Vision for Robotics (A Gentle Introduction)

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CS 545

Why Vision?

- What is a robot?
  - “A goal oriented machine that can sense, plan and act.” ~ Peter Corker (QUT). Sense - Plan - Act view of robotics
  - Another view: Perception - Action - Learning view of robotics. “Autonomous movement systems can bootstrap themselves into competent behavior by trial and error learning from interacting with the environment.”
- Perception/Sensing critical
  - Human sensing : look (vision), touch (haptics), hearing (microphones), smell (???), taste (????????)
  - Almost 80% of human perception, learning, cognition and activities are mediated through vision ~ Multiple sources
  - Give robots the ability to see - Camera, Depth Sensors, etc

How is Vision used? (Humans & Robots)

- Visual Motor Integration: Eye - Hand, Eye - Foot and Eye - body coordination
- Visual Auditory Integration: The ability to relate and associate what is seen and heard
- Visual Memory - The ability to remember and recall information that is seen
- Visual (loop) closure - The ability to “fill gaps” or complete a visual picture based on seeing only some of the parts
- Spatial Relationships - The ability to know “where I am” in relation to objects and space around me and know where objects are in relation to one another
- Figure-Ground Discrimination - The ability to discern form and object from background

What is Computer Vision

- The science and technology of machines that can see.
- Formally, the field that includes the acquiring, processing, analyzing and understanding real world data from visual sensors.

- What room is this?
- Is there a refrigerator?
- Where is the sink?
- ...

- Is there a tree?
- How many cars are there?
- Is there an open parking spot?
- ...

The Pillars of Computer Vision: Areas of Research

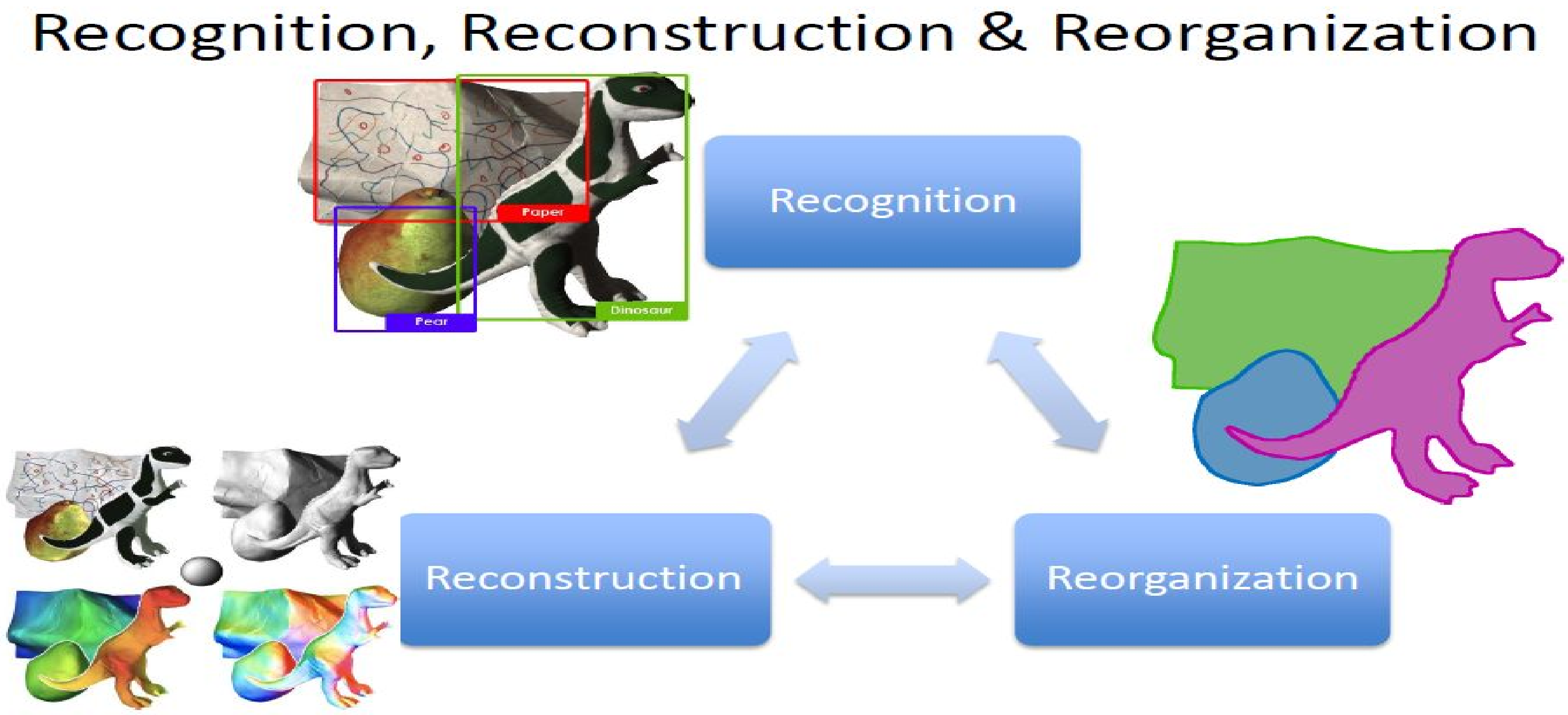


Image courtesy: Jitendra Malik

Some History

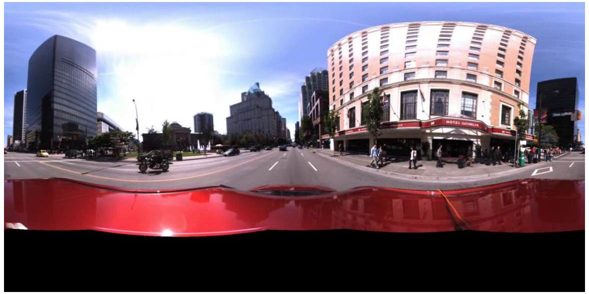
- In 1966, Marvin Minsky at MIT asked his undergraduate student Gerald Jay Sussman to "spend the summer linking a camera to a computer and getting the computer to describe what it saw". We now know that the problem is slightly more difficult than that. (Szeliski 2009, Computer Vision)
- 60 Years of Computer vision (courtesy Jitendra Malik)
  - 1960s: Beginnings in artificial intelligence, image processing and pattern recognition
  - 1970s: Foundational work on image formation: Horn, Koenderink, Longuet-Higgins
  - 1980s: Vision applied mathematics: geometry, multi-scale analysis, probabilistic modeling, control theory, optimization
  - 1990s: Geometric analysis largely completed, vision meets graphics, statistical learning approaches resurface
  - 2000s: Significant advances in visual recognition, range of practical applications, vision meets big data
  - 2010s: Deep Learning??

Main Conferences and Publications

- Main journals of the field:
  - IEEE Pattern Analysis Machine Intelligence (PAMI)
  - Int. Journal of Computer Vision (IJCV)
  - CVIU, IVC, PR, PRL,..
- Main conferences of the field:
  - IEEE Computer Vision Pattern Recognition
  - IEEE Int. Conf. Computer Vision
  - European Conference Computer Vision
- Graphics and Robotics are the nearest fields, great vision papers at SIGGRAPH as well as at ICRA and Transactions of Robotics and IJRR

Visual Sensors 2D vs 3D: Different 2D cameras

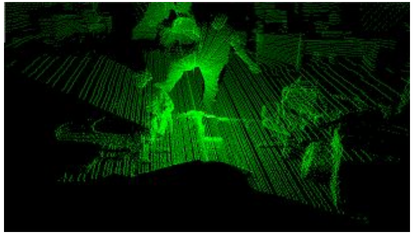
Fisheye camera



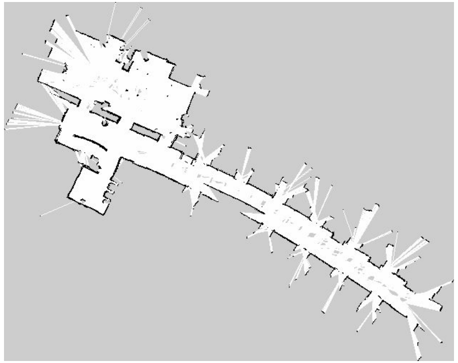
Omni directional camera

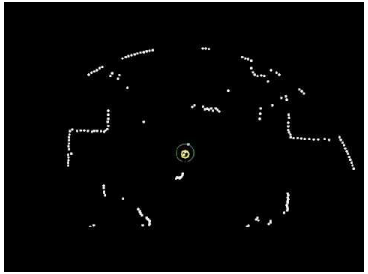
Catadioptric camera

Visual Sensors 2D vs 3D: Different 3D sensors



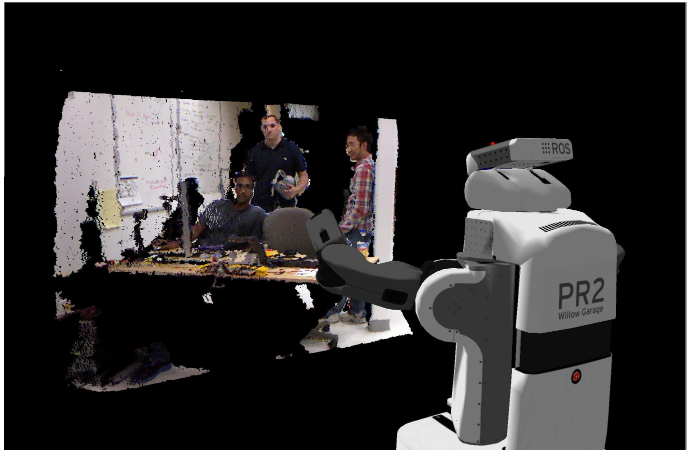
lasers



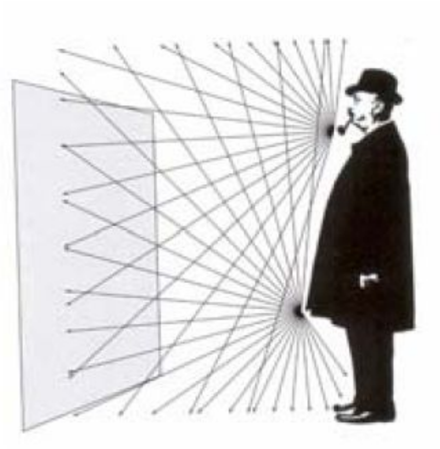


RGBD Stereo Cameras

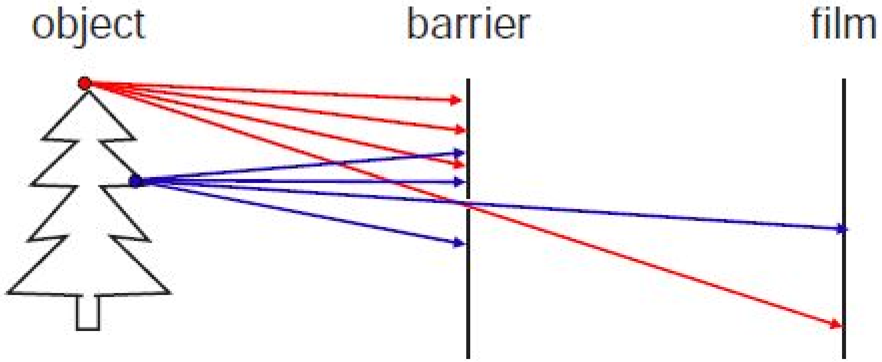
Other depth sensors, eg: time of flight



2D Image formation



What happens when light reflects from you?

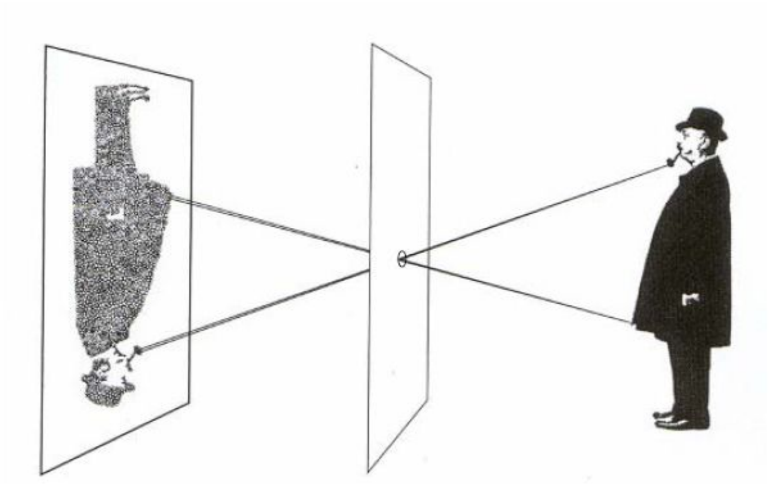


Add a barrier to block of most of the light

- Reduces blurring
- The opening in the barrier is called an aperture
- What happens to the image? How does it transform

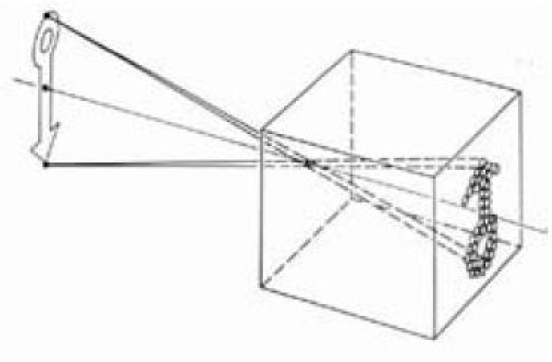
Images courtesy Alex Vasilescu (MIT)

2D Image formation - The Pinhole camera model



What information do we lose?

- Angles
- Distances
- Parallel lines are not parallel



- Captures **pencil of rays.** All rays through one point
- Point is called center of projection (COP)
- Image is formed on image plane
- Focal length **(f)** is the distance from COP to image plane.

Images courtesy Alex Vasilescu (MIT)

Note: Workout perspective projection math on white board .Ideas like tracking, segmentation, pixels moving together etc

2D Image Information

What we see

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

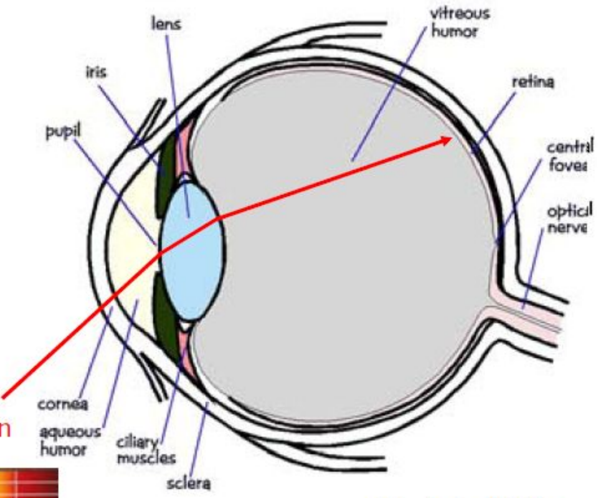
What a computer sees

But why RGB?

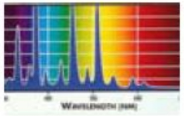
Note : Talk about image formation on CCD, RGB bayering

Why RGB? - Minor digression

(View of R eye from above)

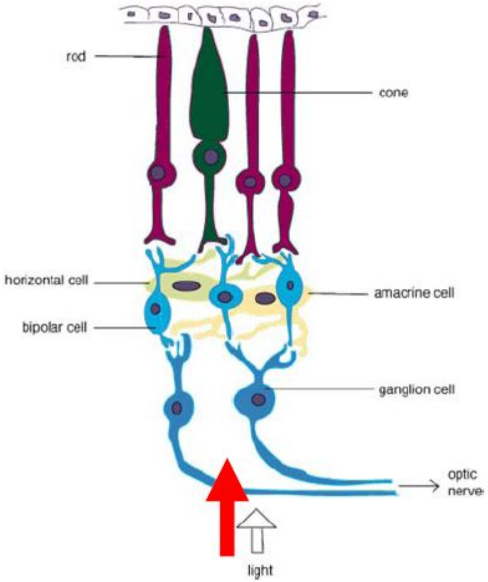


Incident spectral distribution



After Isaka (2004)

Rods and cones



CCDs emulate human visual system

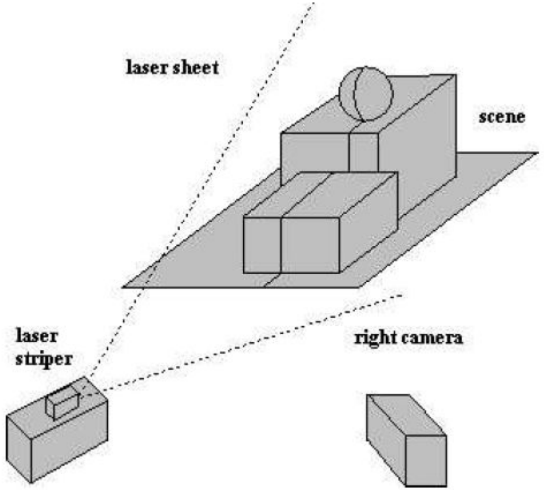
Visible spectrum incident on light sensitive retina - Cones (color)

3D Sensing - Basics

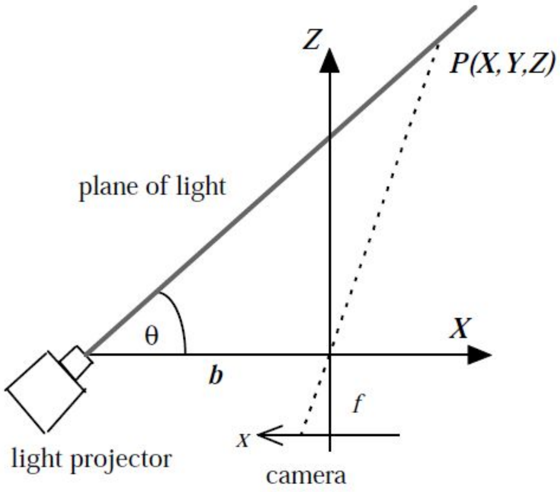
- Active Range Sensing: project energy (light, sonar, pulse) on the scene and detect its position to perform the measure; or exploit the effects of controlled changes of some sensor parameters (e.g. focus), ex: lidar, time of flight etc

- Passive Range Sensing: rely only on image intensities to perform the measure. Ex: stereopsis, structure from motion

Example of an active sensing system

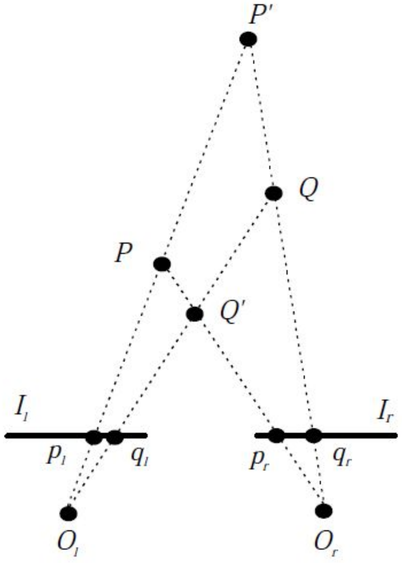


3D Sensing - Active Sensing Basics

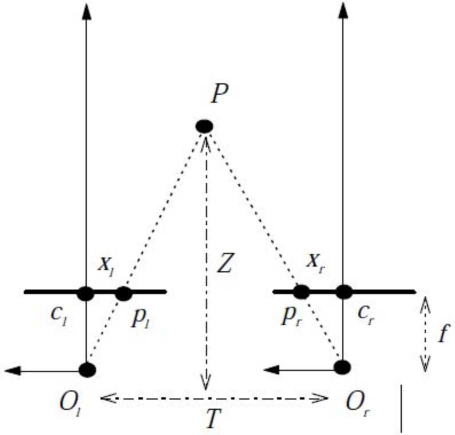


$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{b}{f \cot \theta - x} \begin{bmatrix} x \\ y \\ f \end{bmatrix}$$

3D Sensing - Stereo Basics



(a)



(b)

$$Z = \frac{fT}{d}, d = x_r - x_l$$

RANSAC - Model fitting 3D example

- Choose a small subset of data points uniformly at random
- Fit a model to that subset
- Anything that is close the result is signal, the rest is noise
- Repeat this procedure and choose the best model
- Model examples: Plane (3 points), cylinder (2 points with normals), sphere (2 points), transformations (5 point algorithm, 8 point algorithm, 4 points + 1 direction)

RANSAC - Model fitting 3D example

Algorithm 15.4: RANSAC: fitting lines using random sample consensus

Determine:
    n — the smallest number of points required
    k — the number of iterations required
    t — the threshold used to identify a point that fits well
    d — the number of nearby points required
        to assert a model fits well
Until k iterations have occurred
    Draw a sample of n points from the data
        uniformly and at random
    Fit to that set of n points
    For each data point outside the sample
        Test the distance from the point to the line
            against t; if the distance from the point to the line
            is less than t, the point is close
    end
    If there are d or more points close to the line
        then there is a good fit. Refit the line using all
        these points.
end
Use the best fit from this collection, using the
    fitting error as a criterion

Image courtesy
Marc Pollefeys