Lecture 04

Logic Input/Output
Combinatorial Logic

Agenda

00 . Misc Teensy stuff (Printing)

01. Logic Gates

02. Digital Input / Logic Levels

03. Pullups

04. Schmidtt Triggers

05. Resistor Colors (if there is time)

Stuff

- Acronyms on Piazza – don't worry about registers.
  - http://medesign.seas.upenn.edu/index.php/Guides/Teensy
- Late Policy – Lab 1?
- Toucan Study Hall – one more try?

Answer in Private CHAT

How you feel about each topic below with:

1. I don't understand this topic at all
2. I don't know now, but know what to do to get by
3. I understand some, but expect to get the rest later
4. I understand completely already

A. Registers

B. How Memory works

C. How the timer/counter works on the ATmega32U4

Sample C code

```
/* Name: main.c
 * Author: <insert name here>
 * Copyright: <insert your copyright message here>
 * License: <insert your license reference here>
 *
 */
```

```
/* Project: can put project name here or lab number...
 * Author: Thomas Edison
 * Copyright (C) 1883 Thomas Edison - All Rights Reserved
 *
 * You may use, distribute and modify this code under the
 * terms of the GNU GPLv3.0 license.
 */
```

Using Header Files

- Header files in C are normally used for constants, function declarations and macros – NOT source code.
- Including C source code in header files – works, but so does butting into the front of a line – it's okay if you're alone, but if you have to work with others, they may get angry.
- Normally when you have large projects that you want to break into modular pieces… you have multiple source files ".c" and you change your Makefile to compile together multiple .c files.

Teensy Clock speed

Clock Speed:

- The default speed of the Teensy might not be 16Mhz. It might be 8Mhz. Add this line to be sure it is 16Mhz.

```
teensy_clockdivide(0);
```

`teensy_wait();`

- Uses a built_in macro. It cannot take variables, so wrap `teensy_wait(1);` in a `for` loop if you want variable delay times.

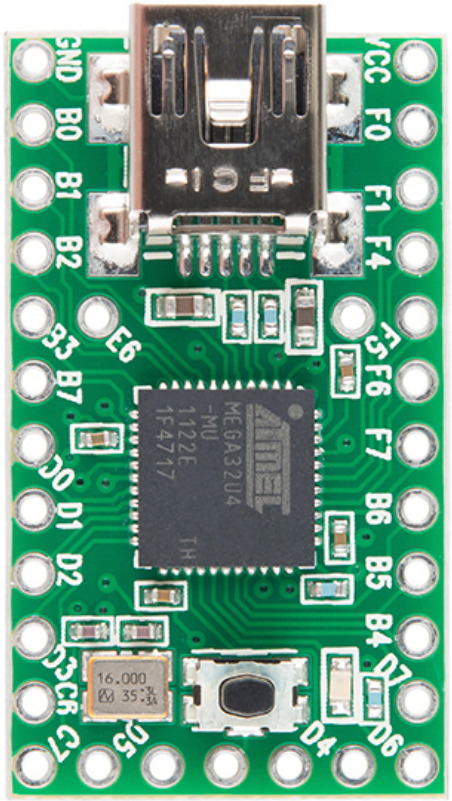
Issues on installing AVR-GCC

- See Piazza @45 for Windows, @41 for MacOS

Printing via USB

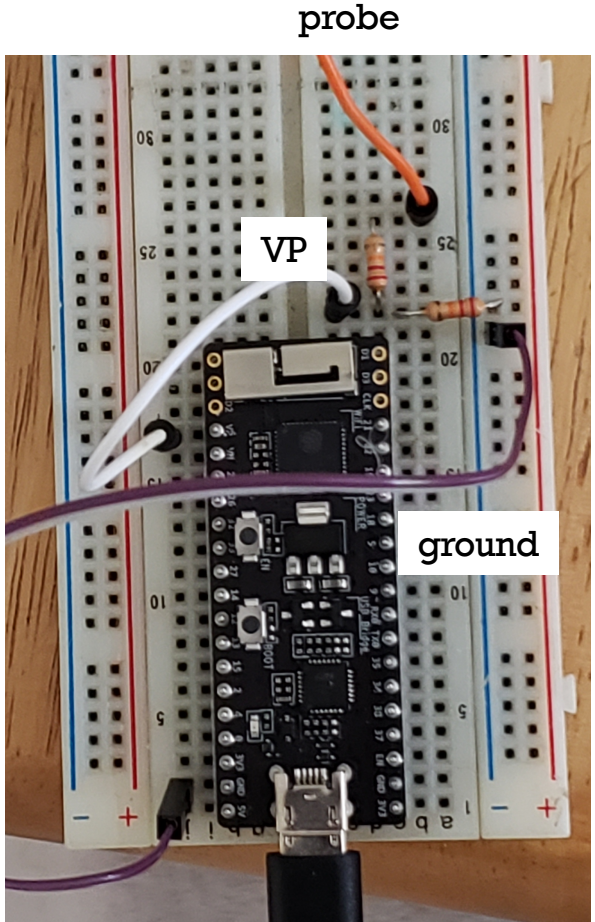
- Download `t_usb.h` and `t_usb.c` from http://medesign.seas.upenn.edu/index.php/Guides/MaEvArM-usb
- Put `t_usb.c` in `src/` directory and `t_usb.h` in `inc/`
- Add `#include "t_usb.h"`
- Use *realterm* on GMlab PC's. Download *putty* for PC or mac or use *screen* on mac. (Need to find /dev/tty.usbmodem####)
- Must initialize the USB before it will work
  - `m_usb_init();` // put this near top of code
- Example print statements for debugging.
  - `m_usb_tx_string("inside for loop\n");`
  - `m_usb_tx_hex(PORTD);// prints the status of the port`
  - `m_usb_tx_int(x);` // x is an integer variable

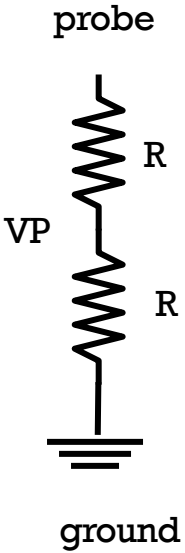
Teensy Loader and USB Demo



Using OscilloSorta with 5V signals

- Since OscilloSorta only measures upto 3.3V, use voltage divider to scale output. Just remember to multiply readings by the ratio.
- E.g. 2:1 voltage divider can measure upto 6.6V -> multiply scope readings by 2



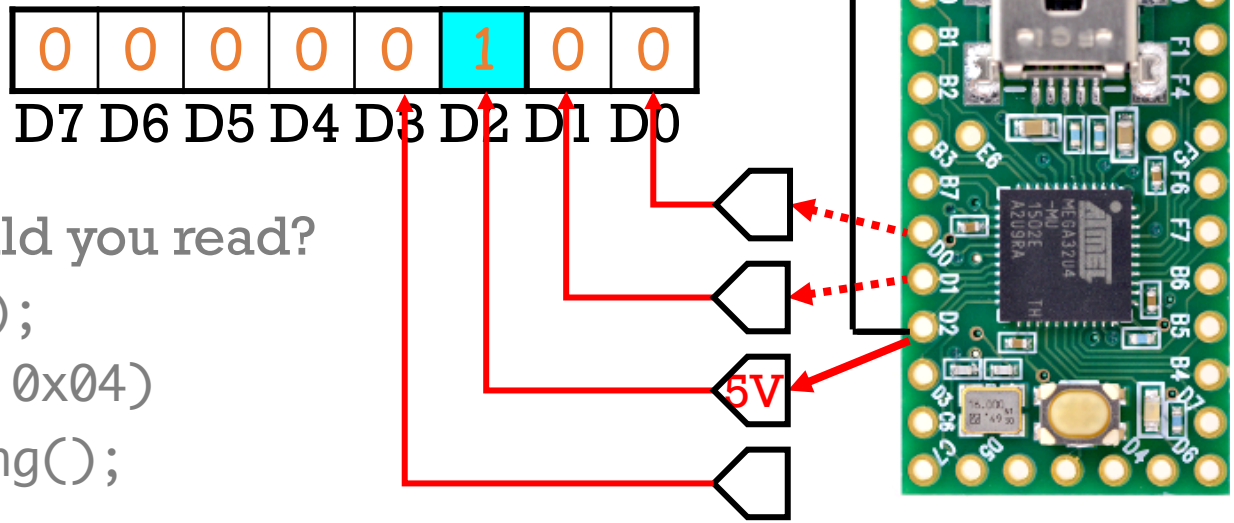


01

Digital Input Logic Levels

Digital Input

- We can set a pin on a port to be INPUT we can read whether something is controlling that pin to be HIGH or LOW.



- What register would you read?

```
clear(DDRD,2);
if (PORTD == 0x04)
    dosomething();
```

  - This doesn't work

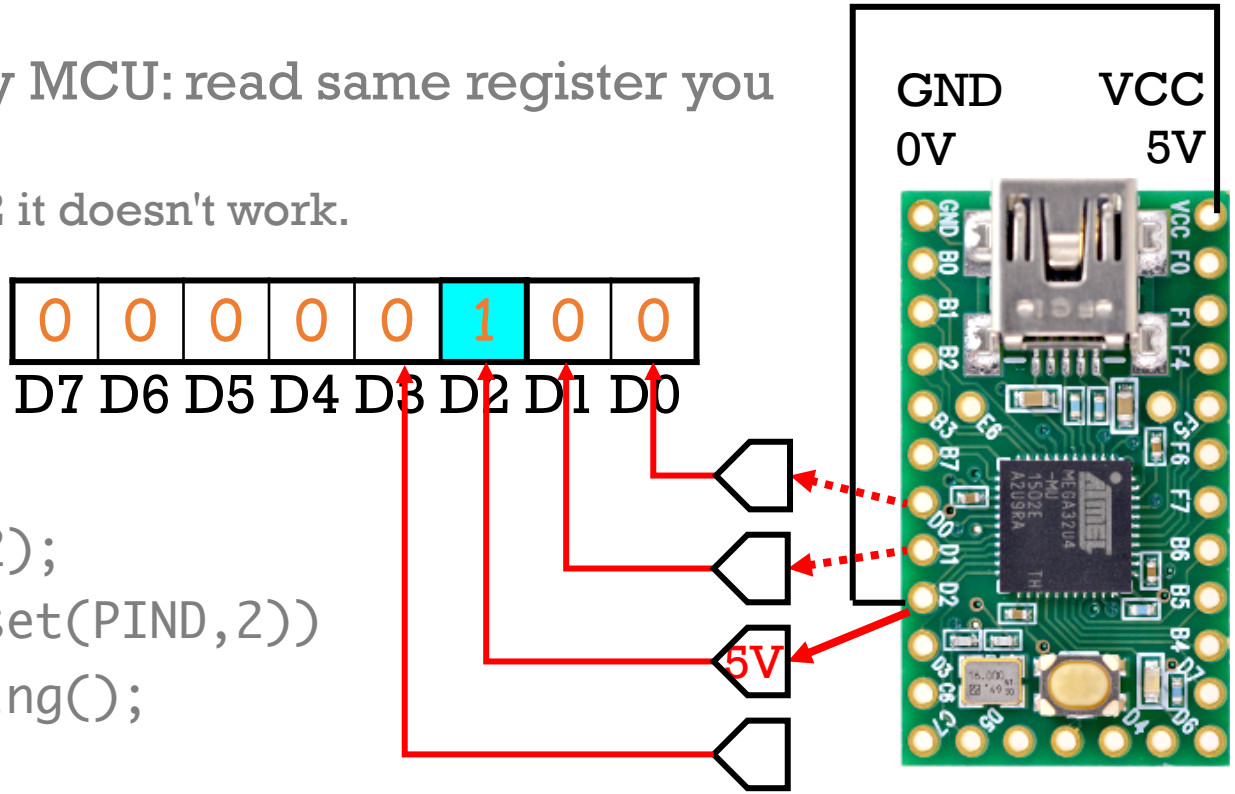
Digital Input on ATMEGA32

- Standard on many MCU: read same register you write to.

  But, on ATMEGA32 it doesn't work.

- Use PINx. e.g.

```
clear(DDRD,2);
if (bit_is_set(PIND,2))
   dosomething();
```

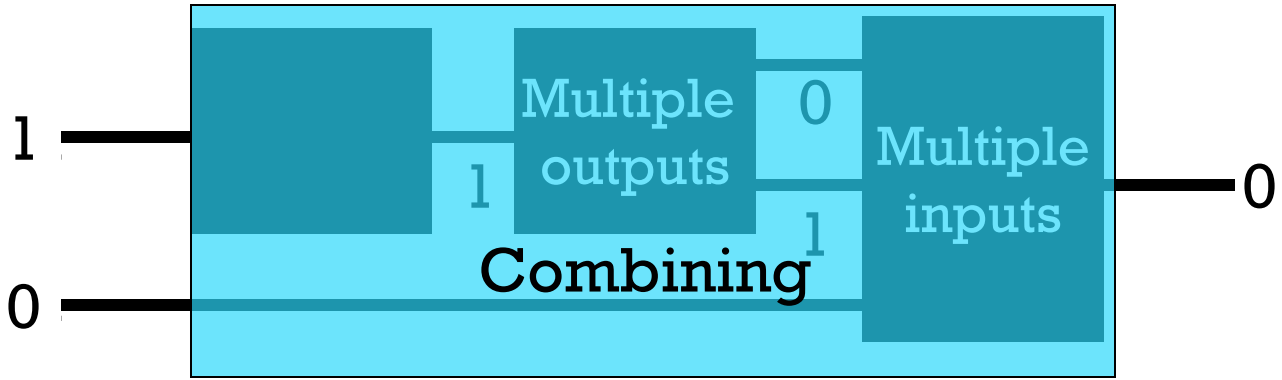


02

Combinatorial Logic Gates

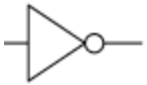
Digital Inputs and Outputs

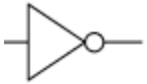
- Black boxes, one end is the input, one end is the output

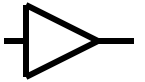


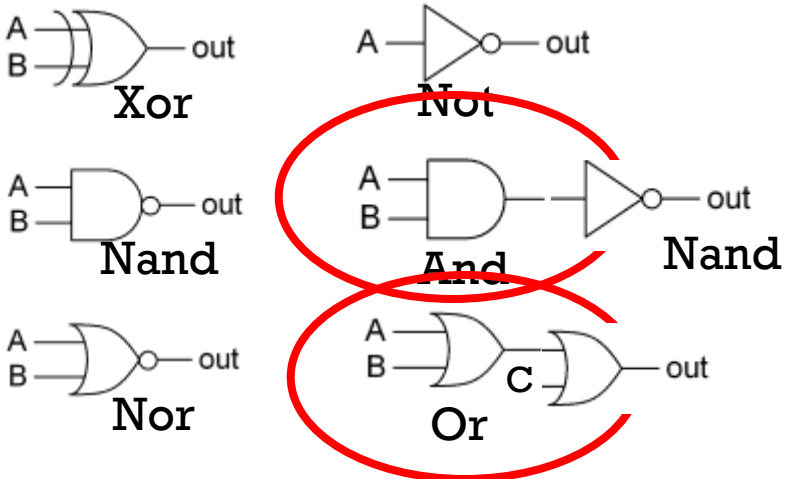
- Digital I/O has logical ones and zeros at inputs and outputs

Combinatorial Logic Gates

Inverter 1  0

0  1

Digital buffer 1  1



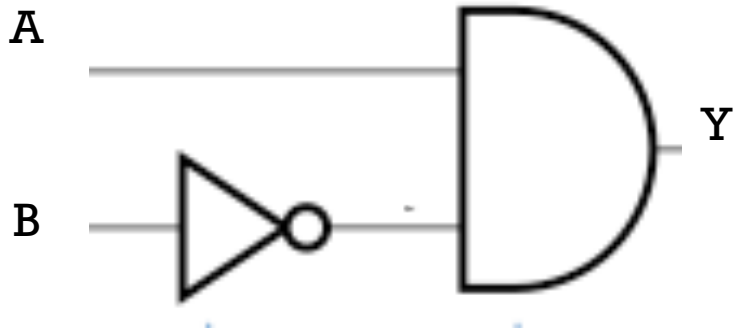
Truth table

INPUT	OUTPUT
A	Not A
1	0
0	1

INPUT		OUTPUT
A	B	A **OR** B
0	0	0
1	0	1
0	1	1
1	1	1

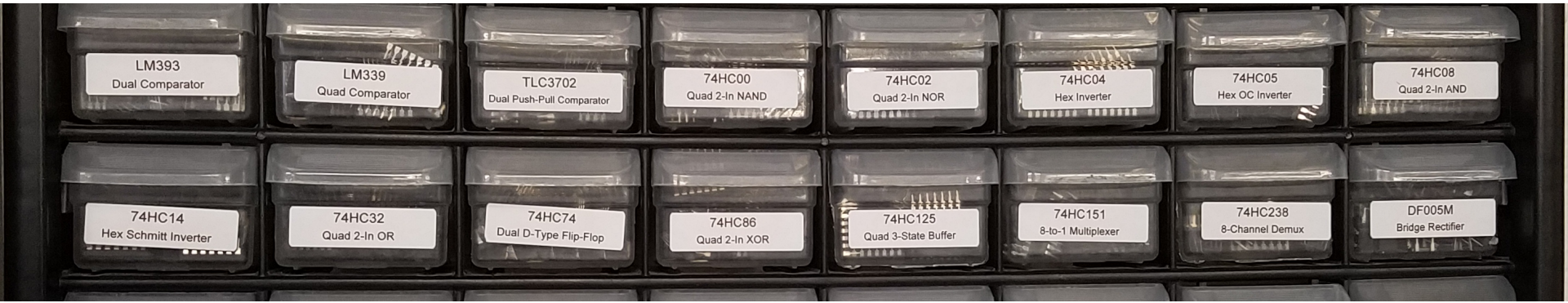
Q1: Truth table example

1) Write the function of each symbol below. Indicate the possible inputs and outputs for the following circuit (e.g. a truth table)



A	B	Y
0	0	0
1	0	1
0	1	0
1	1	0

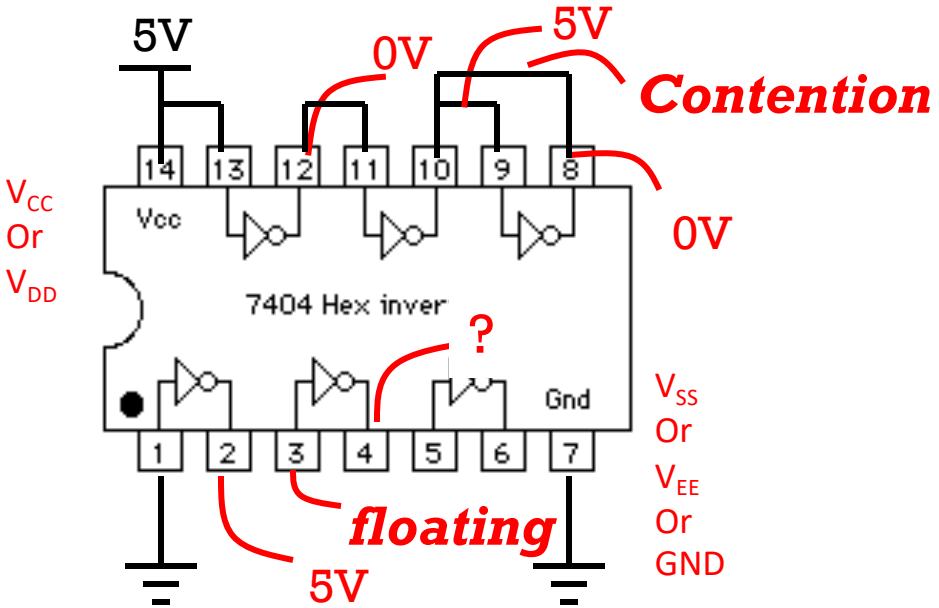
GM Lab ministore



Has variety of logic gates.
Feel free to browse, or to go to http://digikey.com and get your own
But be sure to get DIP packages that can go into your protoboard.

Simple Logic

- Logical ONE = high = 5V
- Logical ZERO = low = 0V



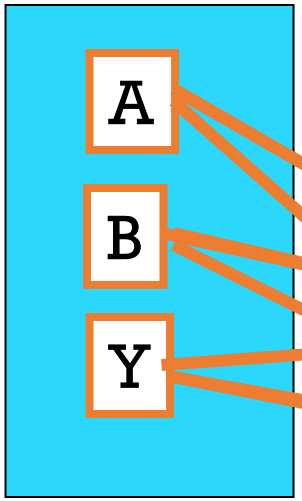
Digital Logic requires POWER and GND

Hex Inverters
7404 74LS04,
74HCT04,74C04
74ALS04… etc.

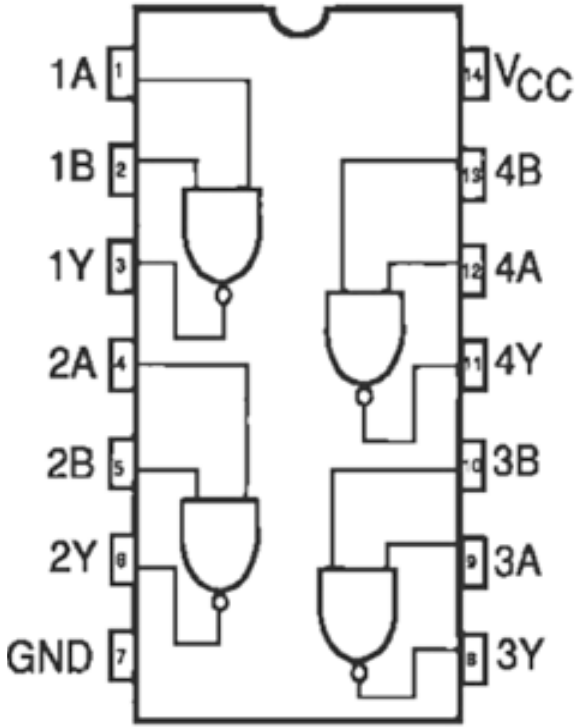
GND 5V

Y = !(A and B)

Y = A and B

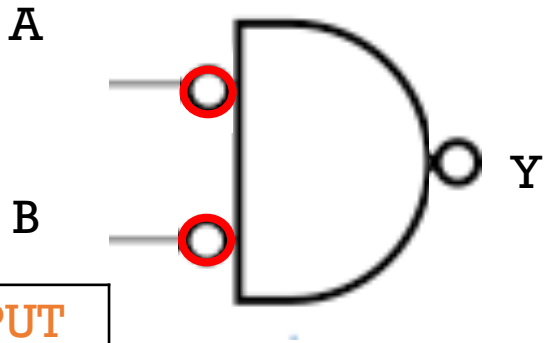


74HC00



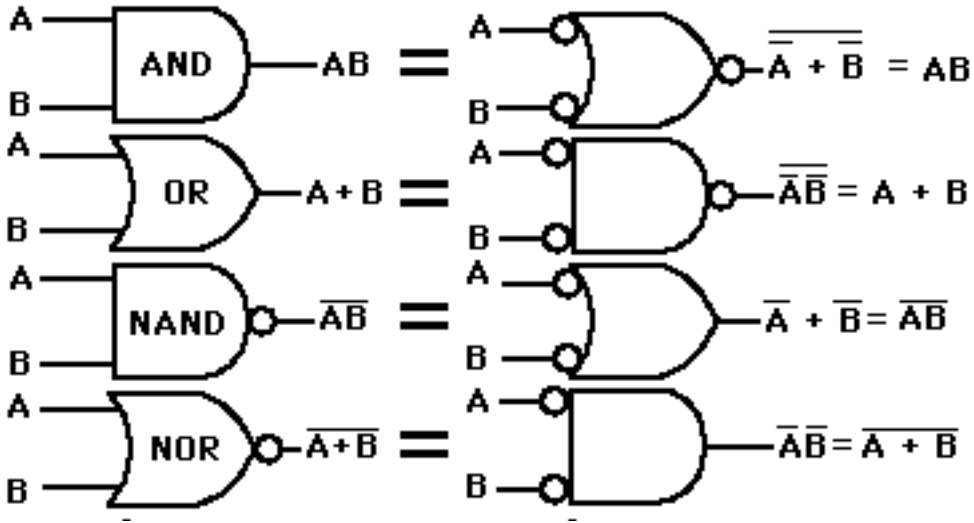
Gate Equivalencies

- Inverting inputs and outputs can turn OR into AND and vice versa.



INPUT		OUTPUT
A	B	Y
0	0	0
1	0	1
0	1	1
1	1	1

Same as OR Gate



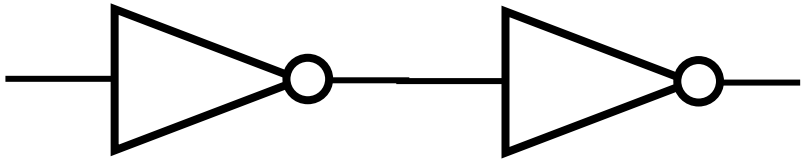
Digital Input/Output States

Three possible states:

1. HIGH
2. LOW
3. Tri-state (high-impedance)

Internal Mode	Internal state	External state	Result
OUTPUT	High	High	High
OUTPUT	High	Low	CONTENTION
OUTPUT	High	Float	High
OUTPUT	Low	High	CONTENTION
OUTPUT	Low	Low	Low
OUTPUT	Low	Float	Low
INPUT	Float	High	High
INPUT	Float	Low	Low
INPUT	Float	Float	unknown

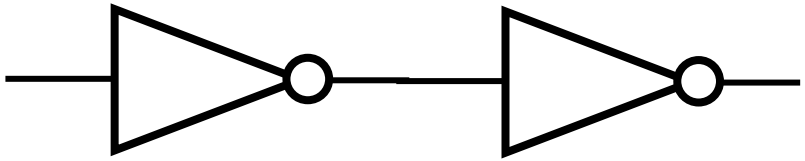
Human Logic



- Hold hands,
- Left is input, Right is output

- Upraised hand is logic high (true)
- Lowered hand is logic low (false)

Human Logic Levels



- Hold hands,
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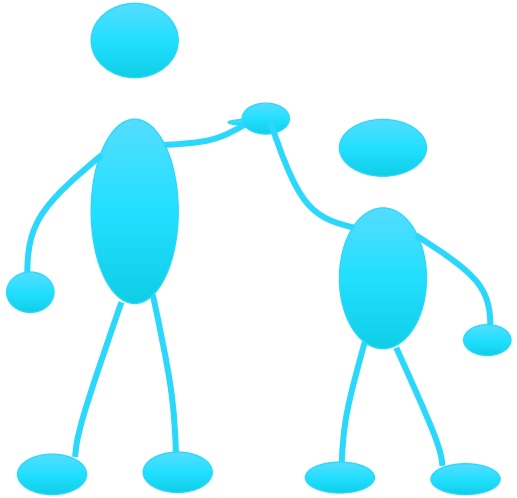


- Upraised hand is logic high (true)
- Lowered hand is logic low (false)

- How high is high? What if you have short arms?

DC Electrical Characteristics (Note 4) 74HC04

Symbol	Parameter	Conditions	V_{CC}	$T_A = 25°C$	$T_A = -40$ to $85°C$	$T_A = -55$ to $125°C$	Units
				Typ	Guaranteed Limits		
V_{IH}	Minimum HIGH Level Input Voltage		2.0V		1.5	1.5	1.5	V
			4.5V		3.15	3.15	3.15	V
			6.0V		4.2	4.2	4.2	V
V_{IL}	Maximum LOW Level Input Voltage		2.0V		0.5	0.5	0.5	V
			4.5V		1.35	1.35	1.35	V
			6.0V		1.8	1.8	1.8	V
V_{OH}	Minimum HIGH Level Output Voltage	$V_{IN} = V_{IL}$ $\lvert I_{OUT}\rvert \le 20\ \mu A$	2.0V	2.0	1.9	1.9	1.9	V
			4.5V	4.5	4.4	4.4	4.4	V
			6.0V	6.0	5.9	5.9	5.9	V
		$V_{IN} = V_{IL}$ $\lvert I_{OUT}\rvert \le 4.0$ mA	4.5V	4.2	3.98	3.84	3.7	V
		$\lvert I_{OUT}\rvert \le 5.2$ mA	6.0V	5.7	5.48	5.34	5.2	V
V_{OL}	Maximum LOW Level Output Voltage	$V_{IN} = V_{IH}$ $\lvert I_{OUT}\rvert \le 20\ \mu A$	2.0V	0	0.1	0.1	0.1	V
			4.5V	0	0.1	0.1	0.1	V
			6.0V	0	0.1	0.1	0.1	V
		$V_{IN} = V_{IH}$ $\lvert I_{OUT}\rvert \le 4.0$ mA	4.5V	0.2	0.26	0.33	0.4	V
		$\lvert I_{OUT}\rvert \le 5.2$ mA	6.0V	0.2	0.26	0.33	0.4	V

For Vcc=5 ~3.5V

For Vcc=5 ~1.5V

For Vcc=5 ~4.5V

For Vcc=5 ~0.5V

How is Voltage Specified?

Q2: What is the minimum voltage output that will be recognized as a valid logic high on a 74LS00?

recommended operating conditions

		SN54LS00			SN74LS00			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.7			0.8	V
I_{OH}	High-level output current			−0.4			−0.4	mA
I_{OL}	Low-level output current			4			8	mA
T_A	Operating free-air temperature	−55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS †			SN54LS00			SN74LS00			UNIT
				MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}	V_{CC} = MIN,	I_I = −18 mA				−1.5			−1.5	V
V_{OH}	V_{CC} = MIN,	V_{IL} = MAX,	I_{OH} = −0.4 mA	2.5	3.4		2.7	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 4 mA		0.25	0.4		0.25	0.4	V
	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 8 mA					0.35	0.5	
I_I	V_{CC} = MAX,	V_I = 7 V				0.1			0.1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.7 V				20			20	μA
I_{IL}	V_{CC} = MAX,	V_I = 0.4 V				−0.4			−0.4	mA
I_{OS}§	V_{CC} = MAX			−20		−100	−20		−100	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			0.8	1.6		0.8	1.6	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			2.4	4.4		2.4	4.4	mA

How do we tell how "strong" the output is if in contention?

recommended operating conditions

		SN54LS00			SN74LS00			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
V_{IH}	High-level input voltage	2			2			V
V_{IL}	Low-level input voltage			0.7			0.8	V
I_{OH}	High-level output current			−0.4			−0.4	mA
I_{OL}	Low-level output current			4			8	mA
T_A	Operating free-air temperature	−55		125	0		70	°C

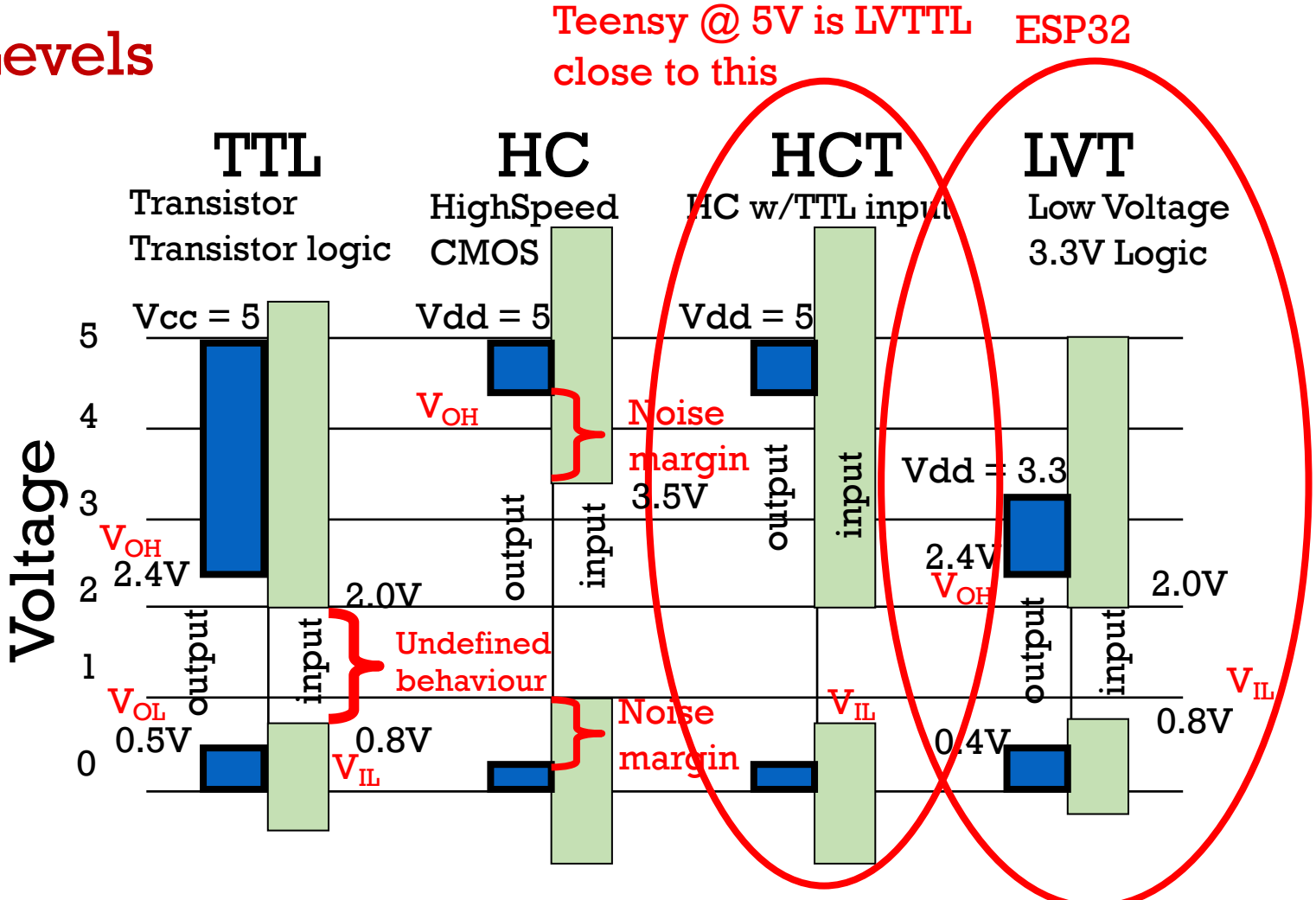
electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS †			SN54LS00			SN74LS00			UNIT
				MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IK}	V_{CC} = MIN,	I_I = −18 mA				−1.5			−1.5	V
V_{OH}	V_{CC} = MIN,	V_{IL} = MAX,	I_{OH} = −0.4 mA	2.5	3.4		2.7	3.4		V
V_{OL}	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 4 mA		0.25	0.4		0.25	0.4	V
	V_{CC} = MIN,	V_{IH} = 2 V,	I_{OL} = 8 mA					0.35	0.5	
I_I	V_{CC} = MAX,	V_I = 7 V				0.1			0.1	mA
I_{IH}	V_{CC} = MAX,	V_I = 2.7 V				20			20	μA
I_{IL}	V_{CC} = MAX,	V_I = 0.4 V				−0.4			−0.4	mA
I_{OS}§	V_{CC} = MAX			−20		−100	−20		−100	mA
I_{CCH}	V_{CC} = MAX,	V_I = 0 V			0.8	1.6		0.8	1.6	mA
I_{CCL}	V_{CC} = MAX,	V_I = 4.5 V			2.4	4.4		2.4	4.4	mA

Logic Levels

Valid Output Levels

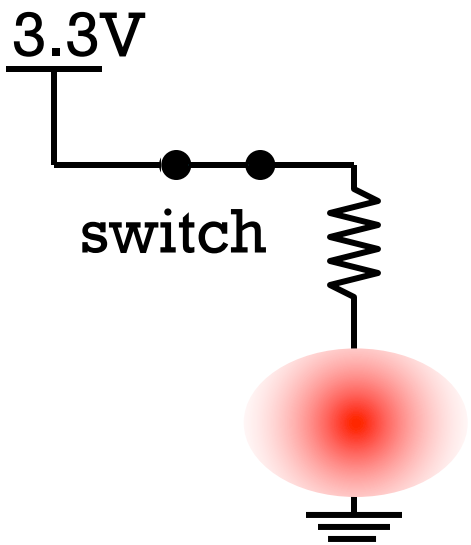
Valid Recognized Input Levels



03

Pullups

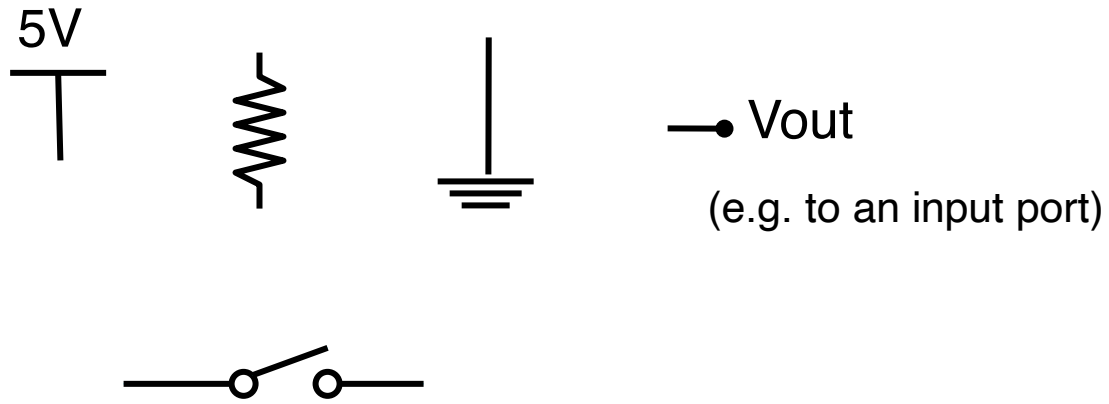
Switches in actuation



Hook up LED to power through an SPST switch

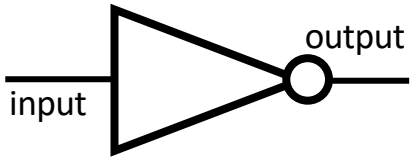
Switches in sensing

Q3: How can a switch be used to generate to different voltages to indicate the two states 0V and 5V of the switch?

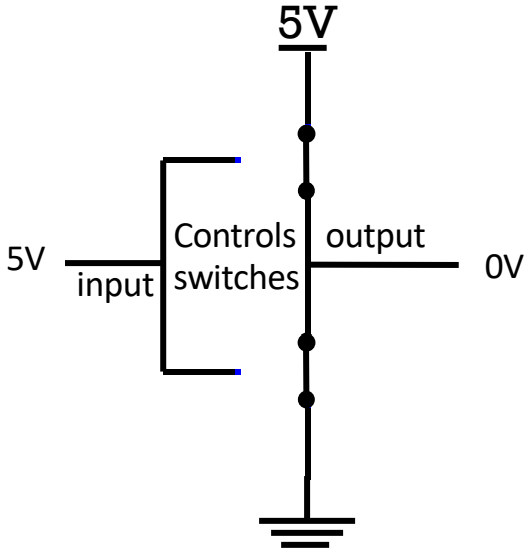


TTL Output (totem pole) vs Open Collector (OC)

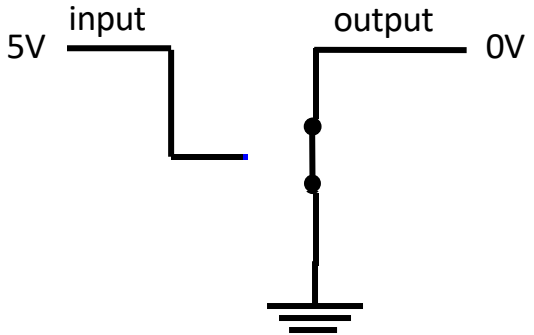
Inverter



Inverting output stage
Totem Pole Driven



Inverting output stage
Open Collector / Open Drain

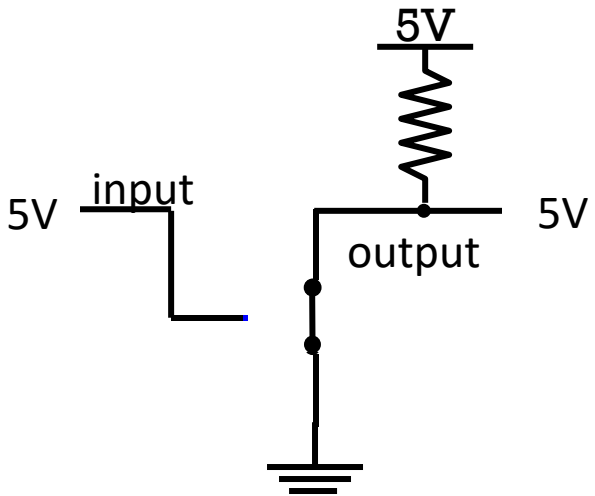


Pull-up Resistors

What size Resistor should we use?

- If **too small** current capability of output not strong enough for valid logic low
- If **too large** the input impedance may not be high enough for valid logic high
- Also if **too large** output may be too slow. (e.g. problem for serial communications)
- A rule of thumb is to use a resistor that is at least 10 times smaller than the value of the input pin impedance. (e.g. 1k to 10k)

Inverting output stage
Open Collector / Open Drain



Read more http://www.resistorguide.com/pull-up-resistor_pull-down-resistor/

Digital Input/Output States

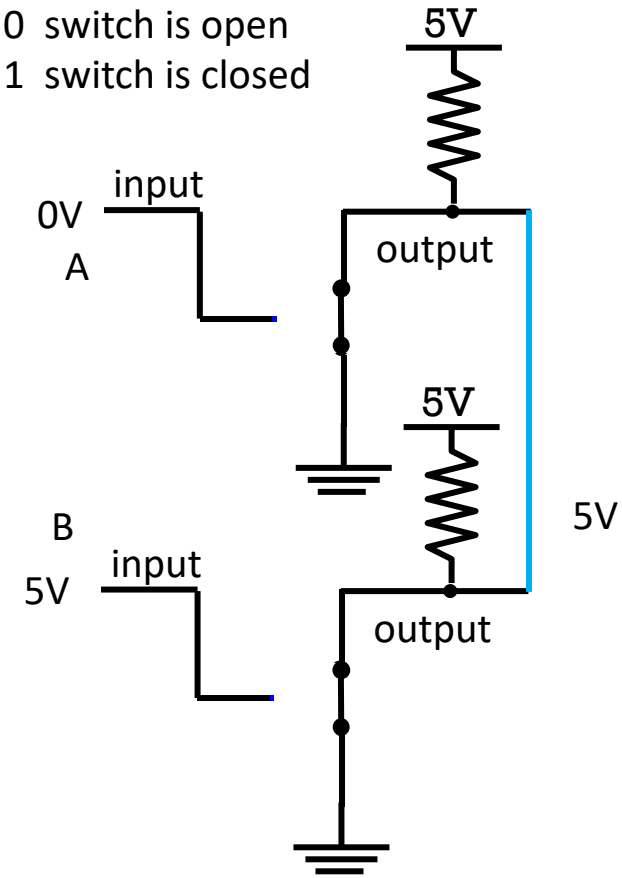
Three possible states:

1. HIGH
2. LOW
3. Tri-state (high-impedance)

Internal Mode	Internal state	External state	Result
OUTPUT	High	High	High
OUTPUT	High	Low	CONTENTION
OUTPUT	High	Float	High
OUTPUT	Low	High	CONTENTION
OUTPUT	Low	Low	Low
OUTPUT	Low	Float	Low
OC w/pullup	High	High	High
OC w/pullup	High	Low	Low
OC w/pullup	High	Float	High
OC w/pullup	Low	High	**CONTENTION**
OC w/pullup	Low	Low	Low
OC w/pullup	Low	Float	Low

Wired NOR, Wired OR

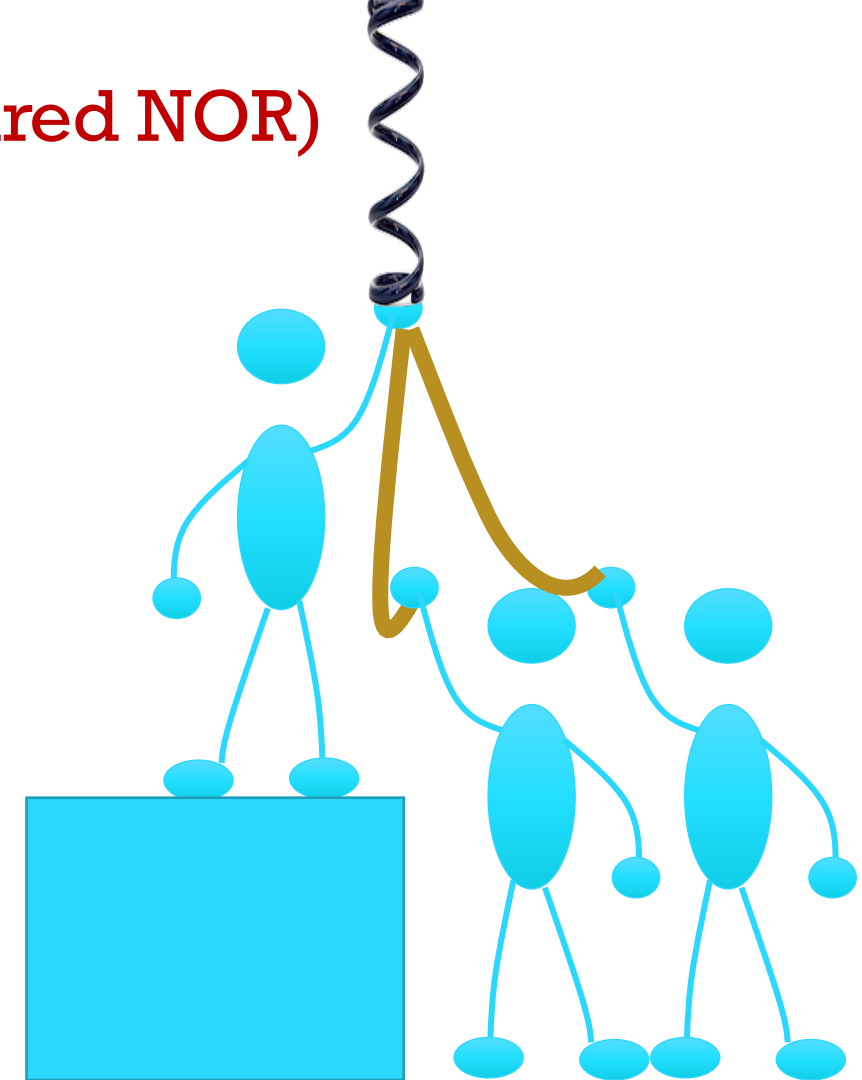
0 switch is open
1 switch is closed



Truth table

INPUT		OUTPUT
A	B	
0	0	1
1	0	0
0	1	0
1	1	0

Human Wired-OR (wired NOR)



ATMEGA32 Internal Pullups

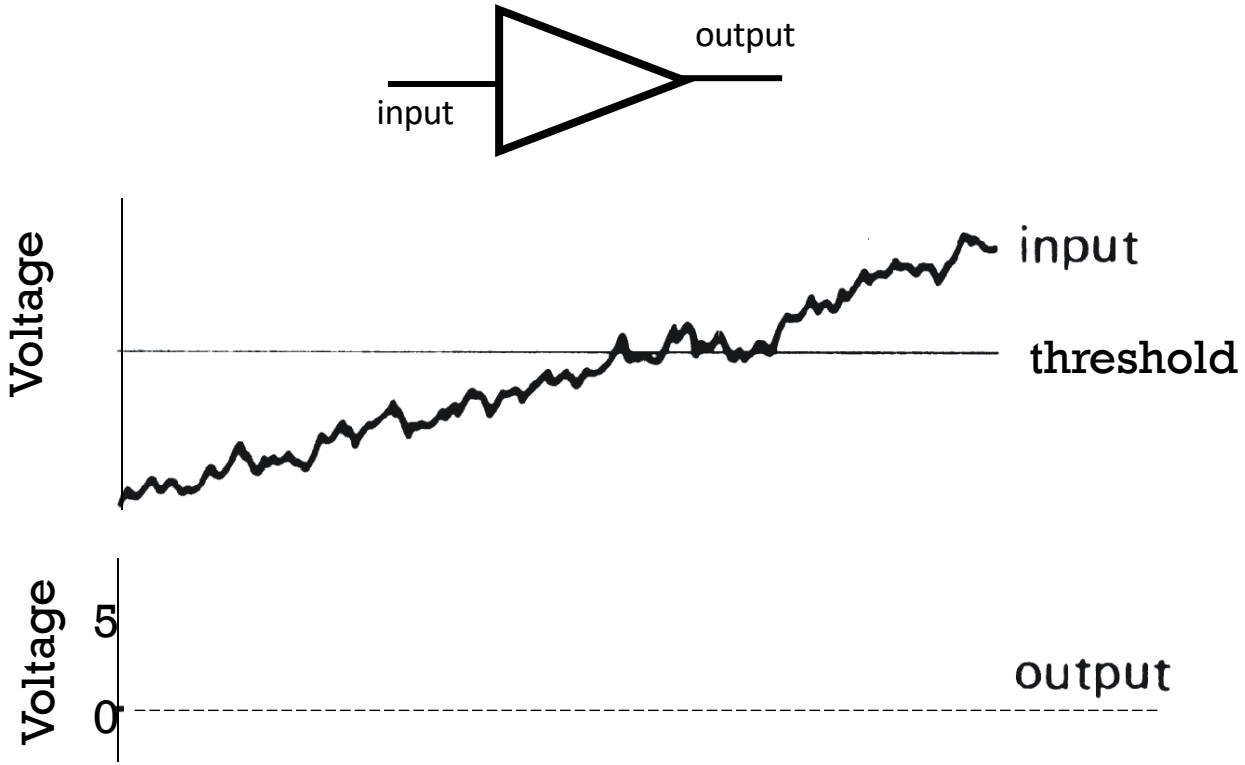
- Every port has a switchable weak internal pullup (20-50k) when in input mode. (Doesn't make sense in output mode)
- By writing 1 to PORTx to turn on (*when in input mode*), or 0 to PORTx to turn off
- Example:

```
clear(DDRD,4);    // PORTD bit 4 is an input
set(PORTD,4);     // write a 1 to port, turn ON pullup
clear(PORTD,4);   // write a 0 to port, turn OFF pullup
```

04

Schmitt Triggers

Noisy input, what would logic output look like?



MM54HC14/MM74HC14
Hex Inverting Schmitt Trigger

General Description

The MM54HC14/MM74HC14 utilizes advanced silicon-gate CMOS technology to achieve the low power dissipation and high noise immunity of standard CMOS, as well as the capability to drive 10 LS-TTL loads.

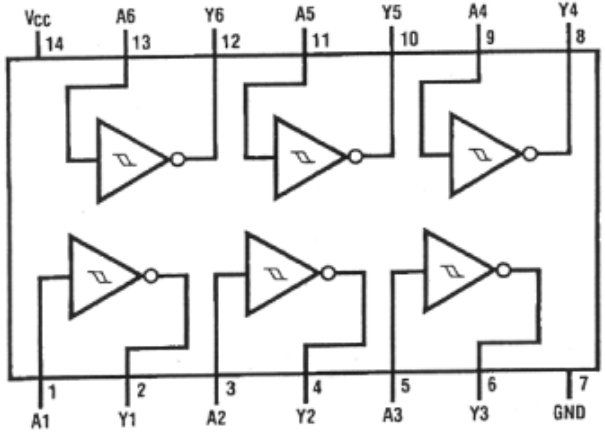
The 54HC/74HC logic family is functionally and pinout compatible with the standard 54LS/74LS logic family. All inputs are protected from damage due to static discharge by internal diode clamps to V_{CC} and ground.

Features

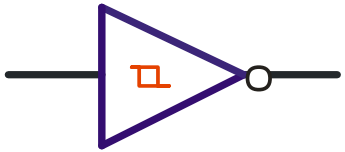
- Typical propagation delay: 13 ns
- Wide power supply range: 2–6V
- Low quiescent current: 20 μA maximum (74HC Series)
- Low input current: 1 μA maximum
- Fanout of 10 LS-TTL loads
- Typical hysteresis voltage: 0.9V at V_{CC} = 4.5V

Connection and Schematic Diagrams

Dual-In-Line Package

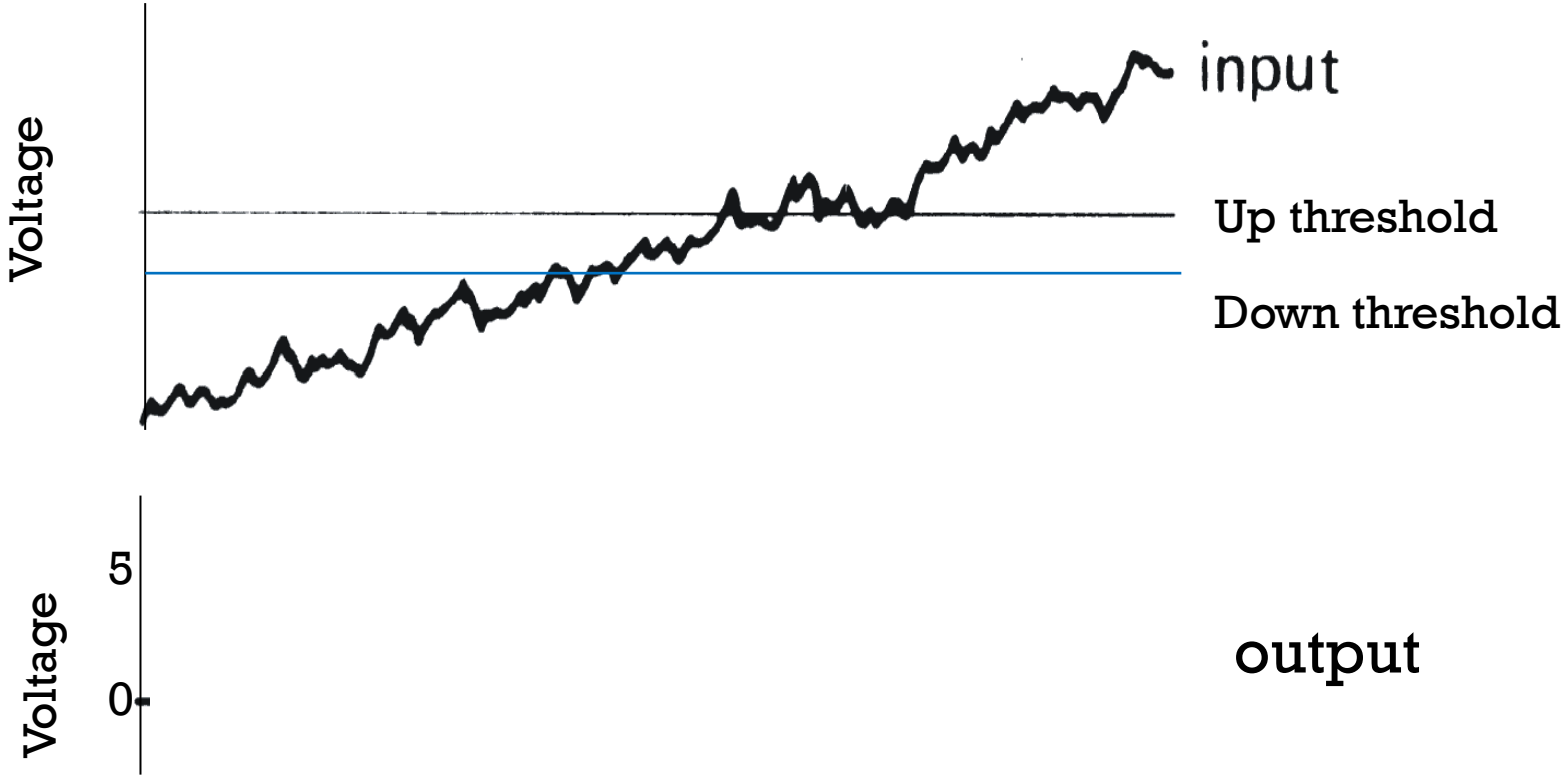


TL/F/5105–1



Uses Hysteresis on input

Q4 Now what would the output look like?



74HC14

Our Vcc = 5, but look at 4.5 for an example

PARAMETER	V_{CC}	T_A = 25°C			SN54HC14		SN74HC14		UNIT
		MIN	TYP	MAX	MIN	MAX	MIN	MAX	
V_{T+}	2 V	0.7	1.2	1.5	0.7	1.5	0.7	1.5	V
	4.5 V	1.55	2.5	3.15	1.55	3.15	1.55	3.15	
	6 V	2.1	3.3	4.2	2.1	4.2	2.1	4.2	
V_{T-}	2 V	0.3	0.6	1	0.3	1	0.3	1	V
	4.5 V	0.9	1.6	2.45	0.9	2.45	0.9	2.45	
	6 V	1.2	2	3.2	1.2	3.2	1.2	3.2	
$V_{T+} - V_{T-}$	2 V	0.2	0.6	1.2	0.2	1.2	0.2	1.2	V
	4.5 V	0.4	0.9	2.1	0.4	2.1	0.4	2.1	
	6 V	0.5	1.3	2.5	0.5	2.5	0.5	2.5	

Hysteresis maybe most useful parameter

What voltage swing do we need to guarantee transitions?

Summary

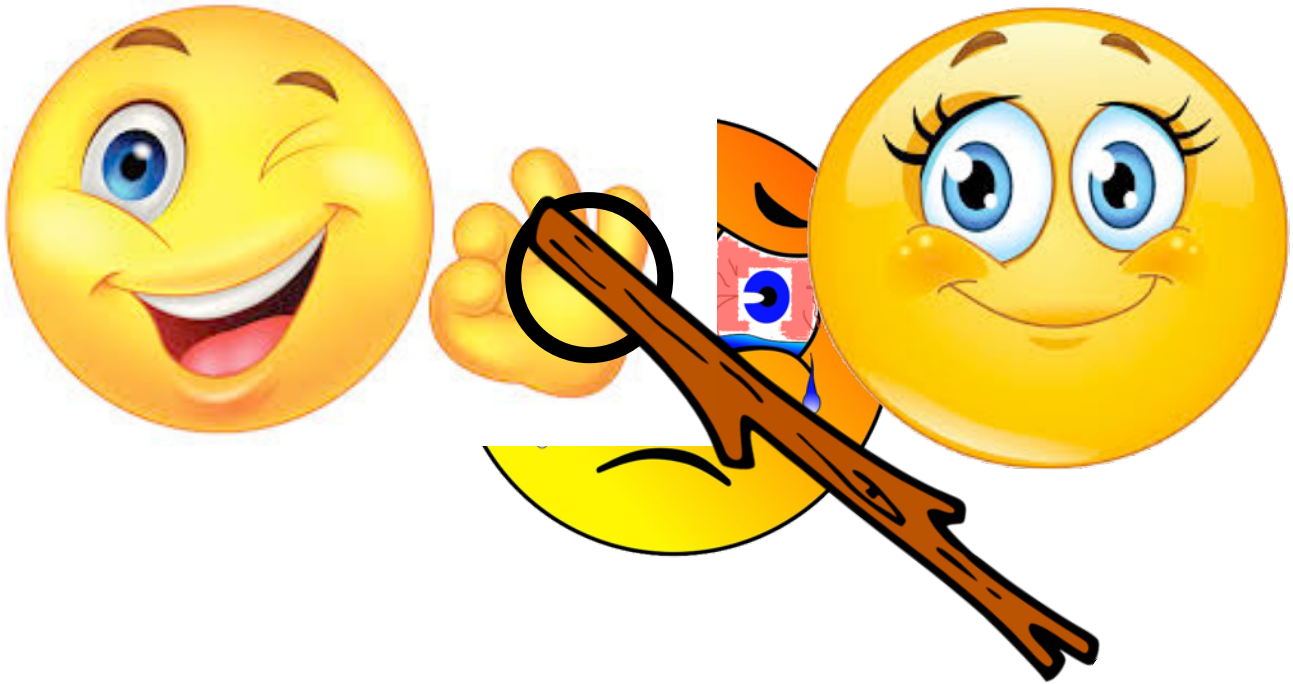
- USB Print statements take time to execute
- Pullups help to read the state of a switch
- Don't connect outputs together
- Valid logic levels depend on convention with some “noise margin”
- Schmidt trigger inputs add hysteresis for cleaning non-valid logic outputs (e.g. analog signals)

05

Resistor Colors (a dumb story)

Lab Cleanliness

Resistor Colors



Resistor Colors

Resistor Colors

Resistor Colors

Resistor colors

- What number is?
  - grey
  - yellow
  - red
  - orange
  - green
- What color is
  - six
  - zero
  - nine
  - one
  - seven

- What number is?
  - white
  - blue
  - brown
  - black
  - violet
- What color is
  - four
  - two
  - five
  - three
  - eight

Quiz Question

- Q1: What value is this resistor?

Answer in CHAT

Answer how you feel about each topic below with:

1. I don't understand this topic at all
2. I don't know now, but know what to do to get by
3. I understand some, but expect to get the rest later
4. I understand completely already

A. Teensy printing

B. Logic Levels

C. Pullup Resistors