6.270: Autonomous Robot Design Competition

- Assignment 2: General Comments
- More on sensors
- Servos
- RF receiver
- Robot control and state machines
- Threads
- Assignment 3 handed out

Lecture 3: Advanced Techniques

Delinquent Teams

- Assignment 2 teams not finished:
  - 11, 14, 15, 18, 22, 40, 55
- Assignment 3 handed out today, due tonight!!

Rules Clarifications

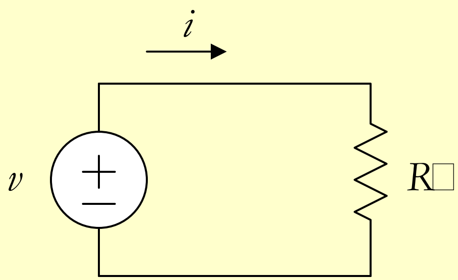
- Are prices measured in 1-u or 100-u quantities?
  - We'll use 100-u quantities for pricing purposes
- Can we use rubber bands to add friction with game balls?
  - Yes
- Can we disable an opponent?
  - You cannot intentionally damage or flip
  - You can drive into the other robot or push them around
- Can we cut apart the baseplate and glue it back together?
  - Yes, but things glued together are not structural

Power Usage

- Your HandyBoard has 8 rechargable 1.5 volt batteries built in
- They don’t last too long when driving actuators
- Next week, we’ll give you high capacity lead acid batteries from Hawker to power actuators

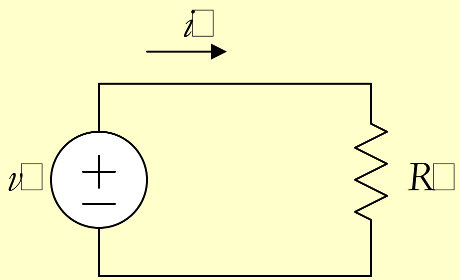
Some 6.002/8.02 Lovin'

- Voltage, Current, Resistance: V = I · R
  - Resistance: ohms (Ω)
  - Current: amps (A)
  - Voltage: volts (V)
- Power: P = I · V



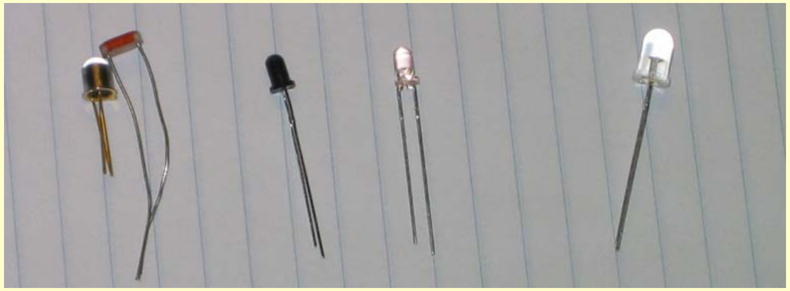
Shorting the Batteries

- v = 6 V, R = 0.02 Ω
- i = 300 A
  - Household wiring rated 15 A
- p = 1800 W
  - Thirty 60-watt light bulbs
- Lesson: ensure battery leads are well-insulated!



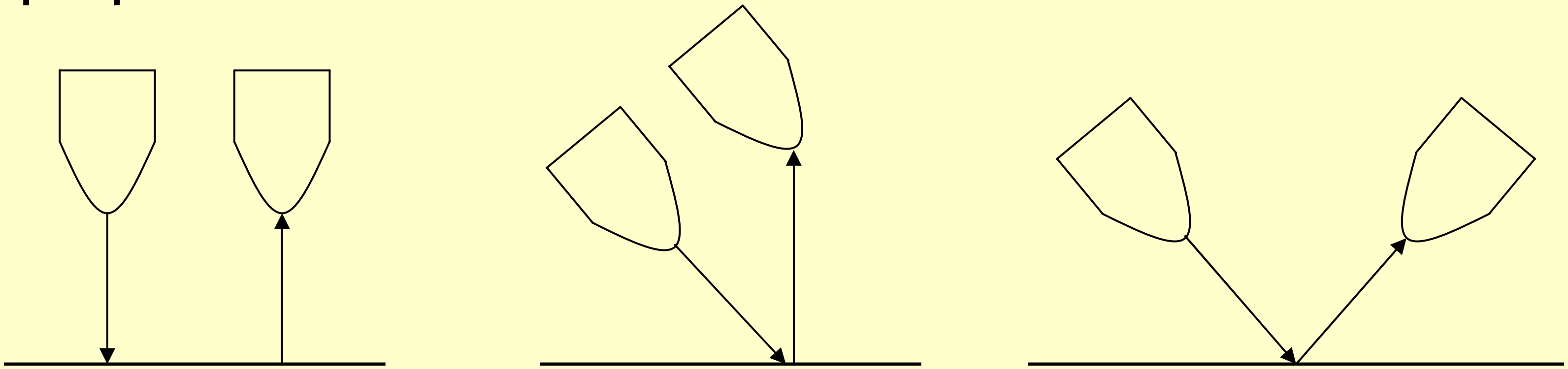
Phototransistors

- It's an art
- Need to figure out an effective way of reading the color off the board or object
  - Factors: glossiness, ambient lighting
  - It's not really color; it's grayscale
  - Contest night
  - Wear and tear of contest board
  - Can't rely on just light provided by the world alone



Providing Your Own Light

- LEDs are polarized, and you must use a resistor
- Light dispersion
  - What is the best way to put LEDs
  - For color detection, look for reflection at an angle, not perpendicular to surface

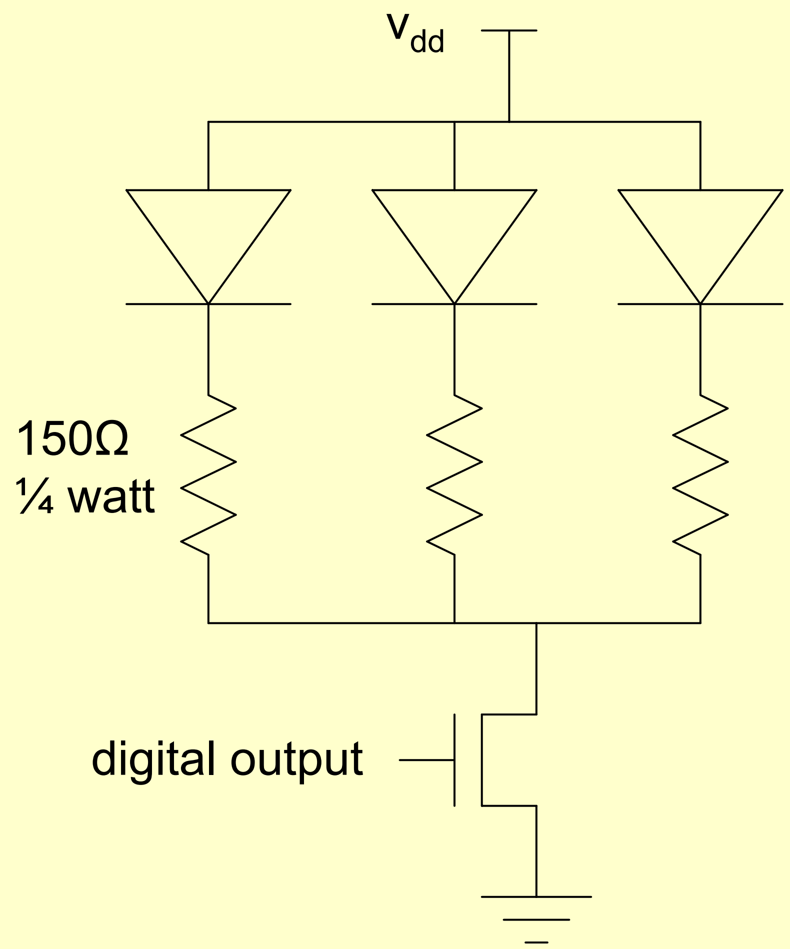


Providing Your Own Light

- Turning LED on and off gives more info
- Use FET to turn multiple LEDs on and off using the digital output
- See handouts page for FET datasheet

Wiring Multiple LEDs

- Use a separate resistor for each LED

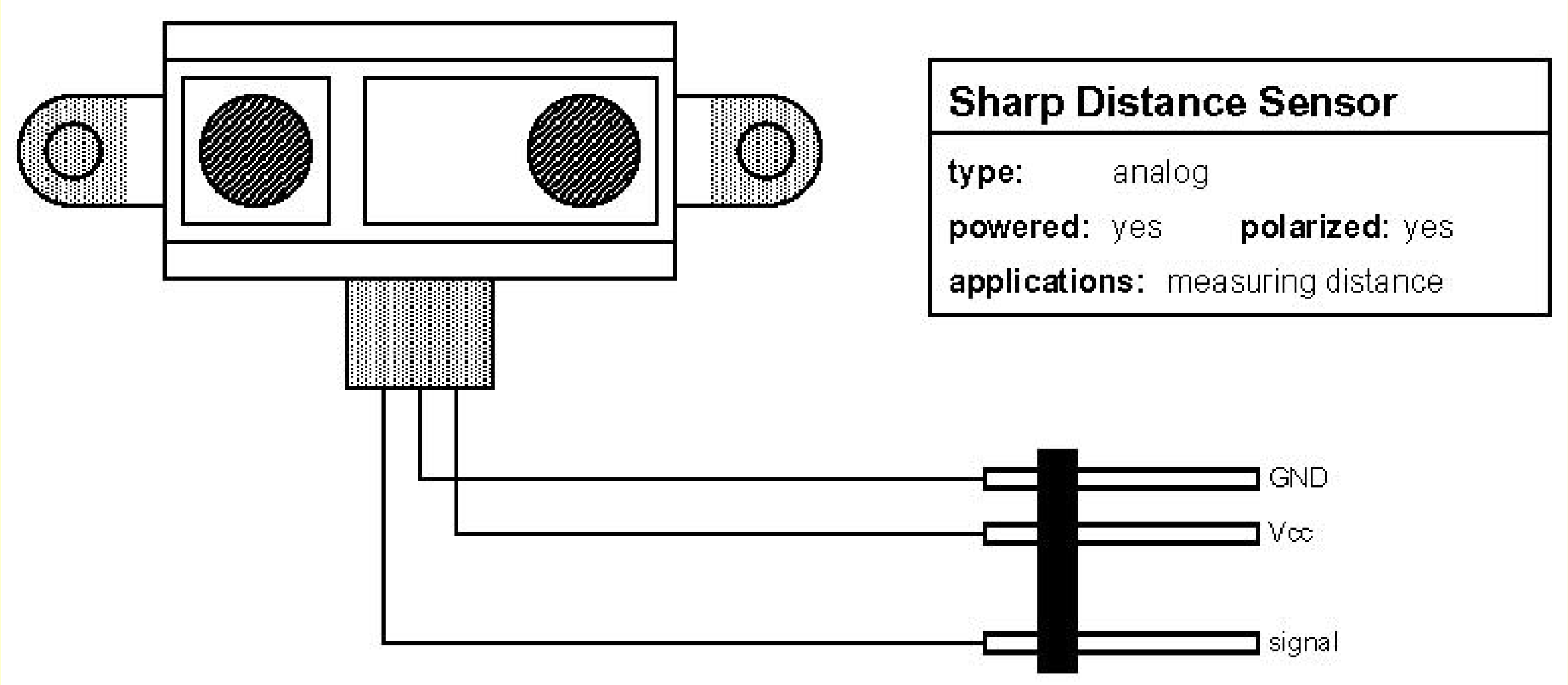


Shielding

- Control the light made available to the sensor
- Help focus what the sensor is looking at
- Cardboard, heat shrink (black), electrical tape
- Some things aren't as opaque as you think
- Calibration (and 60-second set-up time)

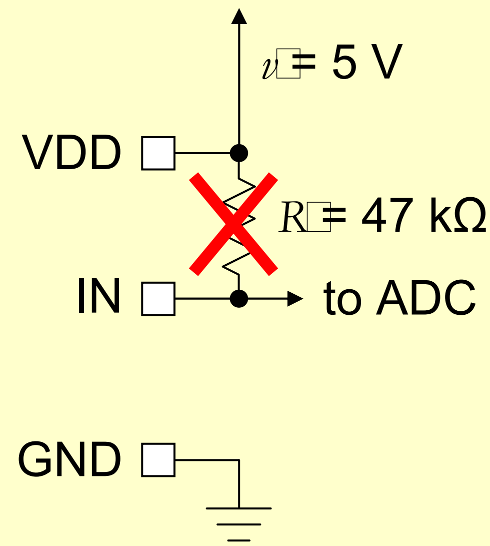
Distance Sensor

- Follow hookup instructions in the notes



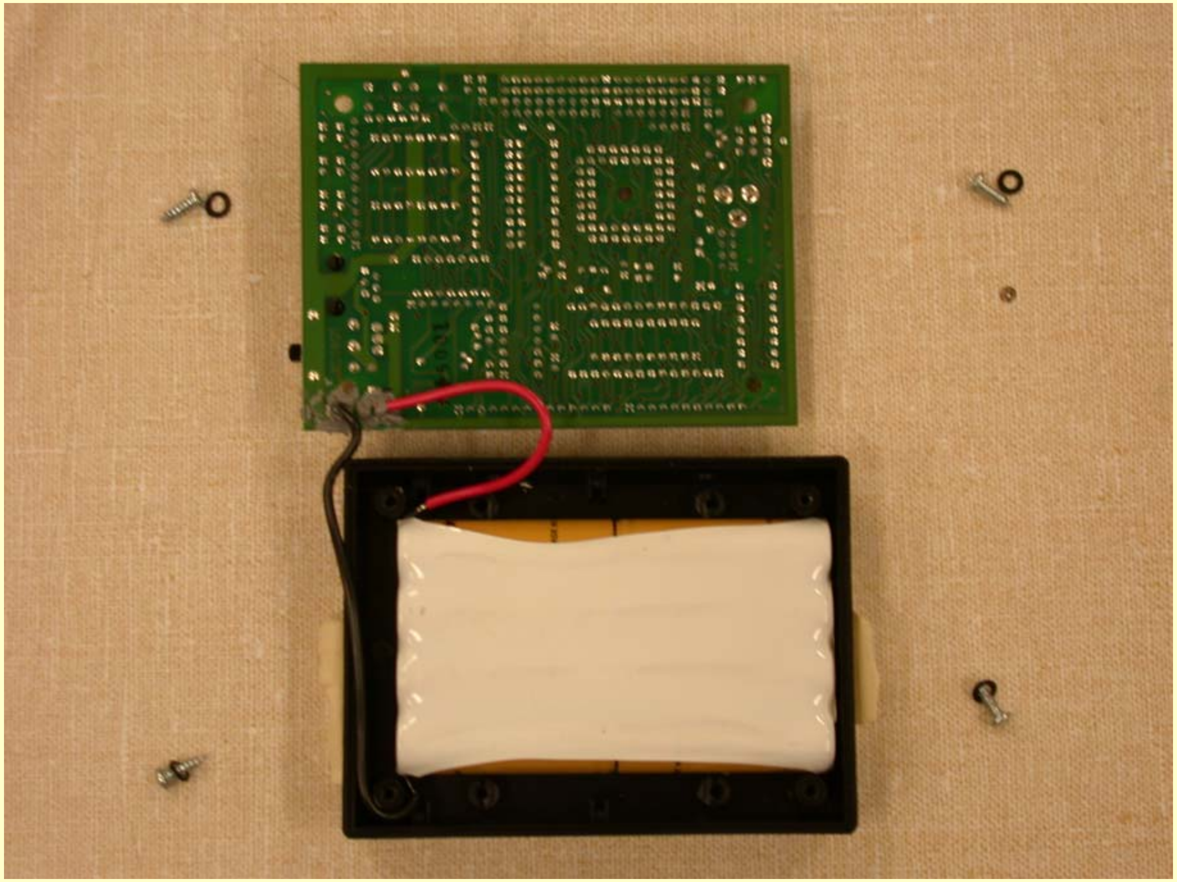
Distance Sensor on the HB

- Distance sensor provides variable voltage output
- Must disconnect internal pull-up resistor



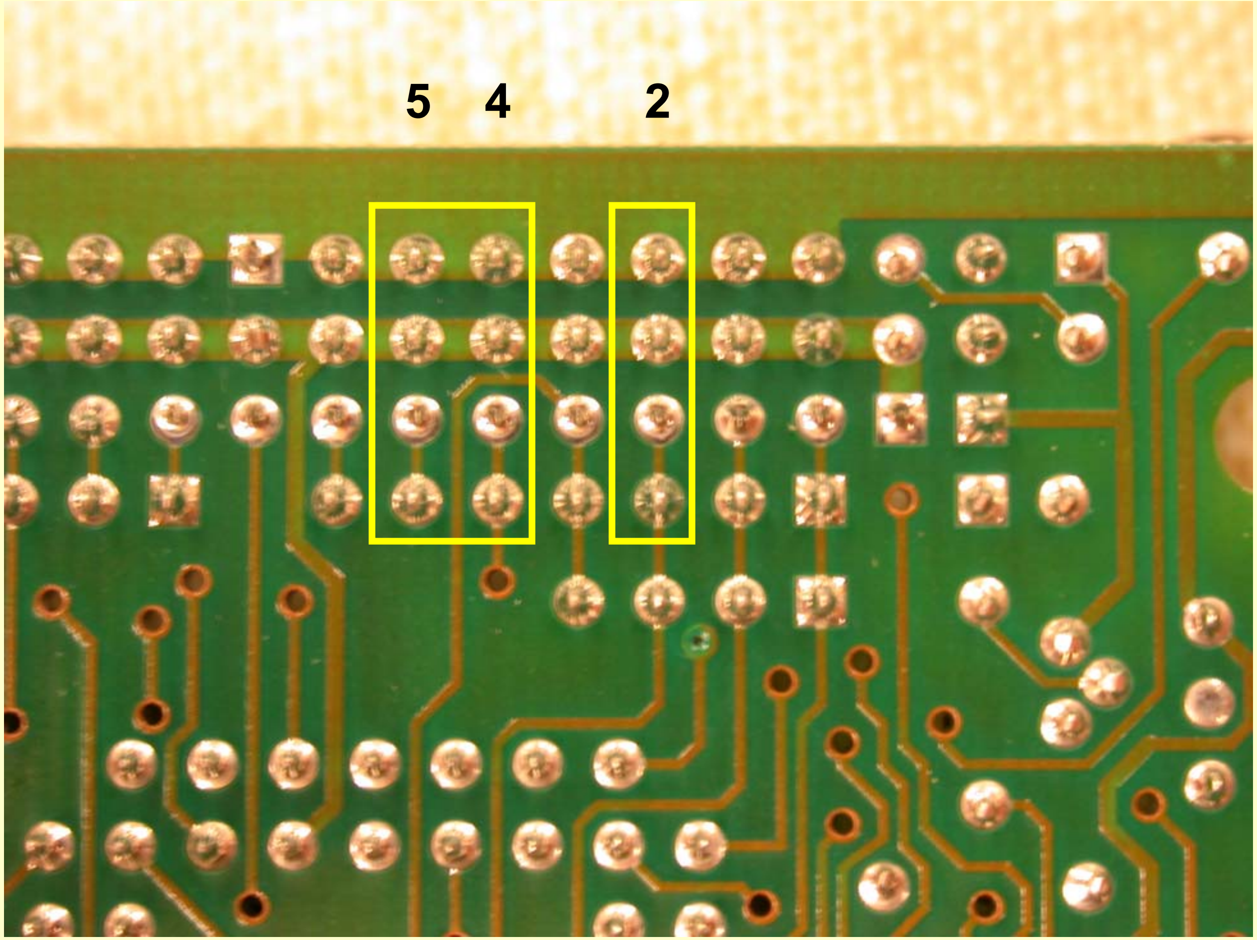
Disconnecting the 47kΩ Pull-Up

- Remove main HB PCB from the plastic case



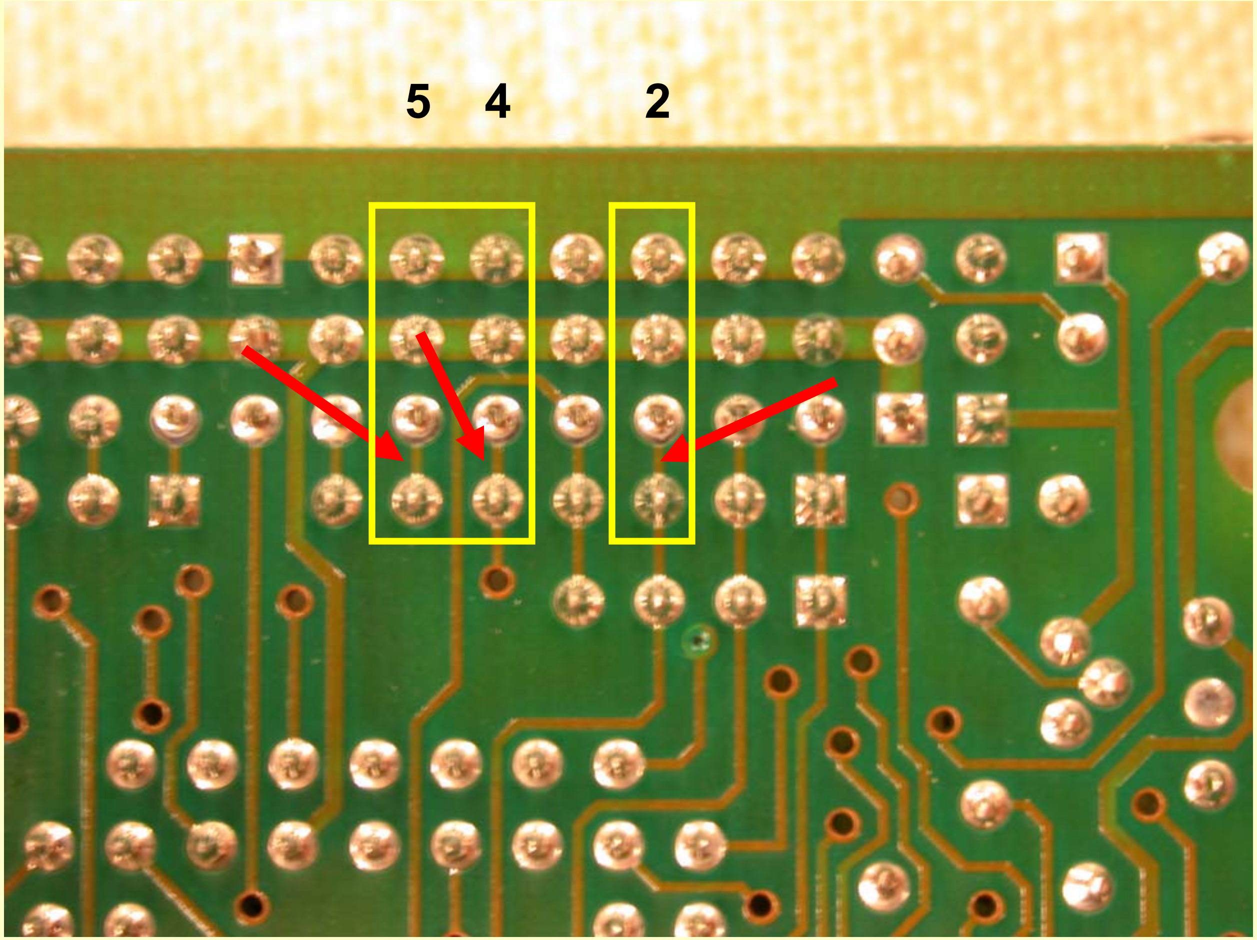
Disconnecting the 47kΩ Pull-Up

- Analog Inputs 2, 4, and 5 can be modified



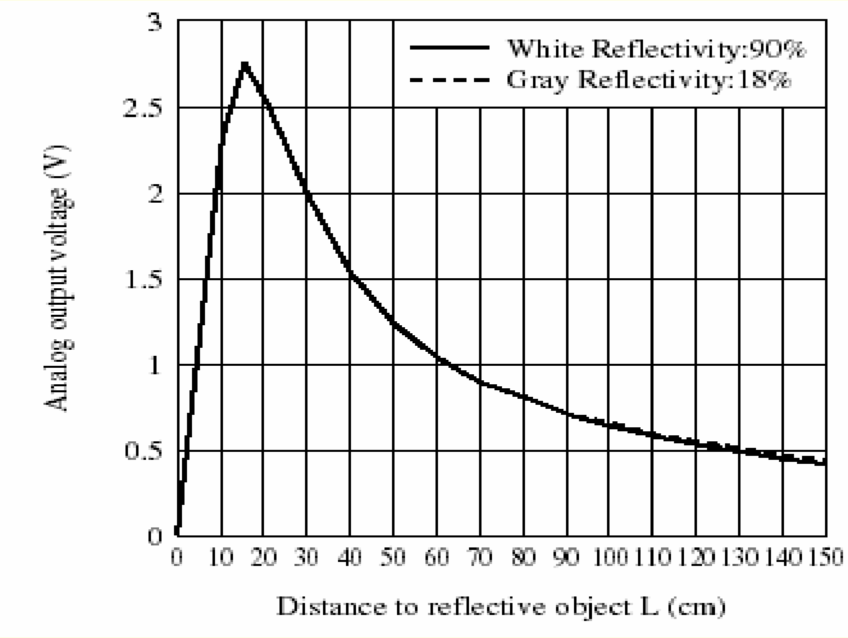
Disconnecting the 47kΩ Pull-Up

- Cut traces (make sure you know where!)



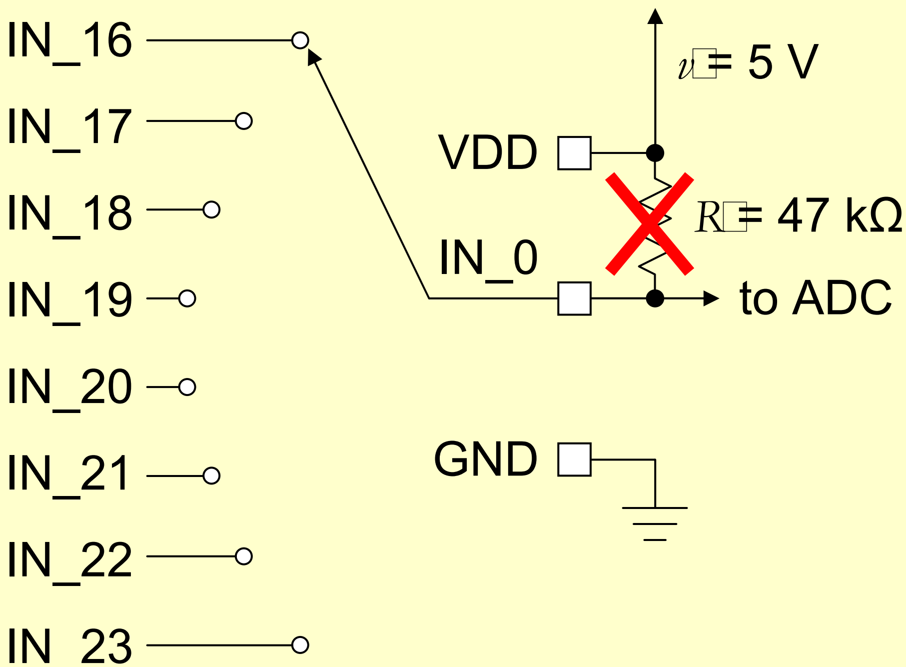
Distance Sensor

- Range: 15-150 cm
  - 6-60 in



Distance Sensor

- You probably don’t need more than 3
- But if you’re really *that* needy, cut port 0 or 1



The Gyroscope

- Gives you a rate of rotation
- You can integrate to get a position
  - Usually accurate to within a couple of degrees over 60 seconds
- Example code given on contestant’s information page

Gyroscope Considerations

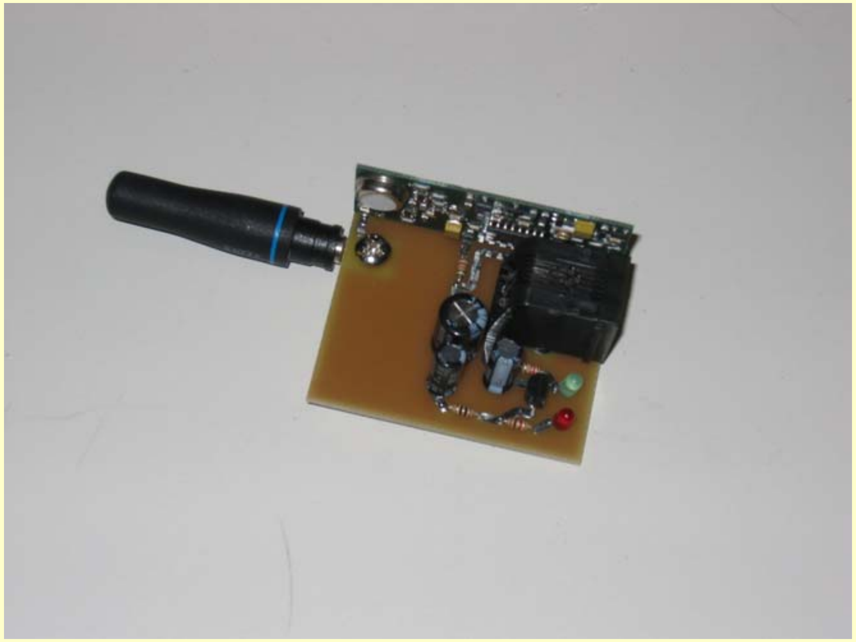
- Reducing drift and inaccuracy
  - Correct gyroscope data when you know what it must be
    - Backed against a wall
  - Use relative positioning
    - Make turns based on a change of 90 degrees, rather than turning to 270 absolute degrees

Gyroscope Usage

- You can have ONE gyroscope
  - 5 sensor points
  - Talk to us about how to hook it up
  - We will not replace broken gyroscopes
  - Use any analog sensor port

The RF Receiver

- Lets us give you information during the match:
  - Start/end of match
  - Vote tally
  - Position of robots



Using the RF receiver

- First thing in your code:
  - `rf_team = YOURTEAMNUMBER;`
  - `rf_enable();`
- This will disable the IC interface
  - To turn on your handyboard without enabling RF, hold START while turning on
- Plug your telephone cable into the HandyBoard and the RF receiver

Start/stop of match

- Use the function `start_machine()` (described in the course notes)
- Will automatically start your robot when the match begins, and stop it when the match ends

Voting Information

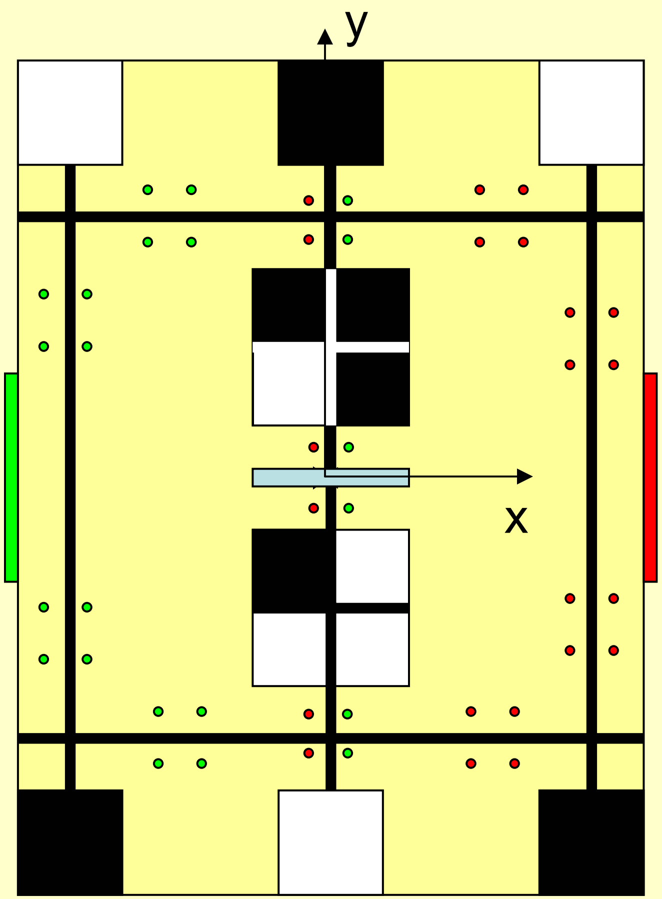
- `rf_vote_red`
- `rf_vote_green`
- `rf_vote_winner`
  - You need some way of determining a winner when there is a tie
  - All automagically updated

Position Information

- `rf_x0, rf_y0`
- `rf_x1, rf_y1`
  - Tell you the x and y coordinates of the two robots
  - No guarantees about which of the two robots you will be
    - Consistent during the match, but not across matches
  - Also automagically updated

Position Information

- `rf_x0, rf_y0`
- `rf_x1, rf_y1`
  - Approximately 8000 units per foot
  - Center of table is (0,0)



Position Information

- How do we determine the position information?
  - You'll be required to put a colored swatch (which we provide) on top of your robot
  - We look at the table and find the swatches
  - More details later

The Bigger Picture

The Bigger Picture

- You have tools:
  - Sensors
  - Actuators
  - Mechanical chassis
  - Task-specific mechanical devices
  - Processor
- How to put it all together?

The Bigger Picture

- Combining Sensors
  - Servo + distance sensor
  - Servo + beacon
  - Beacon + distance sensor
- Do you even need sensors?
  - Wall following / going straight
  - Making precise turns

What Are the Sensors Doing?

- They prevent you from dead reckoning
- What matters is where the robot is, not where it thinks it is
- Provide information to make decisions

The AI: How to Code a Robot

- Programming language is easy; programming style is difficult, especially with a team (any 6.170 alums?)
- Some patterns have emerged in regards to having an effective coding style
  - Finite State Machines
  - Control
  - Coding Techniques

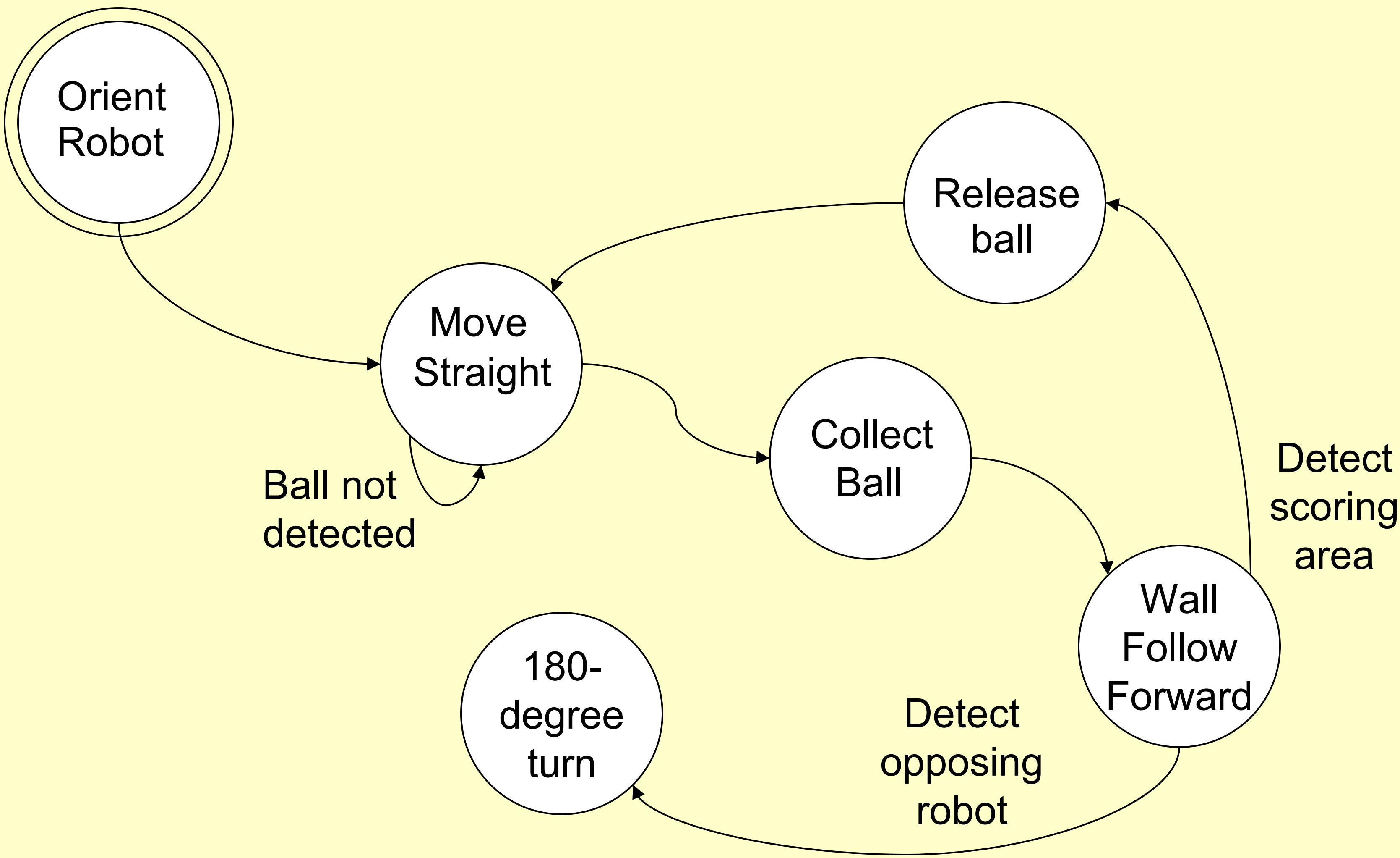
Finite State Machines

- What is a finite state machine (FSM)?
  - Defines what the robot should do at a given point in time
  - Each state has predefined outputs
  - Transitions to other states depend on inputs
- Why?
  - Effective way of thinking about your strategy
  - Define what to do for any combination of inputs

Implementing a State Machine

- Each action is a state
  - Moving forward
  - Turning
- Actuators are outputs of the FSM
- Sensor inputs determine next state

Example FSM


Orient Robot
Release ball
Move Straight
Collect Ball
Ball not detected
Detect scoring area
Wall Follow Forward
180-degree turn
Detect opposing robot

Coding an FSM

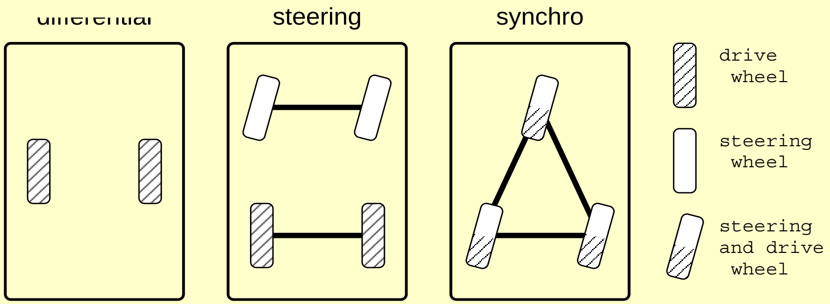
- While loops
  - Continue an action until input is received
- Multithreading
  - Processes that determine the inputs
  - Processes that determine outputs and state transitions
- Don’t do it the 6.111 PAL 20V10 way
  - Don’t need a variable to keep track of what state you’re in
  - Instead think conceptually; think before you code

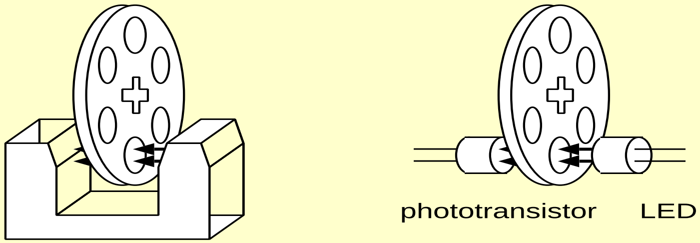
FSM Issues

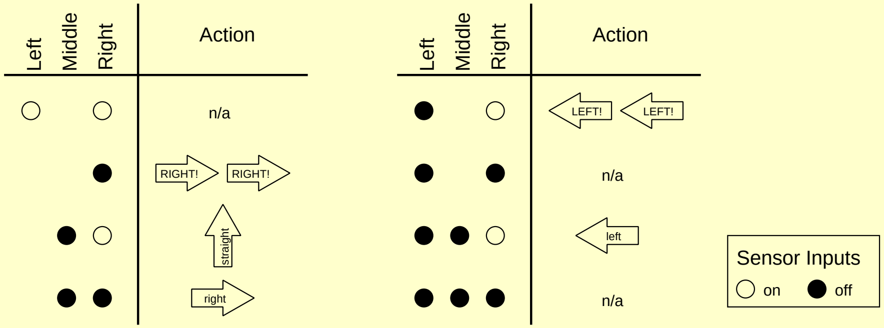
- Inputs
  - Check only those that matter at that state
  - Determine what is important
- Storing State
  - Make your robot smarter
    - Use the state as well as the inputs to determine action
    - Store last actions in state variables
  - Helpful if robot gets disoriented

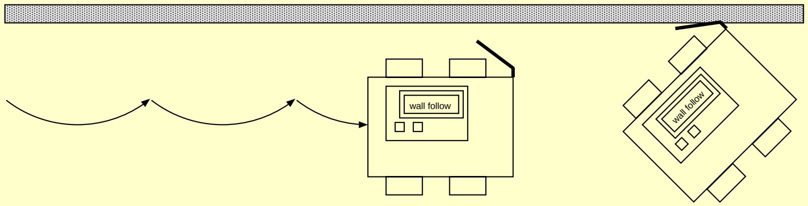
Driving Straight

- Drive mechanism
- Line following
- Shaft encoding
- Wall following



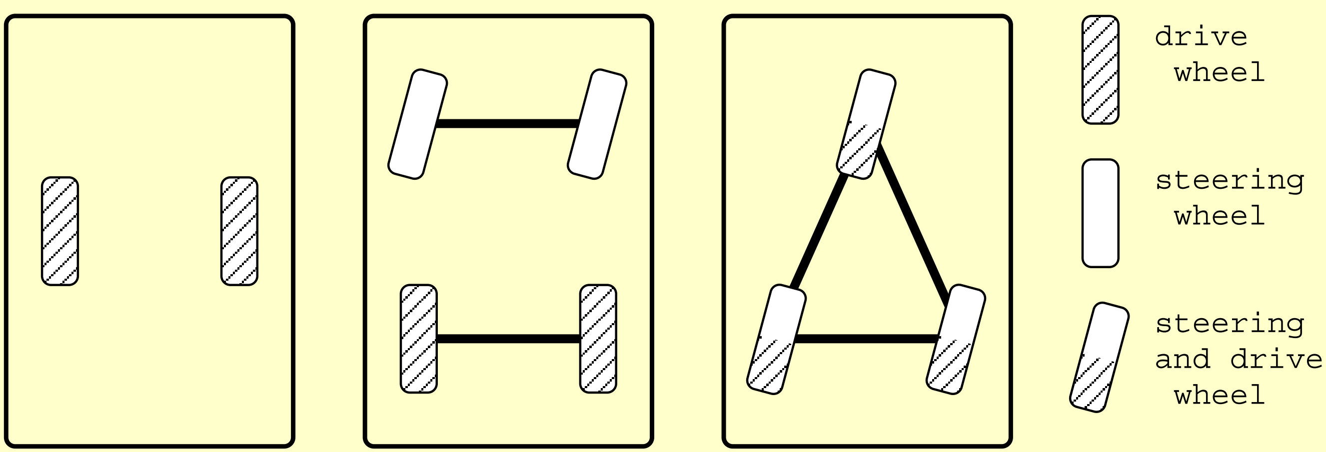






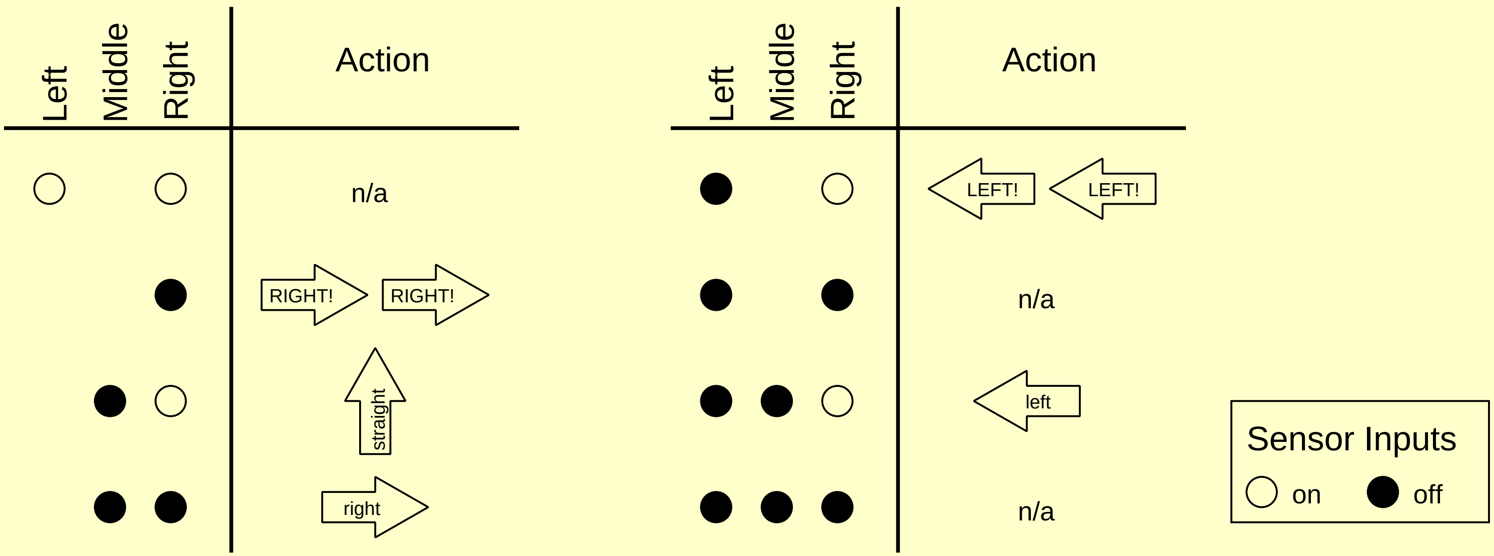
Drive Mechanisms

- Differential Drive
- Synchro Drive (servos)
- Rack-and-Pinion Drive (car)
- Independent Drive (gearboxes; Assignment 2)



Line Following

- Use set of light sensors to look at color under robot
- Set of lines and contrasts on board
- Follow contrast



Line Following

○ ○ ○ | n/a

```
if prev_state == hard_right
    then keep turning right
if prev_state == hard_left
    keep turning left
```

● ● ● | n/a

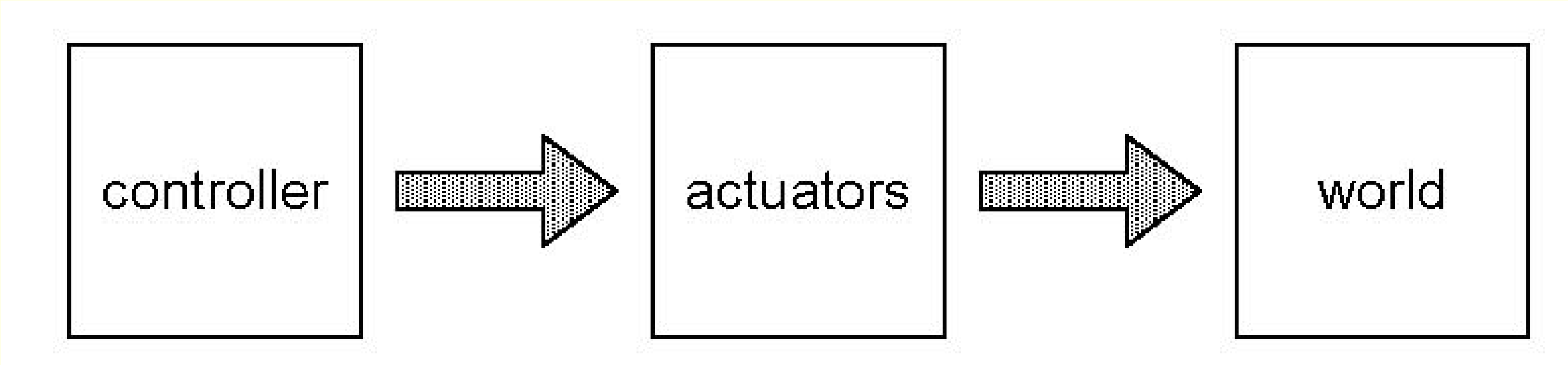
```
if prev_state == right
    turn left
if prev_state == left
    turn right
```

Control Systems

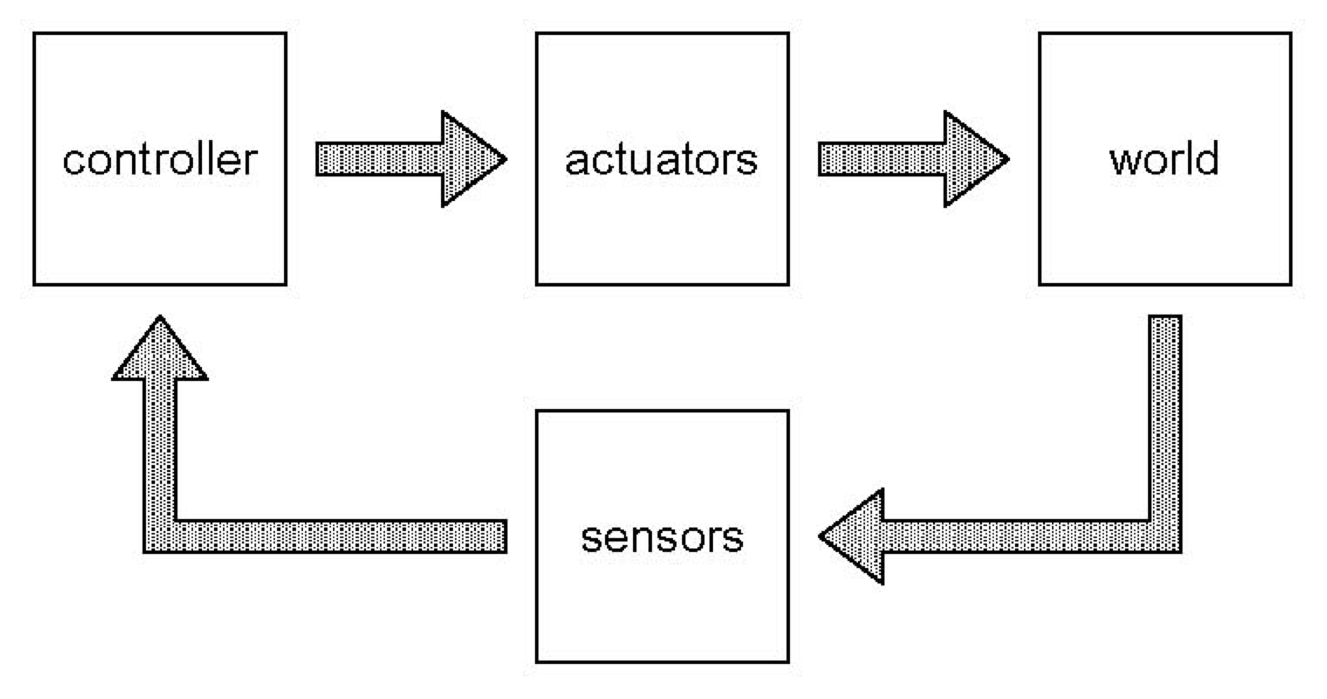
- Robots are deaf, dumb, and blind
  - Only capable of following explicit instructions
- Control systems required to create desired motions

Open Loop Control

- Simply a set of sequential instructions
- Does not rely on external inputs
  - Dead reckoning / using timing
- Errors accumulate



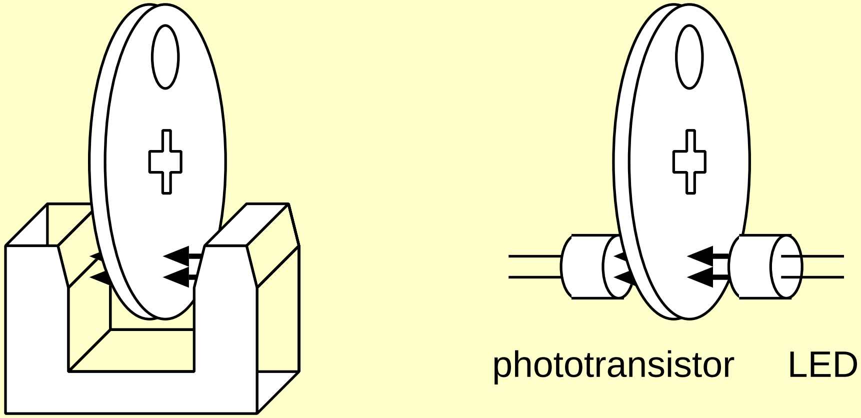
Feedback Control



- Sense environment to correct errors
- Avoid dead reckoning

Shaft Encoding

- Breakbeam sensor + pulley
- Count interruptions to find revolutions
- Driving straight
- Useful for:
  - Turning
  - Moving a specific distance
  - Better than timing
    - Doesn't rely on battery charge



Shaft Encoding

- Works better on some ports:
  - Ports 7 and 8 have hardware counters (faster, more accurate)
  - Others use software counters
  - If you need more than 2, try using ports 2-6
- Both wheels may not turn at same speed
- Use revolutions for feedback
- Determine difference in speed and adjust
- Hint: place encoder high in gear train

Pseudo-Code

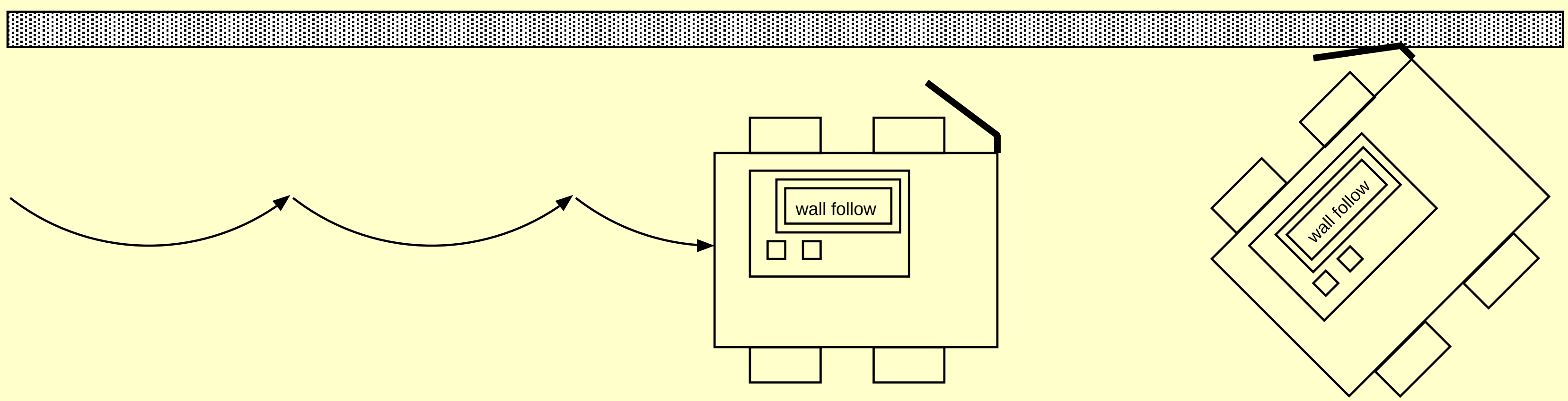
```
if (right encoder value – left encoder
   value) > 100 ticks
   slow down right wheel or speed up left
   wheel

if (left encoder value – right encoder
   value) > 100 ticks
   slow down left wheel or speed up right
   wheel
```

Wall Following

- Easy way to go straight
- Simple to implement
  - Bump sensors on side
  - Distance sensors

```
while (…) {
   if (sensor hit)
        steer away from wall
   else
        steer towards wall
}
```



Driving Straight—Advantages and Disadvantages

- Shaft encoding
  - Relies on initial alignment
  - Relatively fast
  - Can be tricked by slipping
- Line following
  - Robust
  - Relatively slow
- Wall following
  - Requires continuous stretch of wall
  - Can be fast

Code Implementation

- Start on paper
- Use functions and comments
  - Code is then legible for everyone on your team and for us (impounding)

Programming Methodology

- Top-down programming
  - Good for initial design
  - Overall view without details
- Bottom-up programming
  - Good for code creation
  - Allows individual testing of functions

Programming Methodology

- Figure out the actions you want to take
- Figure out the functions you need
- Implement
- Test
- Integrate into other code
- Repeat

Testing and Debugging

- Most important part of the design
- Significant testing is necessary to do well
  - Things will break
  - Things will happen that you don't expect
  - Try to see these things in advance
- Test and debug incrementally

Hints

- Test sensors before mounting
- Test small pieces of code before combining into larger procedures
- Use the LCD screen
- Remember mechanical reliability

Error Detection

- Your robot **will** mess up
- How can it find out what's wrong?
- **Timeouts** are key

Timeouts

- Detect when robot is stuck in a state
  - Probably waiting for input – bump into wall, light reading
- Force out of stuck state
  - Error correcting routines

Error Correction

- Try again, harder
- Back up, try again
- Wiggle around
- Guess what it should try next
- Skip to next part of routine
- Line following: what to do about the n/a states
  - In this case, using an FSM may help you figure out what to do

Quick Note on Threads

Quick Note on Threads

- What is a Thread?
  - Separate task running at the same time
  - Allows you to multi-task
    - Motors run *and* watch if a sensor is pressed
- How does one processor run two threads?
    - Executes a process certain number of ticks (ms)
    - Processor switches from one thread to another

The Methods for Threading

- `int start_process(function_call(), [TICKS], [STACK_SIZE]);`
  - Default run is 5 ticks, or 5 ms
  - Stack size is by default 256 bytes
  - Returns process ID (pid) of the new process
  - You shouldn't need to pass `ticks` or `stack_size`
- `int kill_process(int pid)`
  - Returns 0 (process was destroyed), 1 (process not found)

Interacting in IC

- **`kill_all`**
  - Kill all currently running processes
- **`ps`**
  - Prints out list of process status
  - Provides:
    - Process ID
    - Status code
    - Program counter
    - Stack pointer
    - Stack pointer origin
    - Number of ticks
    - Name of function that is currently executing
- Refer to Handy Board manual for more information

Example

```
main() {
   while (true) {
      go forward
      wait until sensor
        pressed
      go backward
      wait until sensor
        pressed
   }
}
```

```
main() {
   while (true) {
      while (vote is tied)
        play tone 1
      while (red is winning)
        play tone 2
      while (green is winning)
        play tone 3
   }
}
```

Example

```
move() {
   while (true) {
      go forward
      wait until sensor
        pressed
      go backward
      wait until sensor
        pressed
   }
}
```

```
watch_vote() {
   while (true) {
      while (vote is tied)
        play tone 1
      while (red is winning)
        play tone 2
      while (green is winning)
        play tone 3
   }
}
```

Example

```
void move() { … }
void watch_vote() { … }

void main() {
    int move_pid;
    int watch_vote_pid;
    move_pid = start_process(move());
    watch_vote_pid = start_process(watch_vote());
    sleep(60);
    kill_process(watch_vote_pid);
    kill_process(move_pid);
}
```

Why Was the Example Easy?

- Threads are independent of each other
- Do not share any common variables, or common information
- Did not attempt to communicate or change each other's state

How Threads Can Communicate

- Communicate through global variables
- Variables declared above and outside of all functions are global variables (like C)
- One thread can use the global variable that another thread is changing

For the Contest

- You will be using threads, even if you don’t know it
  - We provide start code that makes sure that you start and stop at the right times: **`start_machine()`**
- See Appendix A for more details

Thread Tips

- Outside of **`start_machine()`**, you most likely won't need threads
  - Work around threads with control statements: **`for`**, **`while`**, **`if…then…else`**, **`return`**, **`break`**
- Don't use **`reset_system_timer()`**
  - Our start system code depends on the timer
- Don't **`sleep()`**; use **`while`** loops

```
sleep(3.0);
```

```
float start_time = seconds();

while (seconds() - start_time < 3.0) {
   /* check for anything (like sensor inputs) */
   if (you_really_need_to_leave_the_while_loop)
      break;
}
```

Your Winning Strategy

- Sufficient sensors and AI to determine location of robot
- Be able to react to potential problems that the robot might face
- Be aware of your limitations
  - Amount of LEGO
  - Power and speed of the motors
  - Robot size
  - Time of the round (60 seconds)
  - How long until Tuesday, January 25, 5:00 pm

Your Winning Strategy

- Reliability and robustness are the keys
  - 90% reliability means 43% chance of not failing in 8 rounds
  - KISS
  - *Leave a lot of time for testing and debugging*
- Impossible to counter every opposing strategy, so don't try

Assignment 3

- Due Friday night (TONIGHT!) at 11:45 pm
- One task to complete:
  1. Romeo and Juliet
- Pick up assignment after lecture

Assignment 4

- Due Tuesday night (January 11) at 11:45 pm
- Two tasks to complete:
  1. Discuss with your Organizer/TA pair your strategy
  2. Submit a one-page write up of intentions

What’s Next

- No workshops today
- Monday, January 10, and Tuesday, January 11
  - Workshop 5 – Servos, Sensors, and Shaft Encoders
    - Using analog sensors
    - Servo – the other motor
    - Shaft encoding with breakbeam sensor
    - Gyroscopes
  - Workshop 6 – Advanced LEGO
    - Using the unique pieces
    - Interesting gadgets
  - Workshop 7 – Code & Sensors II: Advanced Techniques
    - Open vs. closed loop control
    - Line following
- Don’t forget to sign up for workshops in lab!

Good LUCK!