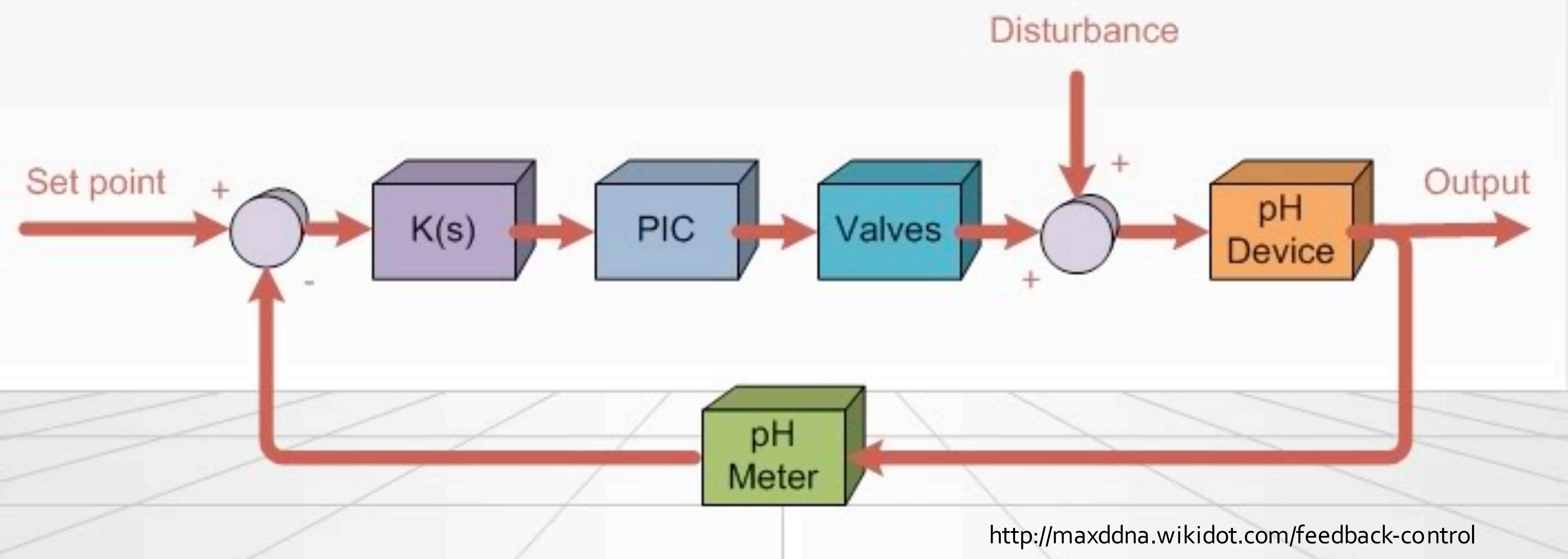
# E11 – Autonomous Vehicles

Feedback Control




http://maxddna.wikidot.com/feedback-control

# Coming Up in E11

- This week's lab:
  - line-following robot
  - completed in teams (within same lab session)
- After fall break:
  - No lab week of 10/23
  - Line-following competition! (in class – Wednesday 10/18)
- Game logistics and guest lectures:
  - 10/23: Game Kickoff!
  - 11/13: Game Scrimmage (in class)
  - 11/20: Final Game Competition!! (Monday, 5:30pm – Galileo)

# E11 Lab Access and Policies

- The door code is: 4- 3 – 12 (Parsons B171)
- Keep lab door open when you're in it – make sure it's closed and locked when you leave, and turn lights off
- Don't remove anything from the lab
- Do not touch other people's robots/stuff
- Keep the lab clean and organized – throw away garbage, put stuff back where it belongs. . The lab should look as good or better as when you got there!
- You must take your robots with you
- Turn off all soldering irons when leaving!!!!!!

# Outline

- Control Loops
- Developing Control Algorithms

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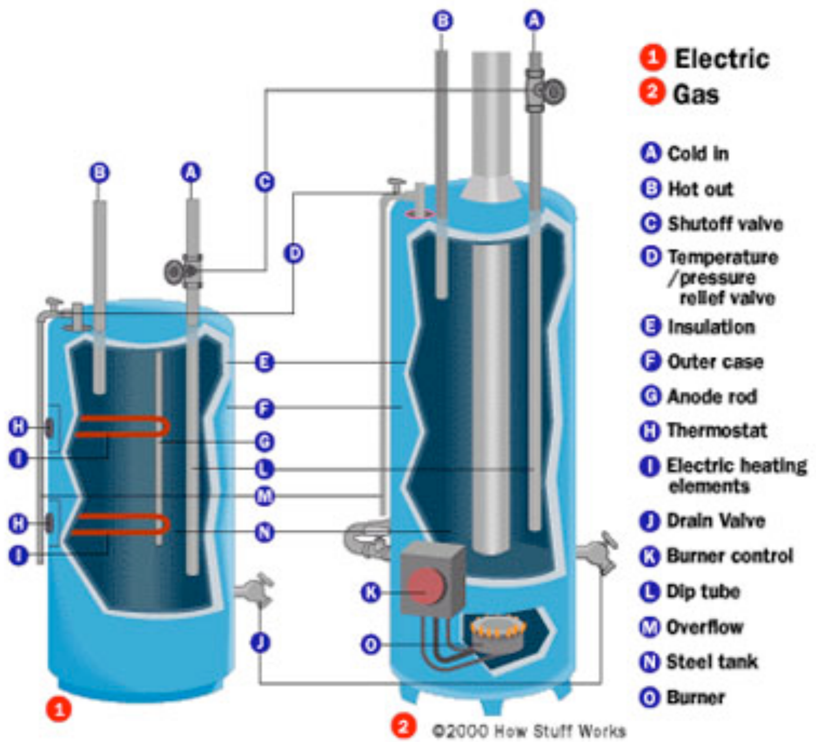
- Control Loops
  - Open loop
  - Closed loop
- Developing Control Algorithms

# Open Loop Control

- Output activated according to preset rules
  - Example 1: sprinklers turn on for 5 minutes every morning, independent of current weather conditions
  - Example 2: a heater turns on for 10 minutes every hour independent of current temperature.

# Closed Loop Control

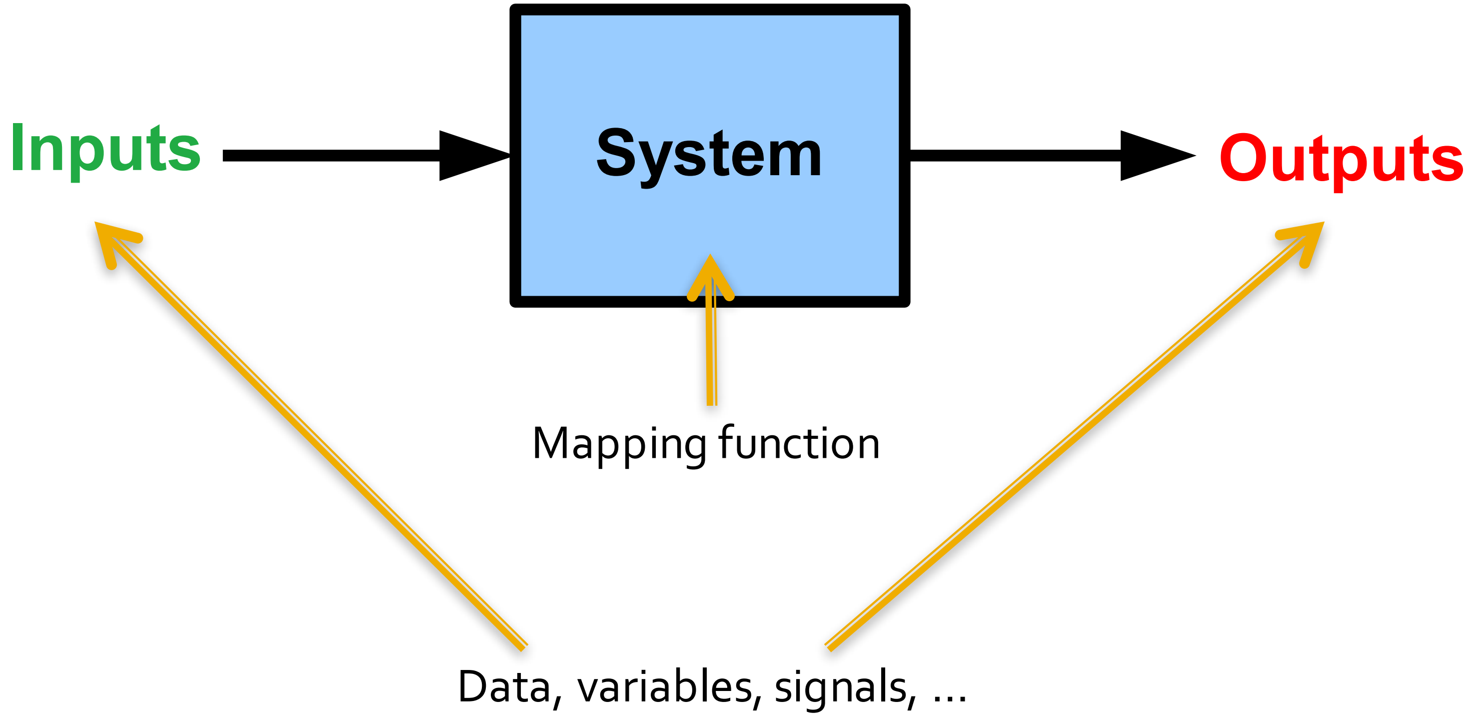
- Output is dependent on and affects inputs
  - Example 1: sprinklers turn on every morning until a desired moisture level is reached (as determined by a moisture sensor)
  - Example 2: a heater turns on until the thermostat reaches a desired temperature (as determined by a thermocouple)




http://home.howstuffworks.com/water-heater.htm

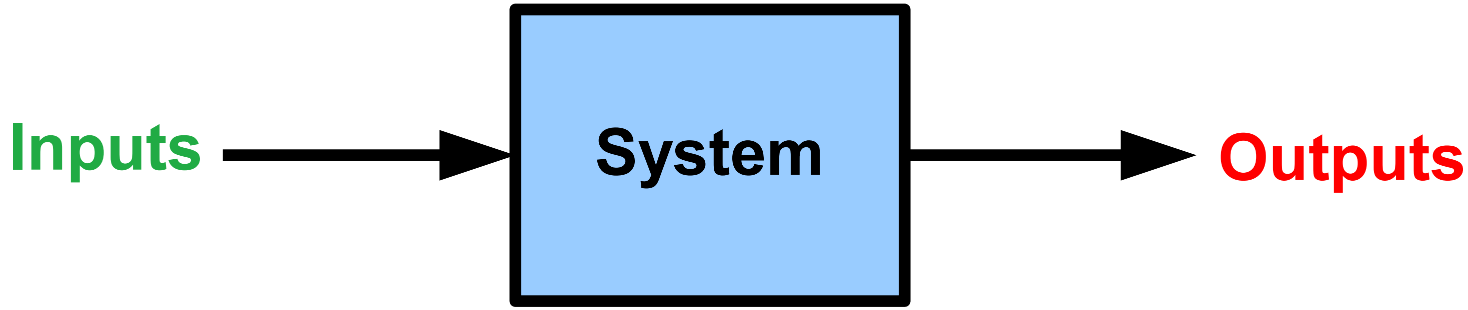
# Block Diagrams

- Represent a system, inputs, and outputs



# Block Diagrams

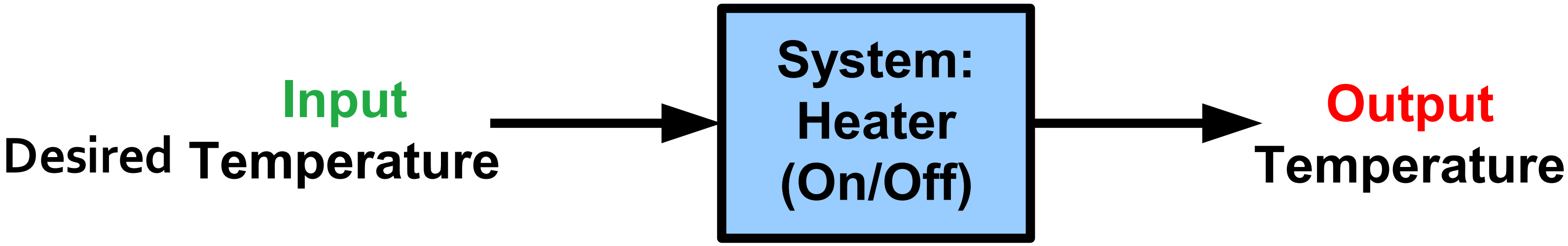
- Represent a system, inputs, and outputs




- Inputs: **Desired states** or **sensors** measurements
  - E.g. Thermocouple, distance sensor, phototransistor, reflectance sensor, force plate
- Outputs: Signals sent to **actuators**
  - E.g. Heater, motor, data collector

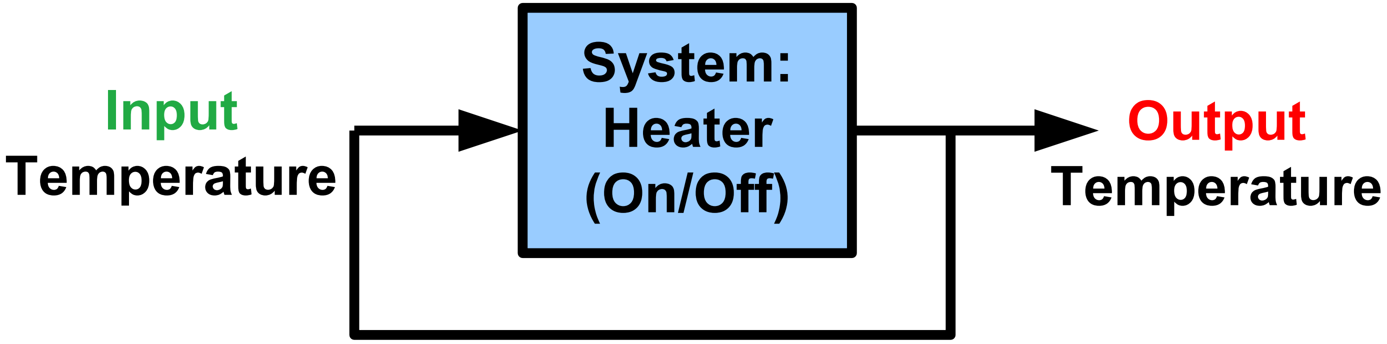
# Block Diagrams

- Open Loop System
  - i.e. **no** loop



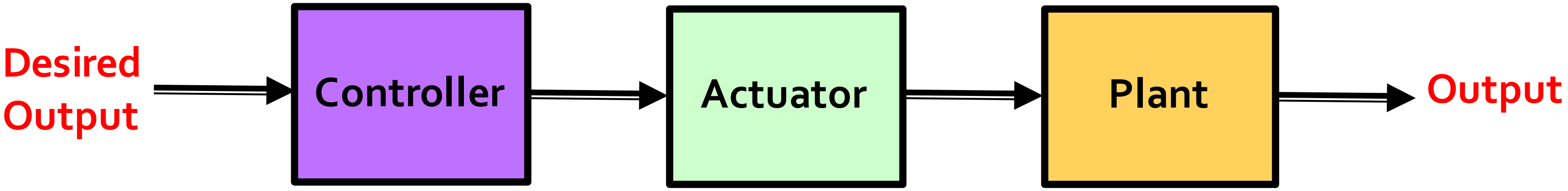
# Block Diagrams

- Closed Loop System:
  - Output affects input
  - Sensor measurements used as input



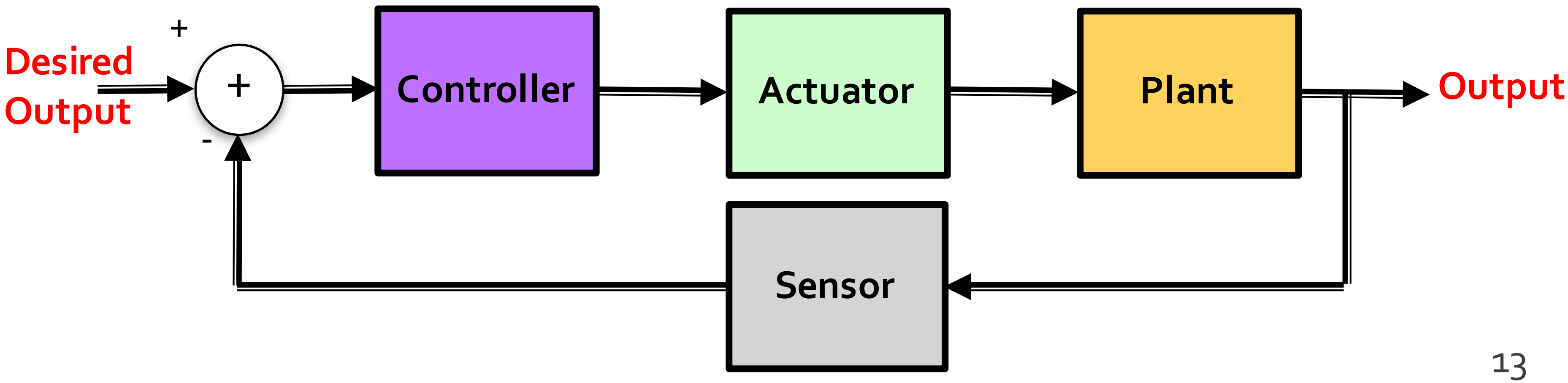
# Detailed System

- Open Loop
    1. Controller
    2. Actuator
    3. Plant



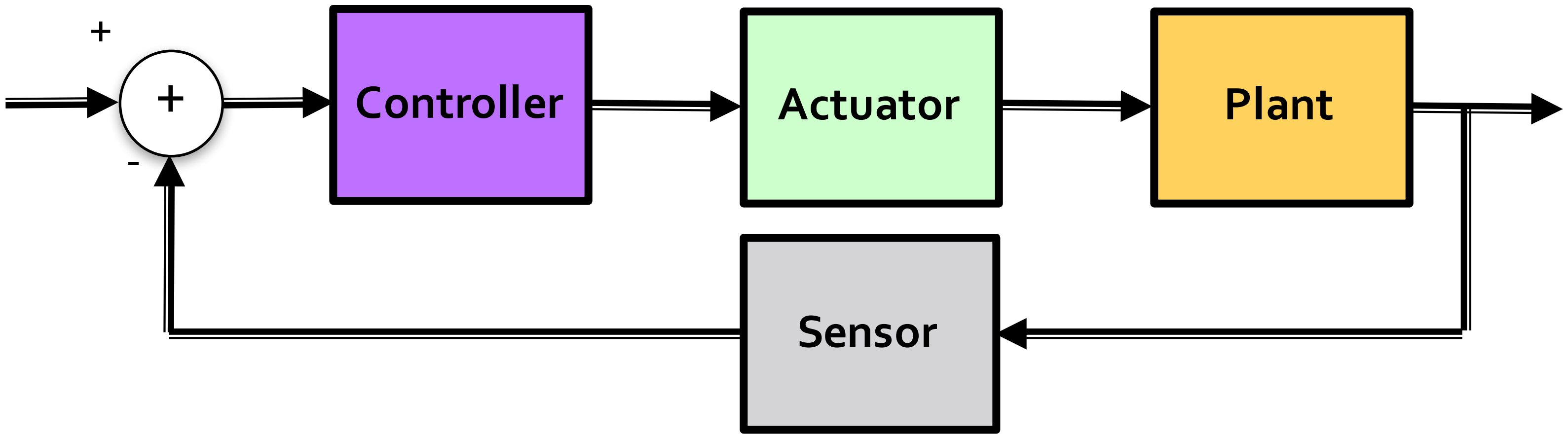
# Detailed System

- Closed Loop
  1. Controller
  2. Actuator
  3. Plant
  4. Sensor



# Control Example

- Controller:
  - Receives input from plant, controls actuator (e.g. thermostat)
- Actuator:
  - Heater/Cooler
- Plant:
  - A room
- Sensor:
  - Temperature Sensor (Thermocouple?)

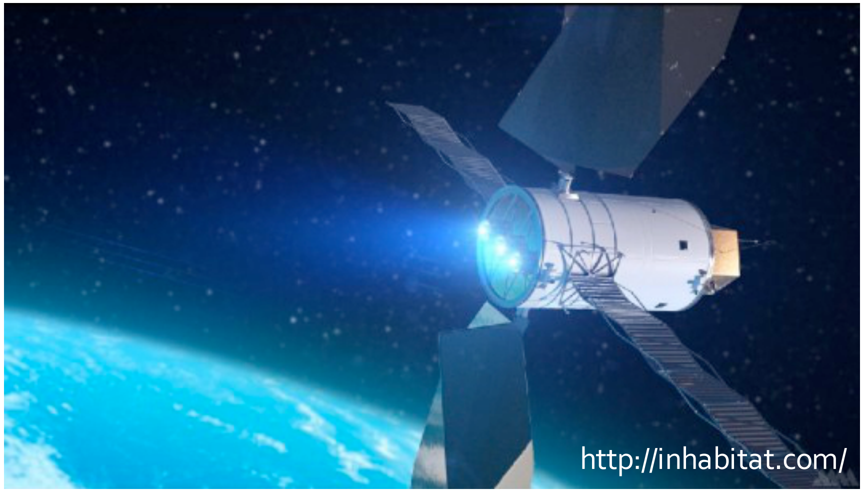


# Outline

- Control Loops
  - Open loop
  - Closed loop
    - Bang-bang control
    - Proportional control
- Developing Control Algorithms

# Feedback Control

- Bang-Bang Control
  - The system checks the input (via a sensor), if it's not a desired value, the controller turns on actuator
  - Otherwise, the controller turns off actuator



# Other Feedback Control Method

- Proportional Control:
  - The system responds proportional to the error:

error = (desired value – measured value)

# Other Feedback Control Method

- Example:
  - Adjusting hot and cold faucets to get the desired temperature
  - If the temperature is much colder than desired, the hot water faucet is opened a lot (proportional to desired-measured temp)
  - If the temperature is slightly colder than desired, the hot water faucet is only opened a little (proportional to desired-measured temp)

# Other Feedback Control Method

- In General

Calculate Error

$$e = x_{des} - x$$

Calculate Control effort

$$u = K_p e$$

# Other Feedback Control Method

- Example:
  - Drive Robot to a distance 10cm from wall.

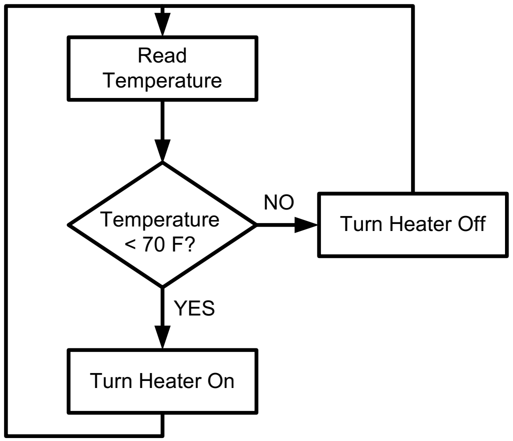
$$
\begin{aligned}
e &= x_{des} - x \\
&= 10 - IR\ Sensor\ Measurement \\
K_p &= 100 \\
motor\ Signal &= min(K_p e,\ 255)
\end{aligned}
$$

# Outline

- Control Loops
- Developing Control Algorithms
  - What are algorithms?
  - How to represent algorithms
  - Example algorithms

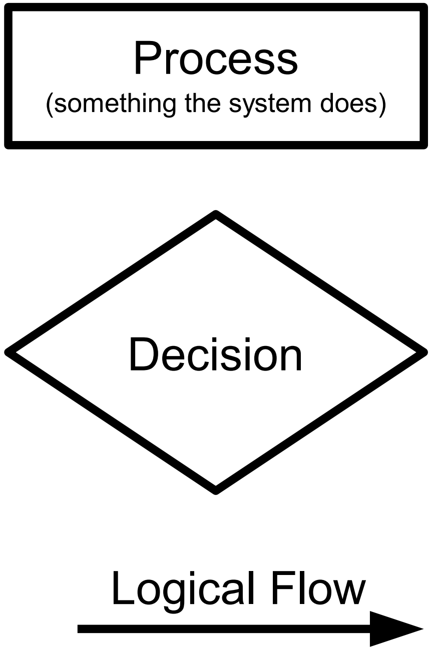
# Control Algorithms

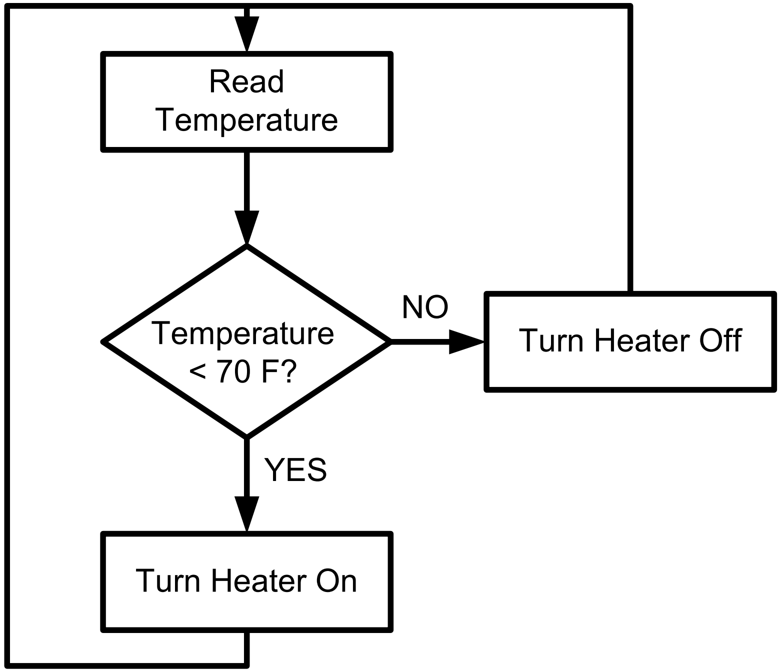
- Algorithm:
  - A sequence of steps needed to accomplish a goal
  - Algorithms are frequently represented using **flowcharts**



# Control Algorithms

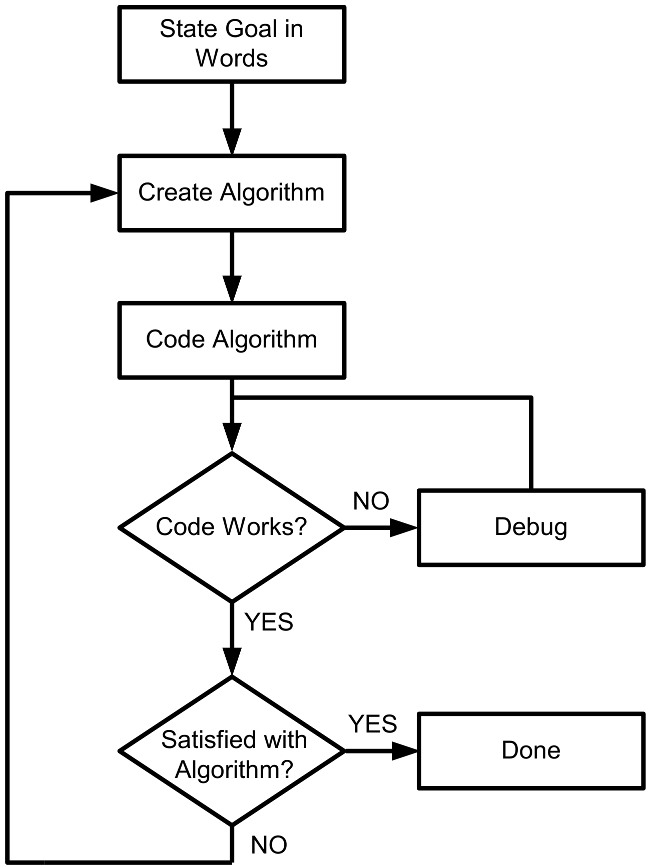
- Flow Chart Primitives



# Control Algorithms

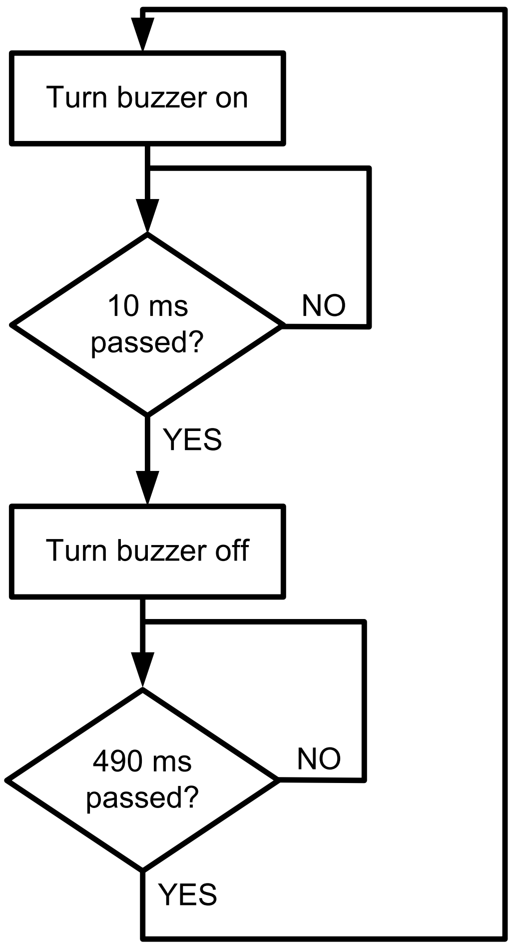
- Problem solving
  1. State goal in words
  2. Create algorithm
  3. Code algorithm
  4. Test / debug
  5. Repeat steps 2-4 until satisfied



# Algorithm Example 1

- Open Loop Control:
  - Design an algorithm that turns the buzzer on twice a second for 10 ms. Draw a flowchart of your algorithm.

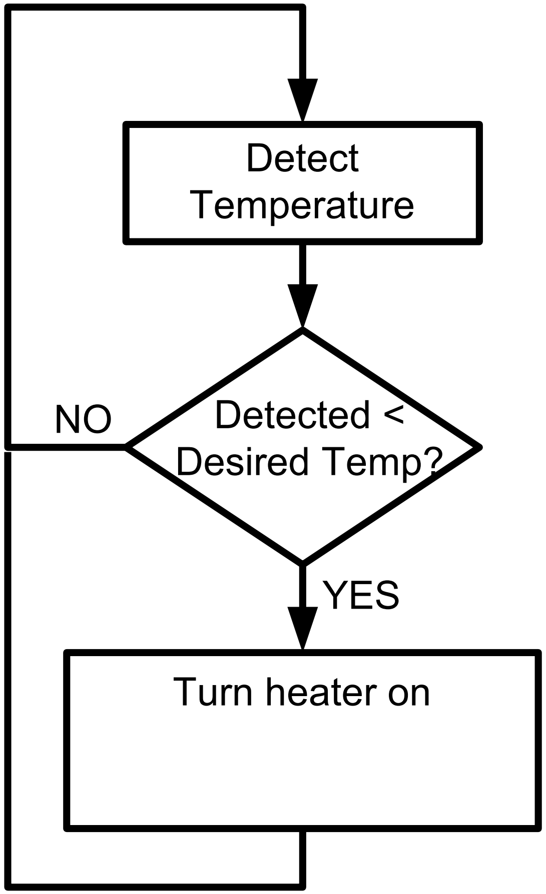
# Algorithm Example 1



# Algorithm Example 2

- Closed Loop Control
  - Use bang-bang control to design an algorithm that turns the heater when the temperature is too low.

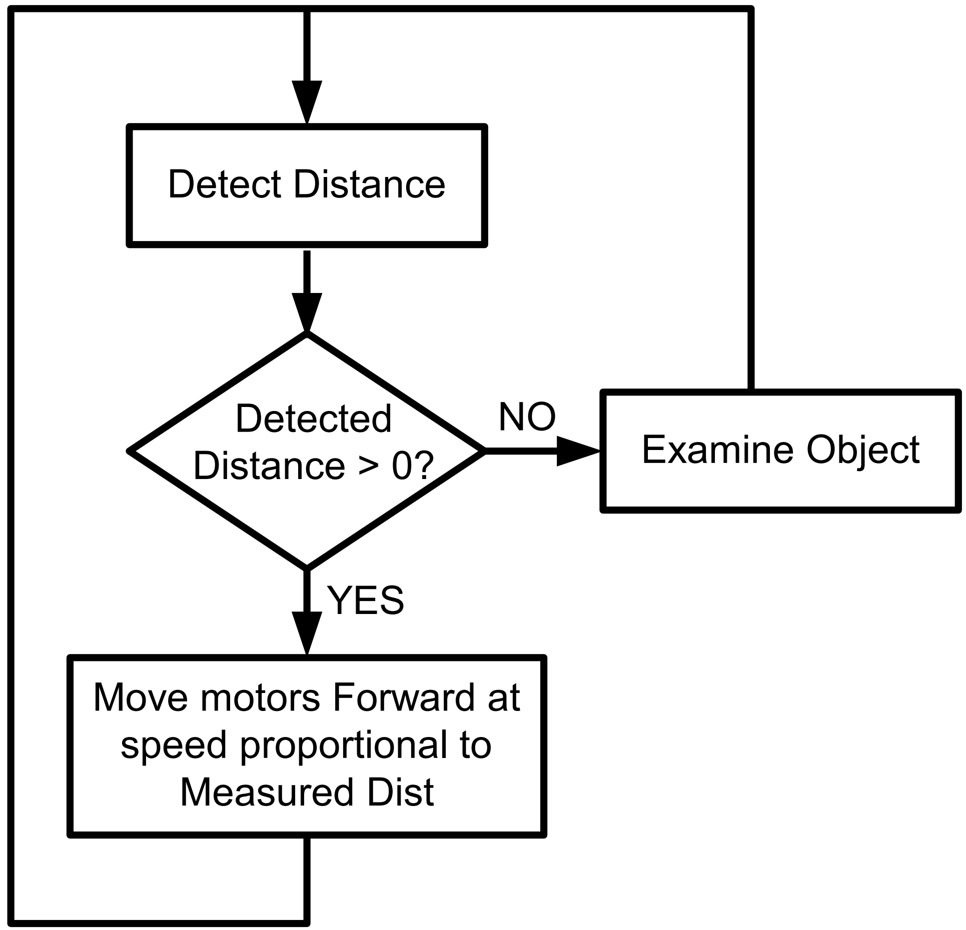
# Algorithm Example 2



# Algorithm Example 3

- Closed Loop Control
  - 
  - Use proportional control to drive your robot up to an object as fast as possible without hitting it. (When your robot reaches the object, it should stop ☺)

# Algorithm Example 4



# Summary

- Open Loop Control:
  - System function does not affect the inputs
- Closed Loop Control:
  - System function affects the inputs
- Types of Feedback Control:
  - Bang-bang control: the system turns on (does something) until a desired value is reached
  - Proportional control: the system responds proportional to the error (desired – measured)
- Algorithm:
  - Sequence of steps needed to accomplish a goal
- Flowchart:
  - Graphical representation of algorithm