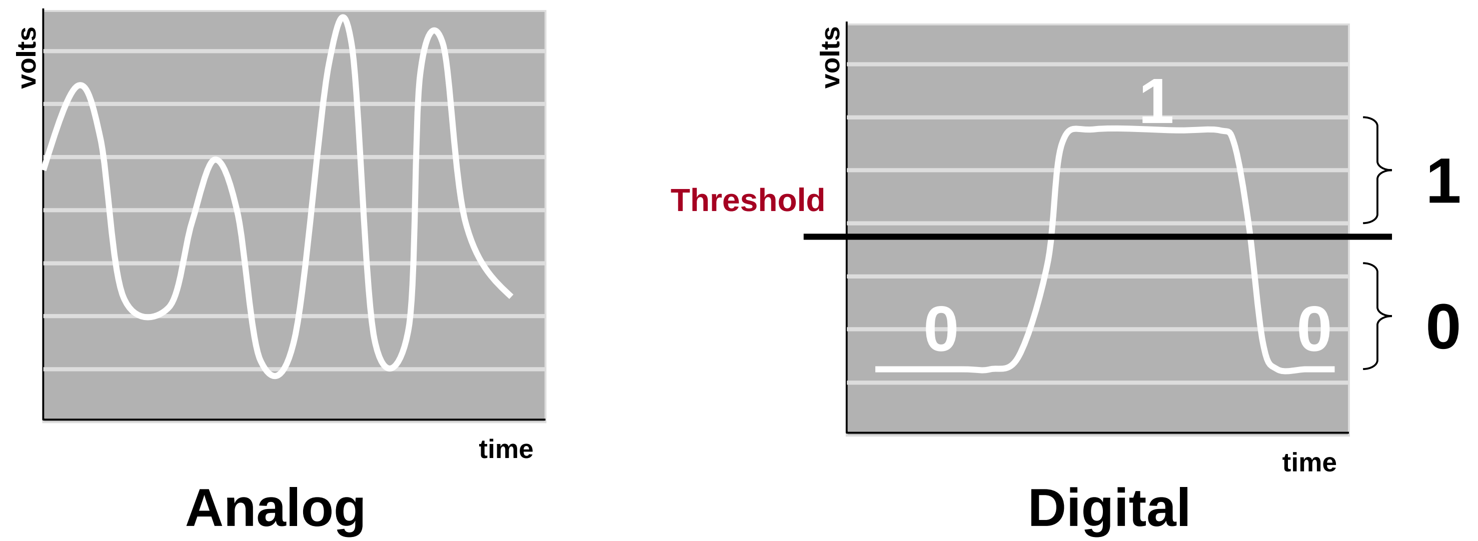
Unit 19

Physical Design Constraints & Issues

Signal Types

- Recall even digital signals are ***just voltages***…
- Analog signal
  - Continuous time signal where each voltage level has a unique meaning
- Digital signal
  - Continuous signal where voltage levels are mapped into 2 ranges meaning 0 or 1



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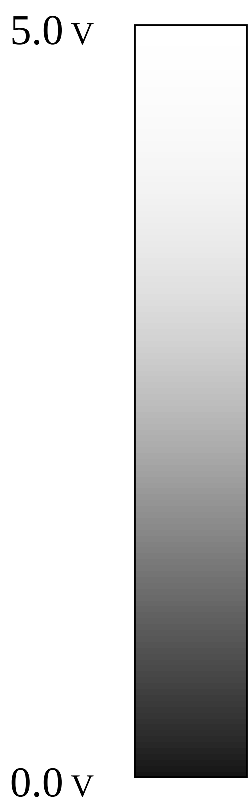
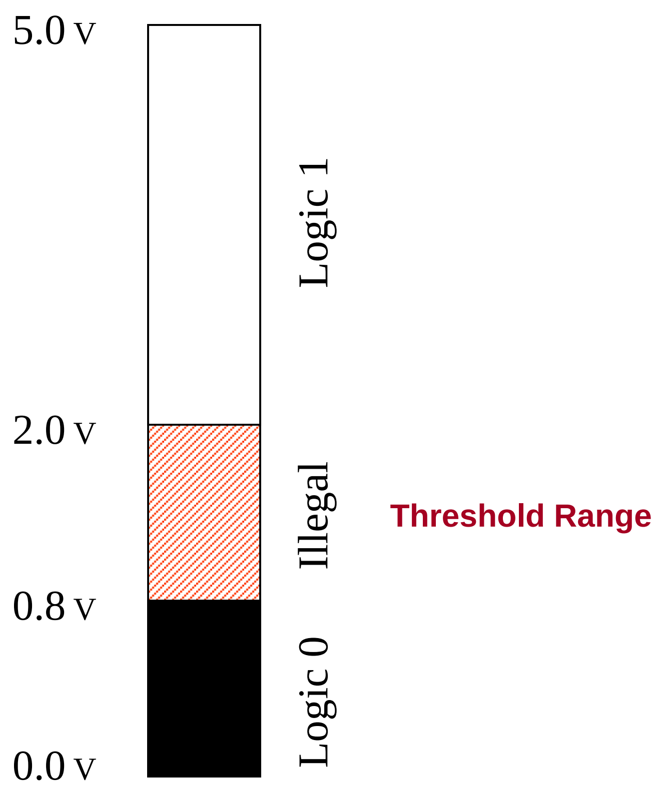
Signals and Meaning

Analog



Each voltage value has unique meaning

Digital



Each voltage maps to ‘0’ or ‘1’
(There is a small illegal range where meaning is undefined since threshold can vary based on temperature, small variations in manufacturing, etc.)

NOISE MARGINS, LEVEL SHIFTERS, & DRIVE STRENGTH

A Motivating Example

Example 1

- You connect an output port to an LED (light emitting diode) and connect everything ***correctly***. The light should turn on when you set your output bit to a high voltage (logic '1').
- When you turn the system on the LED does not glow. You measure the voltage at the gate output with a voltmeter and find it is not 5V but 1.8V? Why isn't it a logic 1?
- The maximum current output ability from the output port is not high enough to adequately supply the LED which then drags the voltage down.

Example 2

- You buy two digital chips (say a microprocessor and GPS reader
- You correctly wire them together and write software to turn 'on' a pin on the microprocessor to a '1' to enable the GPS reader
- When the software runs the GPS unit does not turn on. Why?
- Different circuit implementation techniques use different voltage levels to indicate '1' or '0' and may be incompatible

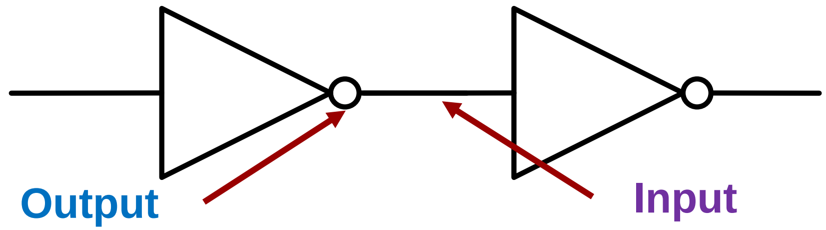
Lesson To Be Learned: ***Not all 1's or 0's are created equal!***

The Digital Abstraction

- Digital is a nice abstraction of voltage and current
  - Lets us just think 'on' or 'off' but not really worry about the voltages and currents underneath
- Until NOW!!!
- Not all 1's and 0's are created equal
  - A '1' can be any 'HIGH' voltage (maybe in the range 2V-5V)
  - A '0' can be any 'LOW' voltage (maybe in the range 0V-0.8V)
  - So 3V and 5V both mean '1' but they aren't equal
- Similarly certain outputs of a chip may connect to other devices that require more current than the output can produce
  - Think of connecting a fire hose to your garden spigot
  - Or even worse your garden hose to a fire hydrant…it would shred it
  - In the same way, inputs and outputs of different devices must be matched to the demands/requirement of what they connect to

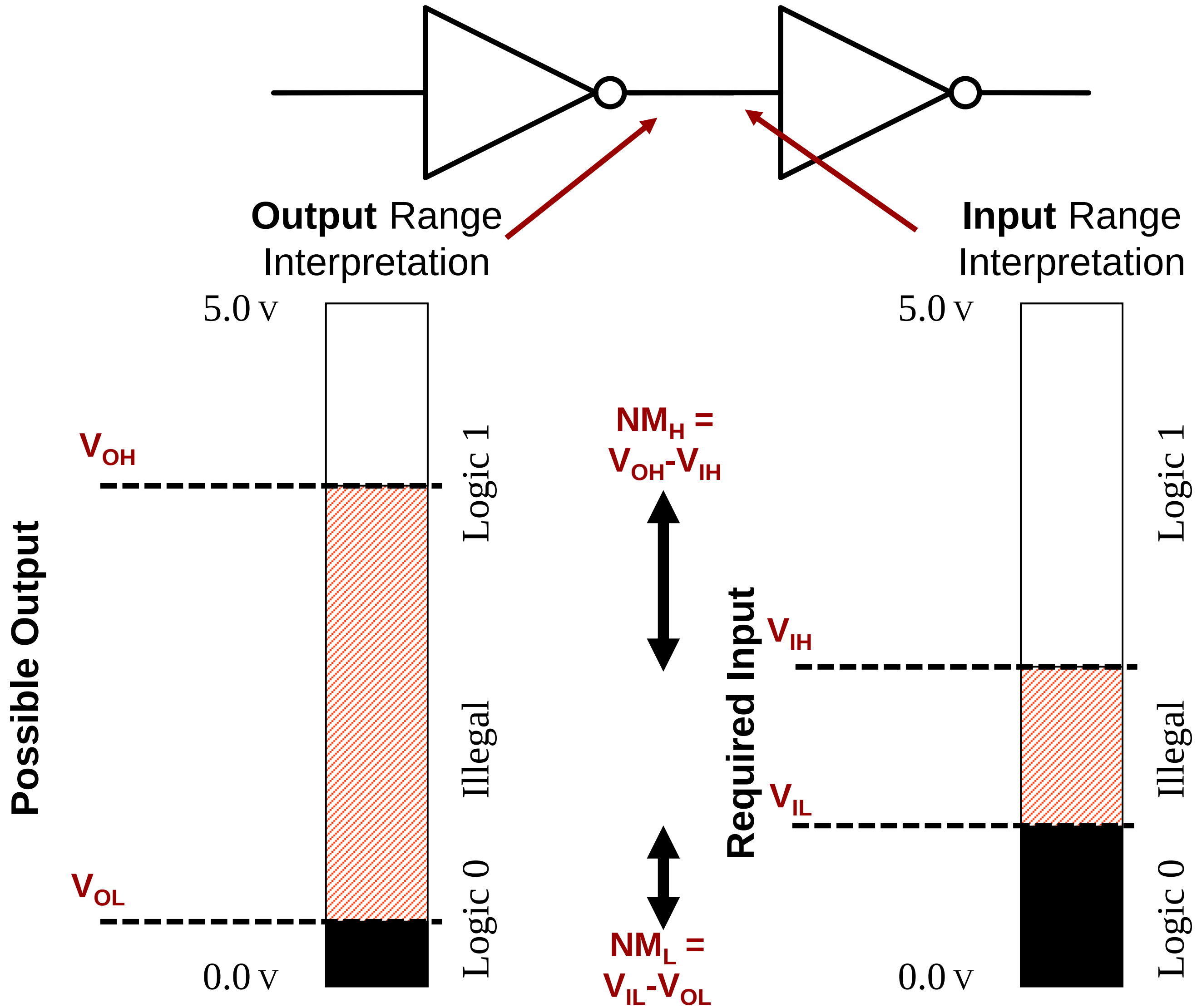
Digital Voltage Noise Margins

- Consider the output of one digital circuit feeding the input of another
  - Assume the devices are from different vendors (families of devices)
- There may be different limits and requirements of the two devices
  - Example: The output may produce 3V to mean logic '1' while the next device's input requires 5V to be used as logic '1'
- Analogy 1: Grades. Suppose the cutoff for an A is 90% (i.e. required input)
  - If you get a 91% (i.e. output result)…**GOOD!**
  - If you get an 89%…(Still good for this class! But **BAD** from the cutoff's perspective.)
- Analogy 2: Tickets. Suppose there are 100 available tickets to an event (i.e. input limit)
  - If you are the 99th person (i.e. output result)…**GOOD!**
  - If you are the 101st person…**BAD!**



Digital Voltage Noise Margins

- Consider one digital gate feeding another



OH = Output High
OL = Output Low
IH = Input High
IL = Input Low
NM = Noise Margin

As long as VOH > VIH and VOL < VIL we are in good shape…

Electromagnetic interference & power spikes can cause this to break down

Class Activity

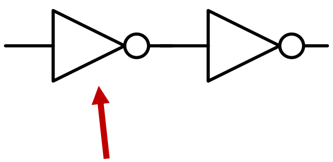
- Do an internet search for "74LS00 datasheet" (this is a chip w/ some 2-input NAND gates) and try to find any PDF and open it
- Skim the PDF and try to find:
  - VOH, VIH, VOL, VIL

Fanout Analogy

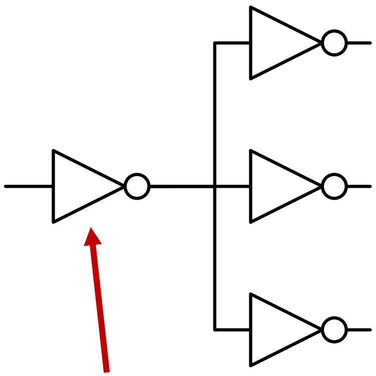
- Can the output of one logic gate be connected to 5 or 10 or 100 gate inputs?
- Consider a sprinkler system…what will happen if you add 100 new sprinklers to your backyard?
- Pressure (voltage) will go way down and reduce water (current) flow coming out of each

Fanout

- Fanout refers the number of gates (aka "loads") an output connects to
- As the fanout increases delay increases proportionally
- In addition, if fanout is too high the circuit may stop working
  - Due to current limitations (see next slide)



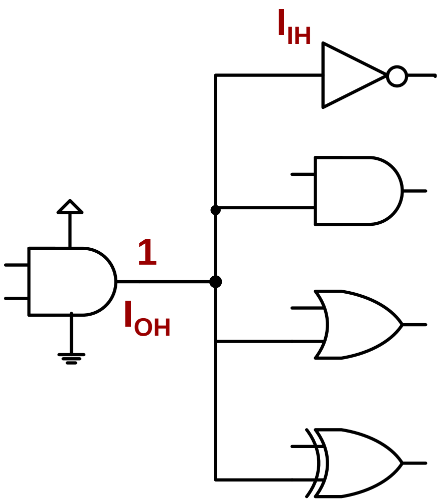
This inverter has a fanout (# of loads) = 1

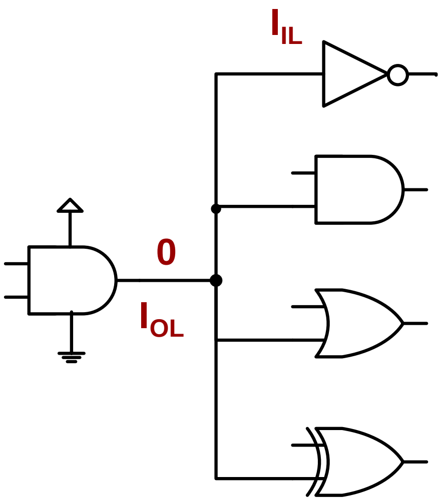


This inverter has a fanout (# of loads) = 3

Fanout & Current Limitations

- When a circuit outputs a 'HIGH' ('1') it can only supply (**source)** so much current (think of your garden hose spigot) = I_{OH}
- When a circuit outputs a 'LOW' ('0') it can only suck up (**sink)** so much current = I_{OL}
- When a circuit receives a 'HIGH' signal on the input side it may need a certain amount of current to recognize the input as 'HIGH' = I_{IH}
- When a circuit receives a 'LOW' signal on the input side it may need a certain amount of current to recognize the input as 'LOW' = I_{IL}





Example

- Consider the example where device A's output connects to device B's input
  - Are the voltage requirements compatible?
  - How many device B inputs can a single device A output drive?
    - Always use worst case of high or low output drive capability

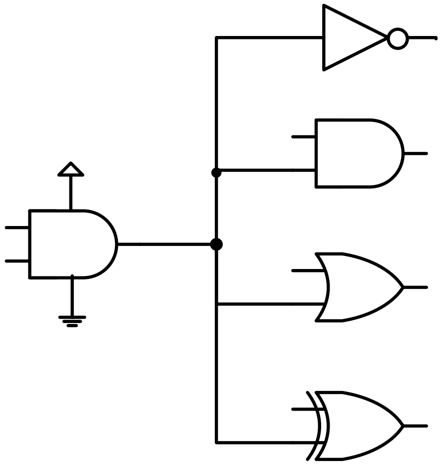
Dev.	VOH	VIH	VOL	VIL	IOH	IIH	IOL	IIL
A	3.4V	3.3V	0.5V	1.0V	-4 mA	-1 mA	10 mA	2 mA
B	3.2V	3.0V	0.6V	0.7V	-2 mA	-1 mA	6 mA	2 mA

Voltage requirement are compatible!
Dev. A VOH > Dev. B VIH
<u>AND</u>
Dev. A VOL < Dev. B. VIL

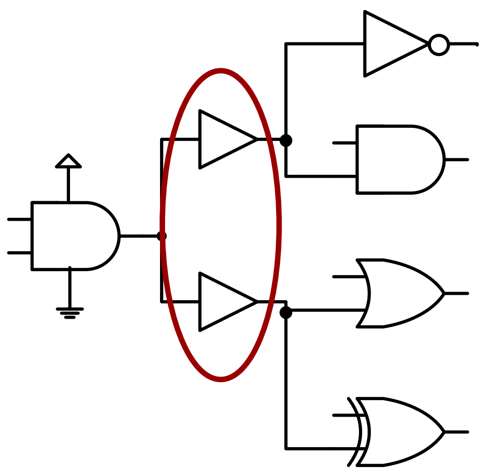
Dev. A's output can drive 4 Dev. B inputs
When outputting '1':
- (Dev. A IOH / Dev. B IIH) = (-4 / -1) = 4
When outputting '0':
- (Dev. A IOL / Dev. B IIL) = (10 / 2) = 5
Drive capability = min(4, 5) = 4

Consideration

- If we attach too many gates to one output it may not be enough to drive those gates
- Need to make sure the current requirements and capabilities match
- Let's say we connect one of the NAND gates on the 74LS00 chip to an input of N other NAND gates…
- Can it produce/suck up the required current…
- …if N = 6?
- …if N = 12?



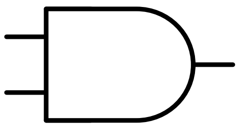
If I_{OH} or I_{OL} is too low we can split the loads by place intermediate buffers



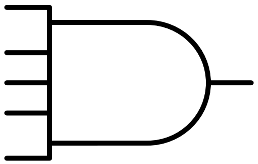
Fan-in

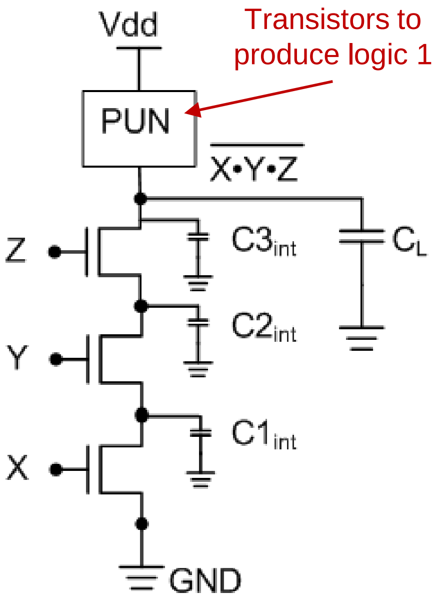
- Fan-in refers to the number of inputs to a gate
- Each input adds additional resistance and capacitance to the circuit and does so in such a way to cause the delay to grow quadratically
- This means delay grows quadratically with fan-in but linearly with fanout
  - Delay ≈ $a_1 FI + a_2 FI^2 + a_3 FO$
- Important: Rarely want FI > 4 or 5

Fanin = 2



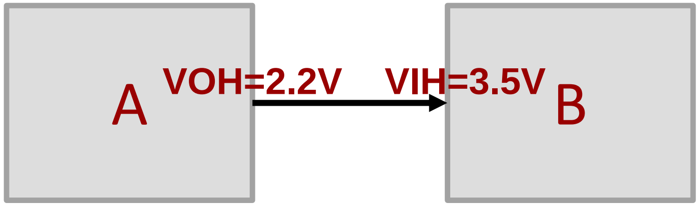
Fanin = 5





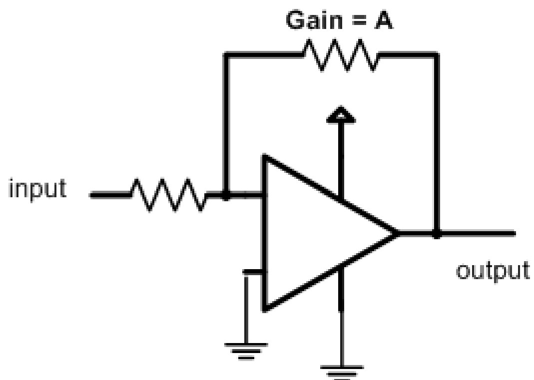
All In the Family

- There are many families of circuit devices that talk different language (Each has a different VOH, VIH, VOL, VIL, IOL, IIL, etc.)
- Examples:
  - CMOS
  - TTL
  - ECL
- Must make sure if you interface two different devices that they are compatible (i.e. VOH of device A is greater than VIH of device B) or use a buffer/amplifier/level shifter circuit to help them talk to each other
  - http://www.ti.com/lit/ds/symlink/cd4504b-ep.pdf



Arduino Limits

- Arduino outputs can sink (suck up) and source (produce) around a maximum of 20 mA on a pin
  - http://www.atmel.com/Images/Atmel-8271-8-bit-AVR-Microcontroller-ATmega48A-48PA-88A-88PA-168A-168PA-328-328P_datasheet.pdf
- Do an internet search for "Standard Servo Motor Datasheet" and find the maximum current it may need
- It doesn't seem like the Arduino would be able to drive the servo motor.
  How is it working?
  - Remember the 3-pin interface: R = Power, B = Ground, W = Signal
  - The signal is separate from the power
  - The power source is used to amplify the signal



Another Example

- Now consider a speaker system where the power and signal are provide together
  - Given our Arduino use 5V = Vcc and its current limitations per pin, how much power can we supply to the speaker?
  - 5V * 20 mA = 0.1W
  - You need an amplifier…