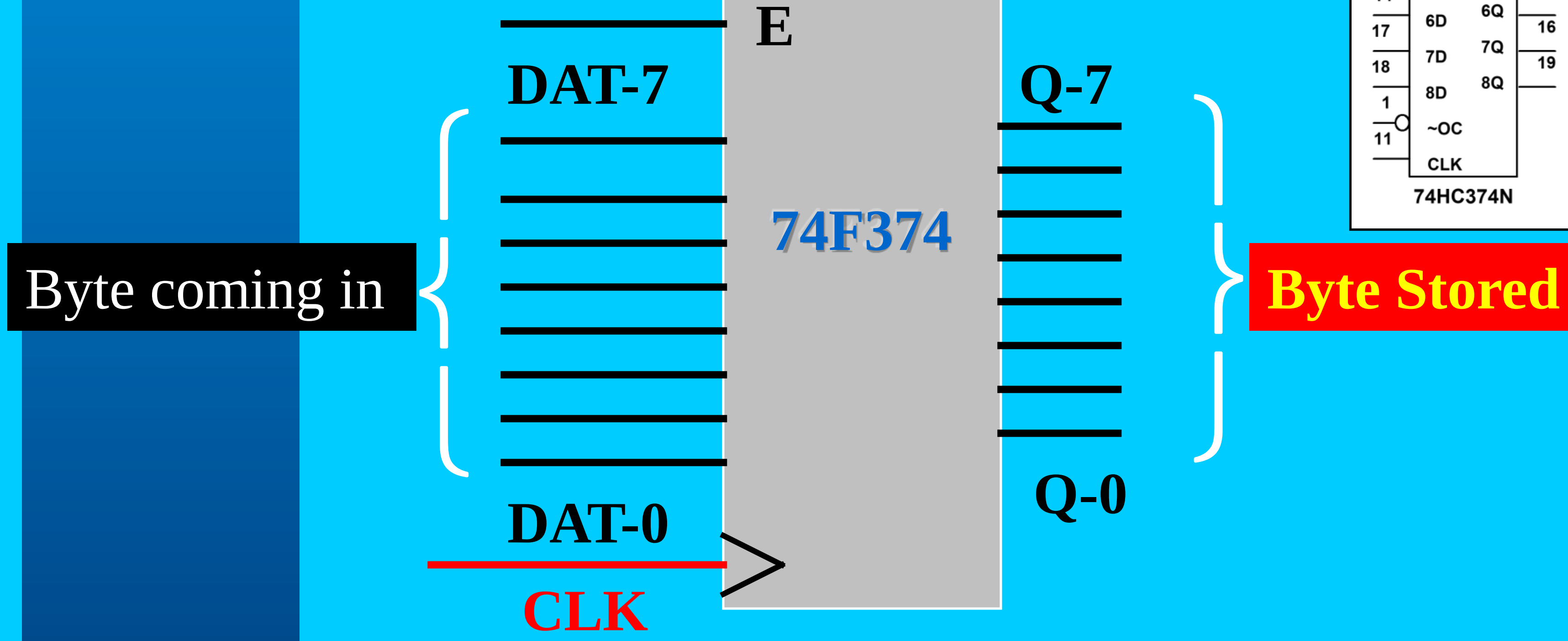
Byte coming in

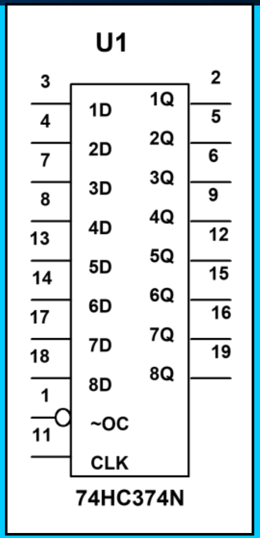



Byte Stored

# Byte Register II

- **It exists in one package :**



# Bits & Bytes :

- **Bit 1,0**
- **Nibble 4 bits**
- **Byte 8 bits**
- **Word 16 bits or 2 bytes**
- **1Kbyte = 1024 Bytes = 8Kbits**
- **1Mbyte = 1024 Kbytes = 8*1024 Kbits**
- **1Gbyte = 1024 Mbytes =……**

# Binary Representation

- **This representation is based on powers of 2. Any number can be expressed in terms of 0 and 1**

Example: $5 = 101_2 = 1 * 2^2 + 0 * 2^1 + 1 * 2^0$

Example: $9 = 1001_2 = 1 * 2^3 + 0 * 2^2 + 0 * 2^1 + 1 * 2^0$

Exercise: Convert any way you can the numbers 19, 38, 58 from decimal to binary. (use calculator or C program)

# Hexadecimal Representation

- This representation is based on powers of 16. Any number can be expressed in terms of:

**0, 1, 2,…,9,A,B,C,D,E,F** (0,1,2,…,9,10,11,12,13,14,15)

Example: $256 = 100_{16} = 1 * 16^2 + 0 * 16^1 + 0 * 16^0$

Example: $1002 = 3EA_{16} = 3 * 16^2 + 14 * 16^1 + 10 * 16^0$

Exercise: Convert any way you can the numbers 1492, 3481, 558 from decimal to hex. (use calculator or C program)

# Boolean Operations

- **NOT: NOT(101) = 010**
- **AND: AND(10101 ; 01010) = 0**
- **OR : OR(10101; 01010) = 11111**
- **SHIFT L: SHIFT L(111) = 1110**
- **SHIFT R: SHIFT R(111) = 011**

Why shift is Important ?
Try SHIFT R(011)

Exercise: (1) Find NOT(AAA)
(2) Find OR(AAA; 555)
(3) Find AND (AEB123; FFF000)

# Negative Numbers

- **How do you represent negative numbers ?**

**Using 2’s Complement Arithmetic**

Recipe : Take the complement of the number and add 1.

Example: Consider the number $3 = 011_2$
Then –3 is NOT(011) + 1 = 100 + 1 = 101

Exercise: Consider a 4 bit machine. Derive all possible positive and negative numbers

# 4-bit Negative Numbers

- **Consider a 4 bit machine. Find all positive and negative numbers you can have:**

| Integer | Sign Magnitude | 2's complement |
|---|---|---|
| +7 | 0111 | 0111 |
| +6 | 0110 | 0110 |
| +5 | 0101 | 0101 |
| +4 | 0100 | 0100 |
| +3 | 0011 | 0011 |
| +2 | 0010 | 0010 |
| +1 | 0001 | 0001 |
| 0 | 0000 | 0000 |
| -1 | 1001 | 1111 |
| -2 | 1010 | 1110 |
| -3 | 1011 | 1101 |
| -4 | 1100 | 1100 |
| -5 | 1101 | 1011 |
| -6 | 1110 | 1010 |
| -7 | 1111 | 1001 |
| -8 | 1000 (-0) | 1000 |

# Characters

- The English characters you see on your computer screen are made also by using numbers.
- There is an one-to-one correspondence between all characters and a set of byte numbers world-wide.
- The computers know to interpret these bytes as characters.

# Characters and the ASCII System

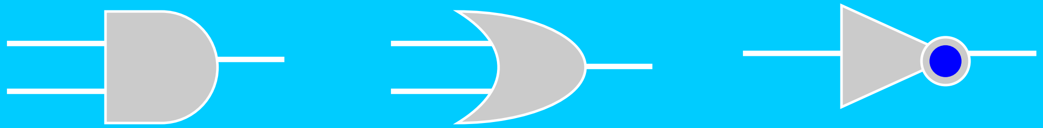
| Dec | Hx | Oct | Char | Dec | Hx | Oct | Html | Chr | Dec | Hx | Oct | Html | Chr | Dec | Hx | Oct | Html | Chr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 000 | NUL (null) | 32 | 20 | 040 |   | Space | 64 | 40 | 100 | @ | @ | 96 | 60 | 140 | ` | ` |
| 1 | 1 | 001 | SOH (start of heading) | 33 | 21 | 041 | ! | ! | 65 | 41 | 101 | A | A | 97 | 61 | 141 | a | a |
| 2 | 2 | 002 | STX (start of text) | 34 | 22 | 042 | " | " | 66 | 42 | 102 | B | B | 98 | 62 | 142 | b | b |
| 3 | 3 | 003 | ETX (end of text) | 35 | 23 | 043 | # | # | 67 | 43 | 103 | C | C | 99 | 63 | 143 | c | c |
| 4 | 4 | 004 | EOT (end of transmission) | 36 | 24 | 044 | $ | $ | 68 | 44 | 104 | D | D | 100 | 64 | 144 | d | d |
| 5 | 5 | 005 | ENQ (enquiry) | 37 | 25 | 045 | % | % | 69 | 45 | 105 | E | E | 101 | 65 | 145 | e | e |
| 6 | 6 | 006 | ACK (acknowledge) | 38 | 26 | 046 | & | & | 70 | 46 | 106 | F | F | 102 | 66 | 146 | f | f |
| 7 | 7 | 007 | BEL (bell) | 39 | 27 | 047 | ' | ' | 71 | 47 | 107 | G | G | 103 | 67 | 147 | g | g |
| 8 | 8 | 010 | BS (backspace) | 40 | 28 | 050 | ( | ( | 72 | 48 | 110 | H | H | 104 | 68 | 150 | h | h |
| 9 | 9 | 011 | TAB (horizontal tab) | 41 | 29 | 051 | ) | ) | 73 | 49 | 111 | I | I | 105 | 69 | 151 | i | i |
| 10 | A | 012 | LF (NL line feed, new line) | 42 | 2A | 052 | * | * | 74 | 4A | 112 | J | J | 106 | 6A | 152 | j | j |
| 11 | B | 013 | VT (vertical tab) | 43 | 2B | 053 | + | + | 75 | 4B | 113 | K | K | 107 | 6B | 153 | k | k |
| 12 | C | 014 | FF (NP form feed, new page) | 44 | 2C | 054 | , | , | 76 | 4C | 114 | L | L | 108 | 6C | 154 | l | l |
| 13 | D | 015 | CR (carriage return) | 45 | 2D | 055 | - | - | 77 | 4D | 115 | M | M | 109 | 6D | 155 | m | m |
| 14 | E | 016 | SO (shift out) | 46 | 2E | 056 | . | . | 78 | 4E | 116 | N | N | 110 | 6E | 156 | n | n |
| 15 | F | 017 | SI (shift in) | 47 | 2F | 057 | / | / | 79 | 4F | 117 | O | O | 111 | 6F | 157 | o | o |
| 16 | 10 | 020 | DLE (data link escape) | 48 | 30 | 060 | 0 | 0 | 80 | 50 | 120 | P | P | 112 | 70 | 160 | p | p |
| 17 | 11 | 021 | DC1 (device control 1) | 49 | 31 | 061 | 1 | 1 | 81 | 51 | 121 | Q | Q | 113 | 71 | 161 | q | q |
| 18 | 12 | 022 | DC2 (device control 2) | 50 | 32 | 062 | 2 | 2 | 82 | 52 | 122 | R | R | 114 | 72 | 162 | r | r |
| 19 | 13 | 023 | DC3 (device control 3) | 51 | 33 | 063 | 3 | 3 | 83 | 53 | 123 | S | S | 115 | 73 | 163 | s | s |
| 20 | 14 | 024 | DC4 (device control 4) | 52 | 34 | 064 | 4 | 4 | 84 | 54 | 124 | T | T | 116 | 74 | 164 | t | t |
| 21 | 15 | 025 | NAK (negative acknowledge) | 53 | 35 | 065 | 5 | 5 | 85 | 55 | 125 | U | U | 117 | 75 | 165 | u | u |
| 22 | 16 | 026 | SYN (synchronous idle) | 54 | 36 | 066 | 6 | 6 | 86 | 56 | 126 | V | V | 118 | 76 | 166 | v | v |
| 23 | 17 | 027 | ETB (end of trans. block) | 55 | 37 | 067 | 7 | 7 | 87 | 57 | 127 | W | W | 119 | 77 | 167 | w | w |
| 24 | 18 | 030 | CAN (cancel) | 56 | 38 | 070 | 8 | 8 | 88 | 58 | 130 | X | X | 120 | 78 | 170 | x | x |
| 25 | 19 | 031 | EM (end of medium) | 57 | 39 | 071 | 9 | 9 | 89 | 59 | 131 | Y | Y | 121 | 79 | 171 | y | y |
| 26 | 1A | 032 | SUB (substitute) | 58 | 3A | 072 | : | : | 90 | 5A | 132 | Z | Z | 122 | 7A | 172 | z | z |
| 27 | 1B | 033 | ESC (escape) | 59 | 3B | 073 | ; | ; | 91 | 5B | 133 | [ | [ | 123 | 7B | 173 | { | { |
| 28 | 1C | 034 | FS (file separator) | 60 | 3C | 074 | < | < | 92 | 5C | 134 | \ | \ | 124 | 7C | 174 | | | \| |
| 29 | 1D | 035 | GS (group separator) | 61 | 3D | 075 | = | = | 93 | 5D | 135 | ] | ] | 125 | 7D | 175 | } | } |
| 30 | 1E | 036 | RS (record separator) | 62 | 3E | 076 | > | > | 94 | 5E | 136 | ^ | ^ | 126 | 7E | 176 | ~ | ~ |
| 31 | 1F | 037 | US (unit separator) | 63 | 3F | 077 | ? | ? | 95 | 5F | 137 | _ | _ | 127 | 7F | 177 | &#127; | DEL |



Source: www.asciitable.com

# How do the computers do all these ?

- You may remember from the first year the gates that form an AND, OR, NOT:



- Any Digital device can be made out of either ORs and NOTs or ANDs and NOTs.

- Truth Tables :

| A | B | AND |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

| A | B | OR |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

| A | NOT |
|---|---|
| 0 | 1 |
| 1 | 0 |

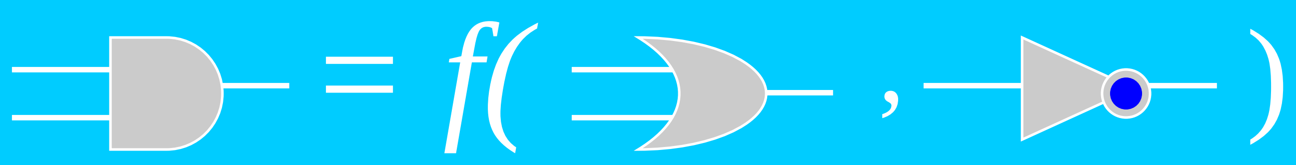
# DeMorgan's Theorem

- **You can swap ANDs with ORs if at the same time you invert all inputs and outputs :**

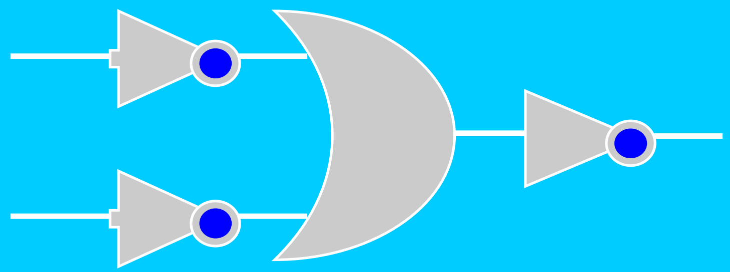
<u>**Exercise:**</u> Write to truth table for both and prove that this is correct

# An AND out of NOTs and ORs

- Exercise: Test the claim that you can make <u>any</u> logic device exclusively out of NOTs and ORs by making and AND out of NOTs and ORs:



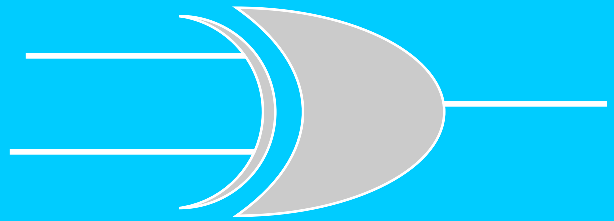
# Answer:



- **One can test explicitly that this device has an identical truth table as the AND gate.**

# Exercise: Exclusive OR

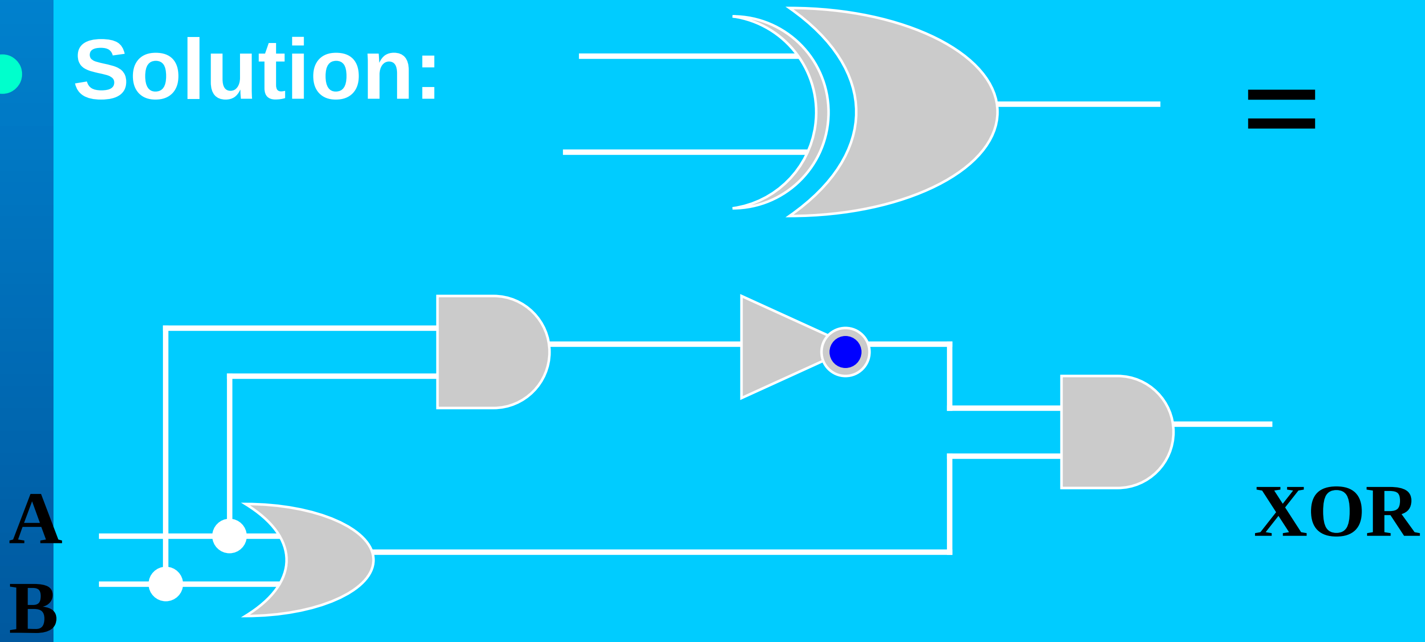
- **Construct an exclusive OR gate using OR, AND, AND NOT:**



| A | B | XOR |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

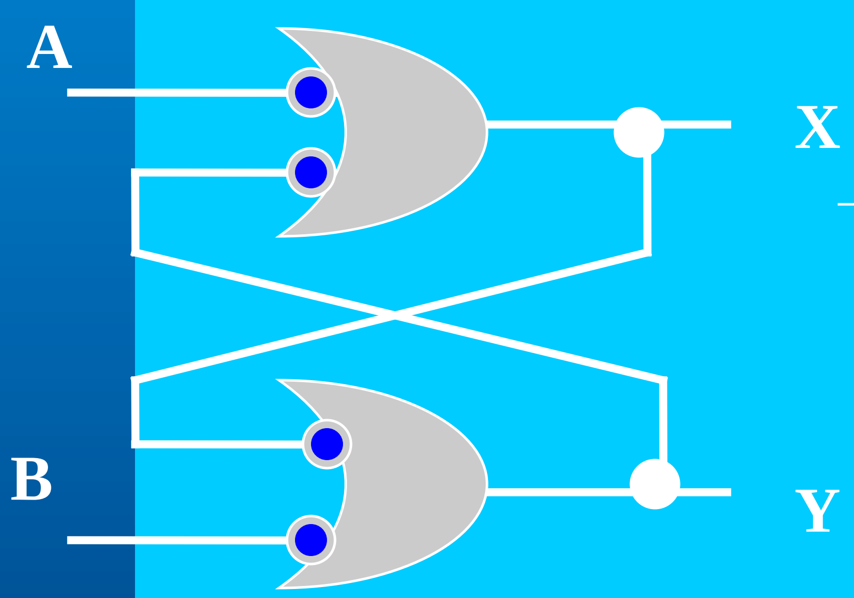
# The Exclusive OR

- **Solution:**



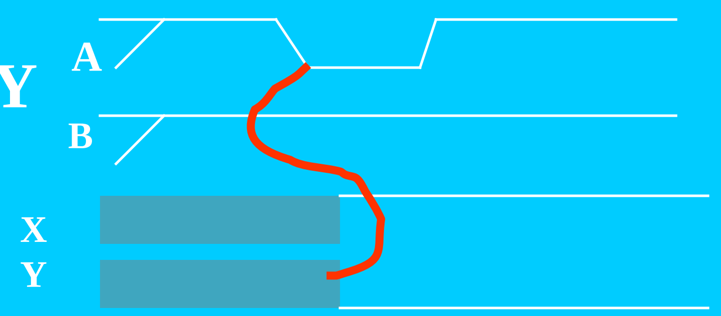
# The D-Flip Flop

- Making a DFF using gates




| A | B | X | Y |
|---|---|---|---|
| H | H | H | L |
| H | H | L | H |
| H | L | L | H |
| L | H | H | L |
| L | L | H | H |

Undefined



# How do Computers Add ?

- Make a 2 bit adder with a carry_in and a carry out :

| Cin | A | B | SUM | Cout |
|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 | 0 |
| 1 | 1 | 1 | 1 | 1 |

BINARY ADDITION EXAMPLE

(3-BIT MACHINE)

$A = 111_2$ , $B = 111_2$ , $C = A+B$

$$
\begin{array}{rl}
111 & (A) \\
+\;111 & (B) \\
\hline
1\underbrace{110}_{\text{Result}} & (C)
\end{array}
$$

Carry



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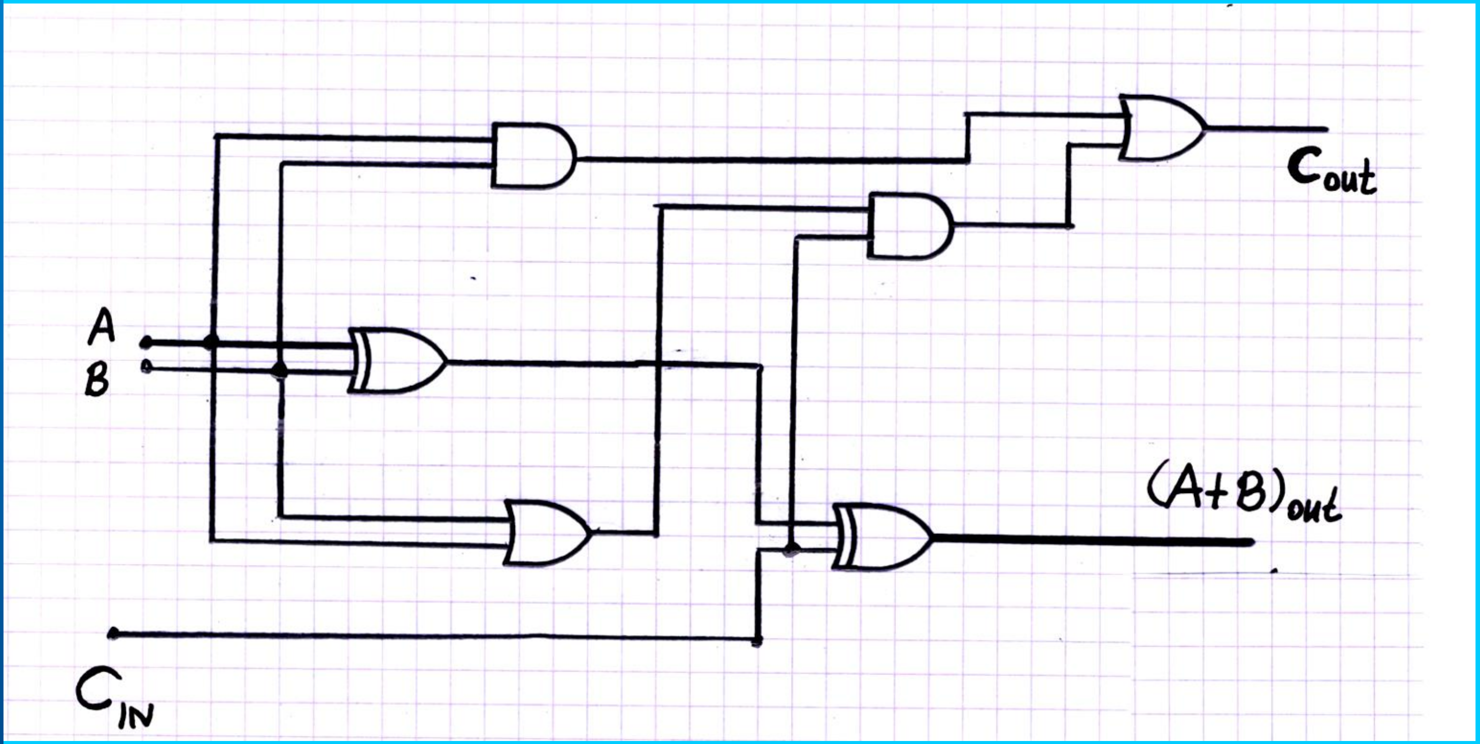
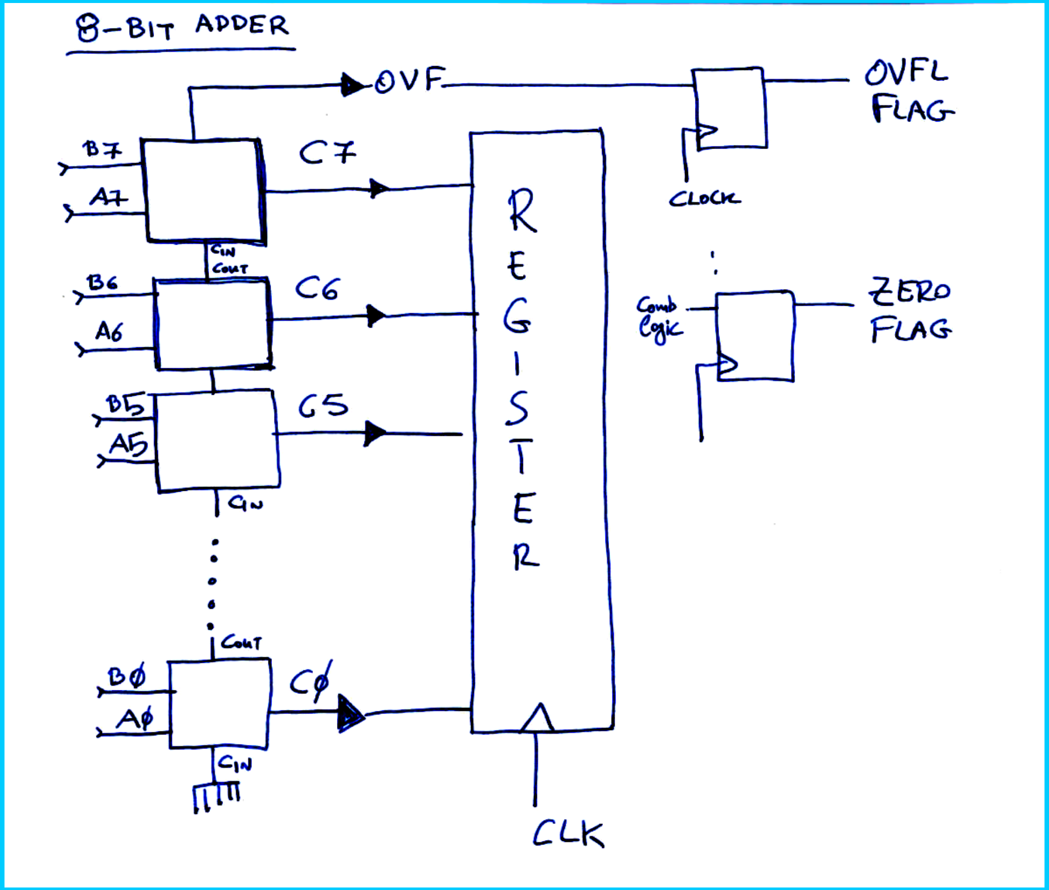
# Two Bit Adder with Carry

- **Answer:**



# Arithmetic Logic Unit (ALU)

- Center of every computer:



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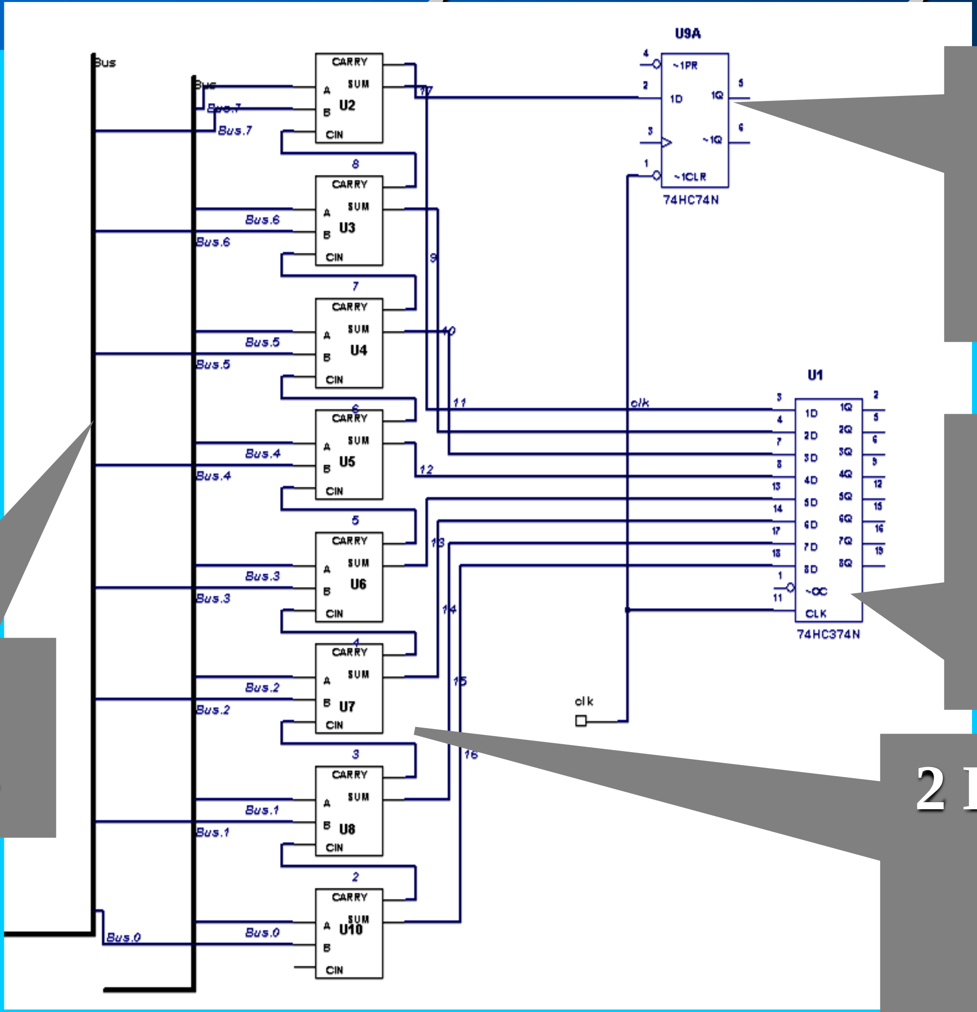
# You can actually design one yourself

# with what you already know




The Arithmetic Overflow Flag is stored here

The result is stored in this register

Eight Bits Wide Bus.

2 Bit adders with carry-in and carry-out



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