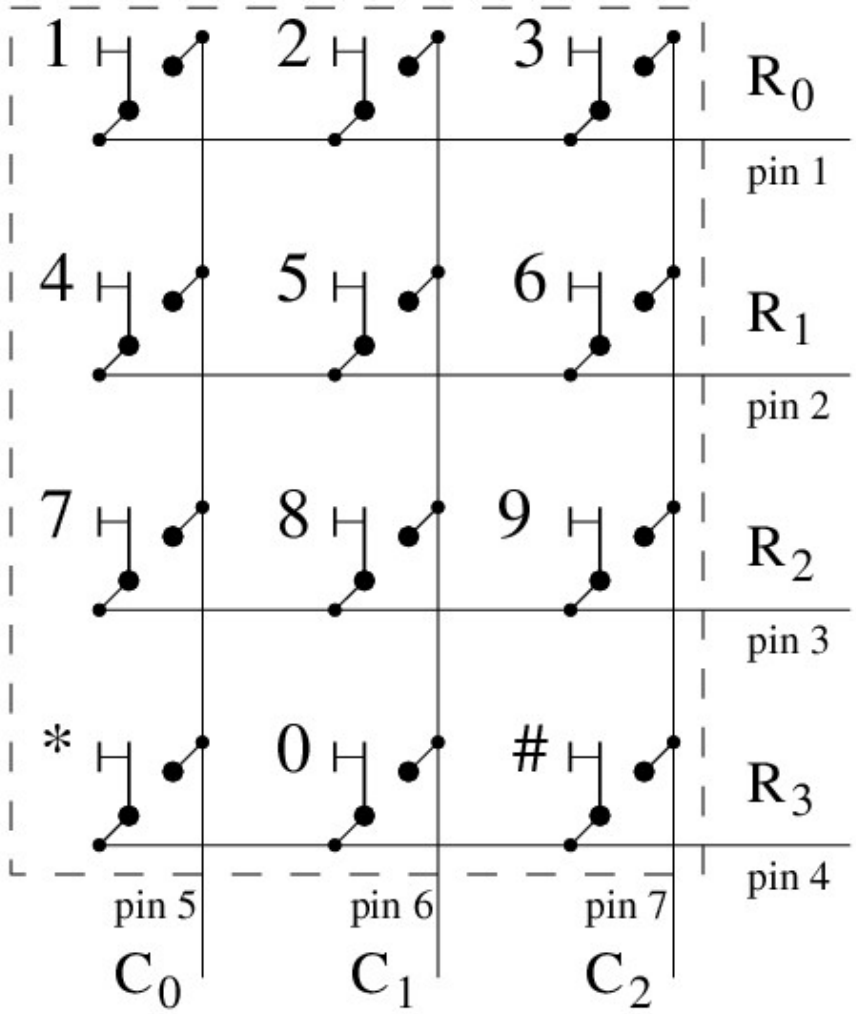
Today: Digital I/O

- Introduction to electronics:
  - Current, voltage, resistance
  - Kirkoff's law
  - Ohm's law
- Digital I/O:
  - Dealing with digital noise issues
  - Scanning push-button arrays
  - Encoders

Sensor of the Day...

Sensor of the Day: Push-Button Array

- Minimize I/O pins by sharing switches across pins
- We currently have 3 units available



First Widgets

- The first milestone is due Monday October 6th:
  - You may demo much earlier (this is strongly encouraged!)
  - You may work in groups of two
  - Minimal requirement: some form of LED control
  - Keep it simple

Matter Matters

Recalling your physics...

- Atoms are composed of:
  - Protons
  - Neutrons
  - Electrons
- Electrons exist on the outer shells of the atom (far from the center of the atom)
- What is the electrical charge of these particles?

Electrical Charge

- Protons: positive
- Neutrons: no charge
- Electrons: negative

- What is the consequence of this charge?

Consequence of Charge

- Particles of opposite polarity (a positive charge and a negative charge) are attracted to each other
- Particles of the same polarity are repelled from one-another
- Charge is measured in units of coulombs

$$1\ coulomb = the\ charge\ of\ 6.24 * 10^{18}\ electrons$$

- Atoms often have a balanced number of protons and electrons

Different Types of Atoms

- Some atoms generally do not release their electrons. These are called **insulators**
- Some atoms will often release electrons. These are called **conductors**.
- Some are in between (will release electrons under specific conditions). These are **semiconductors**

Electron Flow

- Electrons flow through a conductor by hopping from one atom to the next
- A “hop” is only possible when the destination atom is missing an electron (i.e., it is positively charged)
- The source atom is left in a positively charged state – setting it up to receive another electron

- What determines the direction of electron flow along a conductor?

What Determines the Direction of Electron Flow Along a Conductor?

- The difference in charge from one end of the conductor to the other

How do we measure the flow of electrons?

How Do We Measure the Flow of Electrons?

- In essence: the number of electrons that flow through the conductor per unit of time
- The unit of measure is the **Ampere** (**A**)

  Amps = coloumbs/second

Getting Electrons to Do the Work

- Energy is the capacity for something to do work and is measured in units of **joules** (**j**)
- The concentration of potential energy is measured in **volts** (**V**)

  1 volt = 1 joule / coulomb

  - This is the amount of work that a unit charge can do for us

Note that voltage is always measured between two points!

A Physical Analogy

Water flowing through a pipe

- Current (Amps) is like the number of water molecules that flow through the pipe in a given unit of time
- Voltage measures the water pressure

Measuring Work Per Unit Time

- The amount of work (joules) per unit time is:

  voltage * current = joules/second

  - This is measured in units of **Watts** (**W**)

- Examples of work in an electrical system:
  - Amount of light that is emitted by an LED
  - Amount of heat generated
  - Acceleration of a motor
  - Amount of sound generated

Resistance

- The restriction of current flow through a conductor
- Measured in units of **Ohms** (Ω)

- All conductors have some degree of resistance
- You will also see the term impedance (resistance is a special case of impedance)

Ohm's Law

- The relationship between:
  - The flow of current through a conductor
  - The resistance of the conductor
  - The voltage difference between the two ends of a conductor

$$\Delta V = I * R$$

Example

- The PIC specification states that a digital output line can source or sink up to 25mA
- How can we ensure that we do not exceed this with our circuit that contains an LED
  - Assume that the LED is a perfect conductor

LED example

- Voltage difference is 5 V ... So:

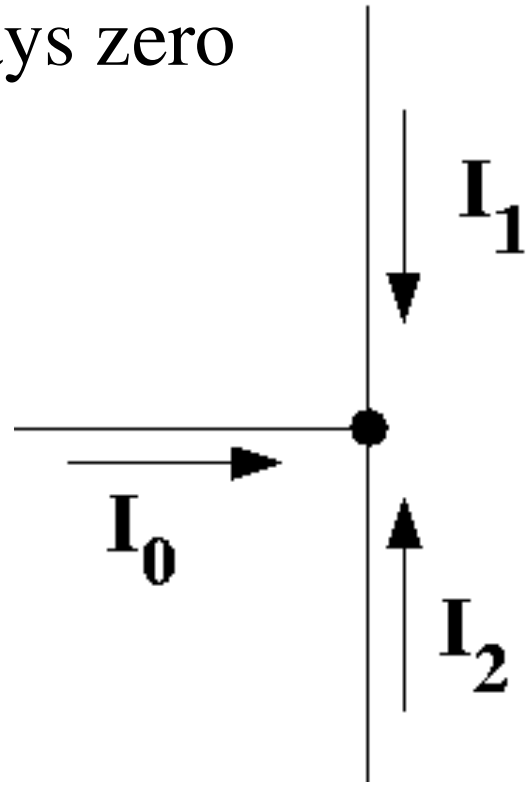
$$
\begin{aligned}
R &= \frac{V}{I} \\
&= \frac{5}{.025} \\
&= 200\,\Omega
\end{aligned}
$$

Kirkoff's Current Law

- Net current flow into a point is always zero

  (conservation of electrons)

$$\sum_i I_i = 0$$

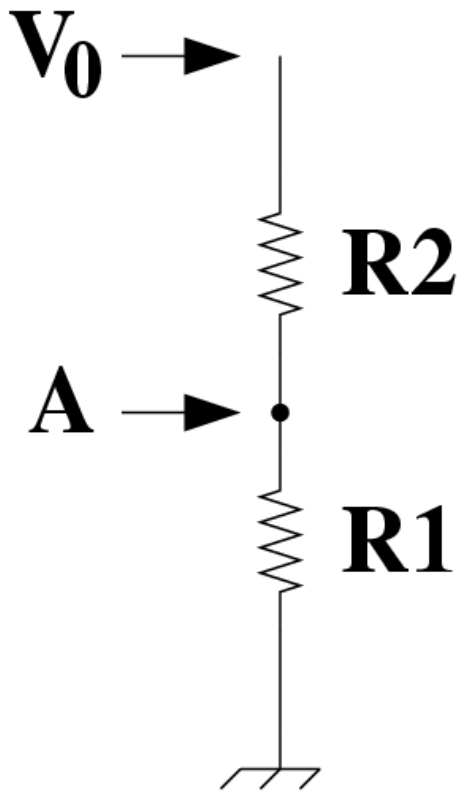


Note: how you represent the direction of current flow is important (if you reverse the arrow, you must reverse the sign)

Resistors In Series

Given V0, R1, and R2:

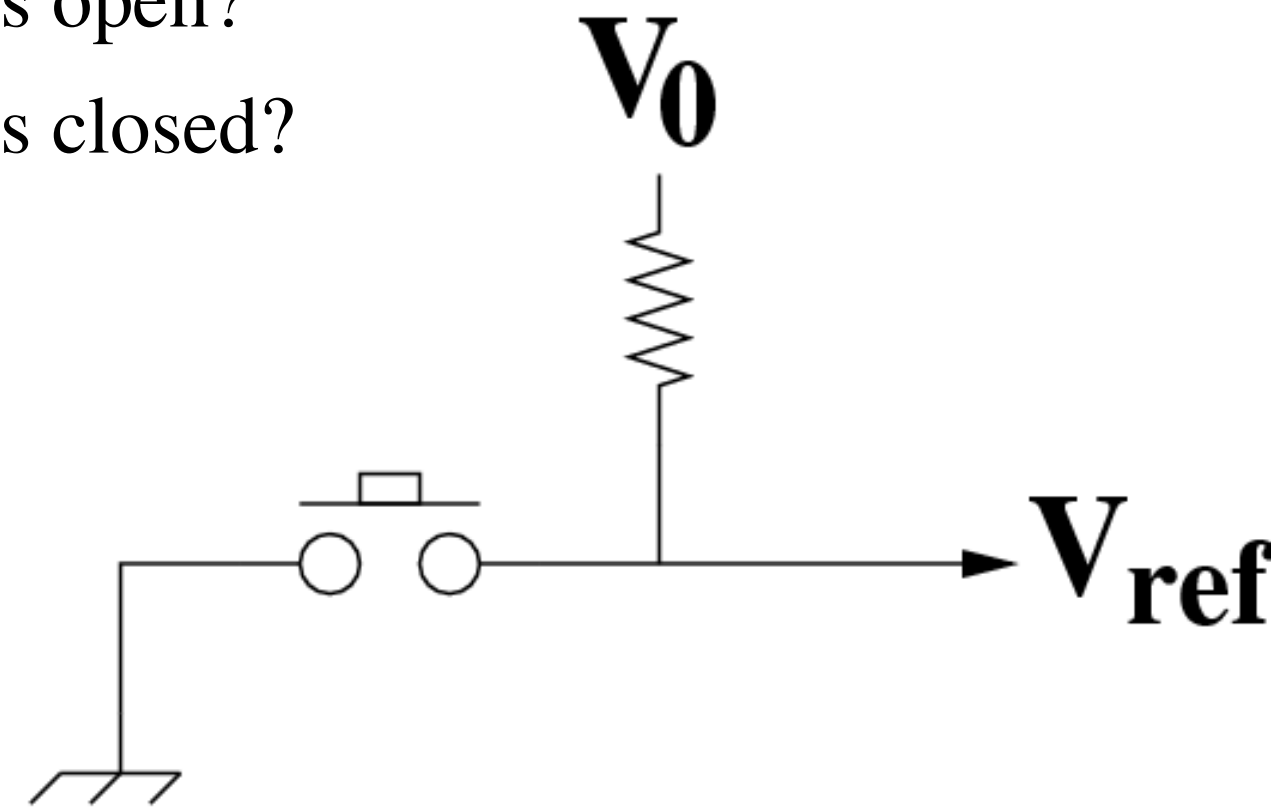
- What is the effective resistance of R1 **and** R2?
- What is the voltage at point A?



Back to Our Switch Example

What is Vref when:

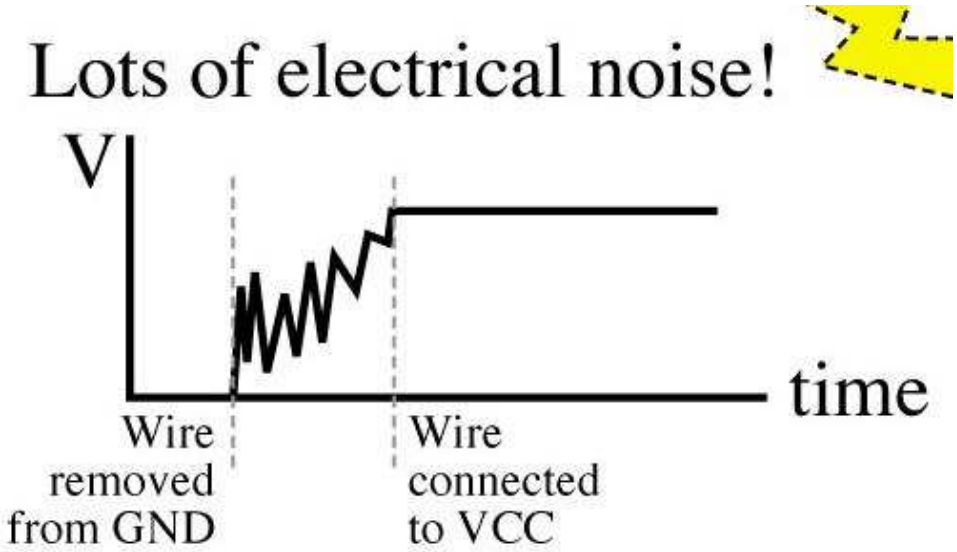
- The switch is open?
- The switch is closed?



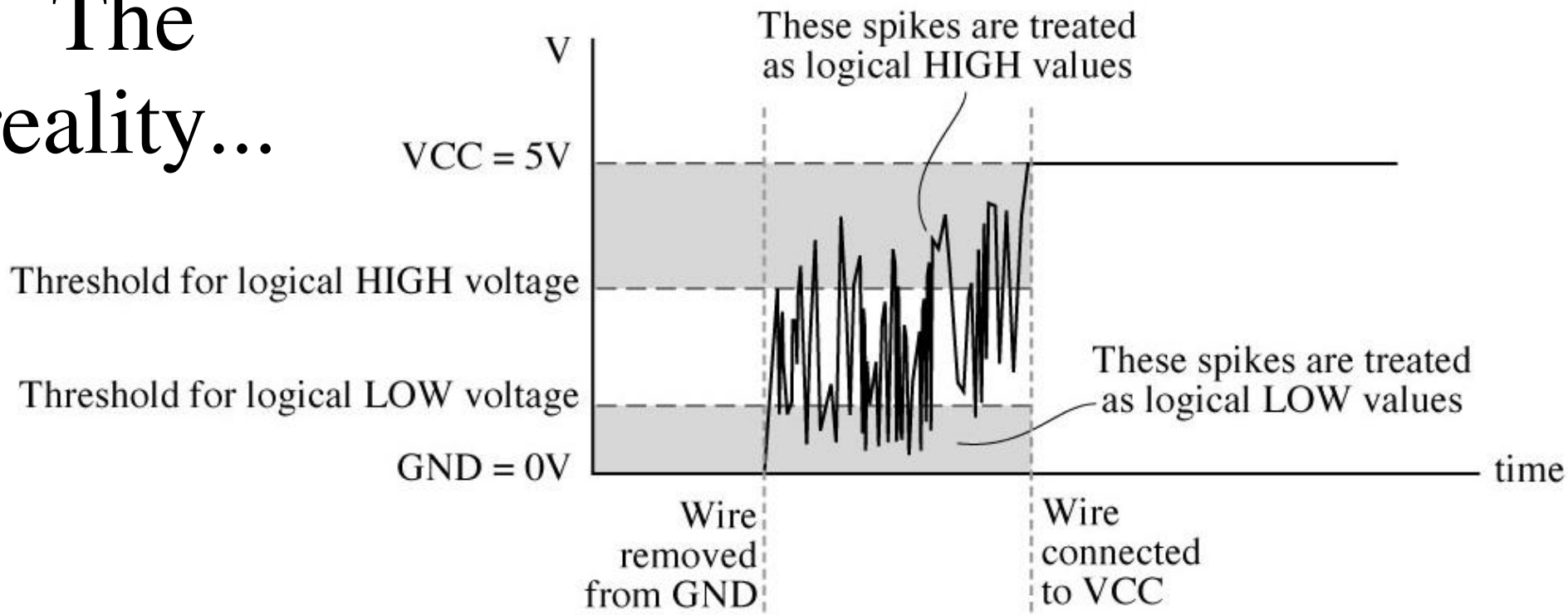
Switches: The Reality

When actuated, the mechanical connection established by the switch is made and broken many times during a short period

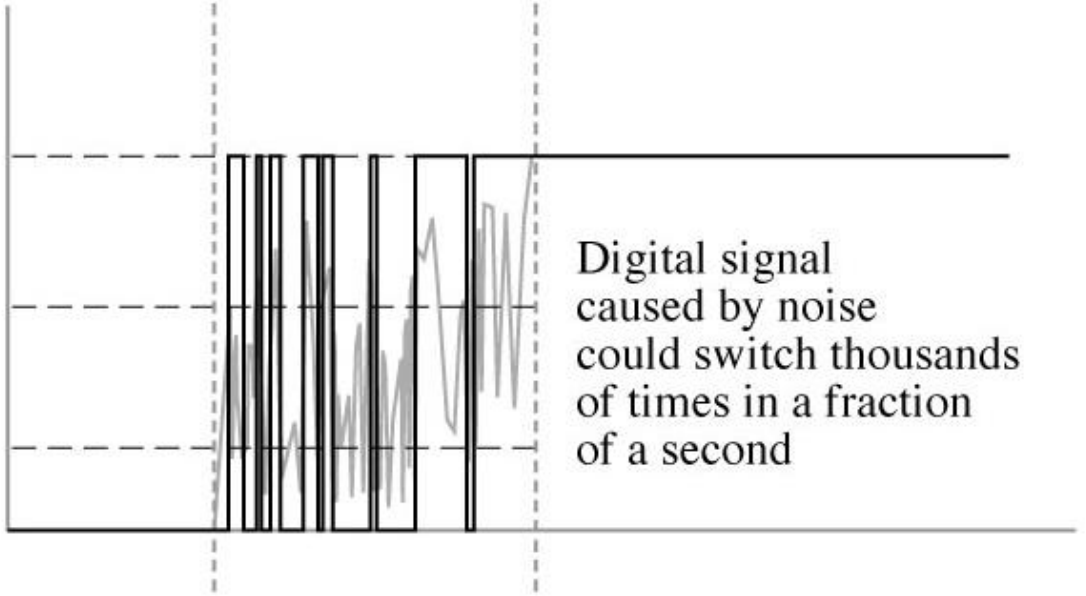
This type of noise is common in many situations



The reality…



What our processor sees…



Challenge

- How do we interpret the signal that results from a single button press as a single button press?

(We call this process **debounce**)

Software Debounce

- Filter the signal in code
  - What is the essence of the algorithm?

Software Debounce (for a momentary switch)

- Read the port multiple times to make sure its state has stopped changing
- Accept the input: do something with it
- Wait for the button to be released: again, read the port multiple times to detect this event

How is this different for non-momentary switches?

Note: the book gives a slightly different algorithm

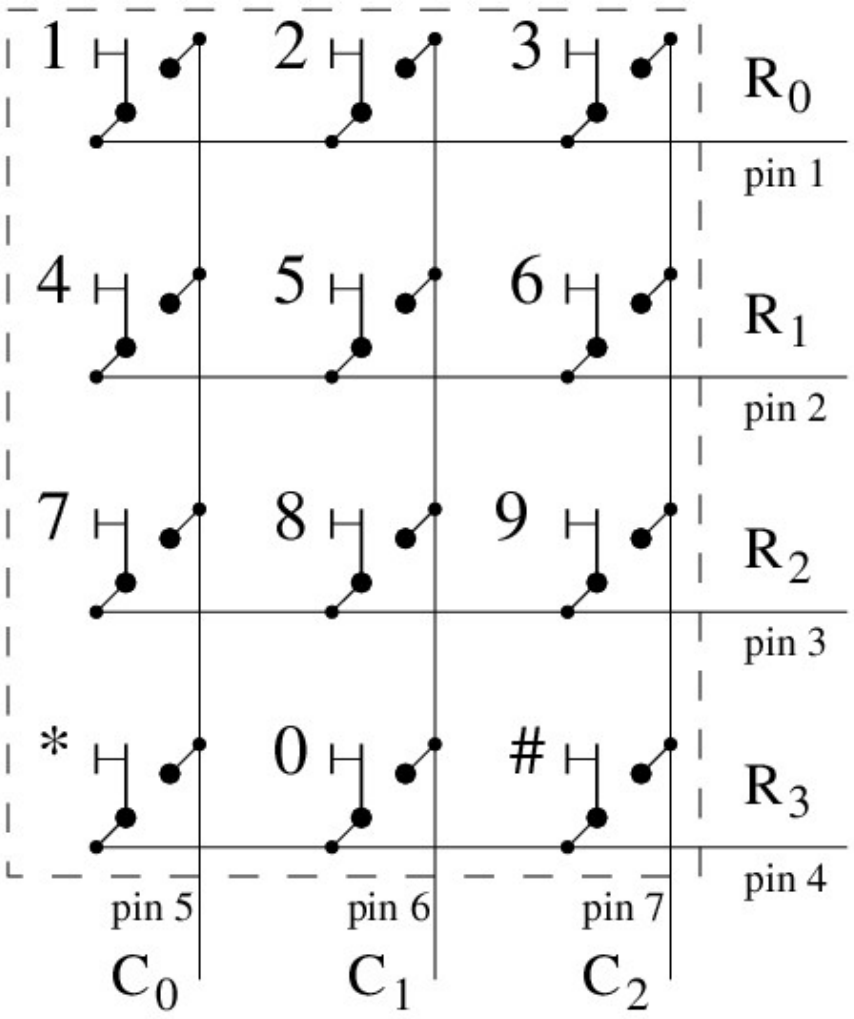
Non-Momentary Switches

- We don't really have to wait for the switch to return to its original state...

Push-Button Array Processing

In general: dealing with more switches than there are I/O pins

- Not only must we face the debounce problem..
- We must also combine control with sensing



What Does the Circuit Look Like?

What Does the Circuit Look Like?

- Drive one set of pins with digital outputs from the PIC (e.g., the vertical ones)
- Connect the remaining pins to digital inputs

Keypad Scanning Algorithm

- What is the essence?

Keypad Scanning Algorithm

- Drive one of the output pins low and the others high
- Read the input pins
  - If one of the pins reads low, then that key is pressed
- Drive the next output pin low (and the others high). Read, etc...

- What happens if two buttons are pressed?

Keypad Scanning

Multiple buttons are pressed at the same time

- We will read multiple low pins during the scan
- In this case, we should reject this input and wait for a valid input

What are we missing from the circuit?

Keypad Scanning

Safety considerations

- As drawn, if two buttons are pressed, a pair of output pins (one high and one low) will at some point be connected together
- What does this mean?
- How do we fix it?

Keypad Scanning Safety

What does it mean?

- A current source is directly connected to a current sink with virtually no resistance in between

  (this is very bad)

- Insert a resistor at each output pin to limit the amount of current that will flow

Keypad Scanning: Putting It All Together

- Inner routine:
  - Scan through all of the keys and determine which one is pressed
- Outer routine:
  - Debounce on the value that is retrieved from the keypad scan
  - Addition: invalid values are rejected and cause the counter to reset

Digital Encoders

- Encoders are all about orientation sensing
- Two digital signals are used to encode changes in orientation

Digital Encoders

- Frequency (cycles/orientation) is constant
  - So: one on-off cycle corresponds to a fixed change in orientation
- Duty cycle is 50%
- The two signals are 90 degrees out of phase

- How do we determine change in position?

Determining Position with Digital Encoders

Simple approach:

- Every time channel A transitions from high to low:
  - If channel B is high, increase the counter
  - If channel B is low, decrease the counter
- One count on every cycle

- Can we do better? (determine position with finer resolution)

Getting Higher Resolution

- Every time the state changes:
  - If channel B leads channel A, then increment the counter
  - If channel B follows channel A, then decrement

How many counts do we get per cycle?

Encoders In Practice

- Rotary Pulse Generator (RPG): tens of cycles per revolution
  - Panel interfaces
- More generally, encoders can have 100s or 1000s of cycles per revolution
  - Knowing motor position for control
  - Our Torso robot uses encoders with 1000 cycles per revolution
- Remember: encoders (plus a counter) only tell us about relative position

Programming Tips

- Remember that the PICs are often about doing things quickly (in many cases, every clock cycle can count)

- Use tables instead of large numbers of comparisons (e.g., switch() statements)
- Unrolling for() loops

- But: try to only use these optimizations when you need them as they make code harder to read

Next Time

- Lab:
  - You must complete “lab 2” by today (blink the LED with the supplied program and generate serial output)
  - Work on those widgets!
  - Lab hours are in full swing
- Thursday/Tuesday lectures:
  - Contine with electronics introduction. Read chapter 2 of DEH
- Next Thursday (October 2nd): Robotics Lab Tour. Meet in Computer Science room 144