Robotics: Principles and Practice

Module 5: Robot Vision

Lecture 10: Stereo vision; epipolar geometry

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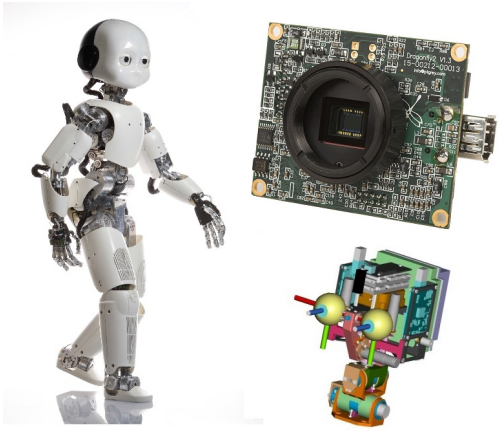
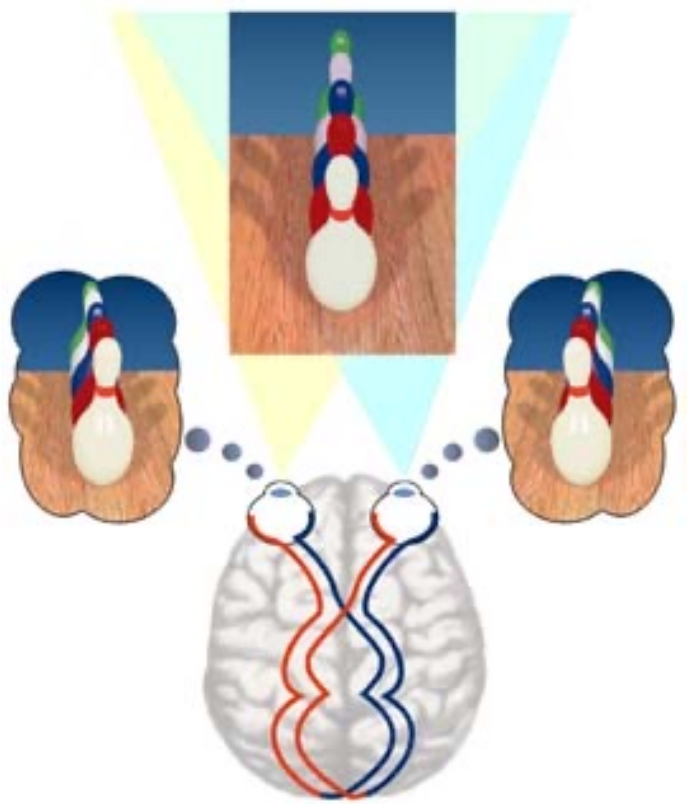
Stereopsis – Stereo Vision

We refer to stereo vision as the problem of inferring 3D information (structure and distances) from two or more images taken from different viewpoints



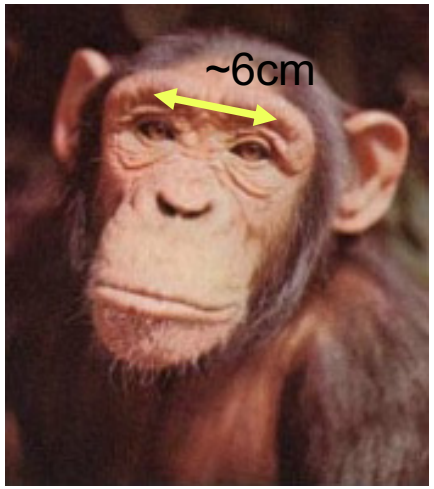
Credit: Francesca Odone, University of Genova

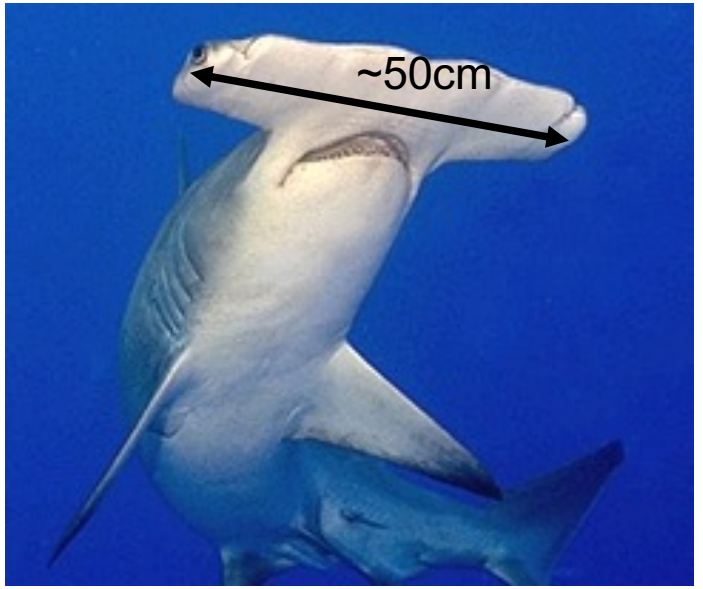
Stereopsis – Stereo Vision



Credit: Markus Vincze, Technische Universität Wien

Stereopsis – Stereo Vision





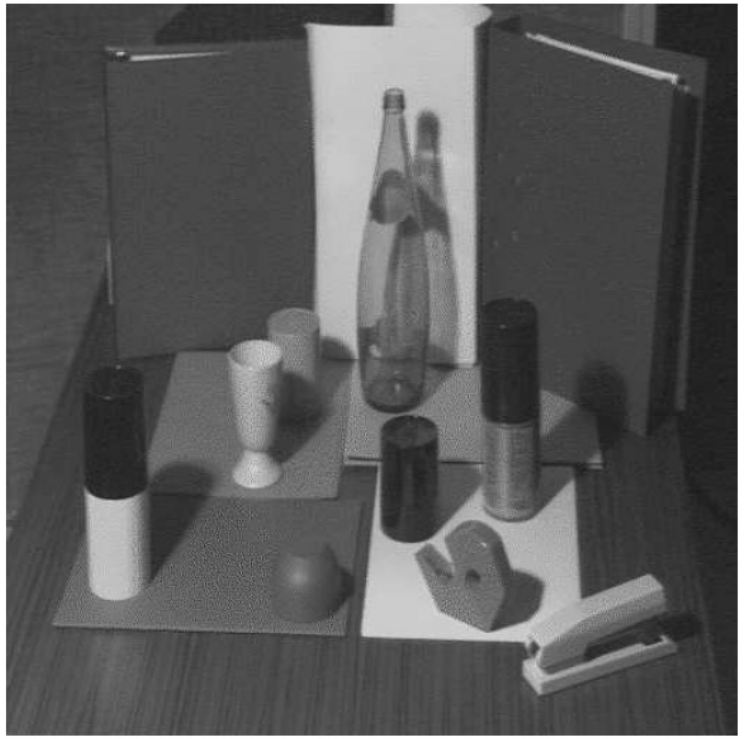
- Larger baseline increases useful range of depth estimated from stereo
- After a few meters disparity is quite small and depth from stereo is unreliable …

Stereopsis – Stereo Vision

[Young]

Credit: Markus Vincze, Technische Universität Wien

Stereopsis – Stereo Vision



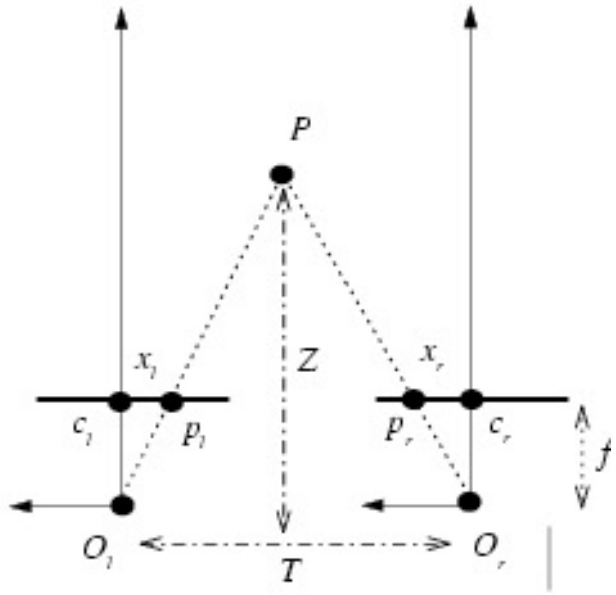
[Young]

Credit: Markus Vincze, Technische Universität Wien

Stereopsis – Stereo Vision

- Disparity d is the relative distance between corresponding points (on the image plane)
- Depth Z is the distance from a 3D point to the viewing system
- Depth is inversely proportional to disparity

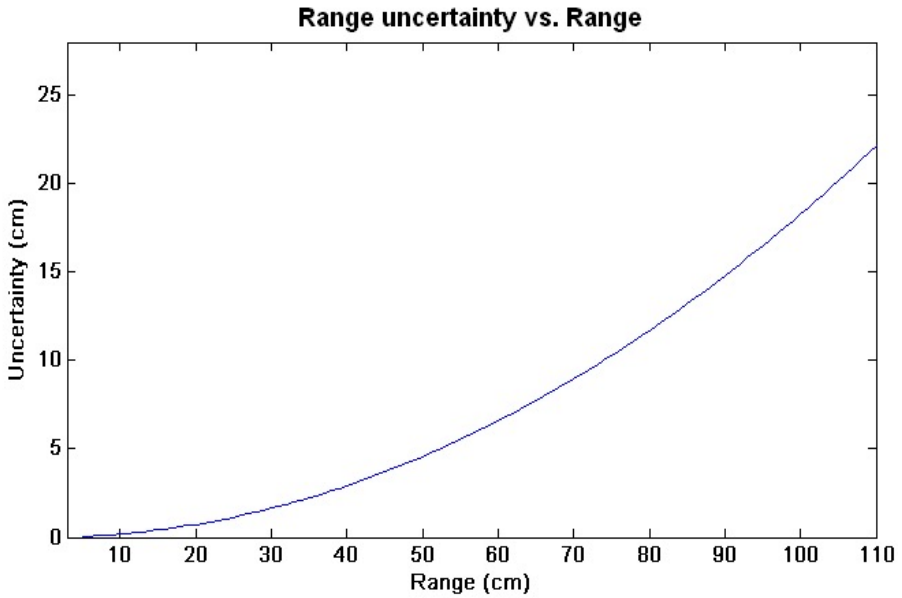
$$Z = \frac{fT}{x_r - x_l} = \frac{fT}{d}$$



Credit: Francesca Odone, University of Genova

Stereopsis – Stereo Vision

- The more distant the object, the larger the depth uncertainty
  - Acute angle: disparity uncertainty grows non-linearly
  - Improve with large focal length and baseline distance
- Humans use stereo only up to arm length
  - Then relative and perspective cues dominate



[S. Ahuja]

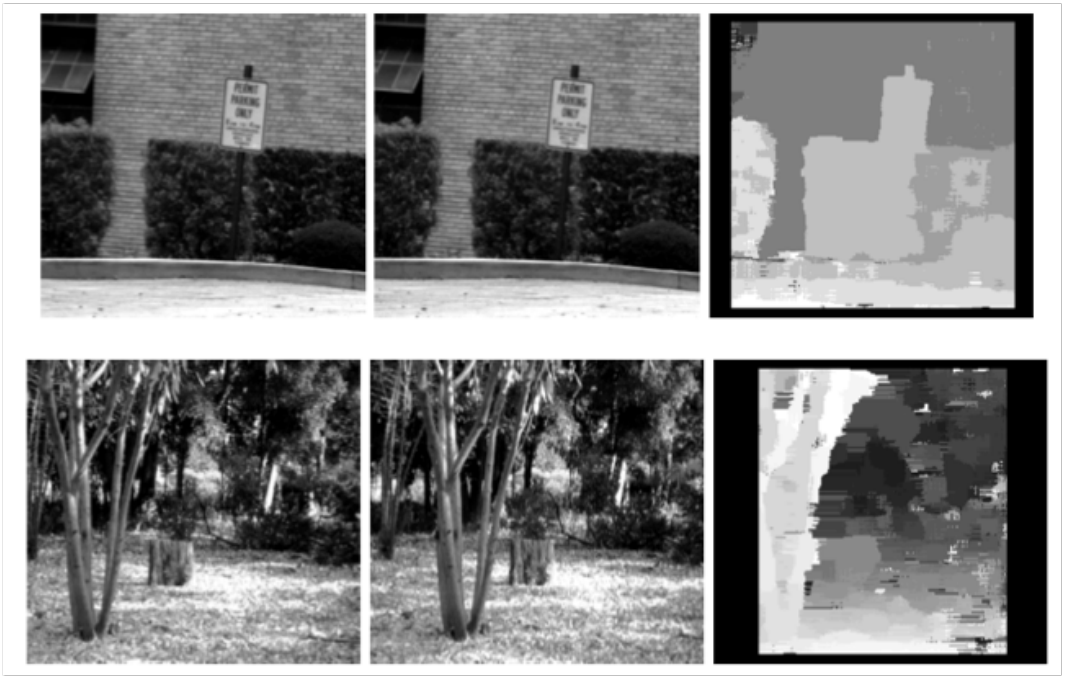
Stereopsis – Stereo Vision

- Dense stereo correspondence
- We assume we have two **rectified** images
  - where conjugate points lie on corresponding scanlines of the image ("rows")
- Our goal is to obtain a **disparity map** giving the relative displacement for each pixel

Credit: Francesca Odone, University of Genova

Stereopsis – Stereo Vision

Assuming a fixation point at infinity, disparity is proportional to the inverse of the distance $Z = \frac{fT}{x_r - x_l} = \frac{fT}{d}$

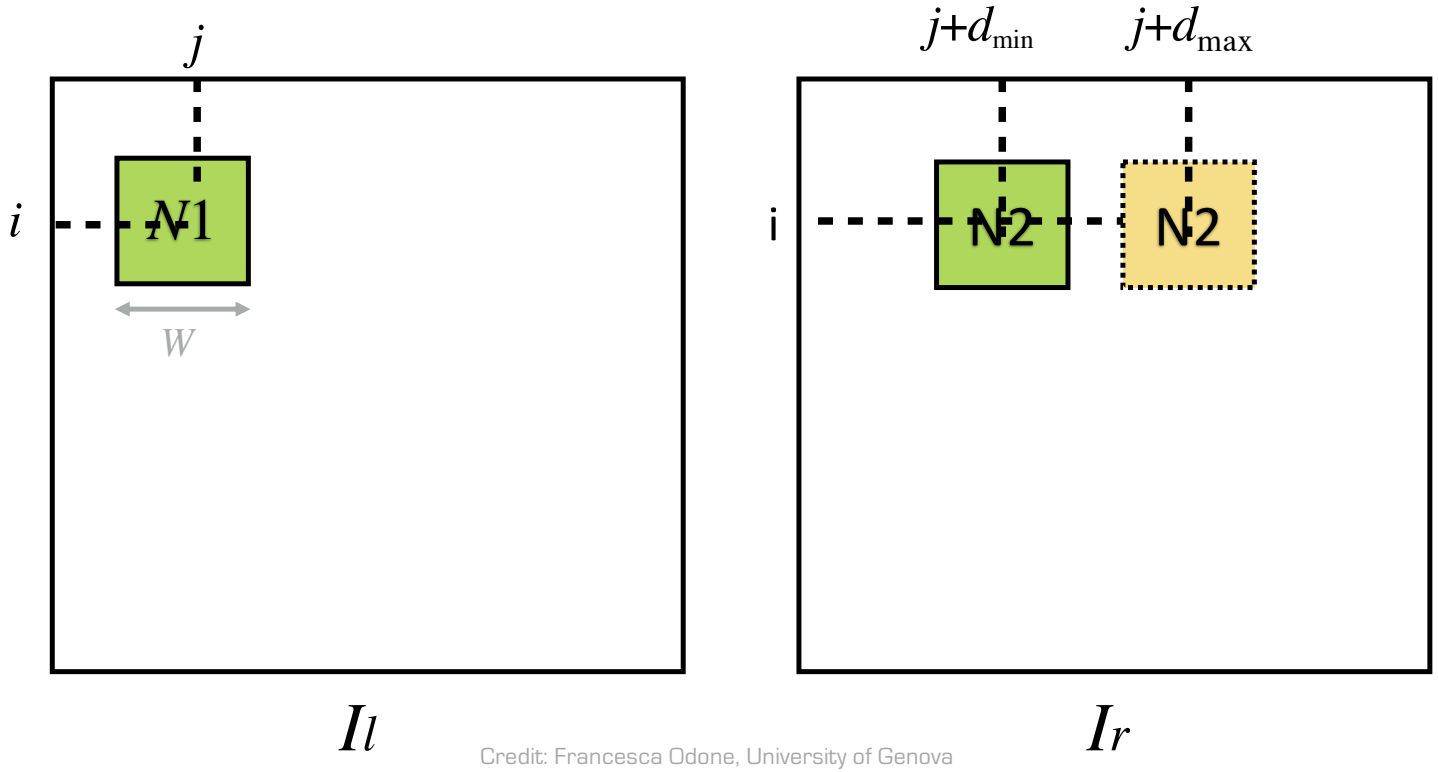


Credit: Francesca Odone, University of Genova

Stereopsis – Stereo Vision

Given a stereo pair of **rectified** images Il and Ir

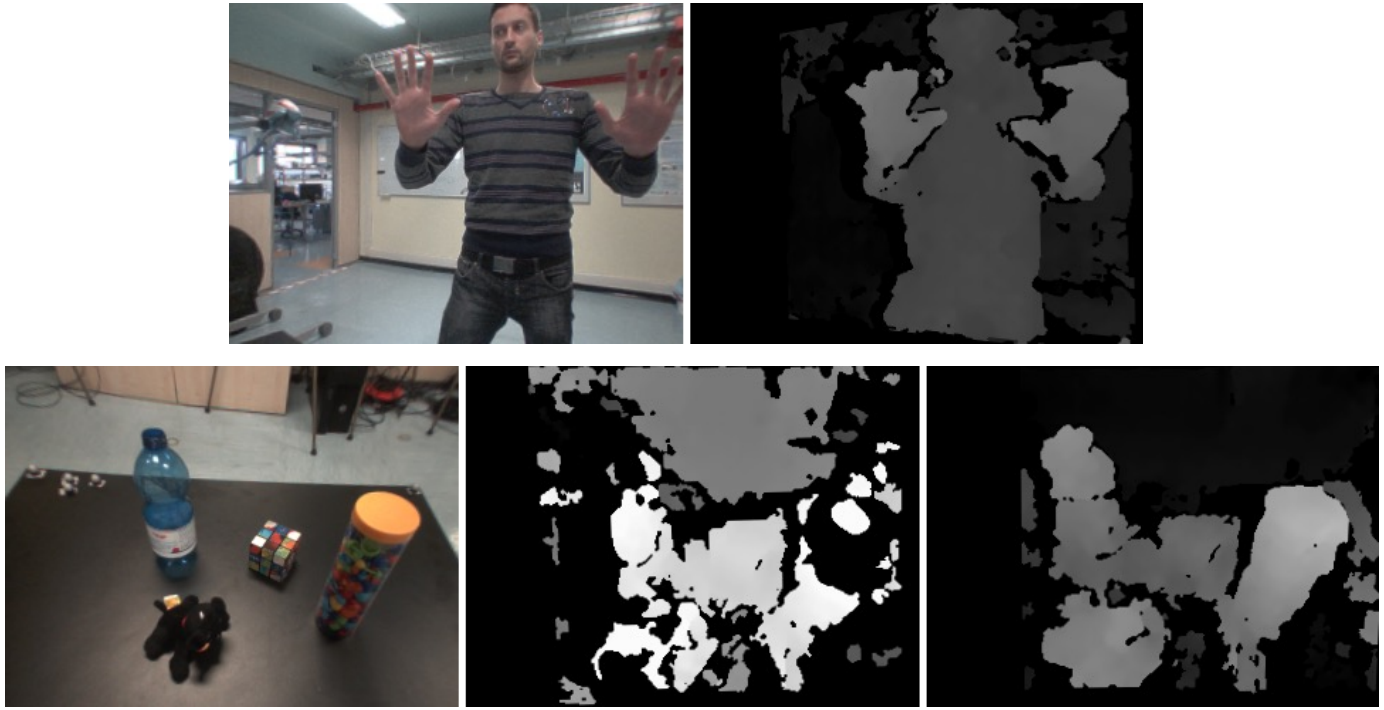
- size of a correlation window W
- a search range $[d_{\min}, d_{\max}]$



Credit: Francesca Odone, University of Genova

Stereopsis – Stereo Vision

Dense correspondences: left-right consistency



Credit: Francesca Odone, University of Genova

Stereopsis – Stereo Vision

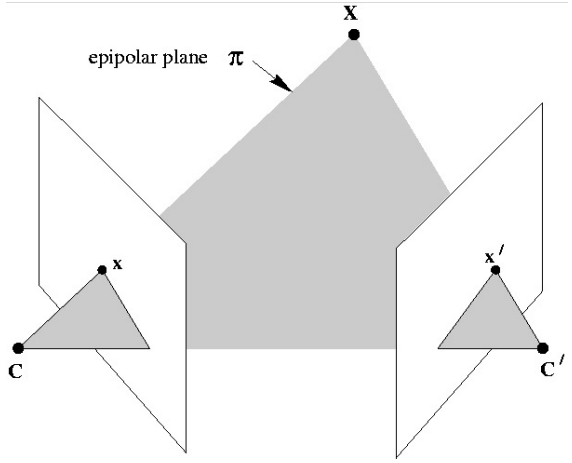
- Correspondence problem: finding the *same* point in both images
- Search in entire image is very costly
- Geometry of cameras produces constraints:
  epipolar plane and epipolar line
  - Limits search to a line in the image
- Finding the same points
  - Correlation (region) or features (edge)

Credit: Markus Vincze, Technische Universität Wien

Stereopsis – Stereo Vision

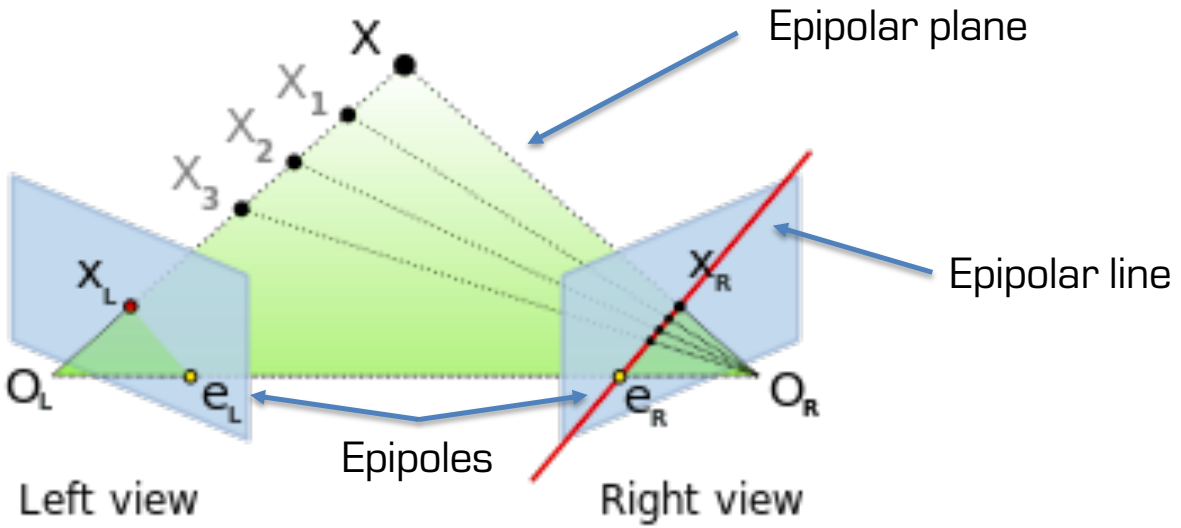
The geometry of a stereo-system is called epipolar geometry

It provides a geometrical prior to the algorithms



Credit: Francesca Odone, University of Genova

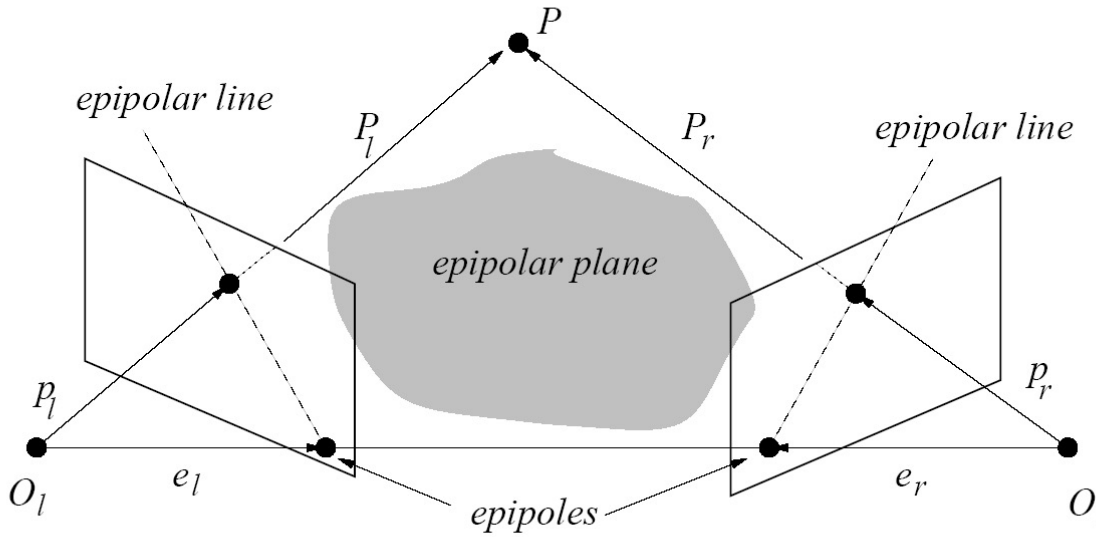
Epipolar Geometry



https://en.wikipedia.org/wiki/Epipolar_geometry

Epipolar Geometry

- Epipolar plane: plane of the two visible rays
- Pre-condition: known camera geometry, calibration

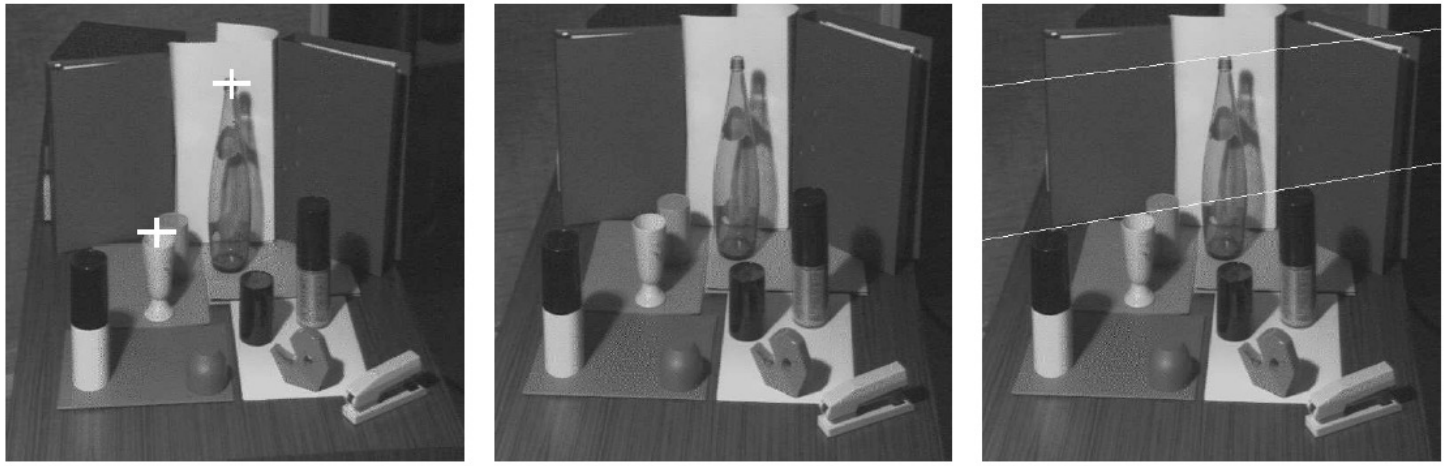


[Young]

Credit: Markus Vincze, Technische Universität Wien

Epipolar Lines

- Each point left defines epipolar line right
- → 1D search for the same feature
- Simplifies correspondence problem



[Young]

Credit: Markus Vincze, Technische Universität Wien

Horizontal Epipolar Lines

- Simple case: parallel cameras (fronto-parallel stereo)
  - In practice not obtainable accurately

- Rectification (calibration and elimination of distortions) of the images to obtain epipolar lines on the pixel array of the camera

Credit: Markus Vincze, Technische Universität Wien

Correspondence along a Line

- Search for left image point in the right image
- Dense depth image: correspondence for every point
- Sparse depth image: only distinctive points

Credit: Markus Vincze, Technische Universität Wien

Reading

R. Szeliski, *Computer Vision: Algorithms and Applications*, Springer, 2010.

Section 2.1.5 3D to 2D projections

Section 6.3 Geometric intrinsic calibration

Vernon, D. 1991. Machine Vision: Automated Visual Inspection and Robot Vision, Prentice-Hall International; Section 8.6

OpenCV documentation on camera calibration:

http://docs.opencv.org/2.4/modules/calib3d/doc/camera_calibration_and_3d_reconstruction.html

Demo

Read "Camera Modelling and Camera Calibration.pdf"
Then walk through the following example applications:

cameraInvPerspectiveMonocular

cameraInvPerspectiveBinocular