Unit 20

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
Signals and Meaning

Each voltage value has unique meaning.

Analog

- 0.0 V
- 0.8 V
- 2.0 V
- 5.0 V

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.)

Digital

- 0.0 V
- 0.8 V
- 2.0 V
- 5.0 V

Logic 0

Logic 1

Illegal

Threshold Range
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

\[ \text{Output Range Interpretation} \]

\[ \begin{align*}
\text{VOH} & \quad \text{Logic 1} \\
\text{VOL} & \quad \text{Logic 0} \\
\text{ILLEGAL} & \quad \text{Illegal}
\end{align*} \]

\[ \text{Input Range Interpretation} \]

\[ \begin{align*}
\text{V_{IH}} & \\
\text{V_{IL}} & \quad \text{V_{IH}}
\end{align*} \]

\[ \text{NM}_H = \text{V_{OH}} - \text{V_{IH}} \]

\[ \text{NM}_L = \text{V_{IL}} - \text{V_{OL}} \]

As long as \( \text{VOH} > \text{VIH} \) and \( \text{VOL} < \text{VIL} \) we are in good shape…

Electromagnetic interference & power spikes can cause this to break down

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

<table>
<thead>
<tr>
<th>Dev.</th>
<th>VOH</th>
<th>VIH</th>
<th>VOL</th>
<th>VIL</th>
<th>IOH</th>
<th>IIH</th>
<th>IOL</th>
<th>IIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.4V</td>
<td>3.3V</td>
<td>0.5V</td>
<td>1.0V</td>
<td>-4 mA</td>
<td>-1 mA</td>
<td>10 mA</td>
<td>2 mA</td>
</tr>
<tr>
<td>B</td>
<td>3.2V</td>
<td>3.0V</td>
<td>0.6V</td>
<td>0.7V</td>
<td>-2 mA</td>
<td>-1 mA</td>
<td>6 mA</td>
<td>2 mA</td>
</tr>
</tbody>
</table>

Voltage requirement are compatible!
Dev. A VOH > Dev. B VIH
AND
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 $\approx a_1FI + a_2FI^2 + a_3FO$
- Important: Rarely want $FI > 4$ or $5$
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
Arduino Limits

- Arduino outputs can sink (suck up) and source (produce) around a maximum of 20 mA on a pin
- 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?
  – $5V \times 20 \text{ mA} = 0.1\text{W}$
  – You need an amplifier...

Power & Signal together