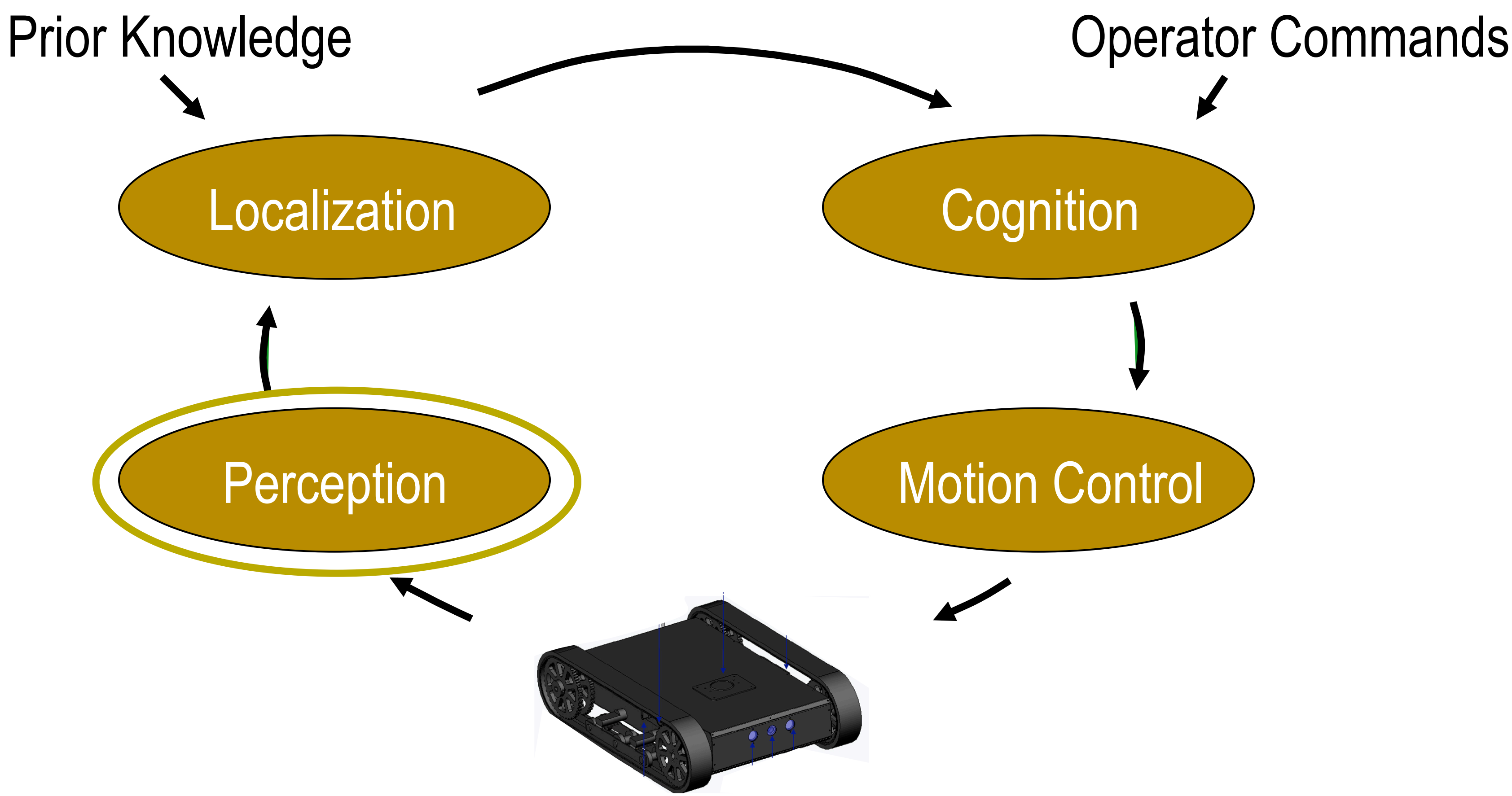
E190Q – Lecture 7
Autonomous Robot Navigation

Instructor: Chris Clark

Semester: Spring 2014

Figures courtesy of Siegwart & Nourbakhsh

Control Structures
Planning Based Control

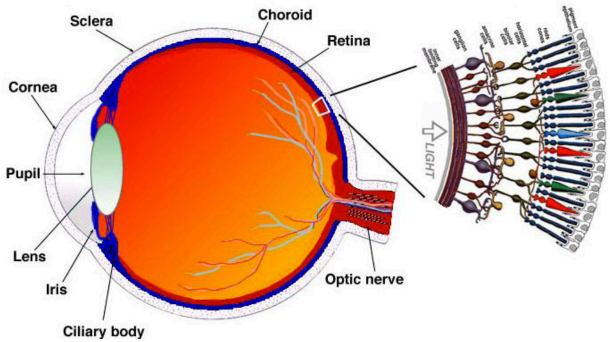


Outline – Vision Systems

1. Introduction
2. Features
3. Stereo Vision
4. Optical Flow
5. Color Tracking

Introduction to Vision Systems

- Vision is our most powerful sense. It provides us with an enormous amount of information about the environment without direct contact.
  - Millions photoreceptors
  - Sample rate of 3 Gbytes/s
  - 60 Billion neurons used to process an image

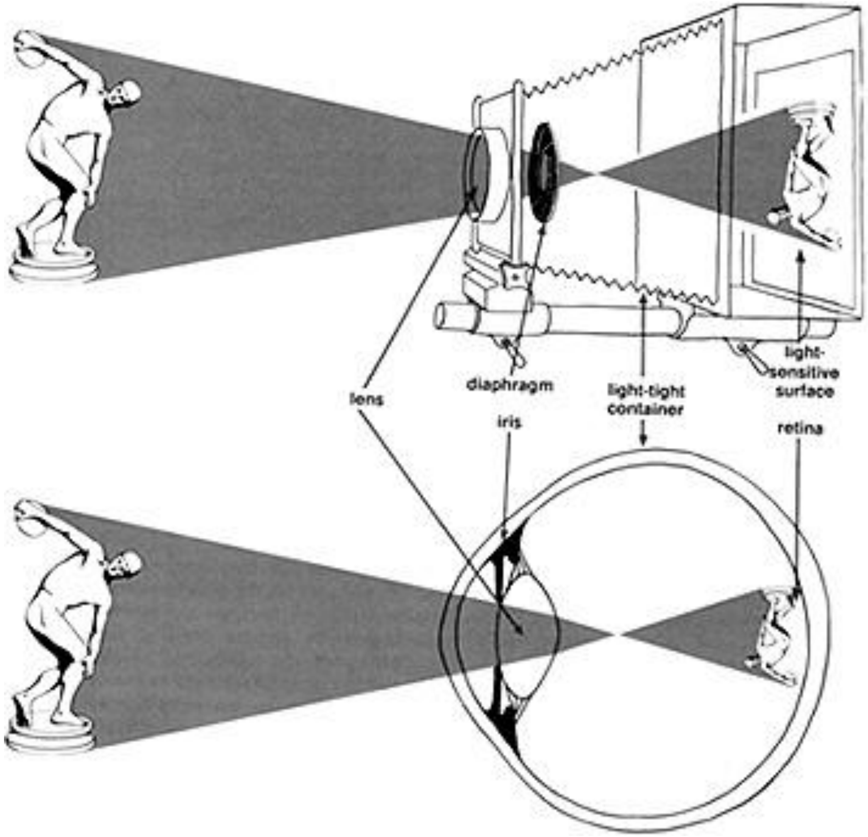


Introduction to Vision Systems

- Our visual system is very sophisticated
  - Humans can interpret images successfully under a wide range of conditions – even in the presence of very limited cues

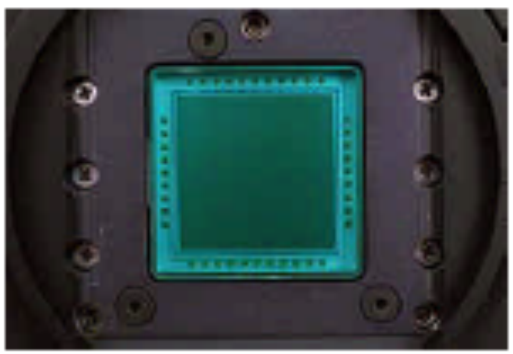
Introduction to Vision Systems

- Not sensible to copy the biology, but learn from it
  - Capture light
  - Convert to digital image
  - Process to get ”salient" information



Introduction to Vision Systems

- There exist a large number of cameras capable of getting these images…



2048 x 2048 CCD array

Orangemicro iBOT Firewire

Sony DFW-X700

Cannon IXUS 300

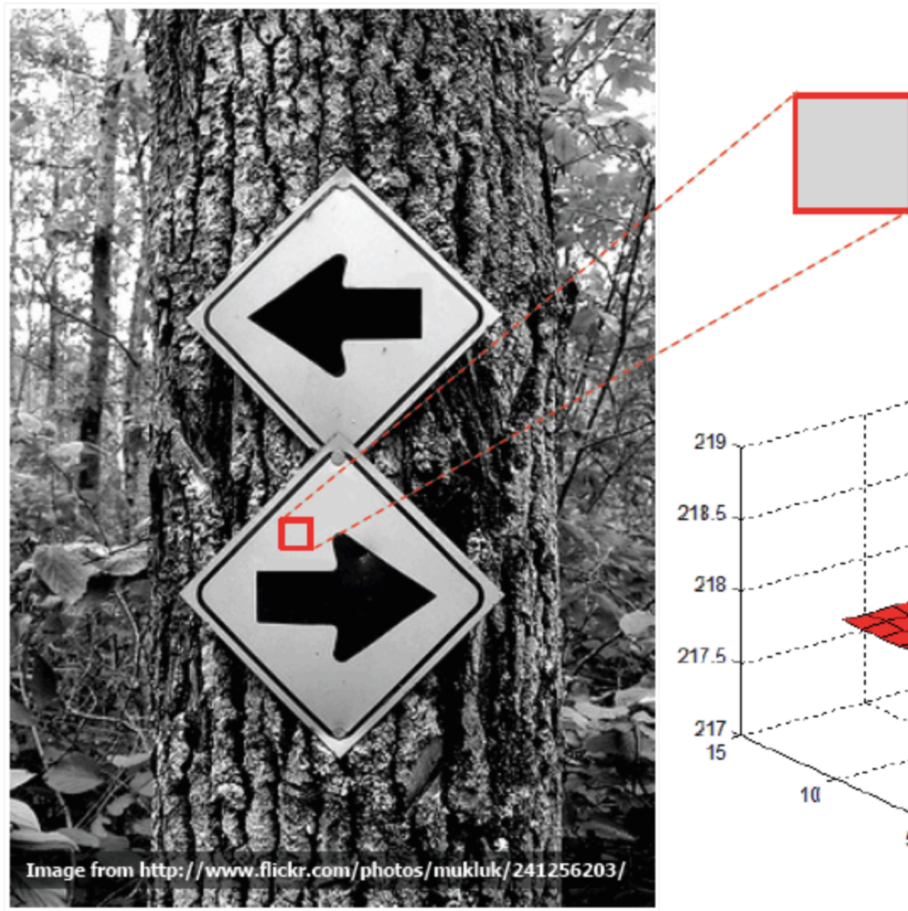
Outline – Vision Systems

1. Introduction
2. Filtering
3. Stereo Vision
4. Optical Flow
5. Color Tracking

Filtering

- The image is represented as an array of intensity values.
- What useful information can we extract from these intensities?

Filtering



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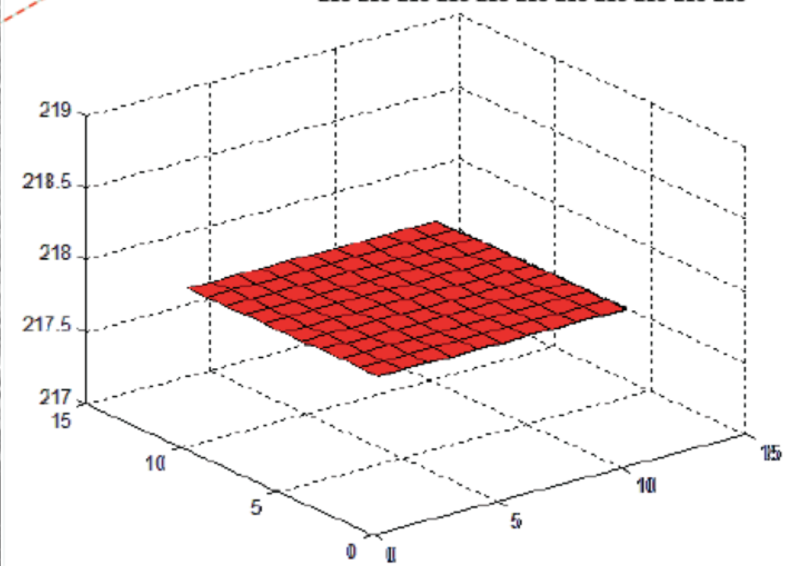
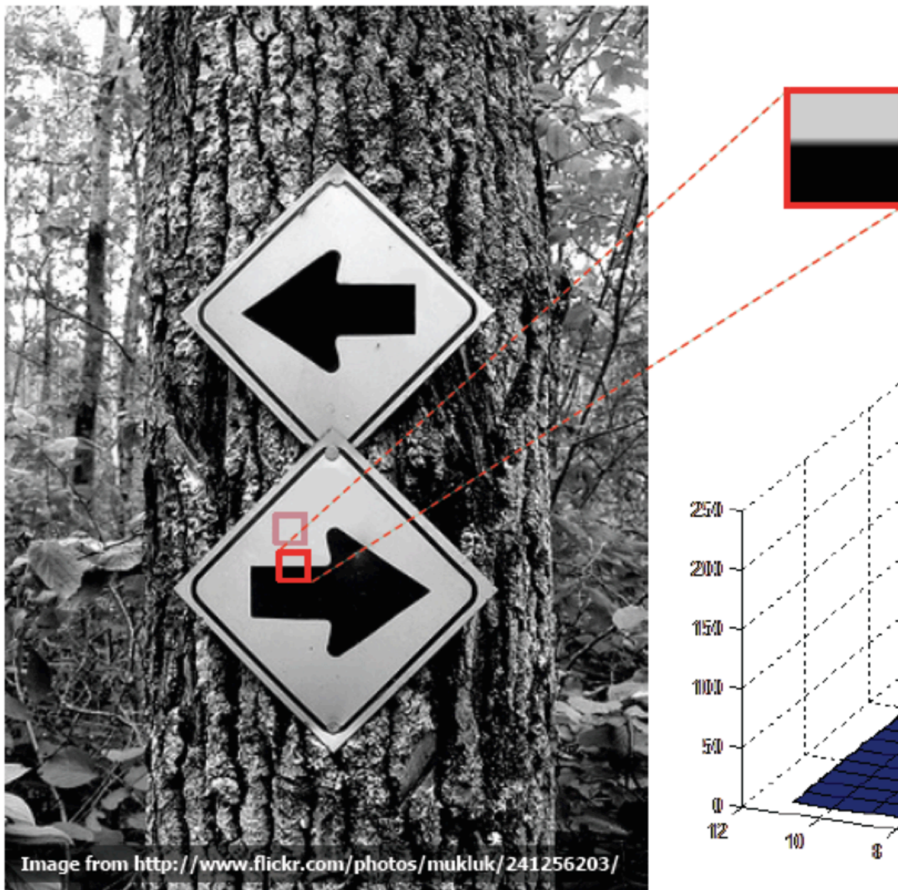


Filtering



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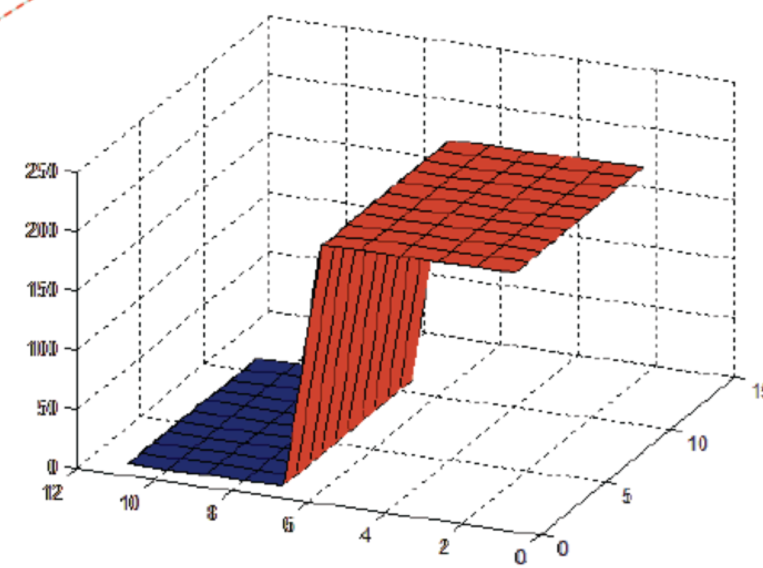

Filtering

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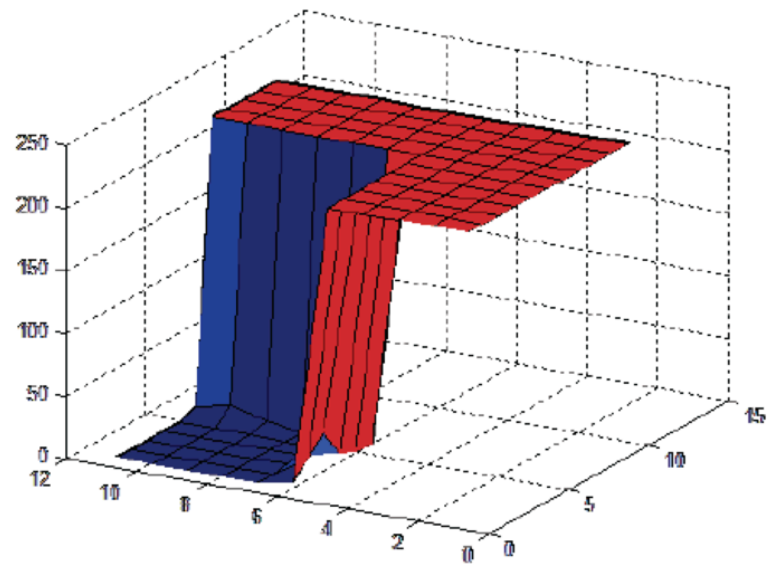


Filtering

- In other courses, we construct **frequency filters** based on frequency, e.g. lowpass/highpass filters
- In Image processing, we construct **spatial filters**

Filtering

Lowpass filtered image

Highpass filtered image

Filtering

- Spatial Filters
  - Given an Intensity Image $I(x,y)$
  - Let $S_{x,y}$ be the neighborhood of pixels around the pixel at (x,y)
  - We can create a filtered image $J=F(I(x,y))$
    - Each pixel (x,y) in J is calculated based on a function of S_{xy}

Filtering

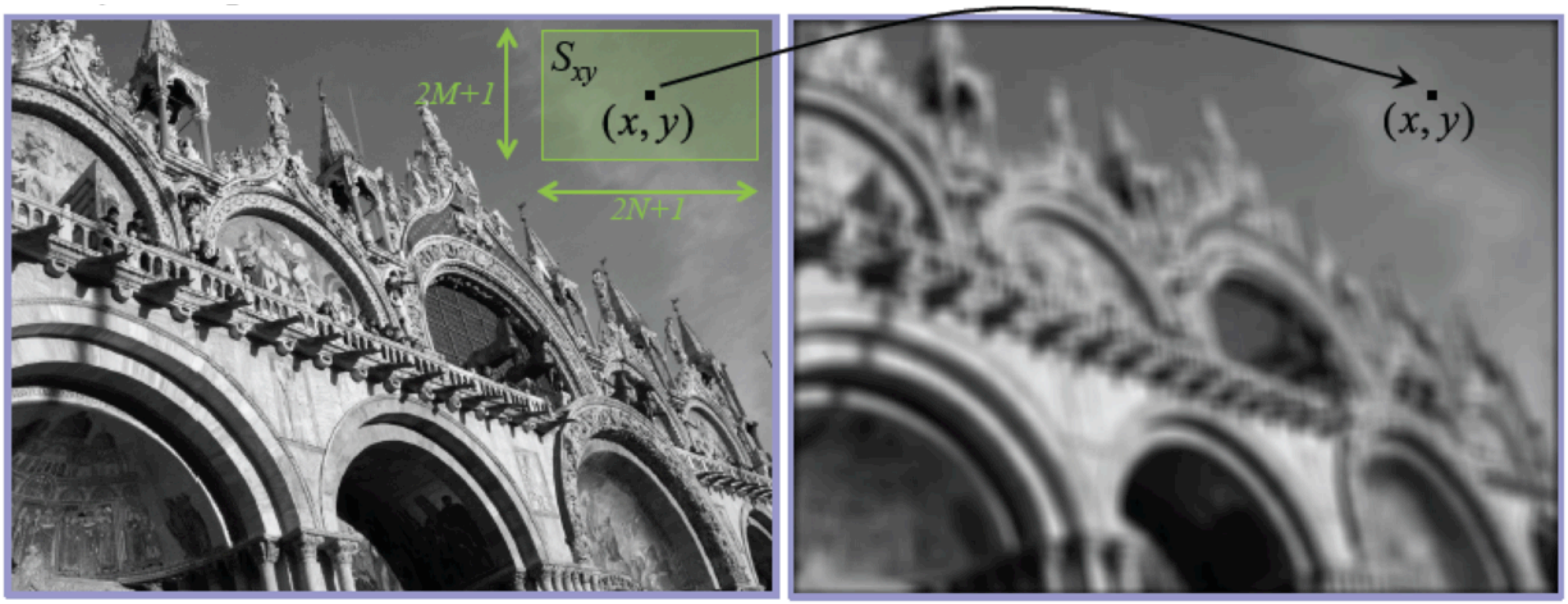
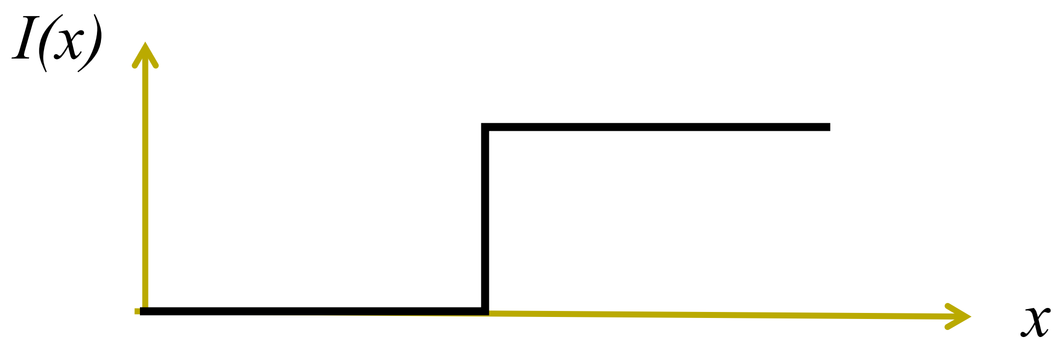


Image I Filtered Image $J = F(I)$

$$J(x,y) = \frac{\sum_{(r,c)\in S_{xy}} I(r,c)}{(2M+1)(2N+1)}$$

Filtering

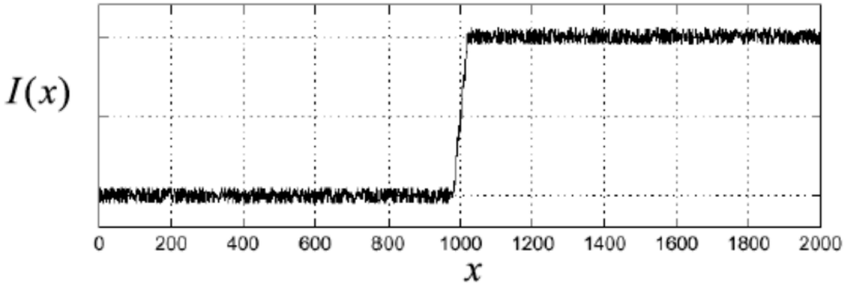
- Edge Detection
  - Edge = intensity discontinuity in one direction



  - First order derivative in 1D should be large
  - 2nd order derivative can also be used…

Filtering

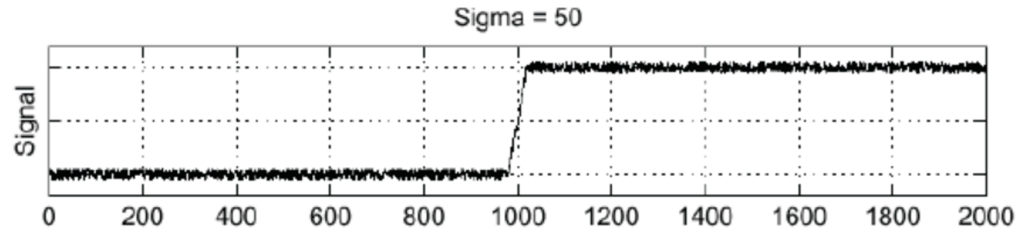
- Edge Detection
  - Actual image intensity might look more like this



Filtering

- Edge Detection

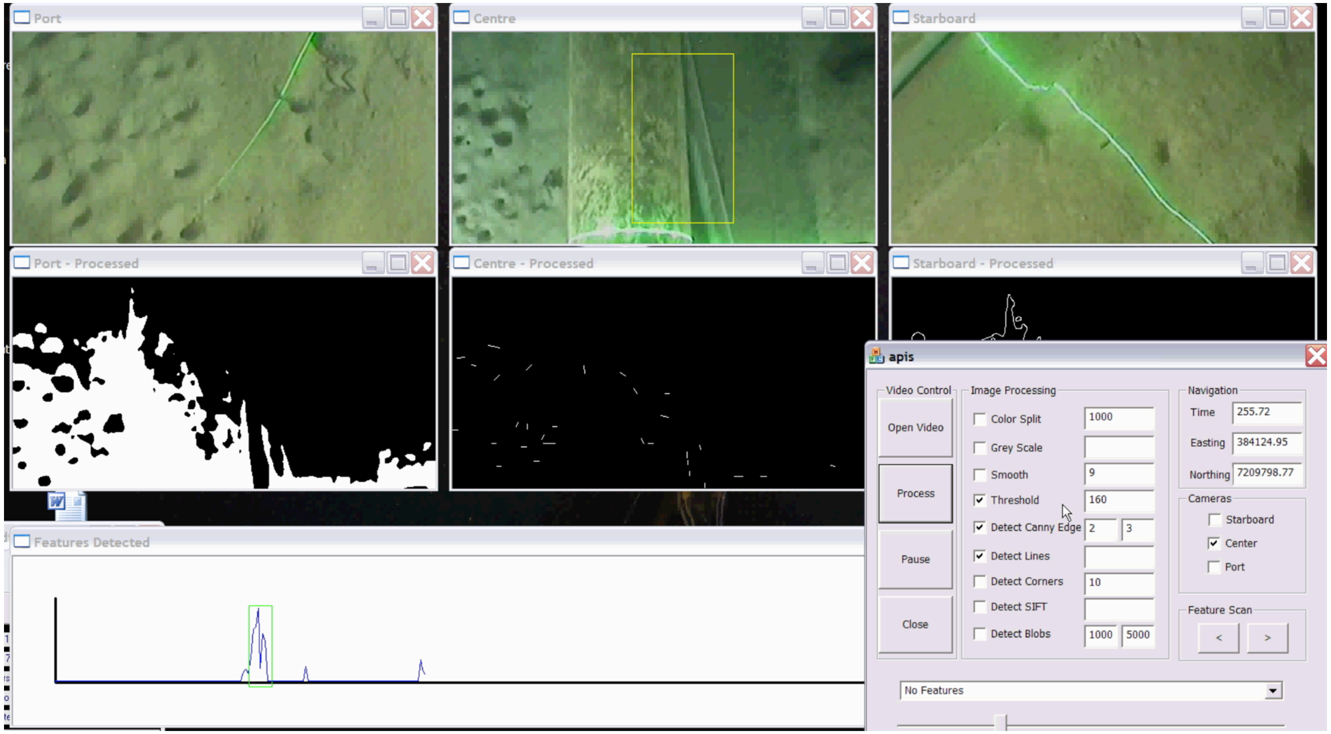
$I(x)$



Peak indicates Edge

Filtering

- Pipe Tracking Example



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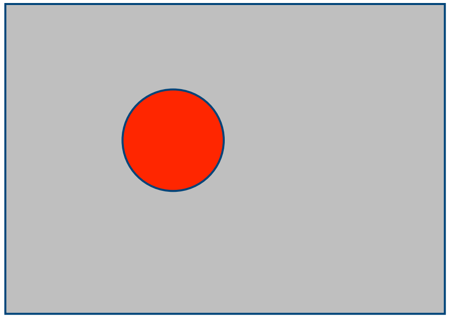
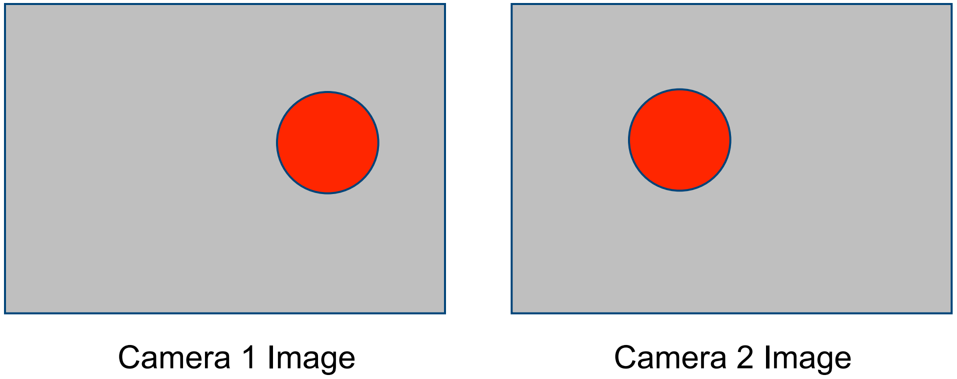
Sensors:
Vision Systems

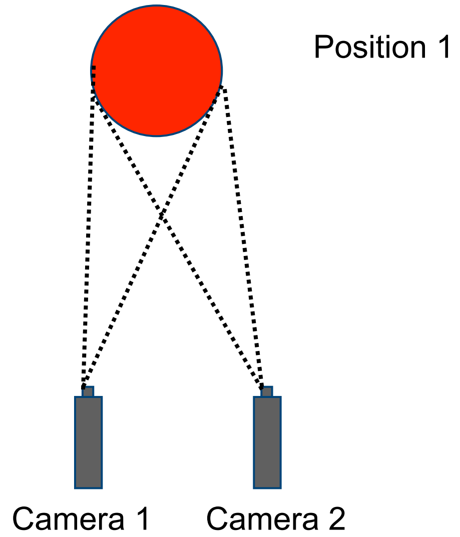
- Monocular Vision:
  - Problem with monocular vision is that you can't tell how far something is from the robot. No Range information!
  - Consider the following image of a red ball:



Sensors: Vision Systems

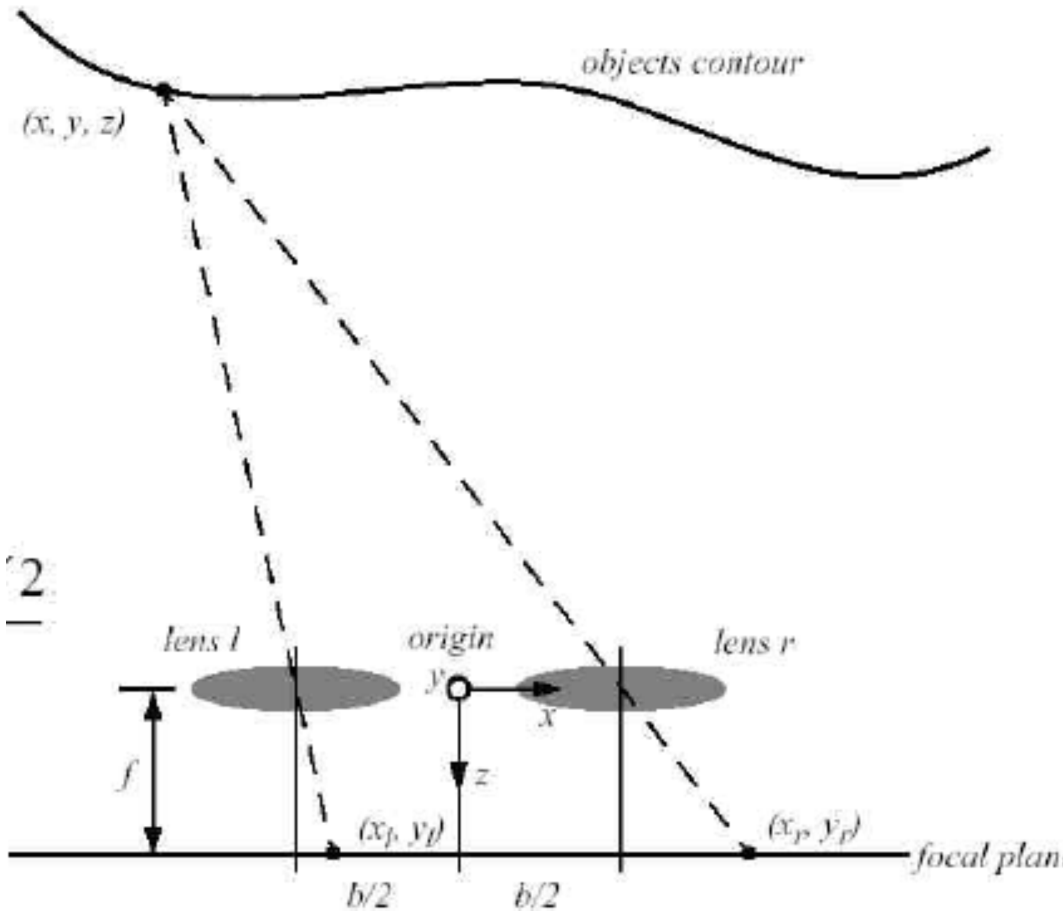
- Stereo Vision:
  - Using two cameras provides enough information to give us the range to the ball
  - The intersection of the two cones must be where the ball lies.





Sensors: Stereo Vision Systems

- Consider idealized camera geometry
- Compare projection of a target on 2 image planes.



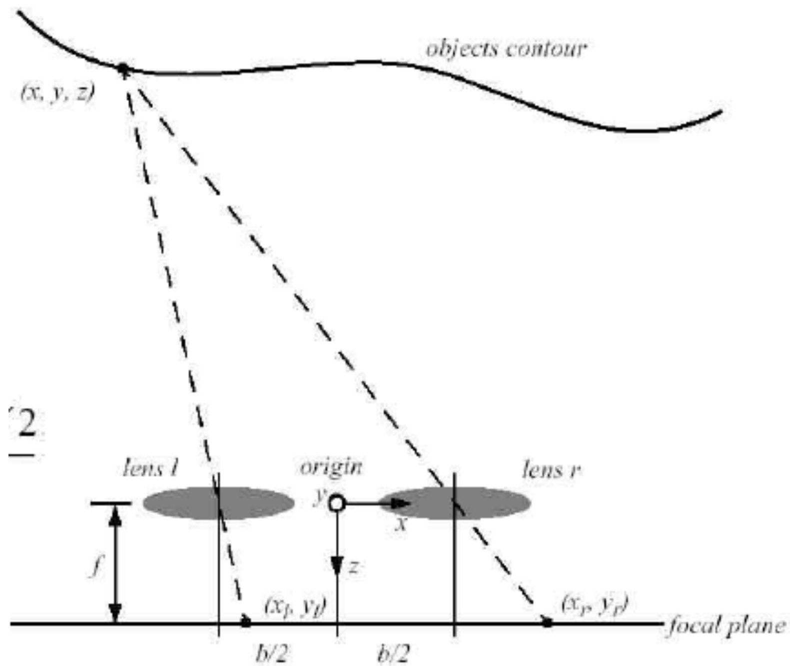
Sensors: Stereo Vision Systems

$$\frac{x_l}{f} = \frac{x + b/2}{z} \text{ and } \frac{x_r}{f} = \frac{x - b/2}{z}$$

$$\frac{x_l - x_r}{f} = \frac{b}{z}$$

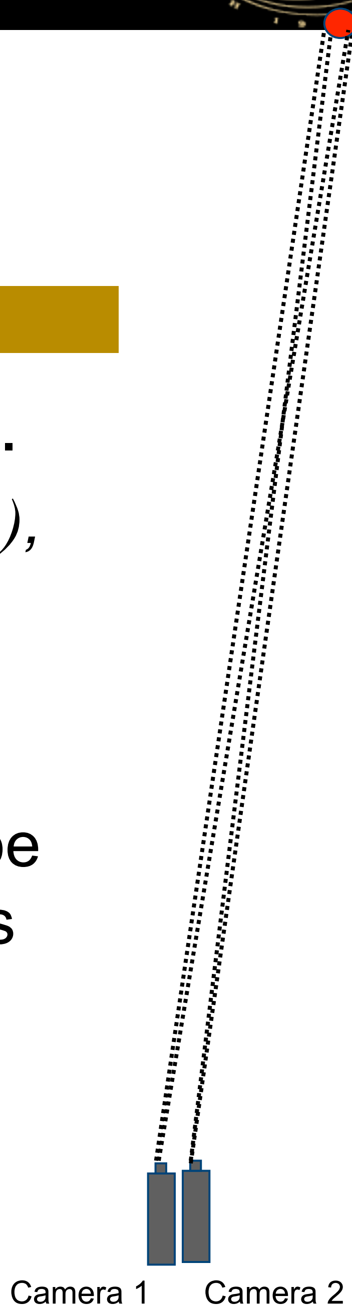
$$x = b\frac{(x_l + x_r)/2}{x_l - x_r} \; ; \; y = b\frac{(y_l + y_r)/2}{x_l - x_r}$$

$$z = b\frac{f}{x_l - x_r}$$



Sensors: Stereo Vision Systems

- There is poor accuracy on far objects.
  - Farther objects have less disparity $(x_l - x_r)$, making it difficult to get accurate depth measurements.
  - This is similar to having cameras colocated so that the object appears to be at the same position in both images. This ends up working like monocular vision



Sensors: Stereo Vision Systems

- Can we tell the difference between something *100* meters away and *101* meters away given our $f = 0.1m$ and $b = 0.5m$?
  - The disparity for $z = 100$ is $(0.1)(0.5)/100 = 0.0005$
  - The disparity for $z = 101$ is $(0.1)(0.5)/101 = 0.000495$
- How about the difference between something 10 meters away and 11 meters away?
  - The disparity for $z = 10$ is $(0.1)(0.5)/10 = 0.005$
  - The disparity for $z = 11$ is $(0.1)(0.5)/11 = 0.0045$
- We can see there is greater difference between the disparities when the object is close, so…
- Easier to get accurate range when the object is closer!

Sensors: Stereo Vision Systems

- Disparity is proportional to b

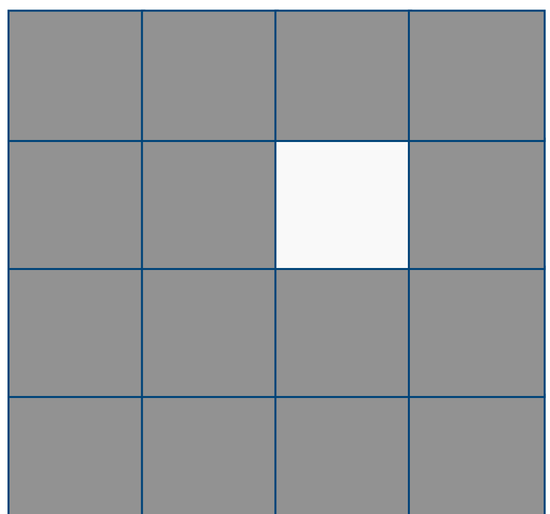
$$\frac{x_l - x_r}{f} = \frac{b}{z}$$

Sensors:
Stereo Vision Systems

- We don’t always have red balls on gray backgrounds…
  - “Zero crossing of Laplacian of Gaussian (ZLoG) is widely used method of identifying feature from 2 images

Sensors: Stereo Vision Systems

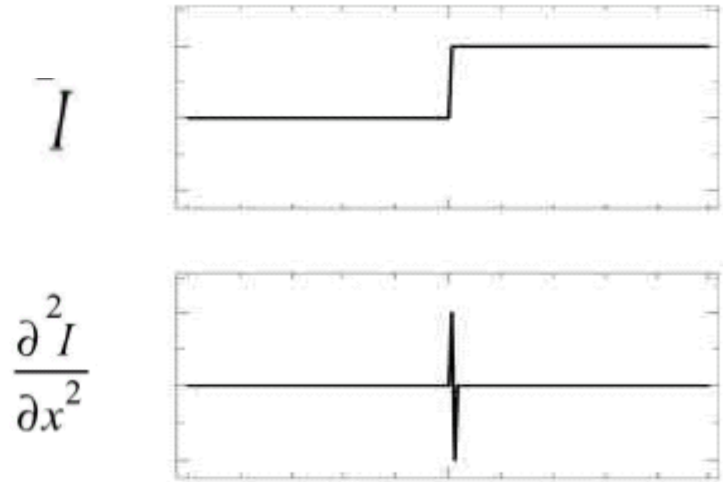
- Consider the 4x4 image:
  - $I(i,j) = \begin{cases} 0.8 & \text{if } i=3,\ j=3 \\ 0.1 & \text{else} \end{cases}$
  - Let's see how we can identify the bright spot



Sensors:
Stereo Vision Systems

- ZLOG method finds features with high intensity contrast as measured by Laplacian.

$$L(x,y) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}$$



- The zero-crossing indicates a feature!

Sensors: Stereo Vision Systems

- To implement the Laplacian, an approximate function is used.
  - The convolution with *P*:

$$L = P \otimes I$$

$$P = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

  - That is, each pixel of L is made by summing over adjacent pixels:

$$L(i,j) = I(i-1, j) + I(i+1, j) + I(i, j-1) + I(i, j+1) - 4I(i, j)$$

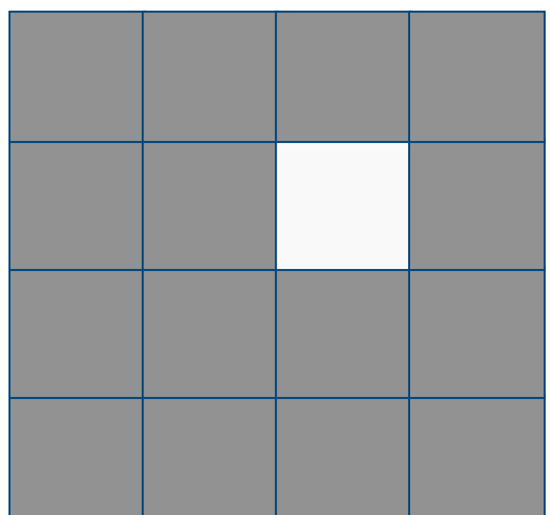
Sensors: Stereo Vision Systems

- Apply the Laplacian to our 4x4 image:

$$L(3,2) = 0.1 + 0.1 + 0.1 + 0.8 - 4\,(0.1) = +0.7$$

$$L(3,3) = 0.1 + 0.1 + 0.1 + 0.1 - 4\,(0.8) = -2.8$$

$$\vdots$$



Sensors: Stereo Vision Systems

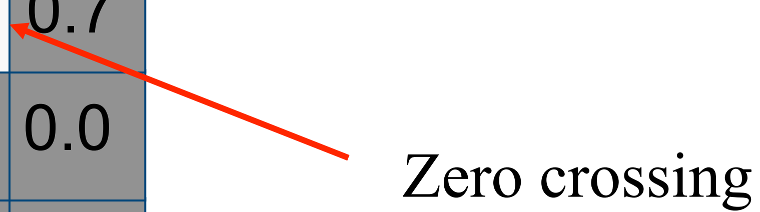
- Apply the Laplacian to our 4x4 image:

$$L(3,2) = 0.1 + 0.1 + 0.1 + 0.8 - 4\,(0.1) = +0.7$$

$$L(3,3) = 0.1 + 0.1 + 0.1 + 0.1 - 4\,(0.8) = -2.8$$

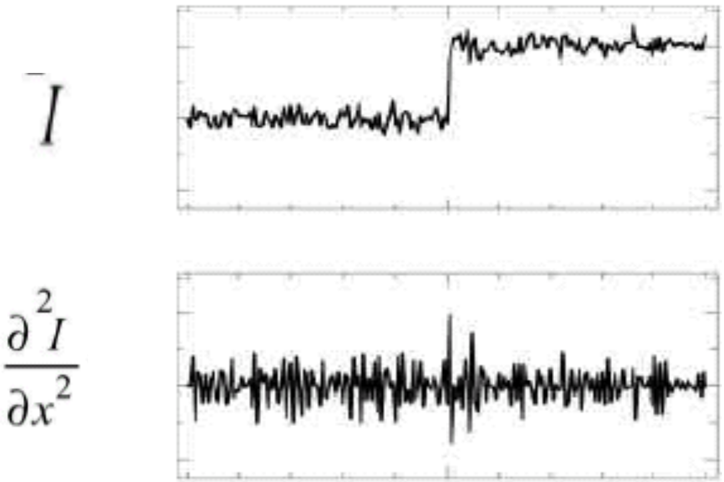
⋮

0.0	0.0	0.7	0.0
0.0	0.7	-2.8	0.7
0.0	0.0	0.7	0.0
0.0	0.0	0.0	0.0



Sensors: Stereo Vision Systems

- There is a problem that noise makes it difficult to detect zero crossings.



- To deal with this we use a gaussian operator to smooth/blur the image.

Sensors: Stereo Vision Systems

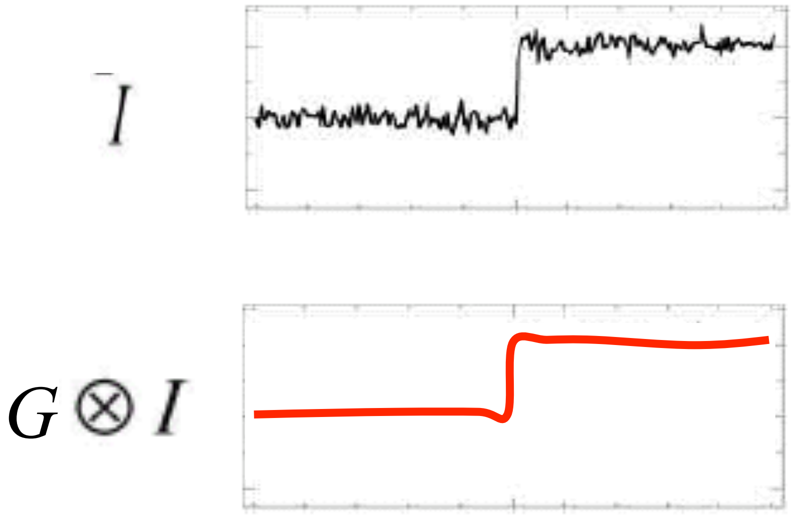
- To deal with noise we use a gaussian operator to smooth/blur the image.

  - *filtering through Gaussian smoothing*

$$G = \begin{bmatrix} \frac{1}{16} & \frac{2}{16} & \frac{1}{16} \\ \frac{2}{16} & \frac{4}{16} & \frac{2}{16} \\ \frac{1}{16} & \frac{2}{16} & \frac{1}{16} \end{bmatrix}$$

Sensors:
Stereo Vision Systems

- The Gaussian operator looks like an operator that averages the pixel values
- This has the effect of smoothing the curve:



Sensors: Stereo Vision Systems

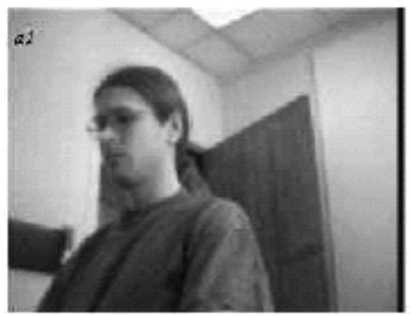
- Apply the Gaussian operator to the image will blur/smooth it so that zero-crossings will not occur simply due to noise.

Sensors:
Stereo Vision Systems

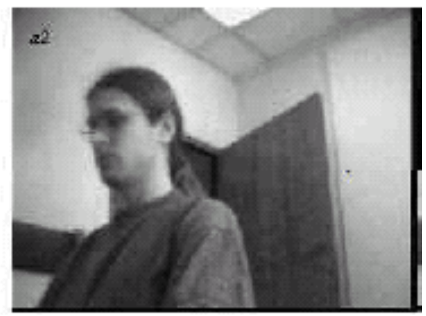
- ZLog Method:
  1. Gaussian Filter
  2. Laplacian Filter
  3. Mark features as zero crossing
  4. Match features between images
  5. Use geometry to recover depth map

Sensors: Stereo Vision Systems

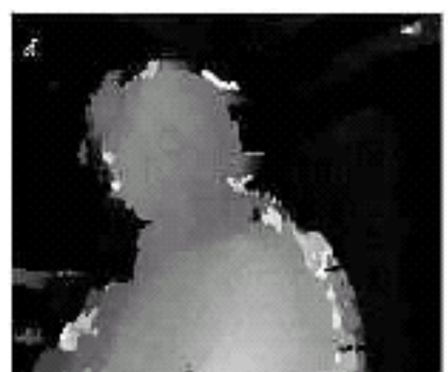
- ZLog Method Example:



Left Image



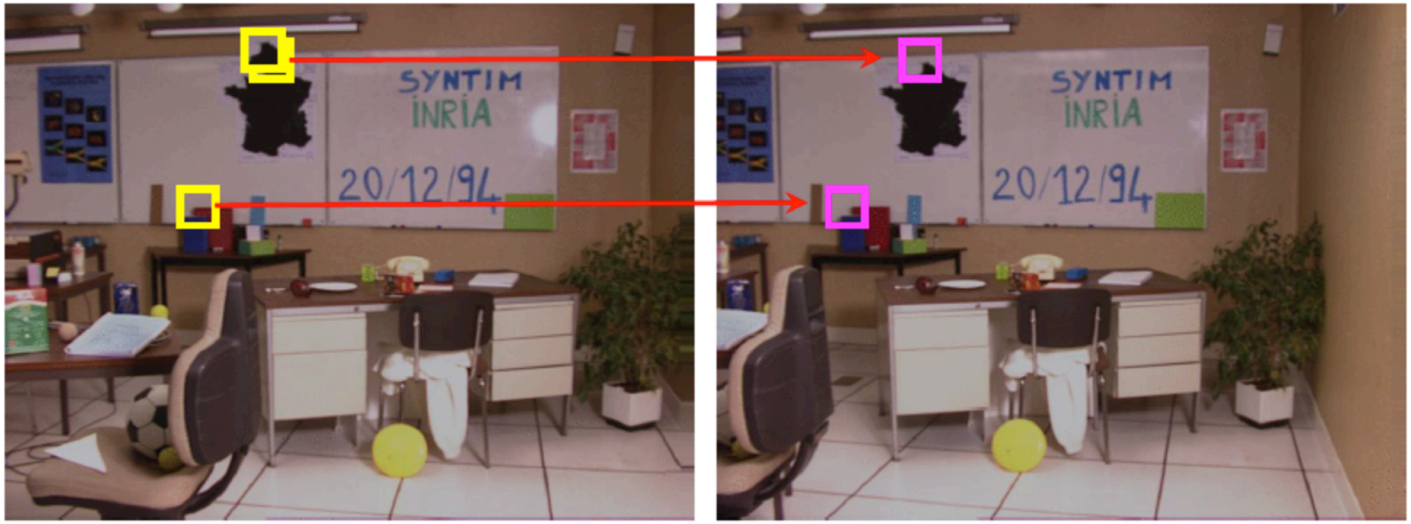
Right Image



Courtesy of Siegwart & Nourbakhsh

Sensors: Stereo Vision Systems

- Key issue is the correspondence problem
  - Identifying same feature from two cameras



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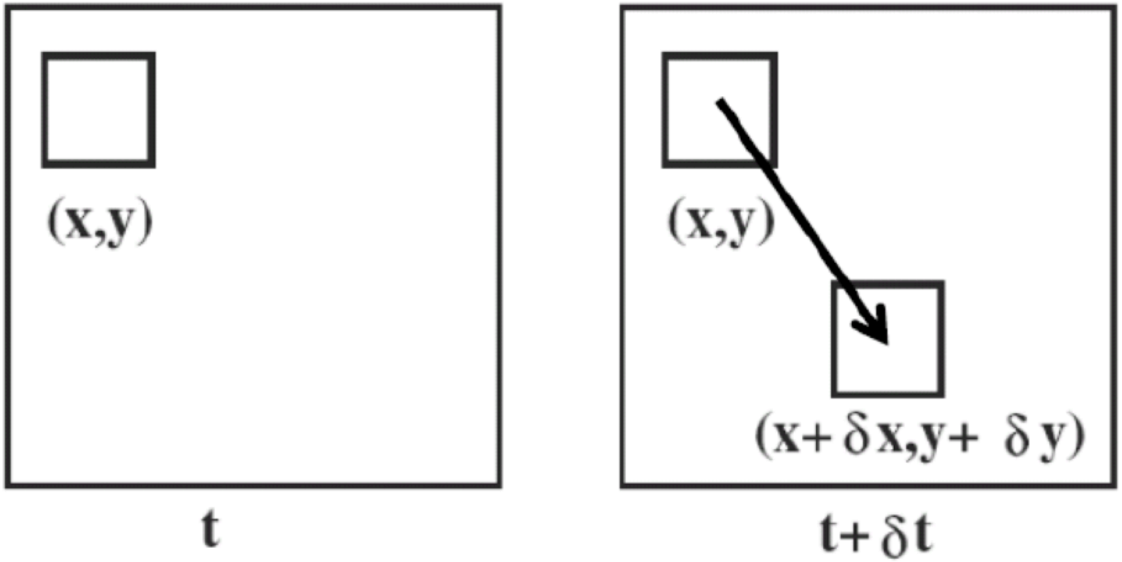
Sensors: Optical Flow

- Motion Field
  - A velocity vector is assigned to every point in an image.
  - Given velocity of point in image, determine velocity of point in the environment.
- Optical Flow
  - Motion of brightness patterns in image.
  - Can be same motion as object motion.

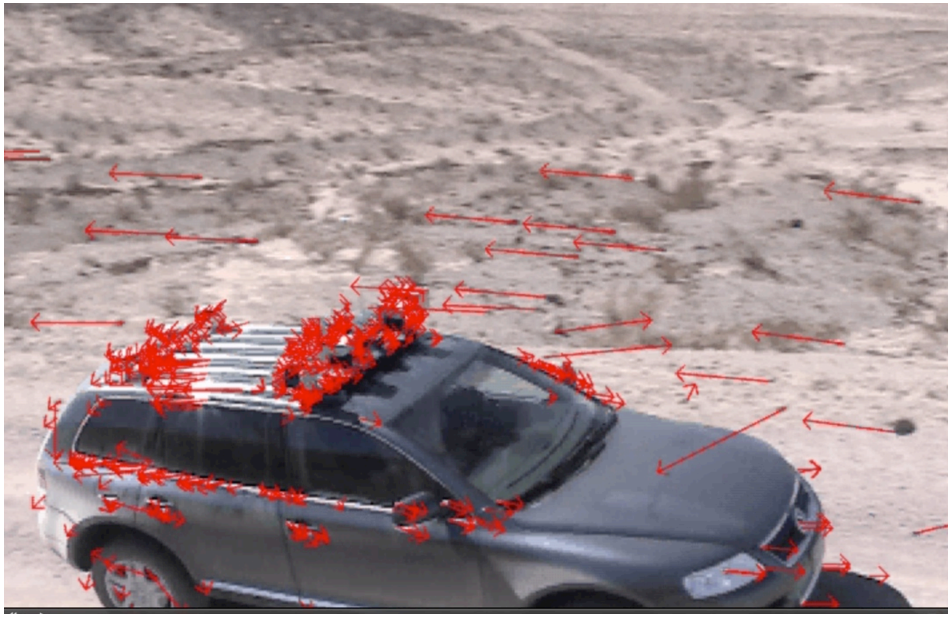
Sensors: Optical Flow

- Optical Flow
  - Computes the motion of all pixels in an image (or subsets of pixels)



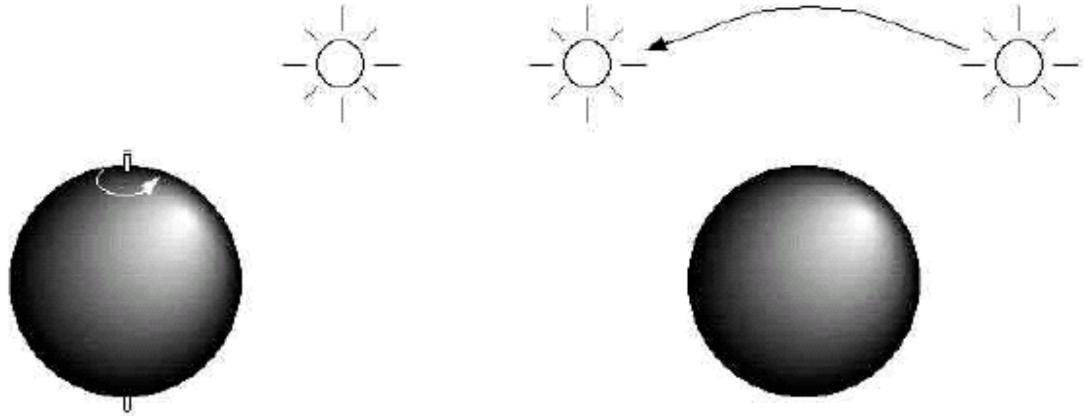
Sensors: Optical Flow

- Optical Flow



Sensors: Optical Flow

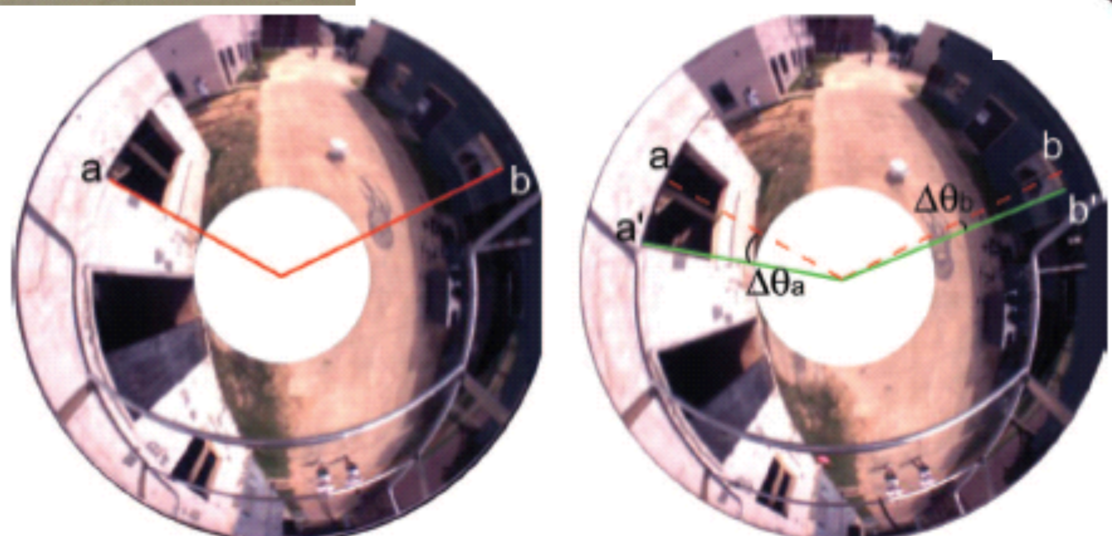
- Problem: with Optical Flow is not always same as motion field.
  - Occlusions lead to discontinuities
  - Moving Light sources
  - Symmetrical Shapes



Sensors:
Optical Flow for Ravine Navigation

Helicopter equipped with an OmniDirectional Camera

Regions used for optical flow calc's.



Courtesy of S. Hrabar and G. S. Sukhatme, USC

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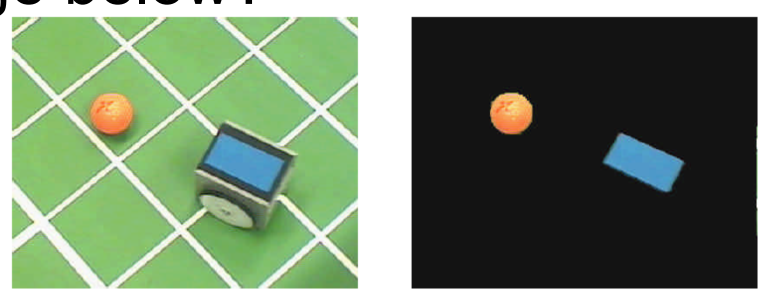
Sensors: Color Tracking

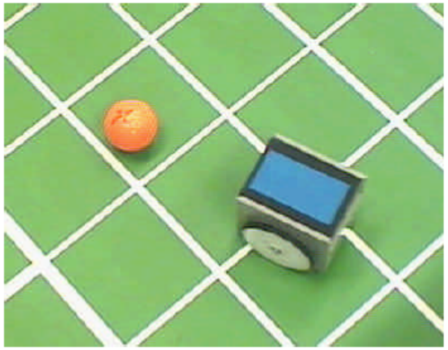
- Goal:
  - Given a color image, extract the pixels that have some specific color of interest.
  - Given the coordinates of these pixels, calculate the coloured object's position in the robot frame.
  - E.g. How do we extract the ball and robot positions from the image below?

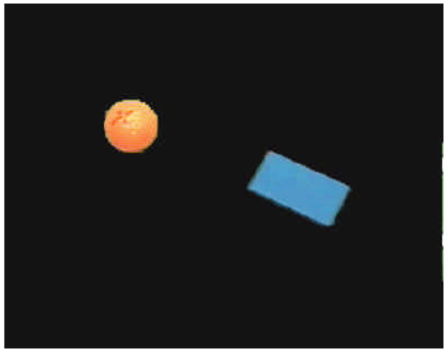


Courtesy of EPFL STeam

Sensors:
Color Tracking

- We are given an R, G, and B value for every pixel in an image…
- Can we match these with some desired RGB values that correspond to the color of the ball and robot?

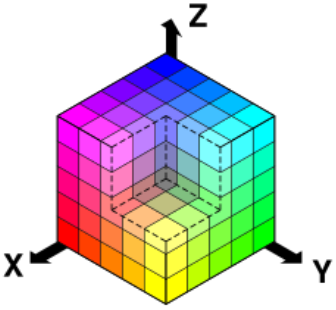




Courtesy of EPFL STeam

Sensors: Color Tracking

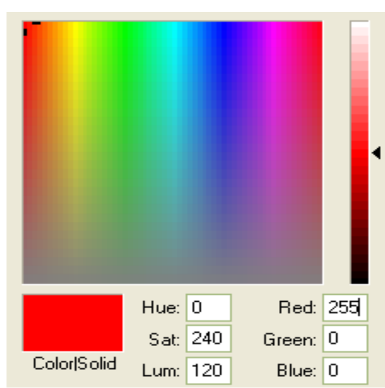
- RGB color representations assign a value from 0 to 255 to each of R, G, and B.
- These colors are additive to form white.
- Examples:
  - [0,0,255] is pure blue
  - [0,255,0] is pure green
  - [0,0,0] is black
  - [255,255,255] is white

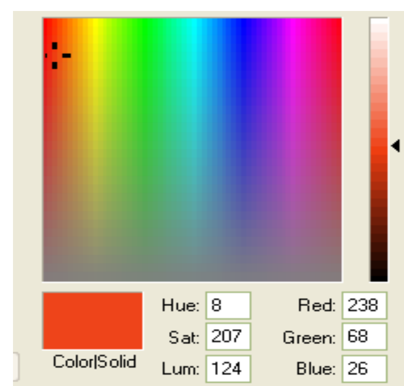


Courtesy of EPFL STeam

Sensors:
Color Tracking

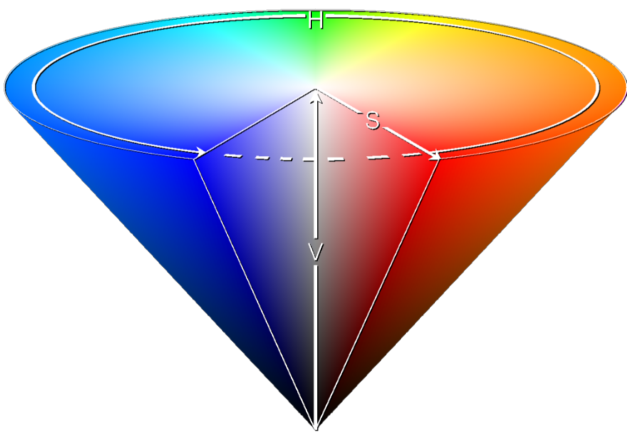
- Unfortunately, the RGB representation is not intuitive for measuring the closeness to a desired color.
  - E.g. what if we wanted to track a ball of color pure red - [255,0,0]?
  - We want to find all pixels that have values close to [255,0,0]
  - It is difficult to make good thresholds for any general color from which to accept as being close to our desired color.





Sensors:
Color Tracking

- HSV color representations are more intuitive for measuring closeness:
  - Hue
    - The “color type” (such as red, blue, or yellow):
    - Ranges from 0-360 (but normalized to 0-100% in some applications)
  - Saturation
    - The "vibrancy" or “purity”
    - Ranges from 0-100%
  - Value
    - The “brightness”
    - Ranges from 0-100%



Sensors: Color Tracking

- Method, for each pixel:
  - Convert to HSV color space
  - Determine if it is close to color being tracked by passing threshold for each parameter.
- Example:
  - To track pure red, H must belong to range [350, 10], S must belong to range [80,100], and V must belong to range [80,100].
  - Once all pixels that don't meet threshold are thrown out, the locations of the remaining pixels can used to determine the relative position of the object being tracked.

Sensors: Color Tracking

- MRS Example:
  - Convoy Search and Track mission

Overhead Vision Systems