ECED3901 Design Methods II

LECTURE #10: NAVIGATION #1

Colin O'Flynn

What are we covering?

- What is Navigation?
- Dead Reckoning
- Inertial Measurements
- Compasses
- Combining Measurements
- Ideas for Navigational Algorithms

What is Navigation?

Fundamental problem:

Where should we go?

Things to Consider

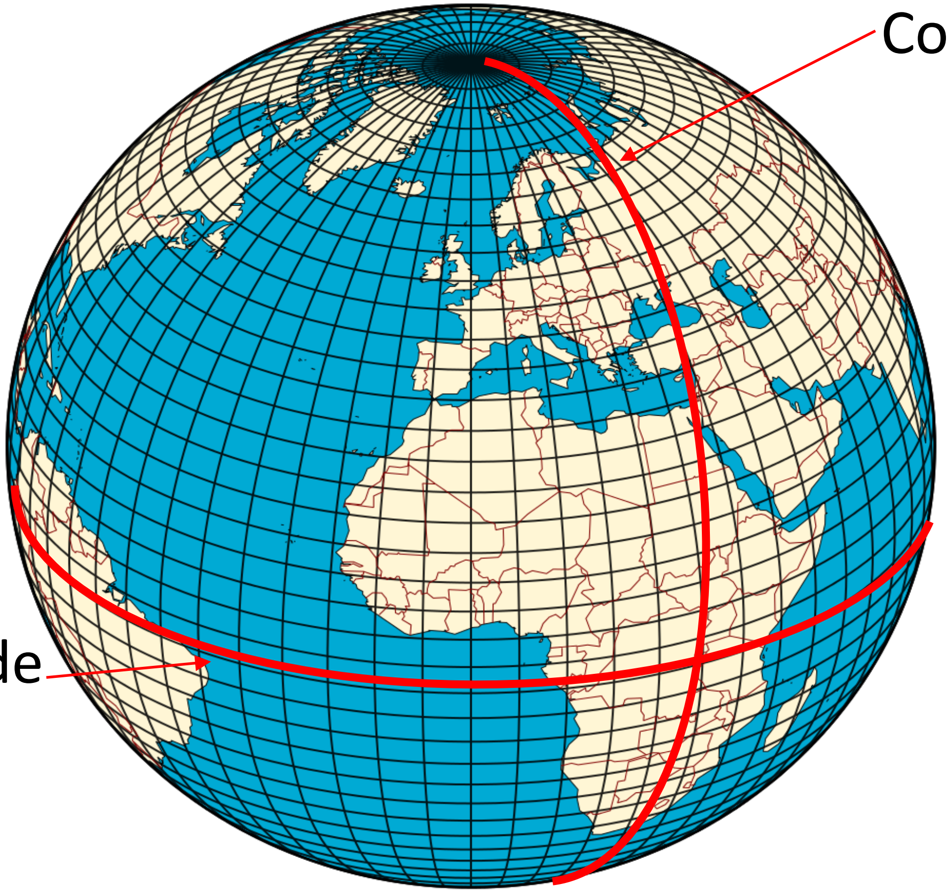
1. What is our objective?
    - Light-Seeking robot?
    - Finding an objective?
    - Exploring?
    - Mapping?
2. Where are we?
    - Do we have a map?
    - Are we building a map?
3. Where can we go?
    - Limitations of our robot (turn radius, battery life, etc.)?
    - Known obstacles?

Interesting History of Navigation

Just a few Tidbits

This is not a history class… but might give you some perspective on the problem

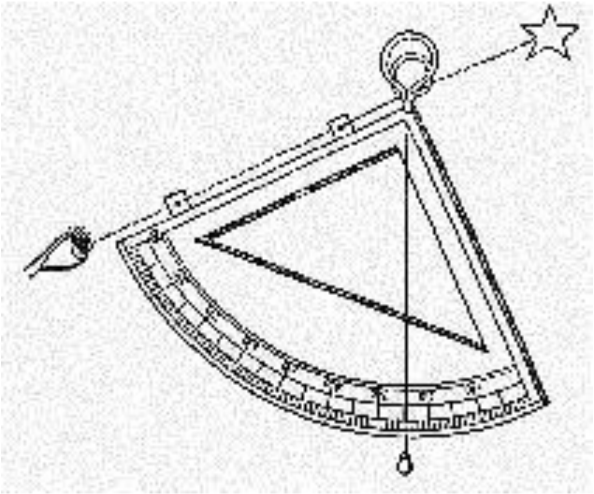
Navigating Oceans



http://en.wikipedia.org/wiki/Latitude#/media/File:Division_of_the_Earth_into_Gauss-Krueger_zones_-_Globe.svg

Finding your (Rough) Location

Latitude → Possible using Stars or Sun



Quadrant

Mariner's Astrolabe (1645)

Finding your (Rough) Location

Longitude→ Much more difficult

“Best” way is to have accurate time-keeper on ship… Earth rotates at fixed rate… if could determine location of reference objective relative to time then can solve problem.

Navigating by Air

Colin O'Flynn

Navigating by Air

Charles Lindbergh on an earlier flight:

Over the Straits of Florida my magnetic compass rotated without stopping…. I had no notion whether I was flying north, south, east, or west. A few stars directly overhead were dimly visible through haze, but they formed no constellation I could recognize. I started climbing toward the clear sky that had to exist somewhere above me. If I could see Polaris, that northern point of light, I could navigate by it with reasonable accuracy. But haze thickened as my altitude increased….

Nothing on my map of Florida corresponded with the earth's features I had seen…where could I be? I unfolded my hydrographic chart [a topographic map of water with coastlines, reefs, wrecks and other structures]…. I had flown at almost a right angle to my proper heading and it…put me close to three hundred miles off route!

From: http://www.airspacemag.com/history-of-flight/even-lindbergh-got-lost-3381643

Dead Reckoning

Basic Principles

- Some known starting point
- Measurements are then added to give us our new position
  - Almost always involves *integration*
  - i.e.: Distance travelled in a car = t * v

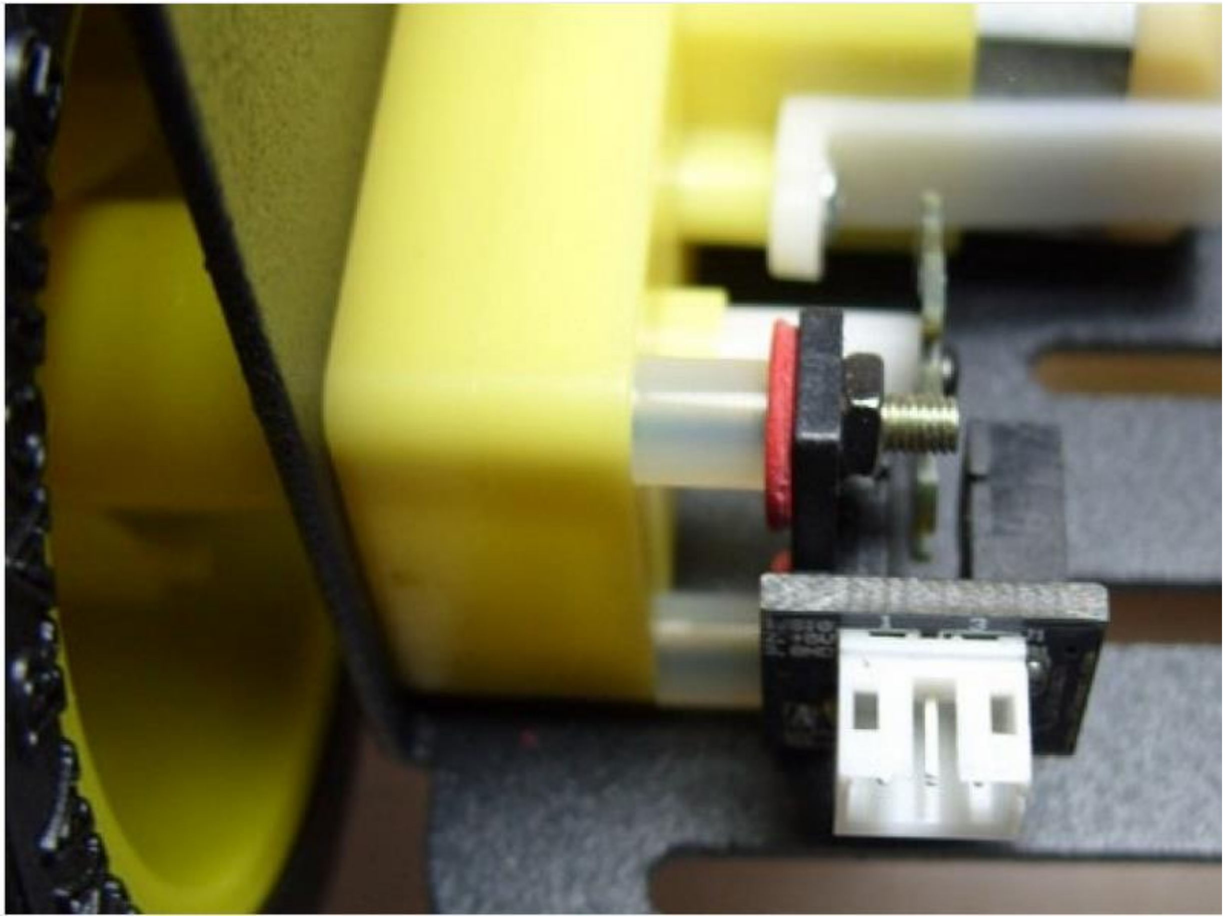
Core Problem with Dead Reckoning

As we are integrating (adding) up measurements, individual errors will **compound** over time

Historic Dead Reckoning…

6th Century or Earlier (depending on source)

Dead Reckoning in Your Robot



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Counting Pulses

- Need to select resistor values for optical device
- Interface pulse output to AVR
- Count pulses to determine rotation of the robot wheels
- Need to calibrate possible errors out

Calibration Method

Calibration Method

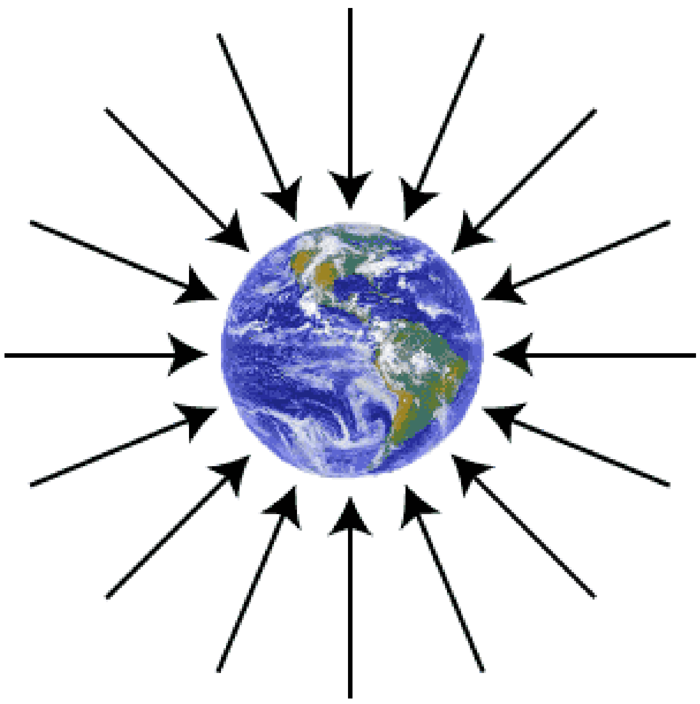
Sources of Error

- Robot moving without wheels rotating (slipping)
- Bad calibration data
- Changing wheel diameter

Inertial Measurements

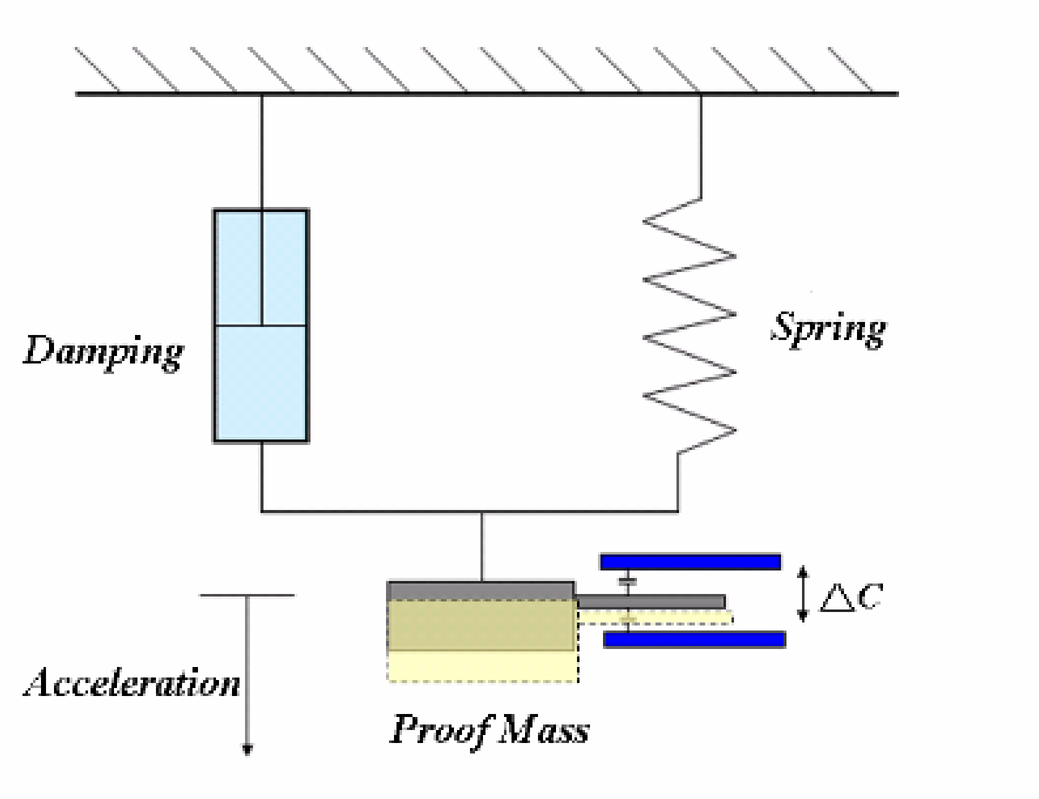
You're stuck in a van...

Measurement #1: Acceleration

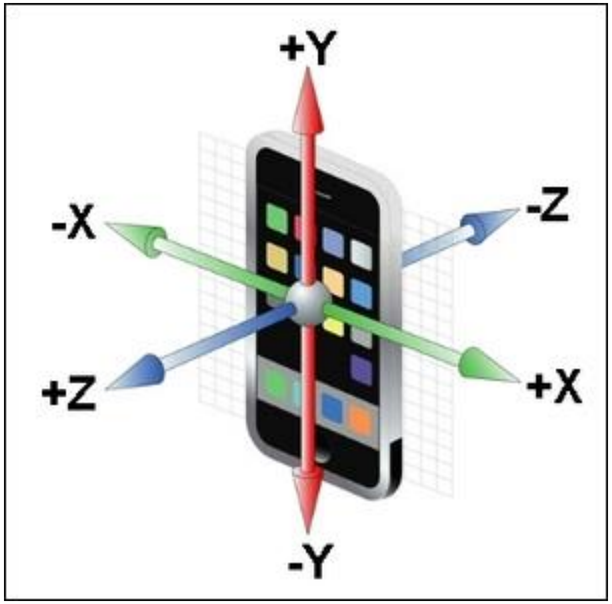


- Gravity Vector points downwards (9.8 m/s^2) always pointing downward
- Acceleration due to movement as well

Basic Principle



3-Axis Accelerometers



Mapping of Gravity Vector

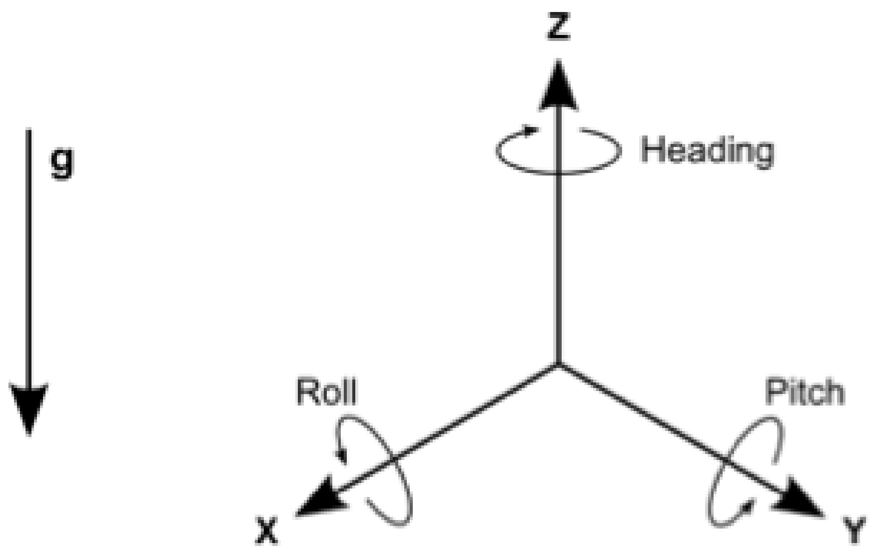
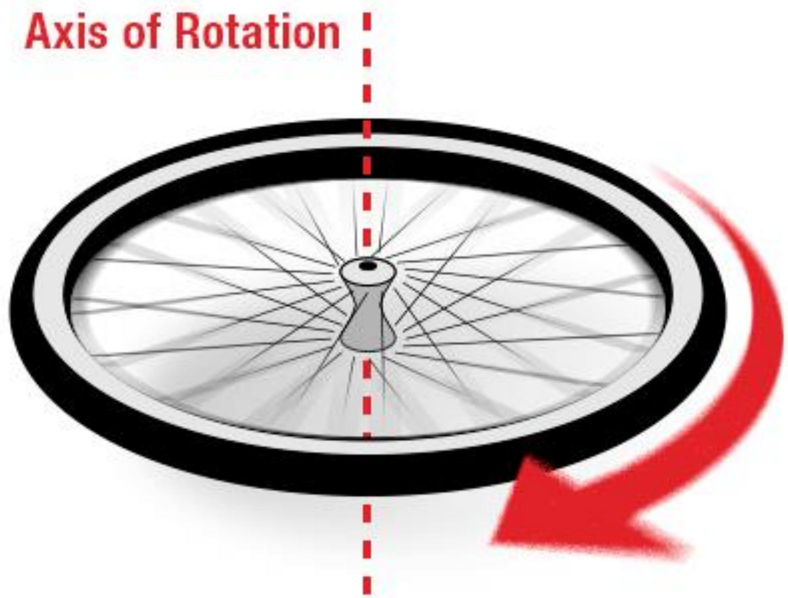


Figure 1: Gravity Vector and Heading, Pitch, & Roll about Axes

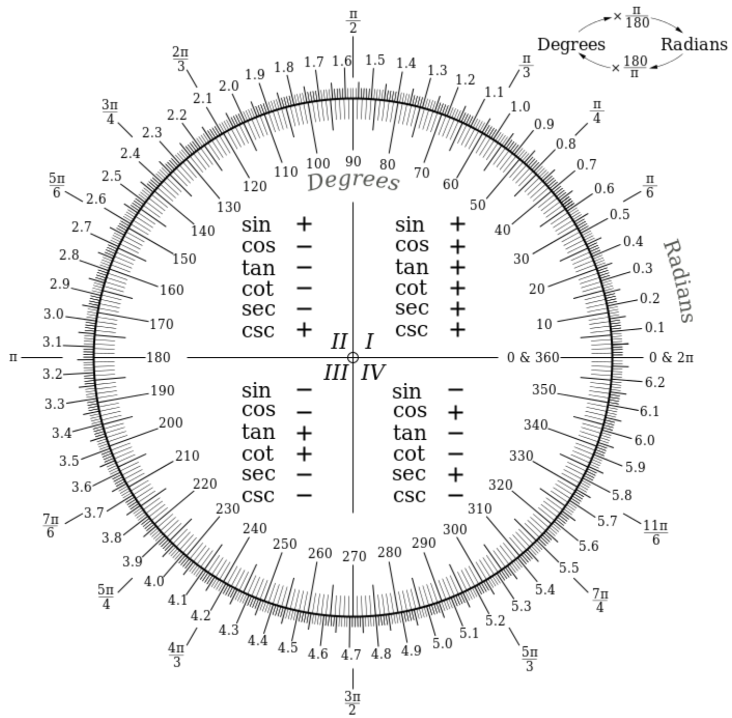
What can it NOT detect

Double-Integration & Errors

Measurement #2: Angular Rate



Rotational Units



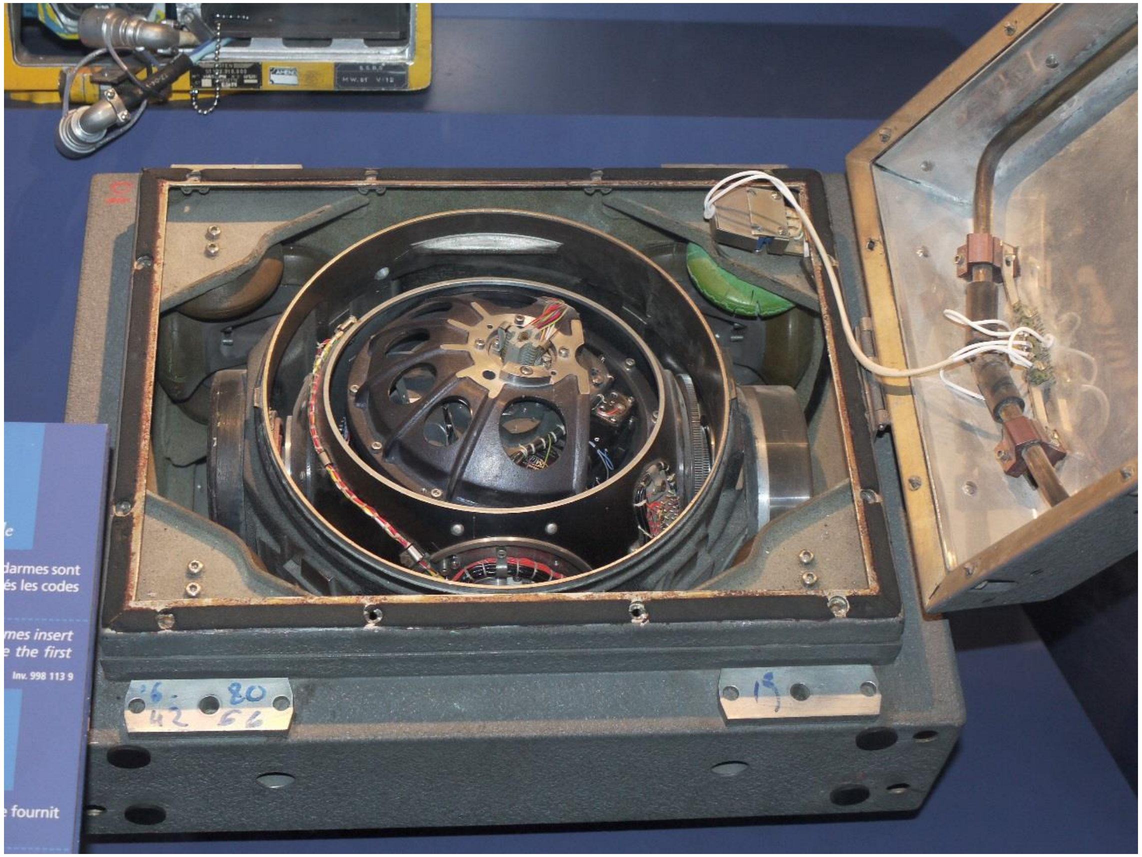
Typically specified in **deg/s** or **rad/s**

http://en.wikipedia.org/wiki/Radian#/media/File:Degree-Radian_Conversion.svg

Sidenote: Gimballed

http://upload.wikimedia.org/wikipedia/commons/d/d5/Gyroscope_operation.gif

Early IMUs



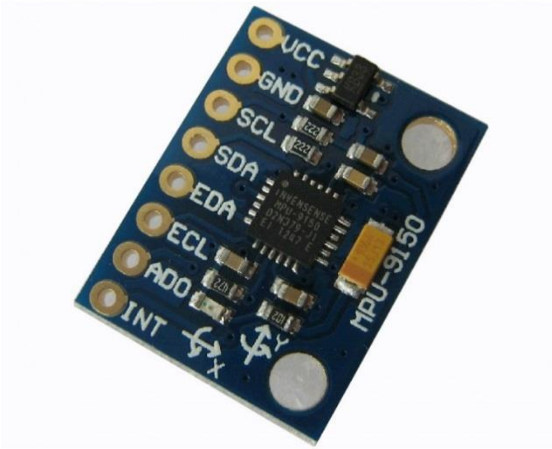
http://en.wikipedia.org/wiki/Inertial_measurement_unit#/media/File:Centrale-intertielle_missile_S3_Musee_du_Bourget_P1010652.JPG

Peacekeeper Missle (ICBM)

http://en.wikipedia.org/wiki/LGM-118_Peacekeeper

Strap-down IMUs

vs.



>$30 000 USD
Difficult to purchase.

Probably going to jail if I travel with it.

>$10 USD
Widely available

Not going to jail.

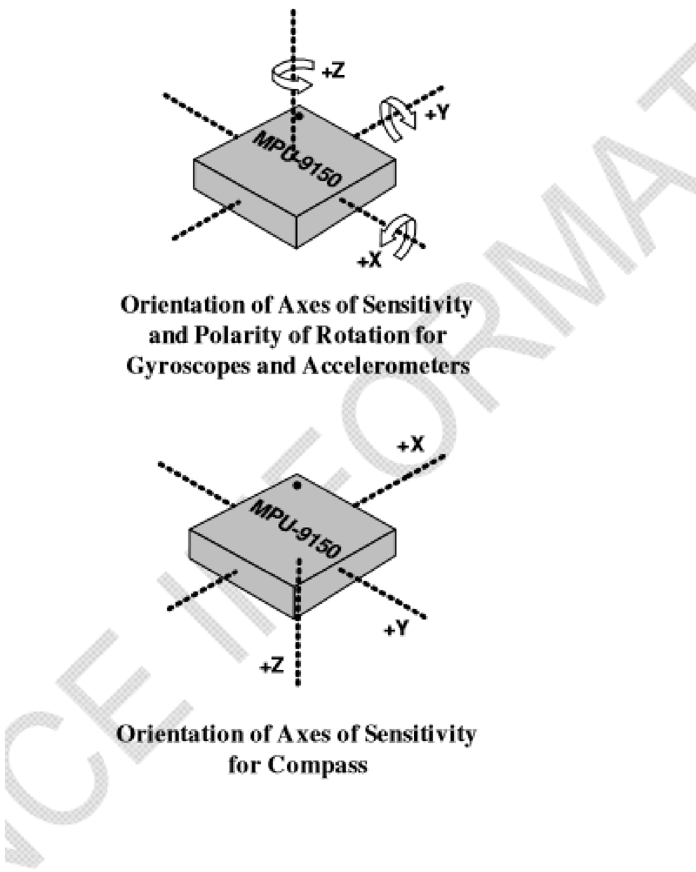
Performance Differences

GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	Component level (25°C)		±20		°/s	
ZRO Variation Over Temperature	-40°C to +85°C		±20		°/s	

LN-200 Core IMU

Performance	
Accelerometer	
Bias Repeatability	300 μg to 3.0 milli-g, 1σ
Scale Factor Accuracy	300 to 5,000 ppm, 1σ
Gyro	
Bias Repeatability	1°/hr to 3°/hr, 1σ
Scale Factor Accuracy	100 to 500 ppm, 1σ
Random Walk	0.07° to 0.15°/√hr Power Spectral Density (PSD) level

Using your MPU 9150



Example of Sensor Readings

Calculating Pitch & Roll

```
if ((Ysqacc + Zsqacc) == 0) {
        pitch = M_PI/2;
} else {
        pitch = atan(Xacc / (sqrt(Ysqacc + Zsqacc)));
}

if ((Xsqacc + Zsqacc) == 0) {
        roll = M_PI/2;
} else {
        roll = atan(Yacc / (sqrt(Xsqacc + Zsqacc)));
}
```

Magnetic Sensor to Compass

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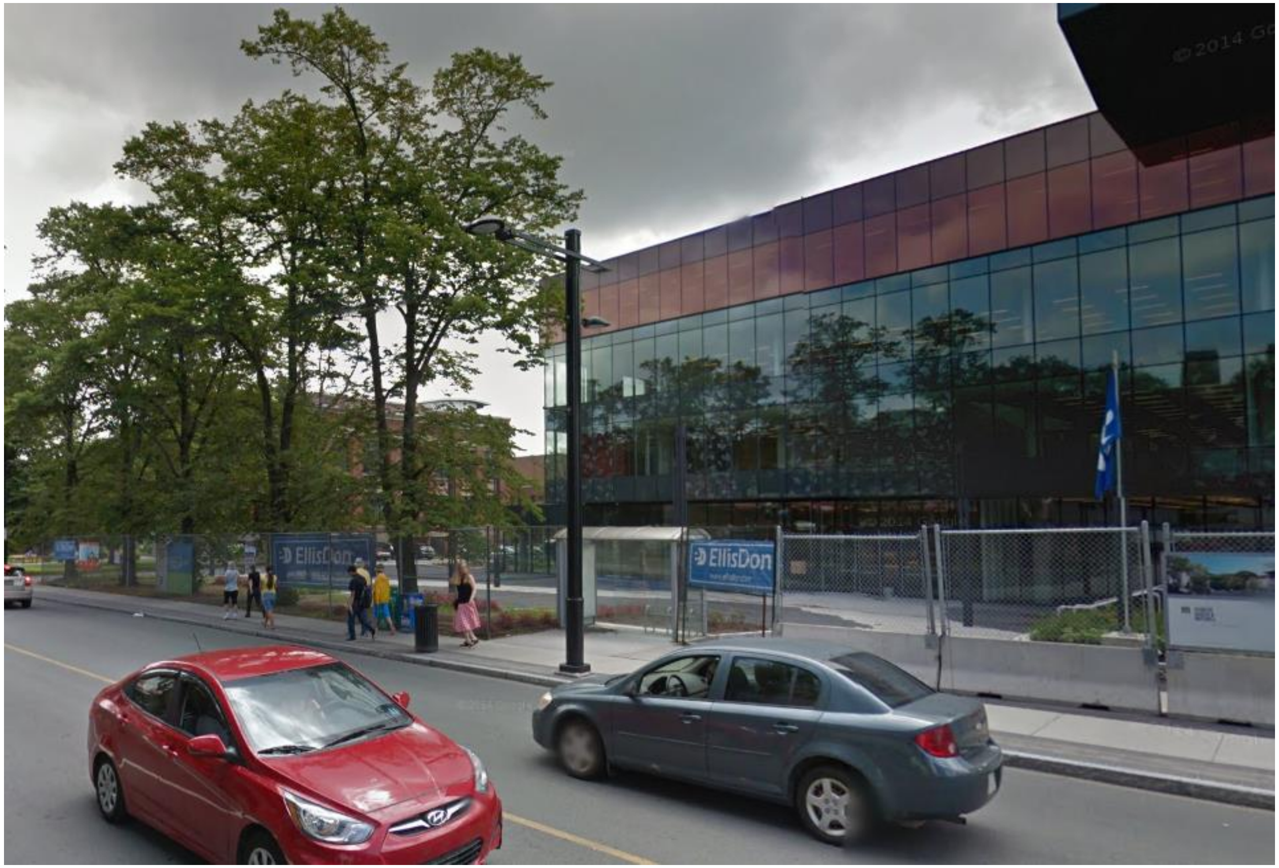
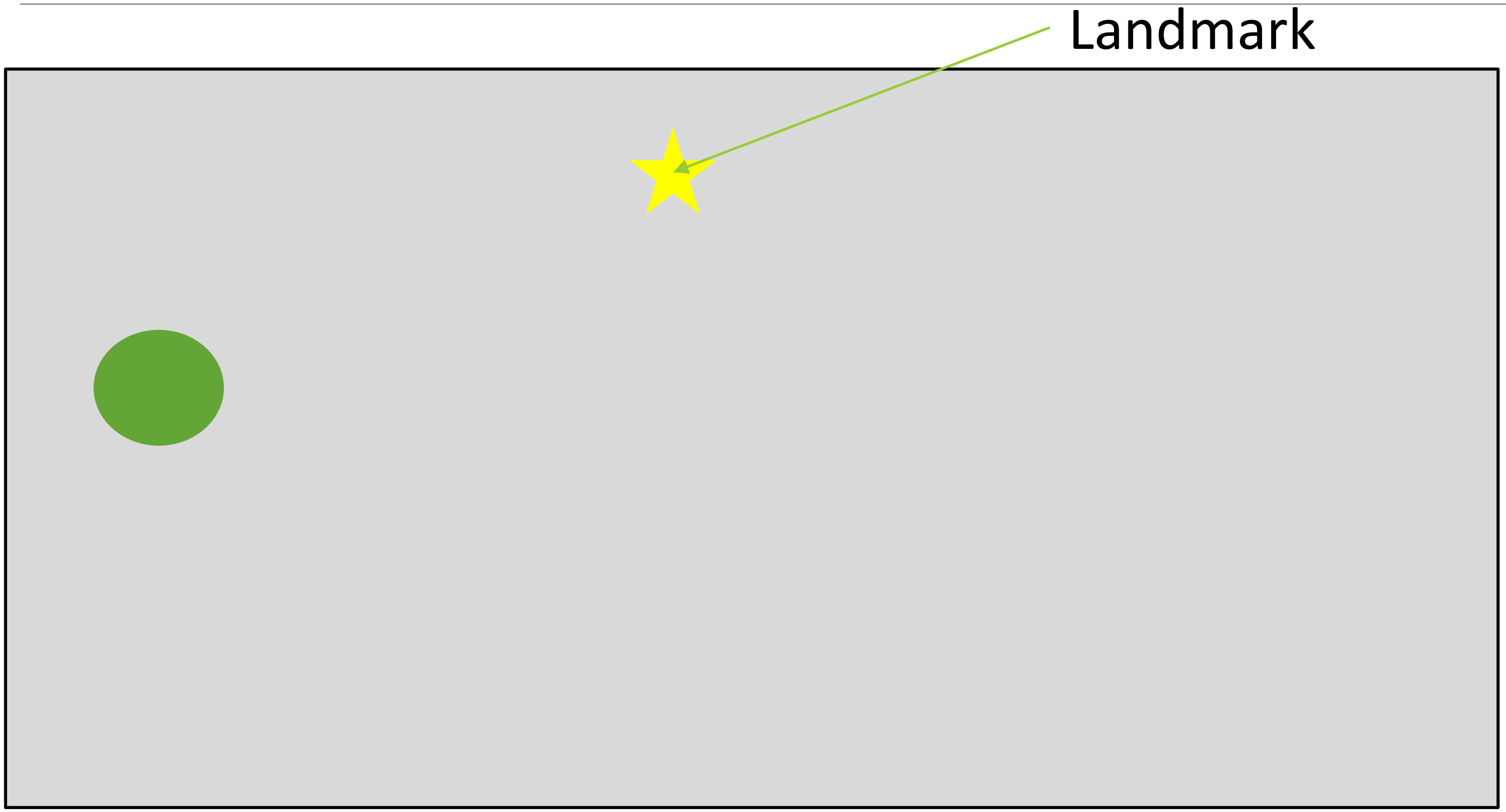
Tilt Compensation

Landmarks

Where are you?



Use Landmarks in your robot



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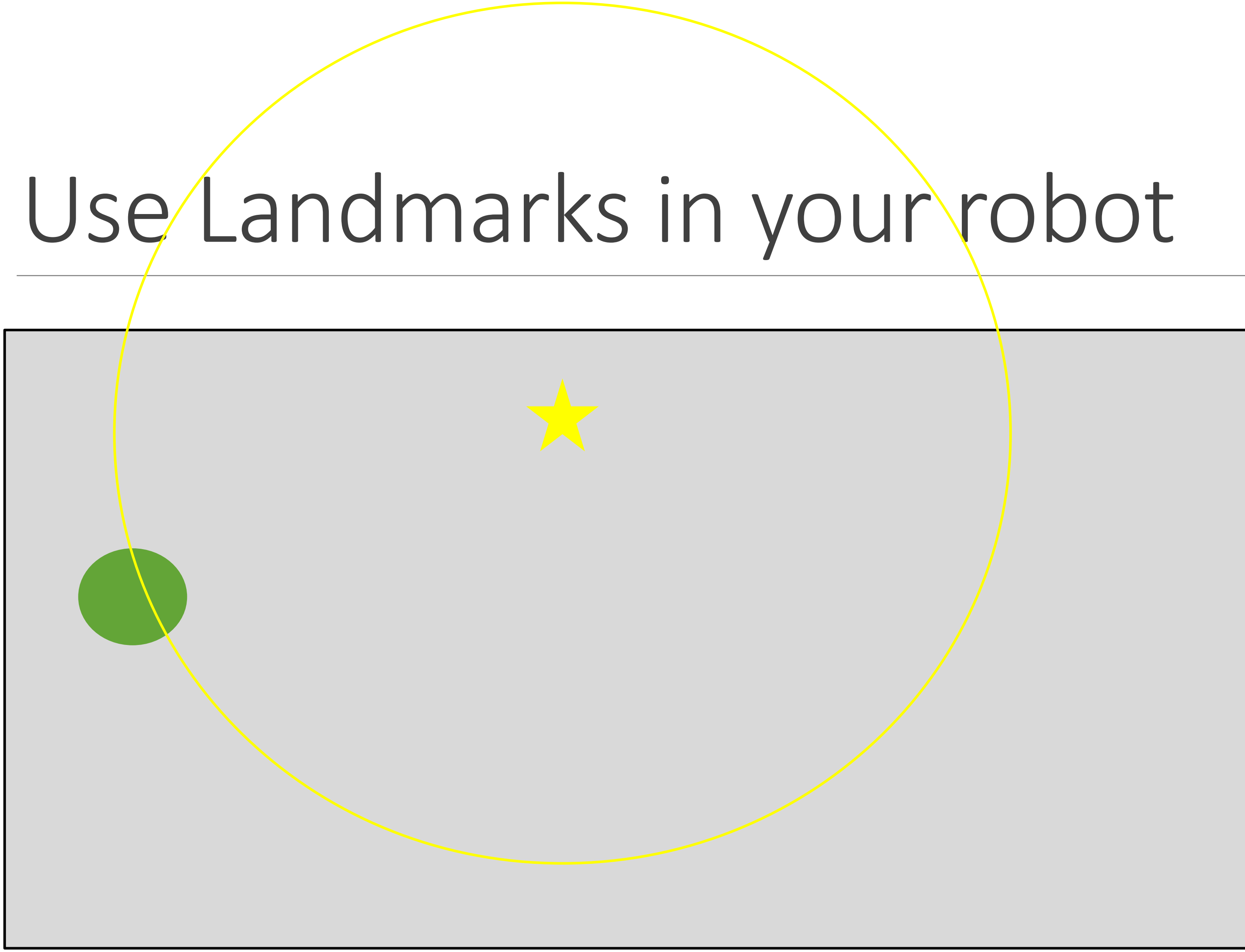

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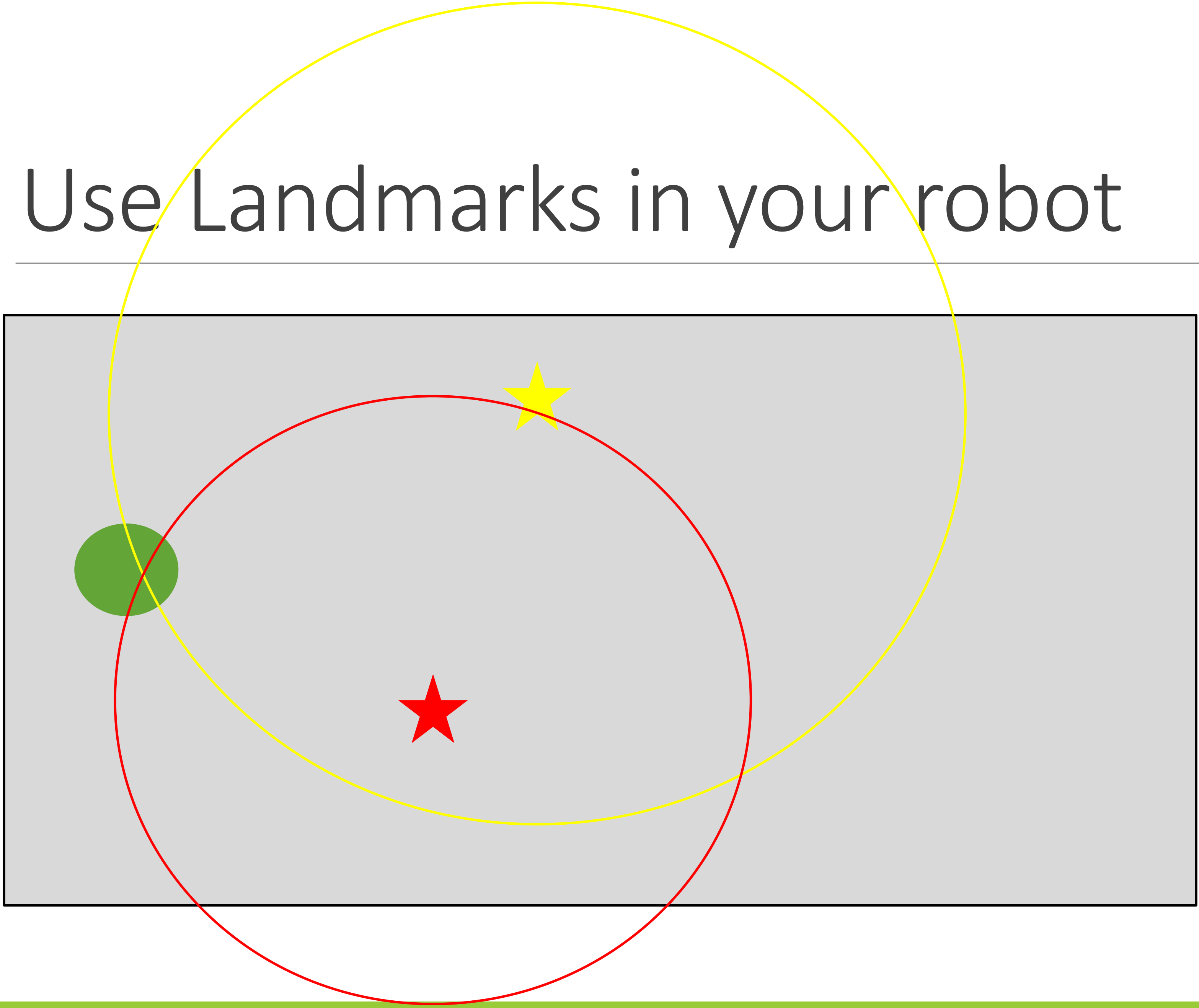

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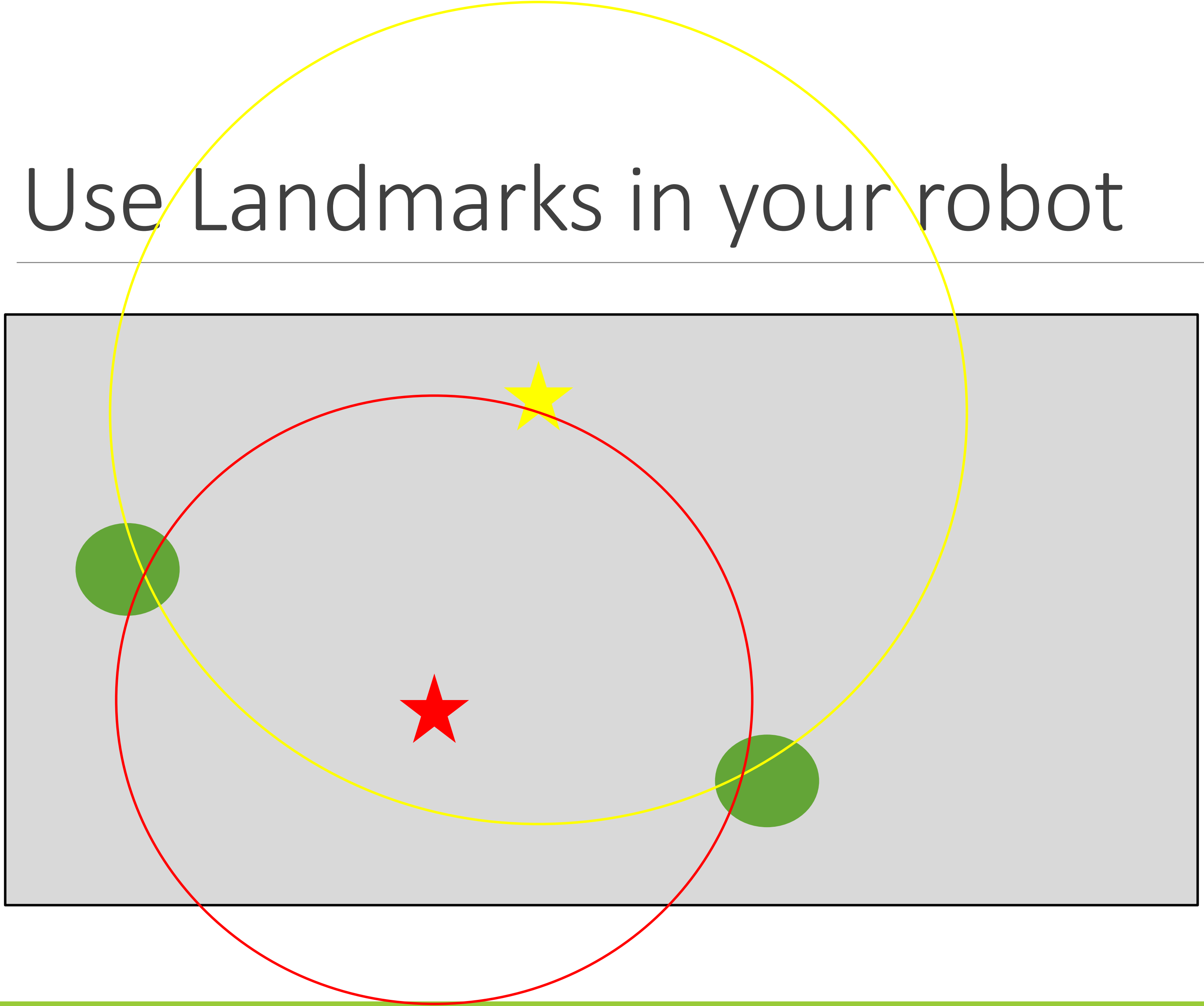
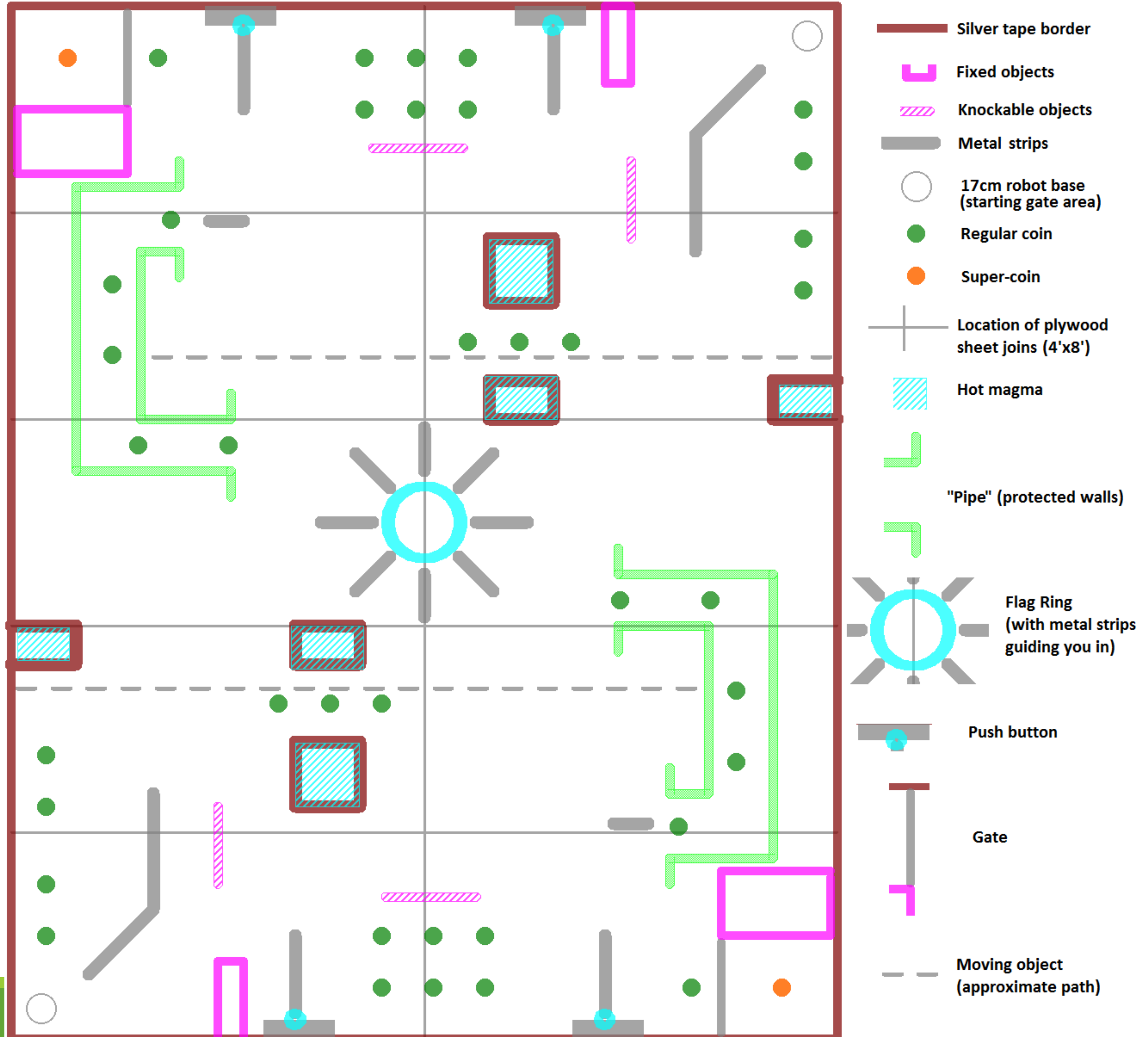



Silver tape border
Fixed objects
Knockable objects
Metal strips
17cm robot base
(starting gate area)
Regular coin
Super-coin
Location of plywood
sheet joins (4'x8')
Hot magma
"Pipe" (protected walls)
Flag Ring
(with metal strips
guiding you in)
Push button
Gate
Moving object
(approximate path)

Combining Measurements

Measurement Example on Car

GPS:

Inertial:

Speedometer:

Kalman Filtering

Has idea of *estimated state…* state being speed, position, etc.

Uses two steps:

1. A *prediction* step which predicts new state
2. A *measurement* step which uses noisy measurements

http://bilgin.esme.org/BitsBytes/KalmanFilterforDummies.aspx

http://blog.tkjelectronics.dk/2012/09/a-practical-approach-to-kalman-filter-and-how-to-implement-it/

Kalman Filtering

$$\overbrace{\hat{X}_k}^{\text{current estimation}} = \underbrace{K_k}_{\text{Kalman Gain}} . \overbrace{Z_k}^{\text{measured value}} + (1 - K_k) . \underbrace{\hat{X}_{k-1}}_{\text{previous estimation}}$$

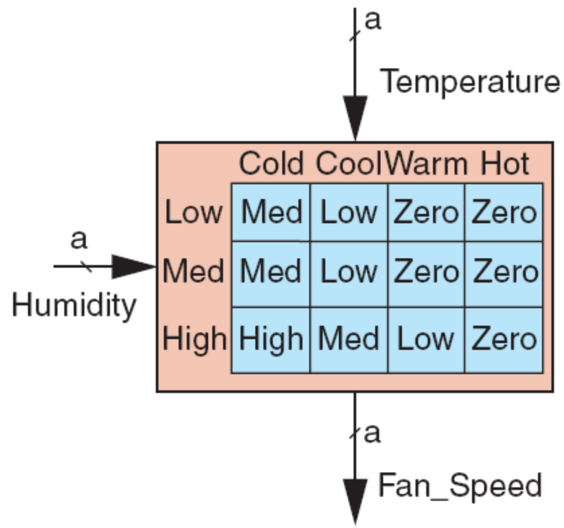
http://bilgin.esme.org/BitsBytes/KalmanFilterforDummies.aspx

http://blog.tkjelectronics.dk/2012/09/a-practical-approach-to-kalman-filter-and-how-to-implement-it/

Fuzzy Logic

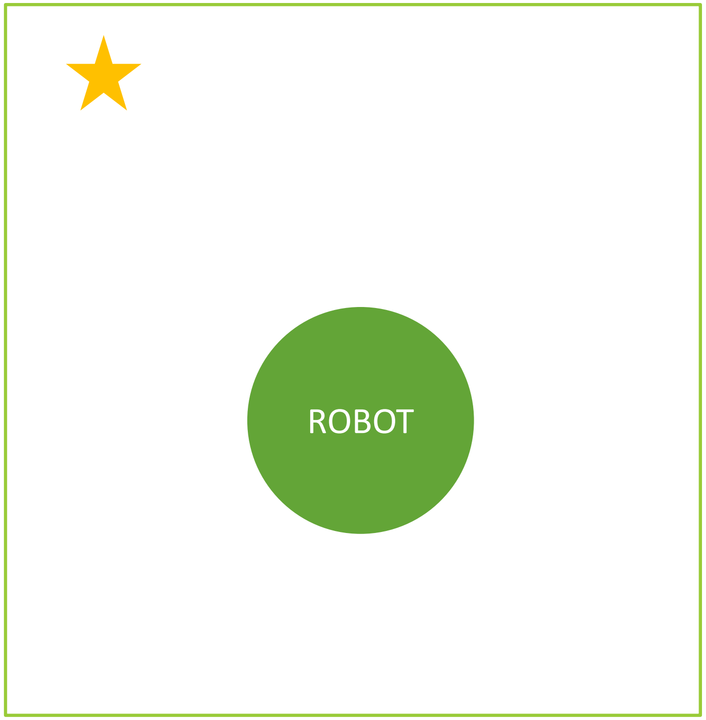
Not this type of fuzzy.

Fuzzy Controller



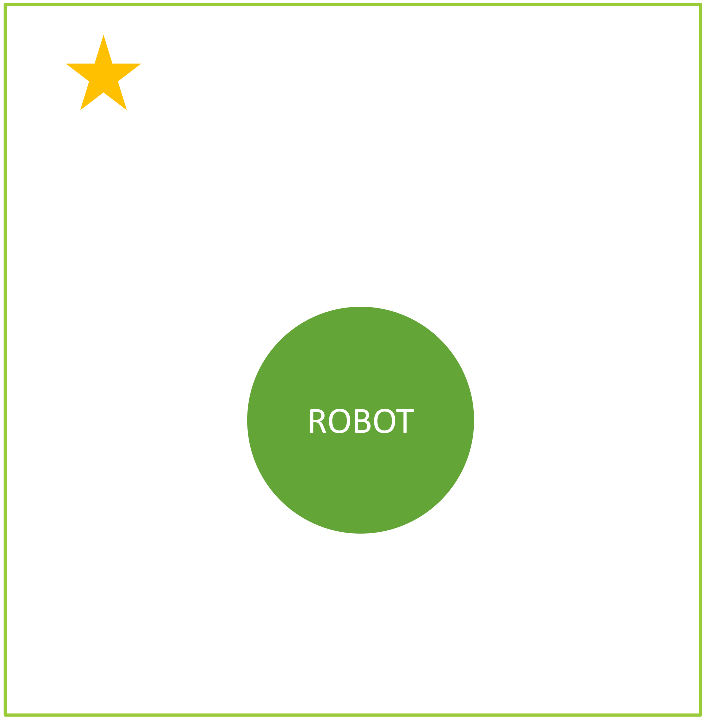
Simple Light-Seeking Robot

```
left = read_light(LEFT);
right = read_light(RIGHT);

if (left < right){
    motorR(ON);
    motorL(OFF);
}

if (right > left){
    motorL(OFF);
    motorR(ON);
}
```



A Quazi-Fuzzy Solution…

```
left = read_light(LEFT);
right = read_light(RIGHT);


motorL(right * ARB_CONST1);
motorR(left * ARB_CONST1);
```



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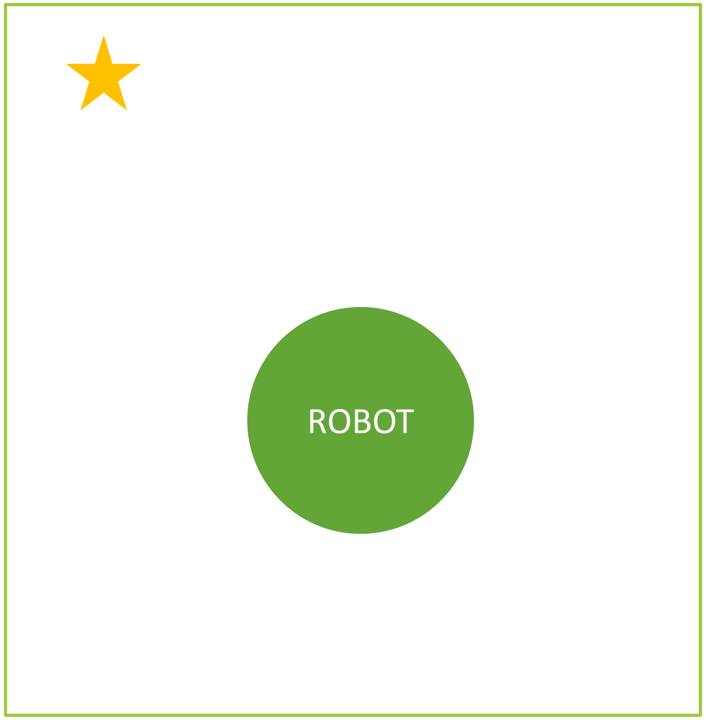


http://www.societyofrobots.com/programming_fuzzy_logic.shtml

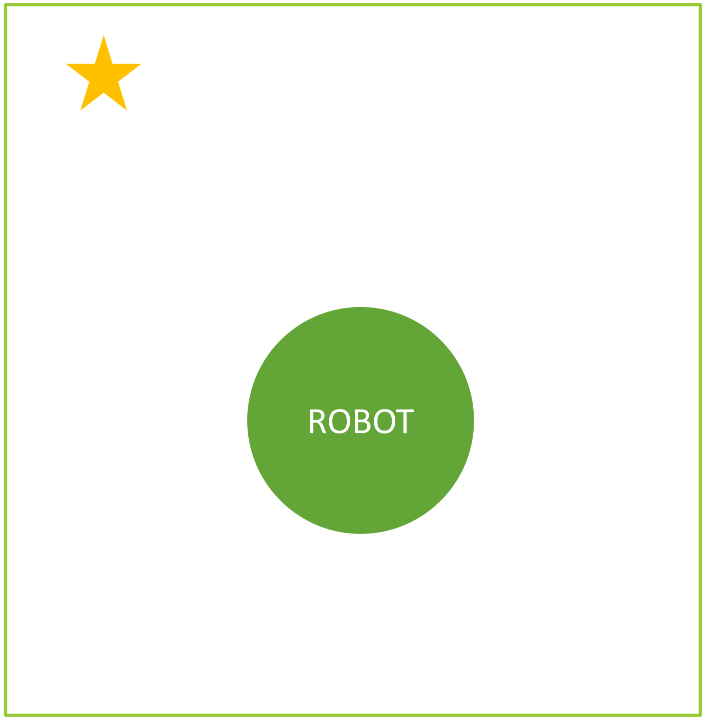
Adding a Touch Sensor

left = read_light(LEFT);

right = read_light(RIGHT);

motorL(left_bumper()*-100 + right * ARB_CONST1);

motorR(right_bumper()*-100 + left * ARB_CONST1);



http://www.societyofrobots.com/programming_fuzzy_logic.shtml

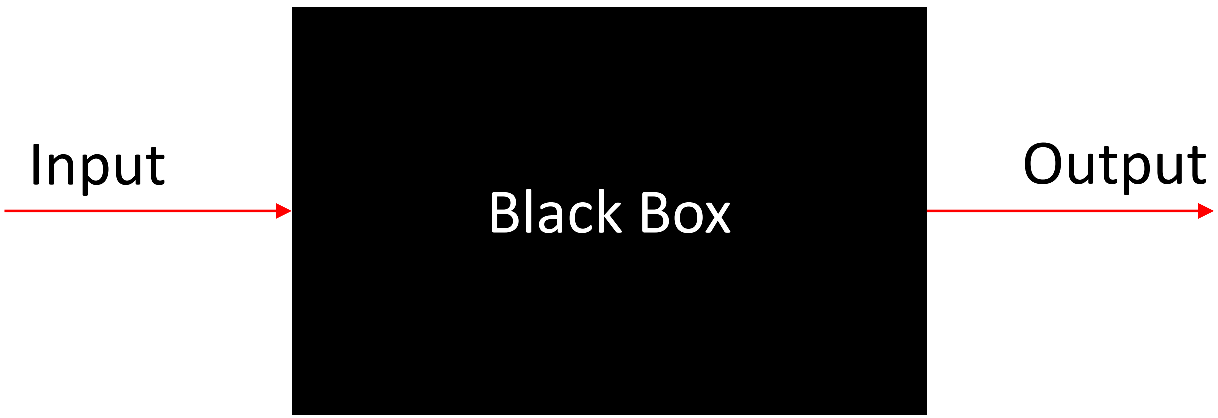
What is Fuzzy Logic?

NOTE: Previous example is *not* a good example classic fuzzy logic, and in fact could be argued is instead a form of analog computer…

Interested in playing around more with fuzzy sets? I'd suggest starting with using http://jfuzzylogic.sourceforge.net/html/index.html

Neural Networks

Pattern Recognition



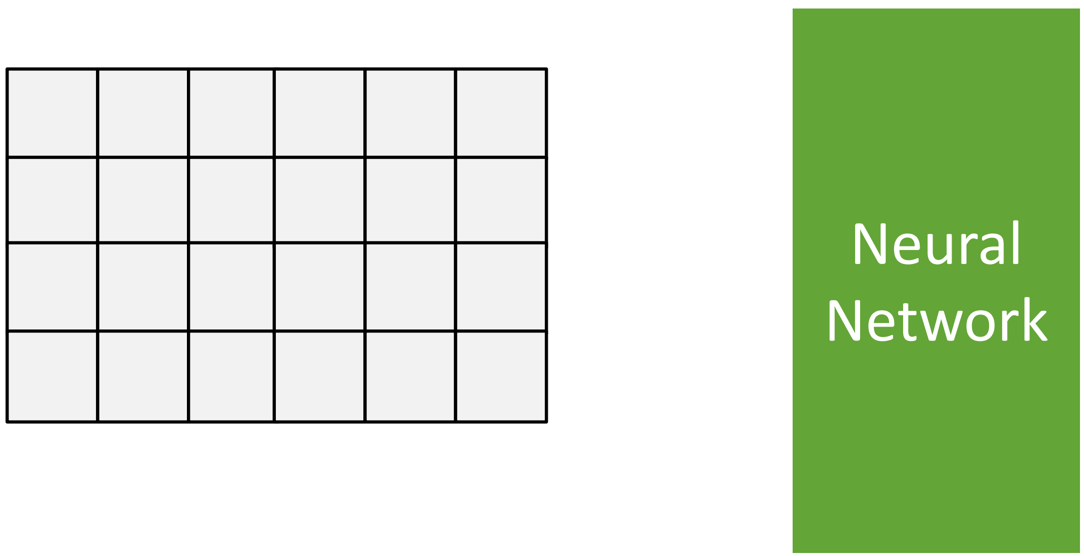
Potential Problems

1) They are *not* magic. You cannot use them for lottery number prediction for example.
   - Also difficult if not clear there *is* a pattern (i.e. stock number prediction)

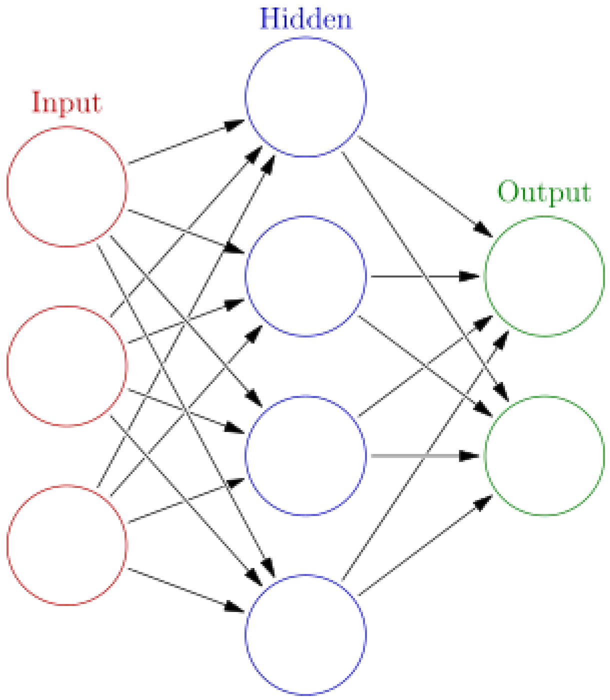
2) Requires diverse training set.
   - For problems which you already have a good model, they will probably perform *worse*.

3) May learn the *wrong* pattern if your training set has errors.

Using a Neural Network



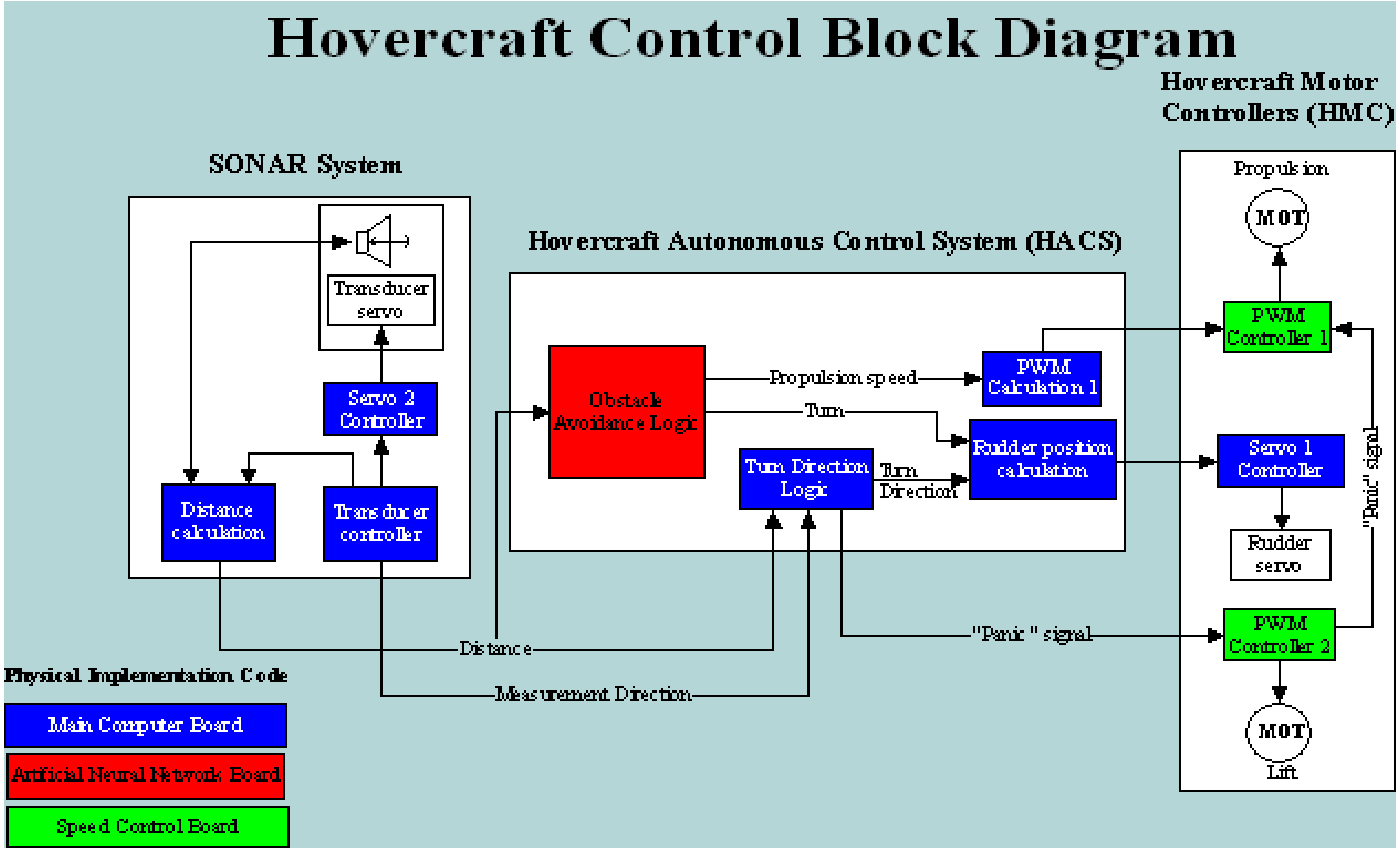
Network Functions



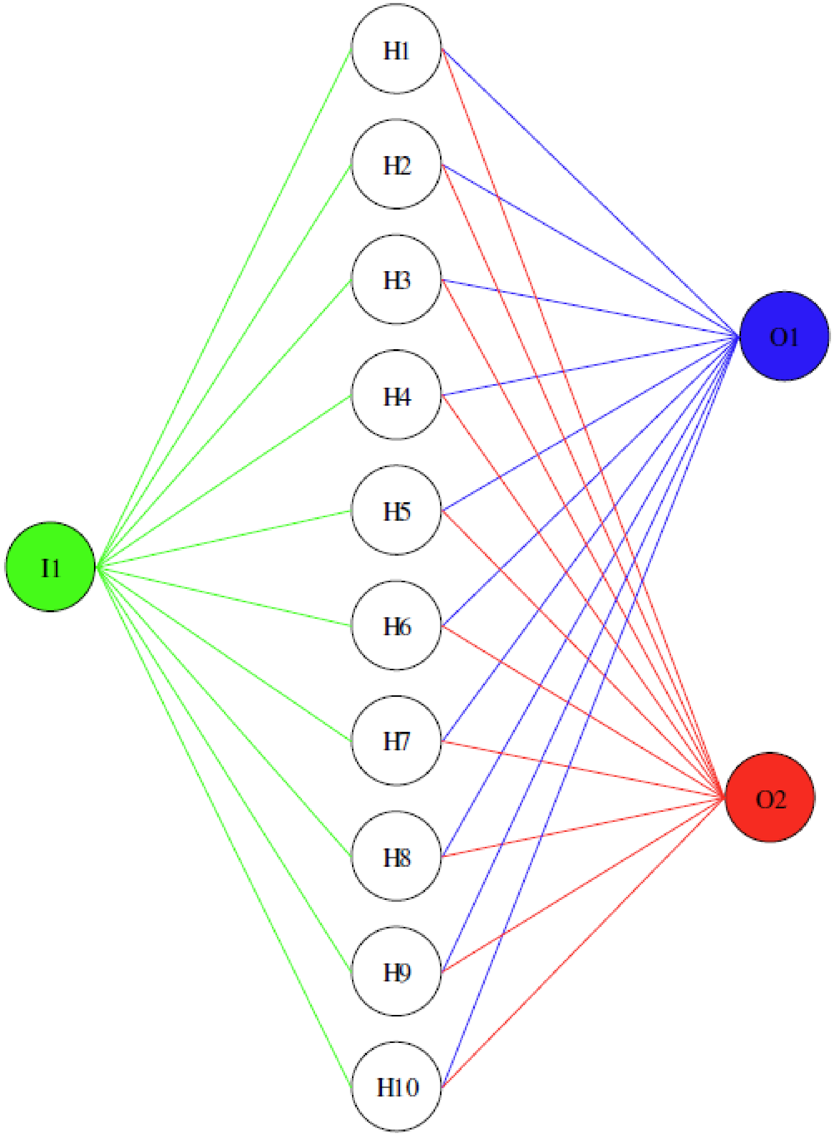
Neural Network Example

http://colinoflynn.com/oldsite/tiki-index.php?page=ProjectHovercraft

Simple Block Diagram



ANN Example

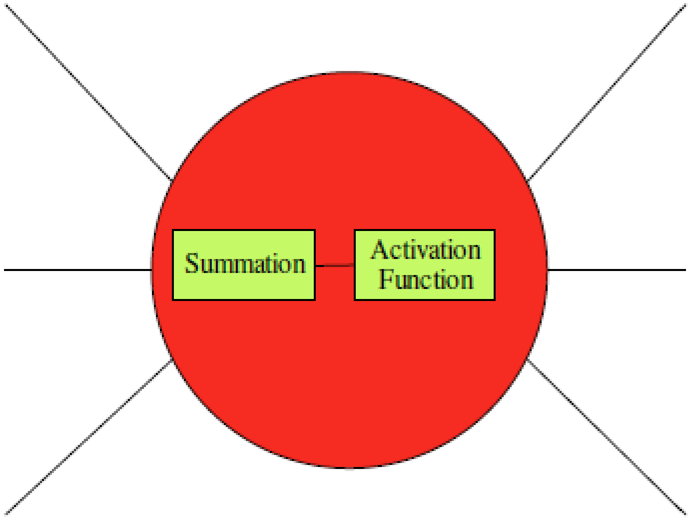


ANN Weights

Neuron	Neuron	Weight
I1	H1	-0.704894
I1	H2	-6.526604
I1	H3	0.568346
I1	H4	4.448008
I1	H5	2.076094
I1	H6	2.238839
I1	H7	2.374001
I1	H8	7.698660
I1	H9	2.429901
I1	H10	2.426541
H1	O1	2.511209
H1	O2	-2.440218
H2	O1	13.311865
H2	O2	13.178253
H3	O1	3.122861

Neuron	Neuron	Weight
H3	O2	-1.016410
H4	O1	1.125672
H4	O2	-2.862084
H5	O1	-3.051573
H5	O2	1.669890
H6	O1	-3.647110
H6	O2	3.076672
H7	O1	-2.520317
H7	O2	4.681576
H8	O1	3.402647
H8	O2	-11.532937
H9	O1	-2.229351
H9	O2	5.593643
H10	O1	-1.643753
H10	O2	5.045427

Neuron Structure

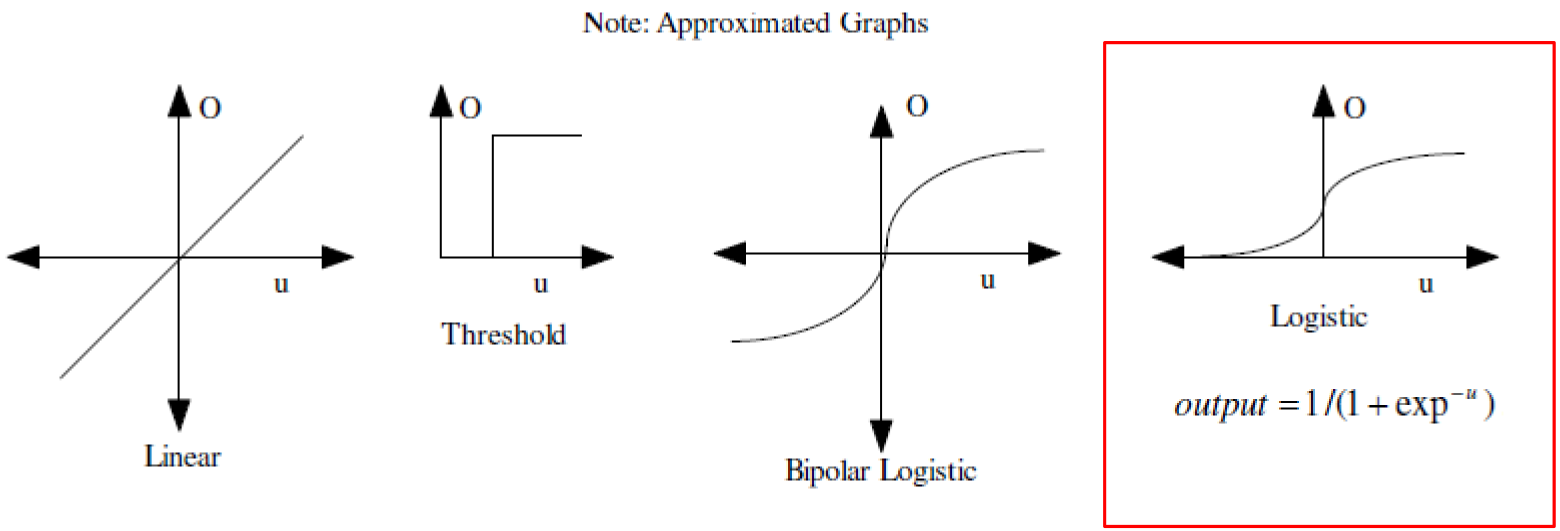


The inputs to the neuron are first passed through a summation function. The summation function is simply:

$$u = (o_1 \bullet w_1) + (o_2 \bullet w_2) + (o_n \bullet w_n)$$

Where O is the output from the connected neuron that is presented as the input to this neuron, and w is the weight of that connection. Once all the weights have been calculated, the output of that is passed into the activation function. The activation function is the key to the neural network, and there are several different types.

Activation Functions



Training Example

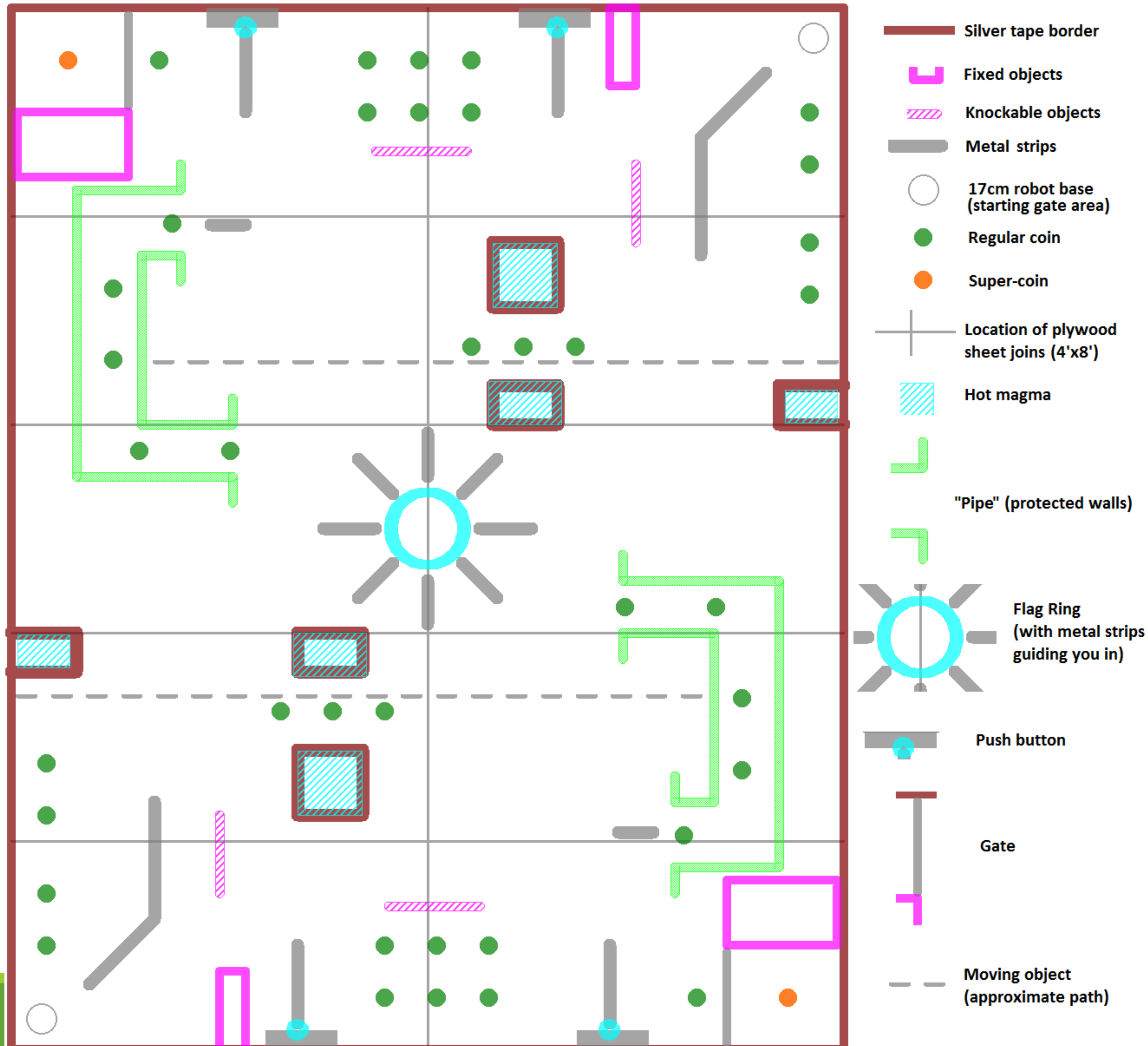
7 1 2
.1 1 1
.2 .8 .9
.3 .4 .7
.4 .2 .6
.5 .1 .6
.7 0.05 .8
1 0 .9

<distance> <speed> <turn>

Notes:

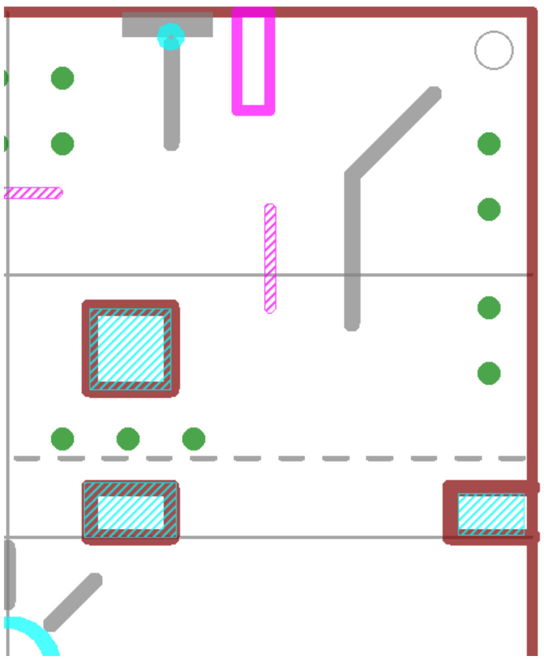
- Training algorithm adjusts weights such that expected response occurs for the known inputs
- This project just has turn as a magnitude – separate logic determines direction (left/right) to turn

Robot Navigational Techniques



Silver tape border
Fixed objects
Knockable objects
Metal strips
17cm robot base (starting gate area)
Regular coin
Super-coin
Location of plywood sheet joins (4'x8')
Hot magma
"Pipe" (protected walls)
Flag Ring (with metal strips guiding you in)
Push button
Gate
Moving object (approximate path)

Map Representation

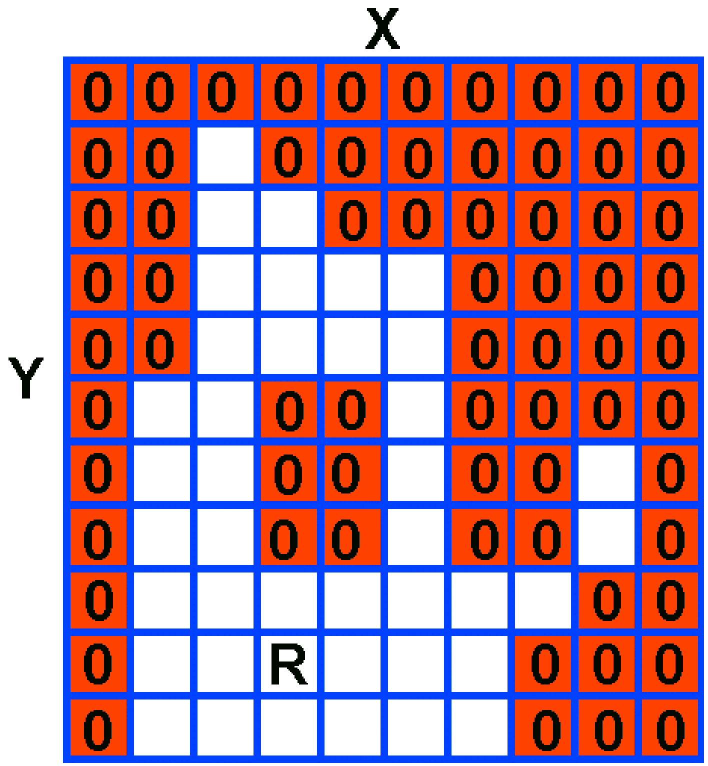


0	0	0	0	0	0	0	0	0	0	0	0	0
						0	0					0
						0	0					0
												0
												0
							0					0
			0	0	0		0					0
			0	0	0		0					0
			0	0	0							0
												0
												0
	0	0	0							0	0	0
	0	0	0							0	0	0
												0
												0
												0

```
uint8_t map[13][16] = {
{0,0,0,0,0,0,0,0,0,0,0,0,0},
{255,255,255,…,0,0,255,…,0},
{255,255,255,…,0,0,255,…,0},
{255,255,…,255,0},
        …
{255,255,…,255,0}};
```

`map[x][y]`

Example: Wavefront



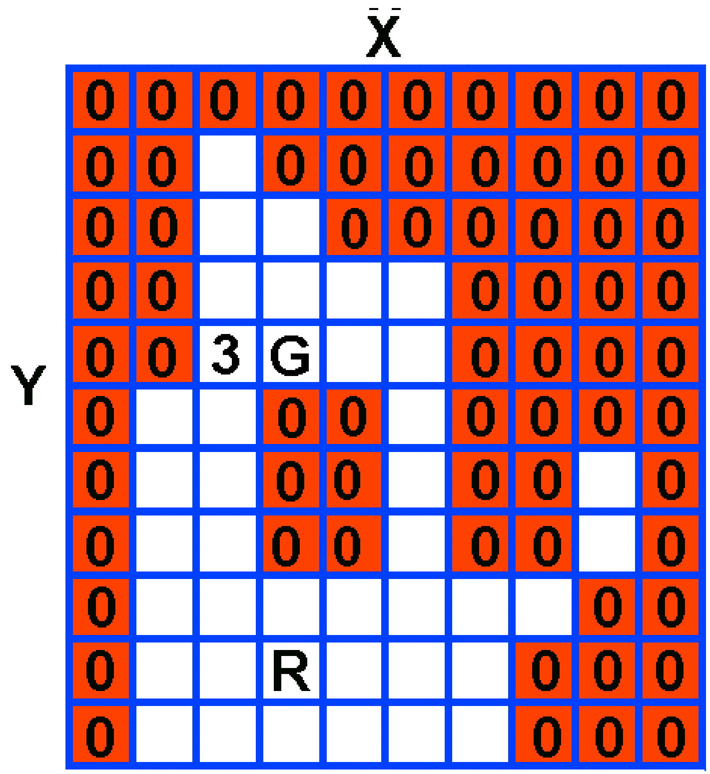
http://www.societyofrobots.com/programming_wavefront.shtml

Wavefront Code

Start at node x=0 y=0:

1. If boundry node is wall →Ignore, goto 5
2. If boundary node is robot location && has number → path found
3. If boundary node has a goal → Mark node with 3, goto 5
4. If boundary node is marked with number → mark node with number+1, goto 5
5. If no path found → node = y+1
6. If no path found after full scan of matrix → node = (x=0, y=0) but do not clear matrix
7. If no path found and matrix full → fail.

Example: Wavefront



http://www.societyofrobots.com/programming_wavefront.shtml

Example: Wavefront

X

	0	0	0	0	0	0	0	0	0	0
	0	0		0	0	0	0	0	0	0
	0	0			0	0	0	0	0	0
	0	0					0	0	0	0
	0	0	3	G			0	0	0	0
Y	0		4	0	0		0	0	0	0
	0		5	0	0		0	0		0
	0		6	0	0		0	0		0
	0		7						0	0
	0		8	R				0	0	0
	0		9					0	0	0

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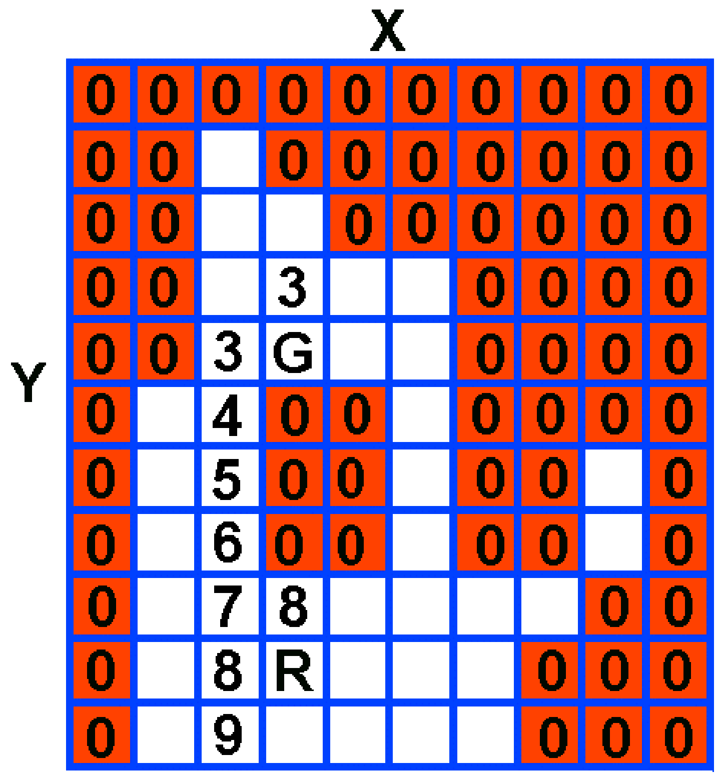
Example: Wavefront



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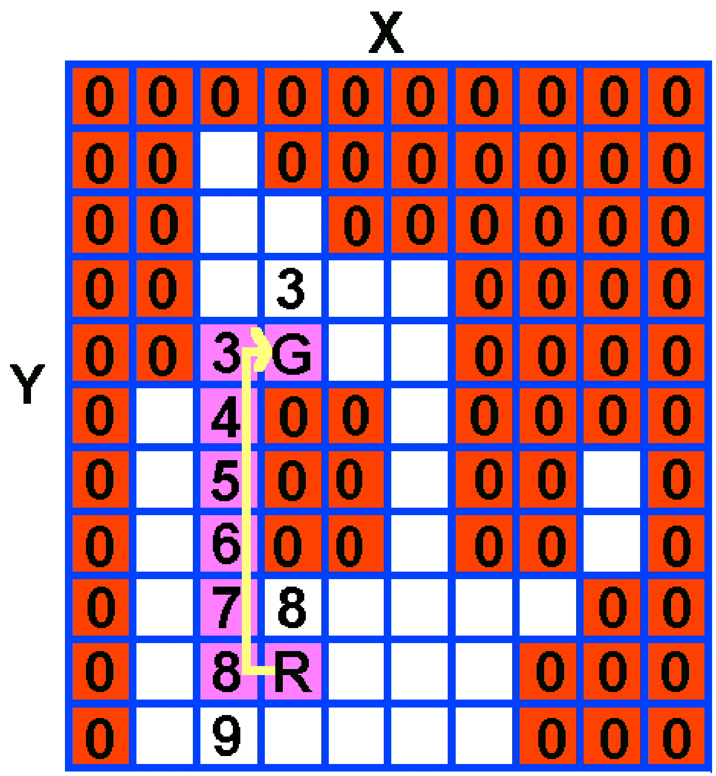

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Conclusions

- Many options for navigation
- Don’t get overloaded – lots of options and things to consider, but making the most robust solution is the best option!
- Use of magnetic compasses *might* be useful… needs experimentation on your surface.
- Use of accelerometers might give you bump detection.