UNIVERSITY OF SOUTH CAROLINA

CSCE 774 ROBOTIC SYSTEMS

Background

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Components

Computer Vision

Filtering Optimization

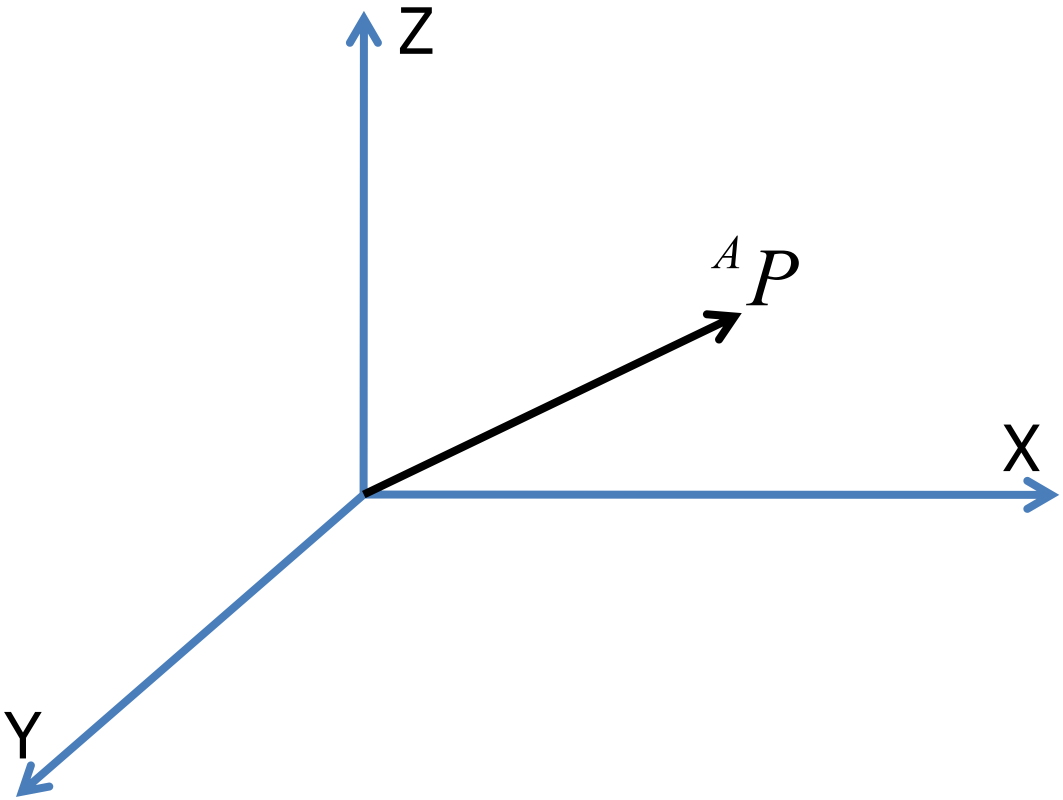
IMU Processing

Loop Closure

Position Representation

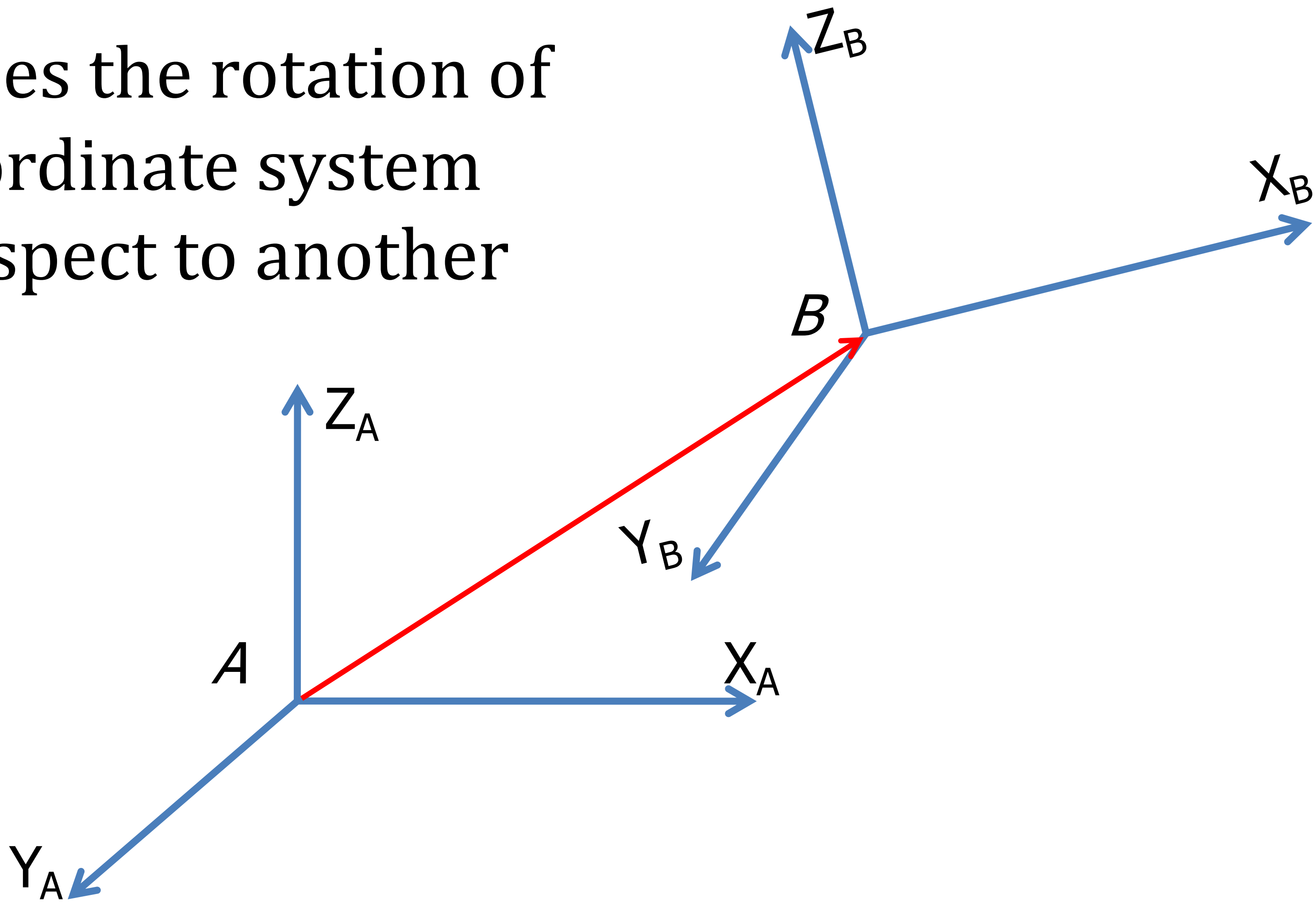
- Position representation is:

$$ {}^{A}P = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} $$



Orientation Representations

- Describes the rotation of one coordinate system with respect to another

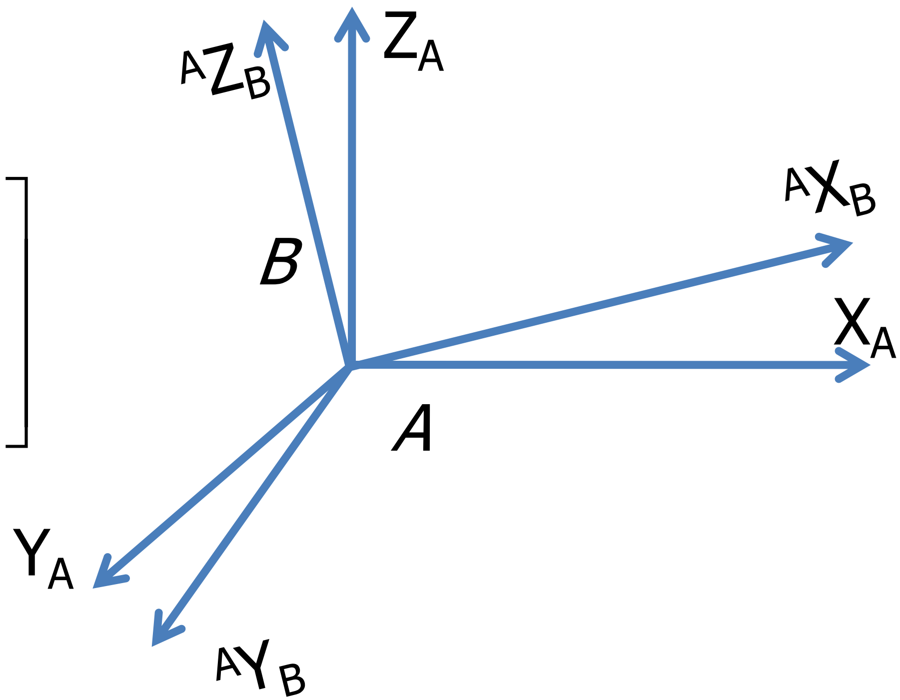


Rotation Matrix

- Write the unit vectors of *B* in the coordinate system of *A*.
- Rotation Matrix:

$$
{}^{A}_{B}R = \begin{bmatrix} {}^{A}\hat{X}_B & {}^{A}\hat{Y}_B & {}^{A}\hat{Z}_B \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}
$$

$$
= \begin{bmatrix} \hat{X}_B \cdot \hat{X}_A & \hat{Y}_B \cdot \hat{X}_A & \hat{Z}_B \cdot \hat{X}_A \\ \hat{X}_B \cdot \hat{Y}_A & \hat{Y}_B \cdot \hat{Y}_A & \hat{Z}_B \cdot \hat{Y}_A \\ \hat{X}_B \cdot \hat{Z}_A & \hat{Y}_B \cdot \hat{Z}_A & \hat{Z}_B \cdot \hat{Z}_A \end{bmatrix}
$$



Coordinate System Transformation

$$M = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} R & T \\ 0_{3\times1} & 1 \end{bmatrix}$$

where R is the rotation matrix and T is the translation vector

Rotation Matrix

- The rotation matrix consists of 9 variables, but there are many constraints. The minimum number of variables needed to describe a rotation is three.

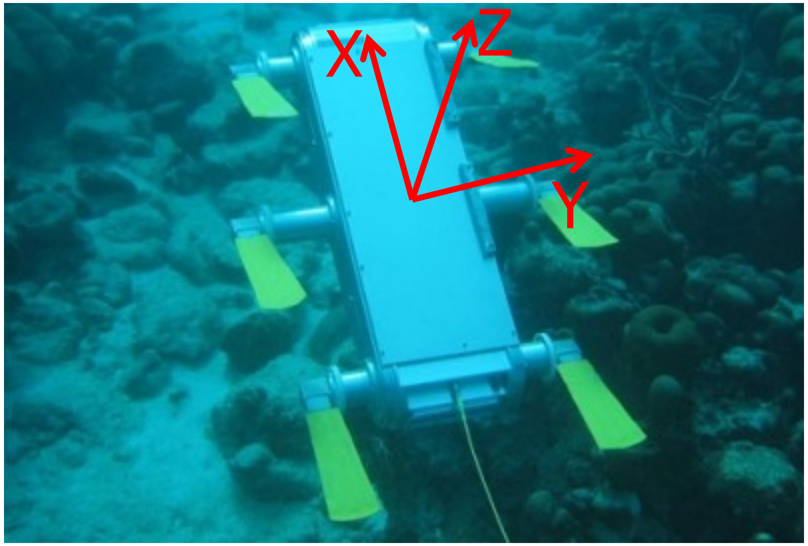
Euler Angles

- **ZYX**: Starting with the two frames aligned, first rotate about the Z_B axis, then by the Y_B axis and then by the X_B axis. The results are the same as with using XYZ fixed angle rotation.

- There are 12 different combination of Euler Angle representations

Euler Angles

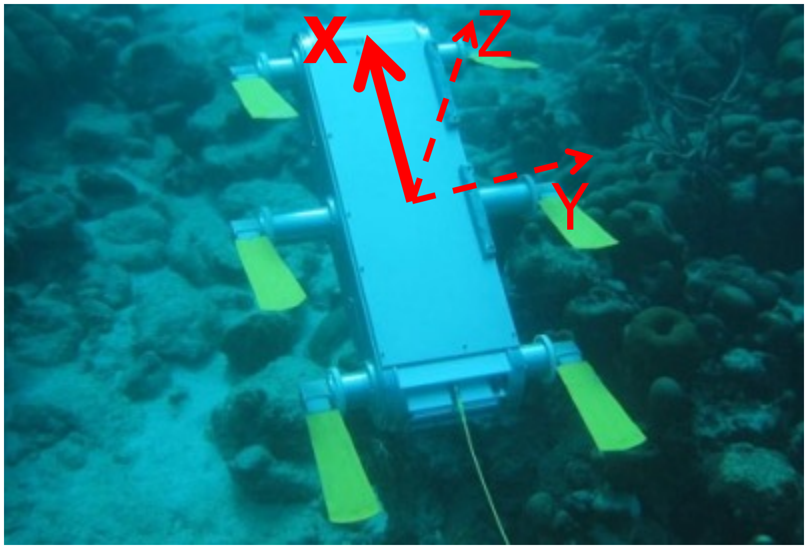
- Traditionally the three angles along the axis are called Roll, Pitch, and Yaw



Euler Angles

- Traditionally the three angles along the axis are called Roll, Pitch, and Yaw

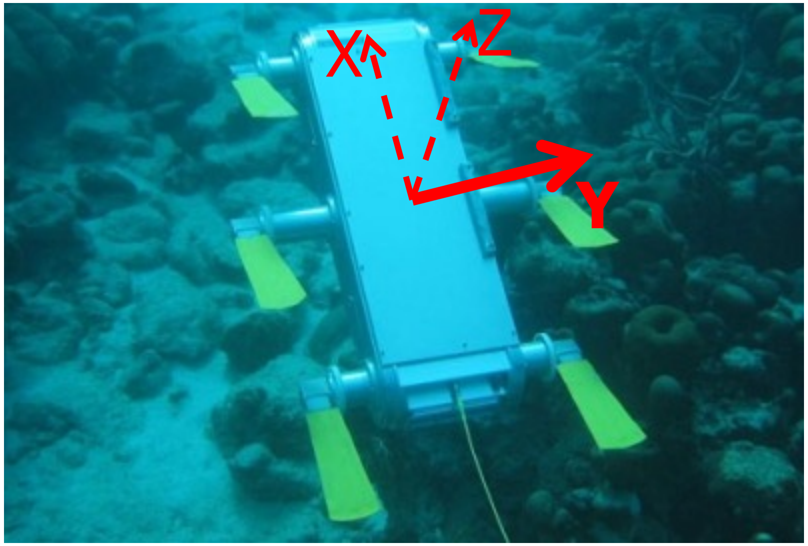
Roll



Euler Angles

- Traditionally the three angles along the axis are called Roll, Pitch, and Yaw

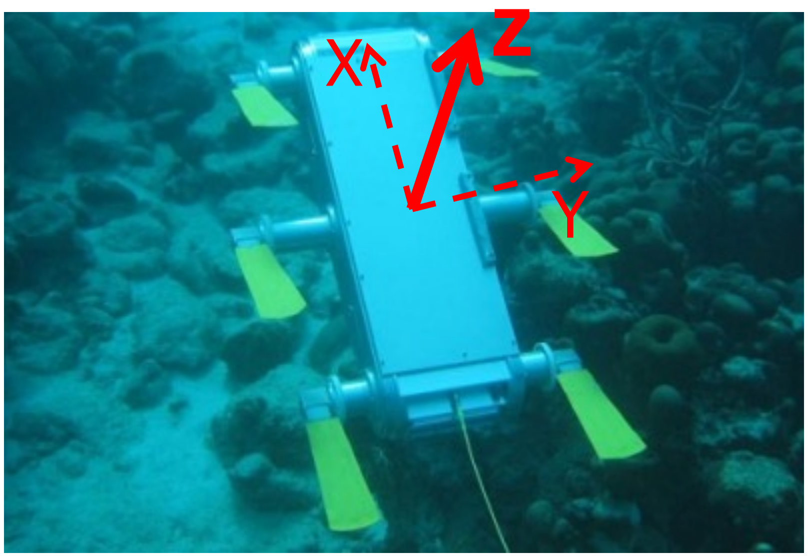
Pitch



Euler Angles

- Traditionally the three angles along the axis are called Roll, Pitch, and Yaw

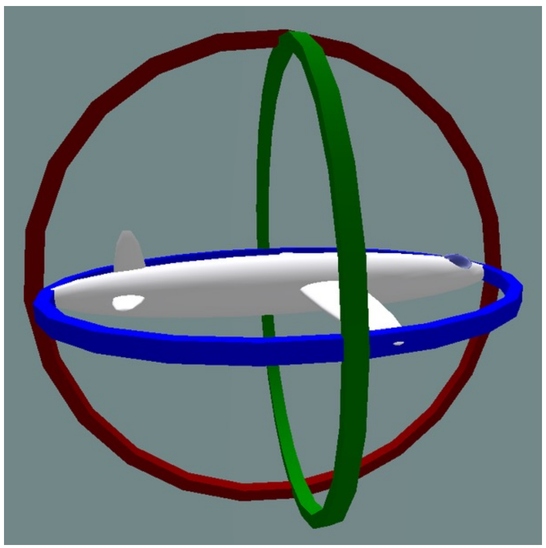
Yaw

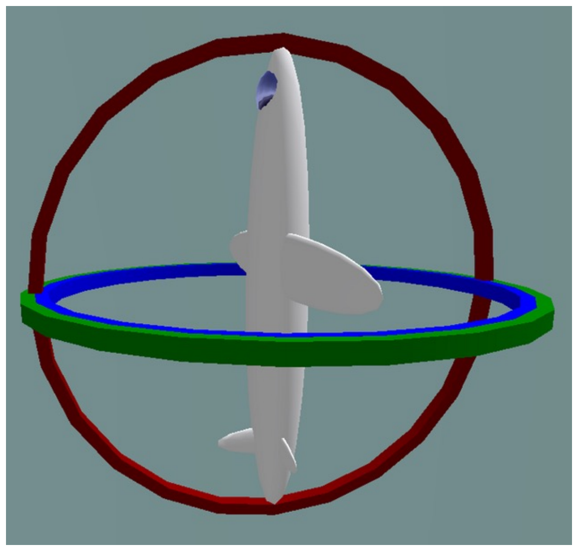


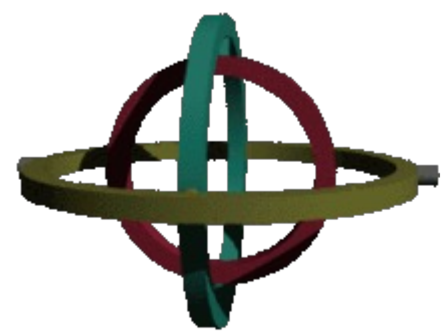
Euler Angle concerns: Gimbal Lock

Using the **ZYZ** convention

- (90°, 45°, −105°) ≡ (−270°, −315°, 255°) multiples of 360°
- (72°, 0°, 0°) ≡ (40°, 0°, 32°) singular alignment (Gimbal lock)
- (45°, 60°, −30°) ≡ (−135°, −60°, 150°) bistable flip

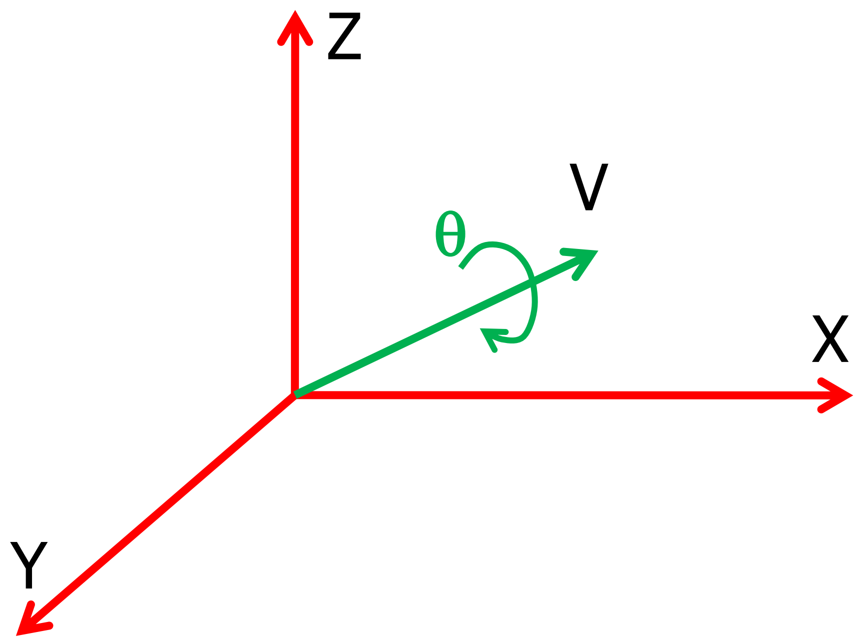






Axis-Angle Representation

- Represent an arbitrary rotation as a combination of a vector and an angle



Quaternions

- Are similar to axis-angle representation
- Two formulations
  - Classical
  - Based on JPL's standards

    W. G. Breckenridge, "Quaternions - Proposed Standard Conventions," JPL, Tech. Rep. INTEROFFICE MEMORANDUM IOM 343-79-1199, 1999.
- Avoids Gimbal lock

- See also: M. D. Shuster, "A survey of attitude representations," Journal of the Astronautical Sciences, vol. 41, no. 4, pp. 439–517, Oct.–Dec. 1993.

Robot Sensors

- Sensors are devices that can sense and measure physical properties of the environment,
  - e.g. temperature, luminance, resistance to touch, weight, size, etc.
  - The key phenomenon is transduction
    - Transduction (engineering) is a process that converts one type of energy to another
- They deliver *low-level* information about the environment the robot is working in.
  - Return an incomplete description of the world.

Robot Sensors

- This information is **noisy** (imprecise).
- Cannot be modelled completely:
  - Reading = *f*(env)   where *f* is the model of the sensor
  - Finding the inverse:
    - ill posed problem (solution not uniquely defined)
    - collapsing of dimensionality leads to ambiguity

Types of sensor

- General classification:
  - **active** *versus* **passive**
    - Active: emit energy in environment
      - More robust, less efficient
    - Passive: passively receive energy from env.
      - Less intrusive, but depends on env. e.g. light for camera
    - Example: stereo vision versus range finder.
  - **contact** *versus* **non-contact**

Sensors

- **Proprioceptive Sensors**
  (monitor state of robot)
  – IMU (accels & gyros)
  – Wheel encoders
  – Doppler radar …

- **Exteroceptive Sensors**
  (monitor environment)
  – Cameras (single, stereo, omni, FLIR …)
  – Laser scanner
  – MW radar
  – Sonar
  – Tactile…

Sensor Characteristics

- All sensors are characterized by various properties that describe their capabilities
  - **Sensitivity**:

    (change of output) ÷ (change of input)
  - **Linearity**: constancy of (output ÷ input)
    - Exception: logarithmic response cameras == wider dynamic range.
  - **Measurement/Dynamic range**:

    difference between min. and max.

Sensor Characteristics

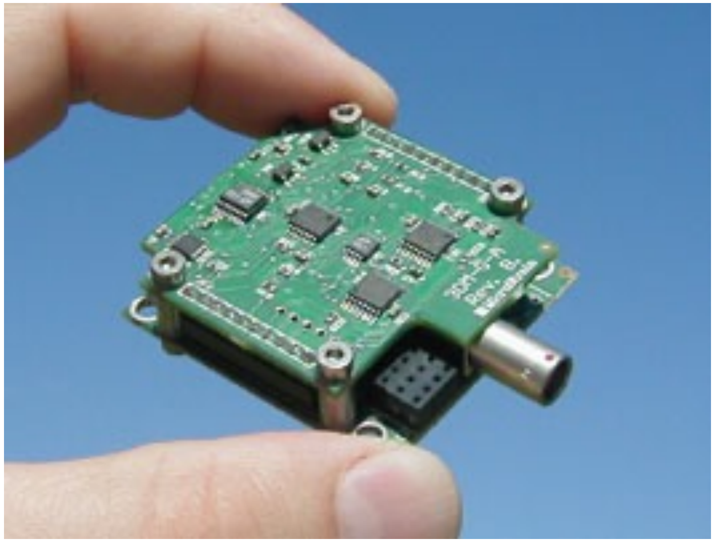
- **Response Time**: time required for a change in input to cause a change in the output
- **Accuracy**: difference between measured & actual
- **Repeatability**: difference between repeated measures
- **Resolution**: smallest observable increment
- **Bandwidth**: result of high resolution or cycle time

Focus on:

- IMU
- Wheel Encoders
- Compass
- Monocular Vision
- Stereo Vision
- RGBd (Kinnect)
- LIDAR

IMU's

- Gyro, accelerometer combination.
- Typical designs (e.g. 3DM-GX1™) use tri-axial gyros to track dynamic orientation and tri-axial DC accelerometers along with the tri-axial magnetometers to track static orientation.
- The embedded microprocessors contains programmable filter algorithms, which blend these static and dynamic responses in real-time.



Why vision?

- Passive (emits nothing).
  - Discreet.
  - Energy efficient.
- Intuitive.
- Powerful (works well for us, right?)
- Long and short range.
- Fast.

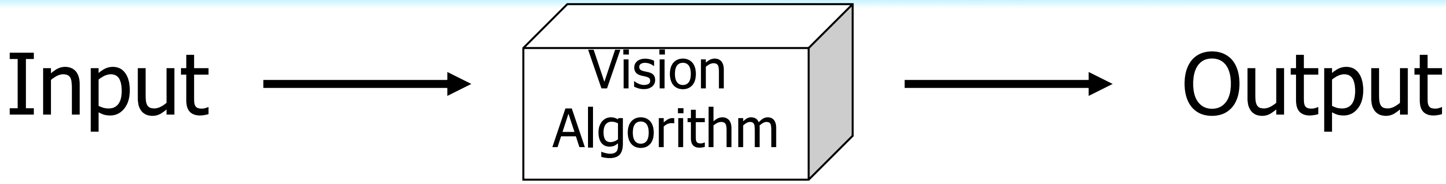
So, what's the problem?

- How hard is vision? Why do we think is do-able?

Problems:

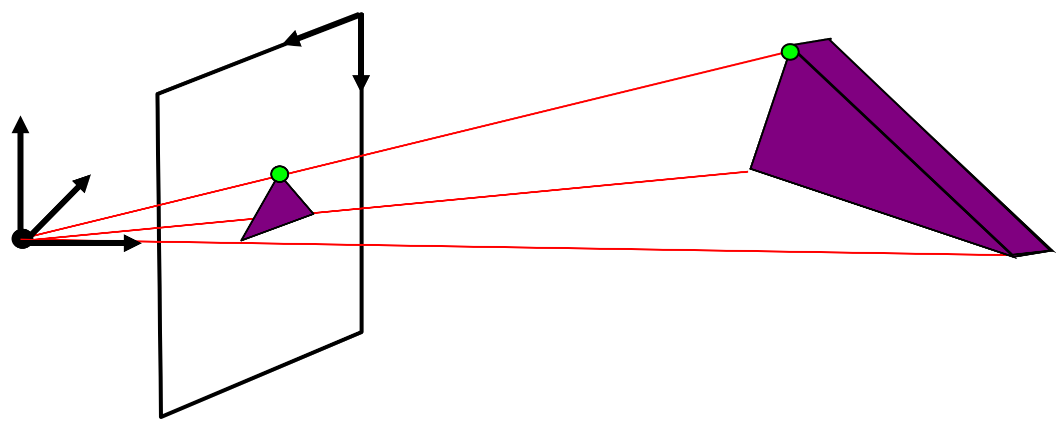
- Slow.
- Data-heavy.
- Impossible.
- Mixes up many factors.

The "Vision Problem"



The vision problem in general...

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.
- Basically, there are too many possible worlds that might (in theory) give rise to a particular image



Ill-posed

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.

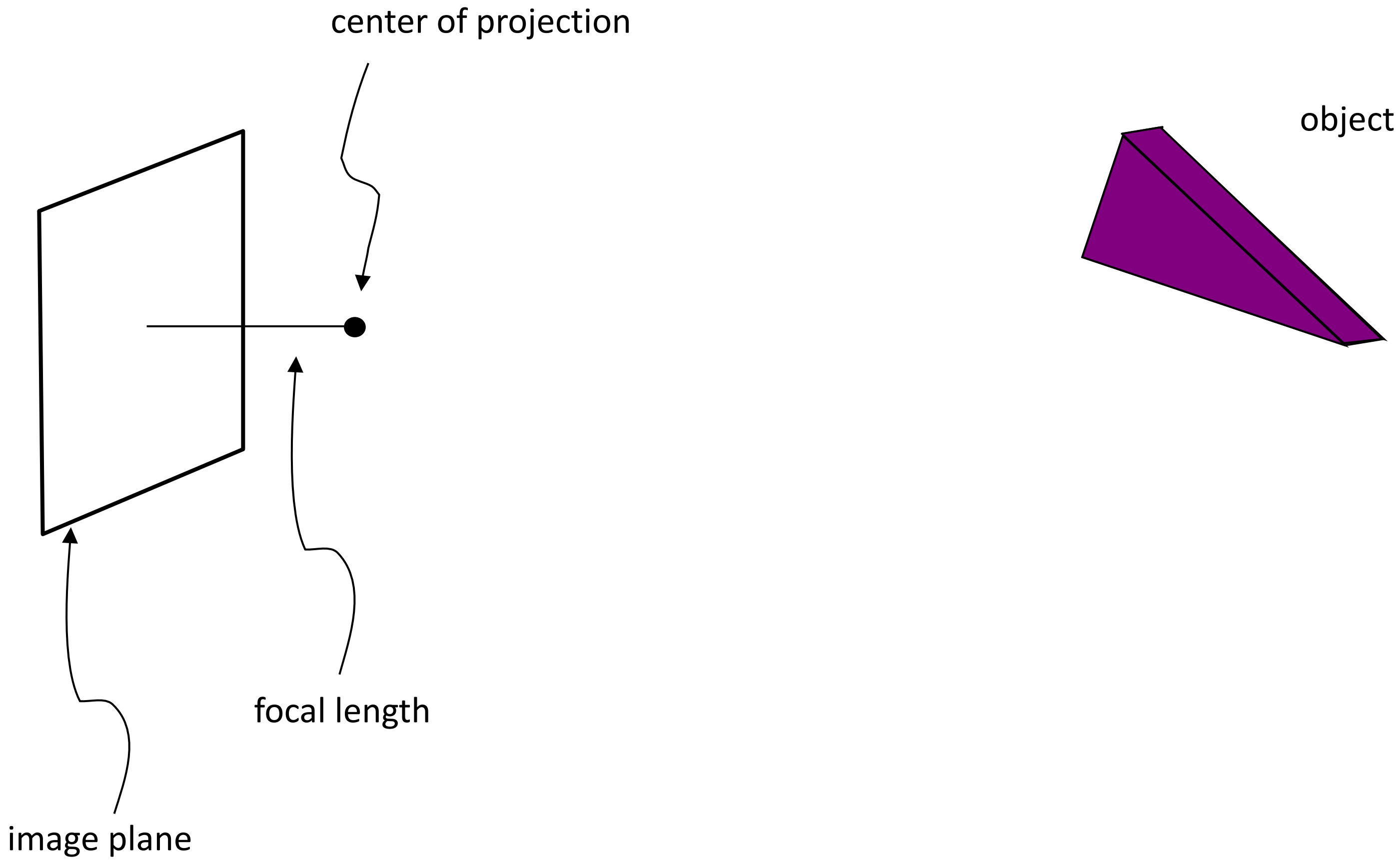
Ill-posed

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.

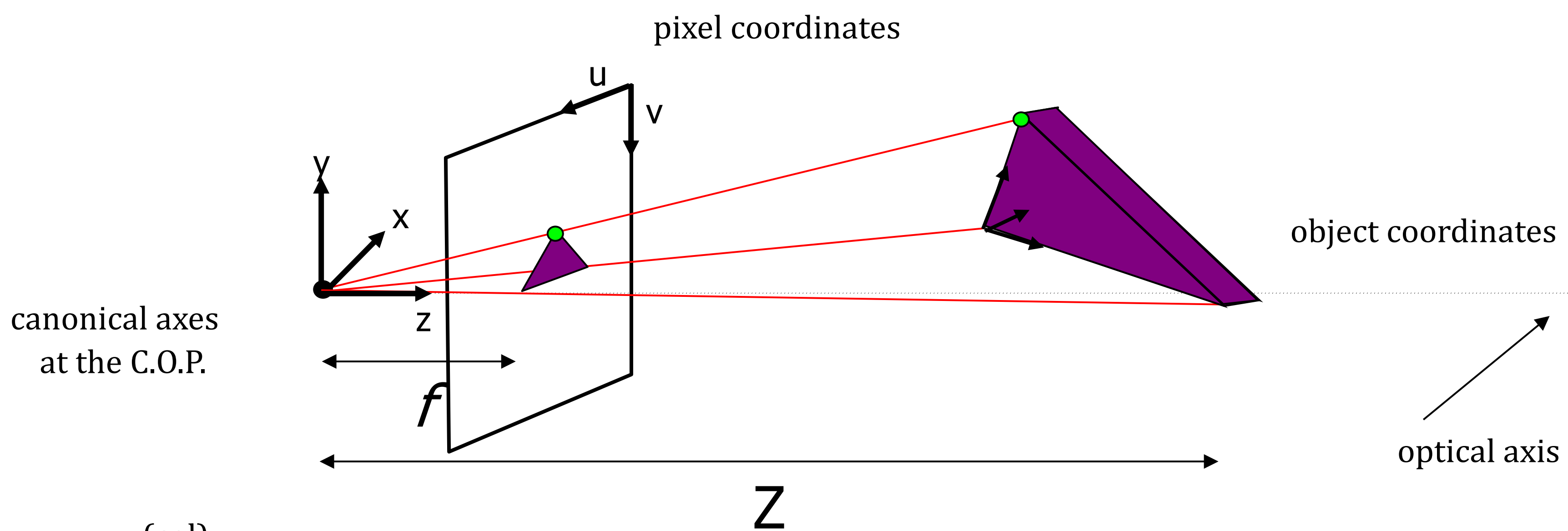
  – An image isn't enough to disambiguate the many possible 3d worlds that could have produced it.

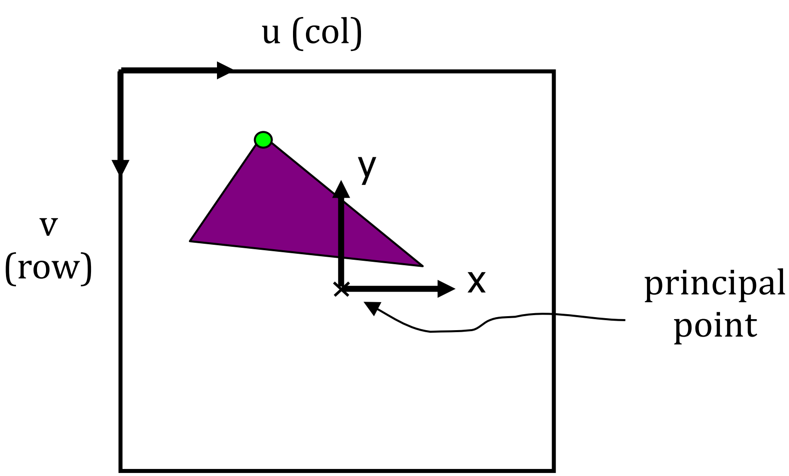
Camera Geometry

3D→2D transformation: perspective projection



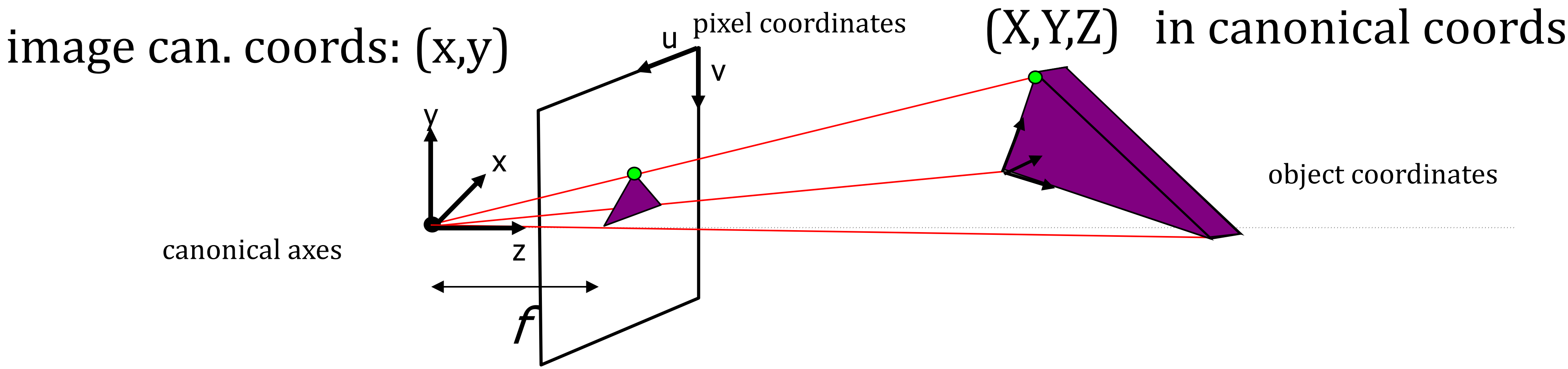
Coordinate Systems



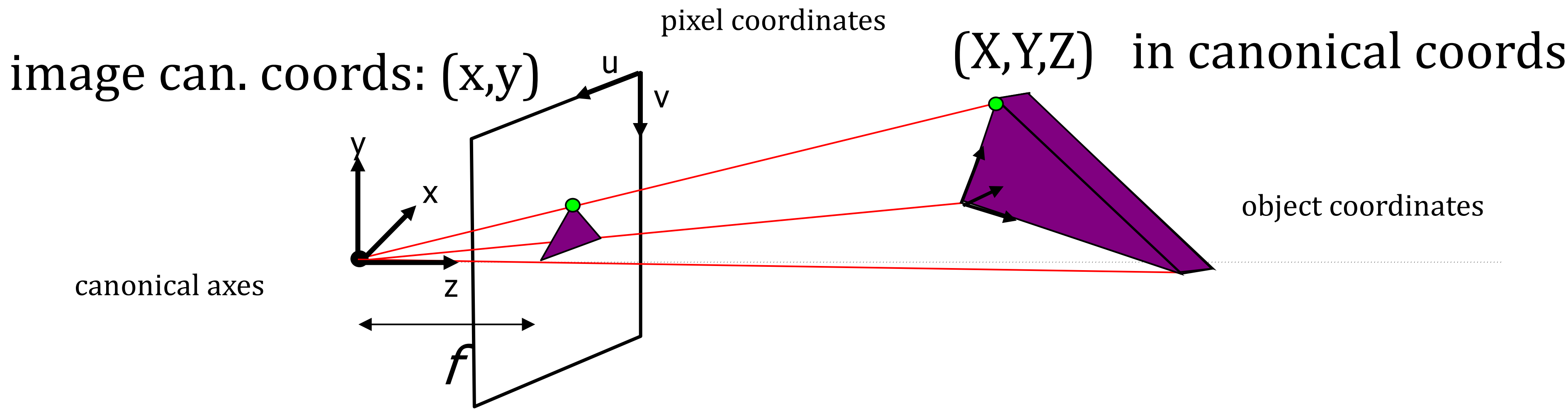


Add coordinate systems in order to describe feature points...

Coordinate Systems



From 3d to 2d



$$x = \frac{fX}{Z} \qquad y = \frac{fY}{Z}$$

a <u>nonlinear</u> transformation

goal: to recover information about (X,Y,Z) from (x,y)

Camera Calibration

- Camera Model
  - [*u v 1*] Pixel coords
  - $[x_w \quad y_w \quad z_w \quad 1]^T$ World coords

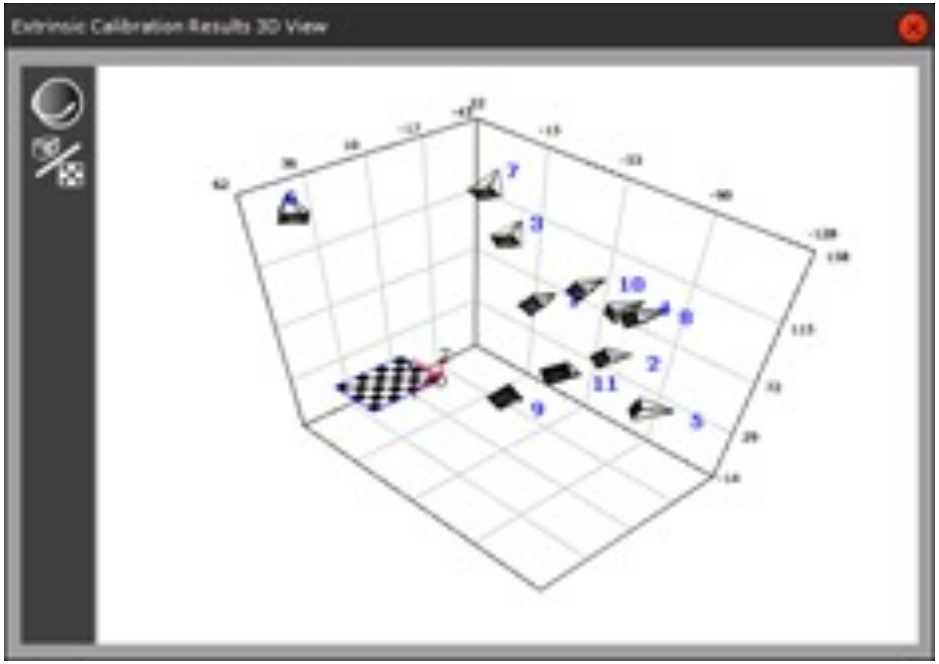
$$z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A[R \quad T] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

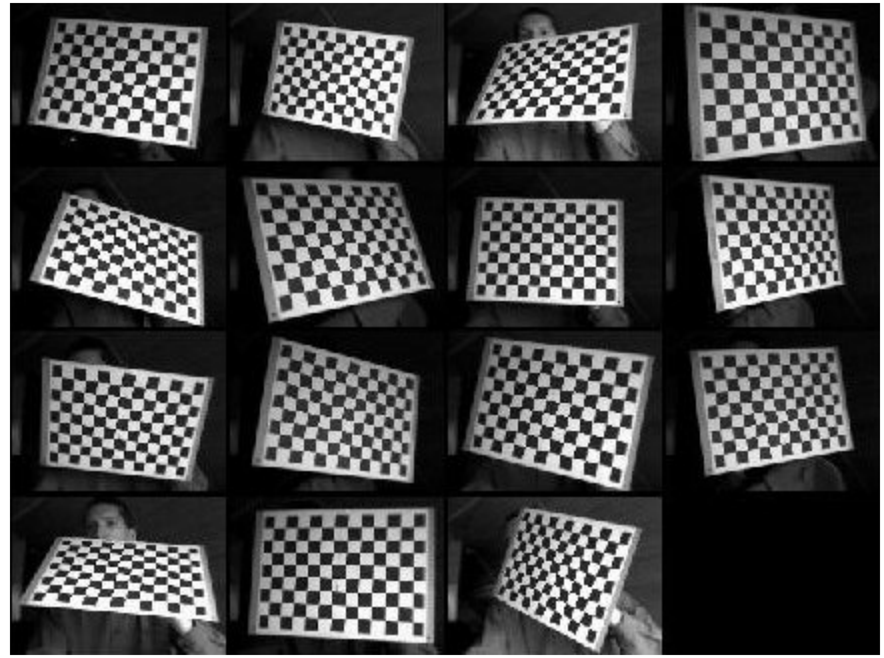
- Intrinsic Parameters
  - $\alpha_x = f \cdot m_x, \alpha_y = f \cdot m_y$ focal lengths in pixels
  - γ skew coefficient
  - u_0, v_o focal point

$$A = \begin{bmatrix} \alpha_x & \gamma & u_0 \\ 0 & \alpha_y & v_o \\ 0 & 0 & 1 \end{bmatrix}$$

- Extrinsic Parameters
  - $[R \quad T]$ Rotation and Translation

Camera Calibration



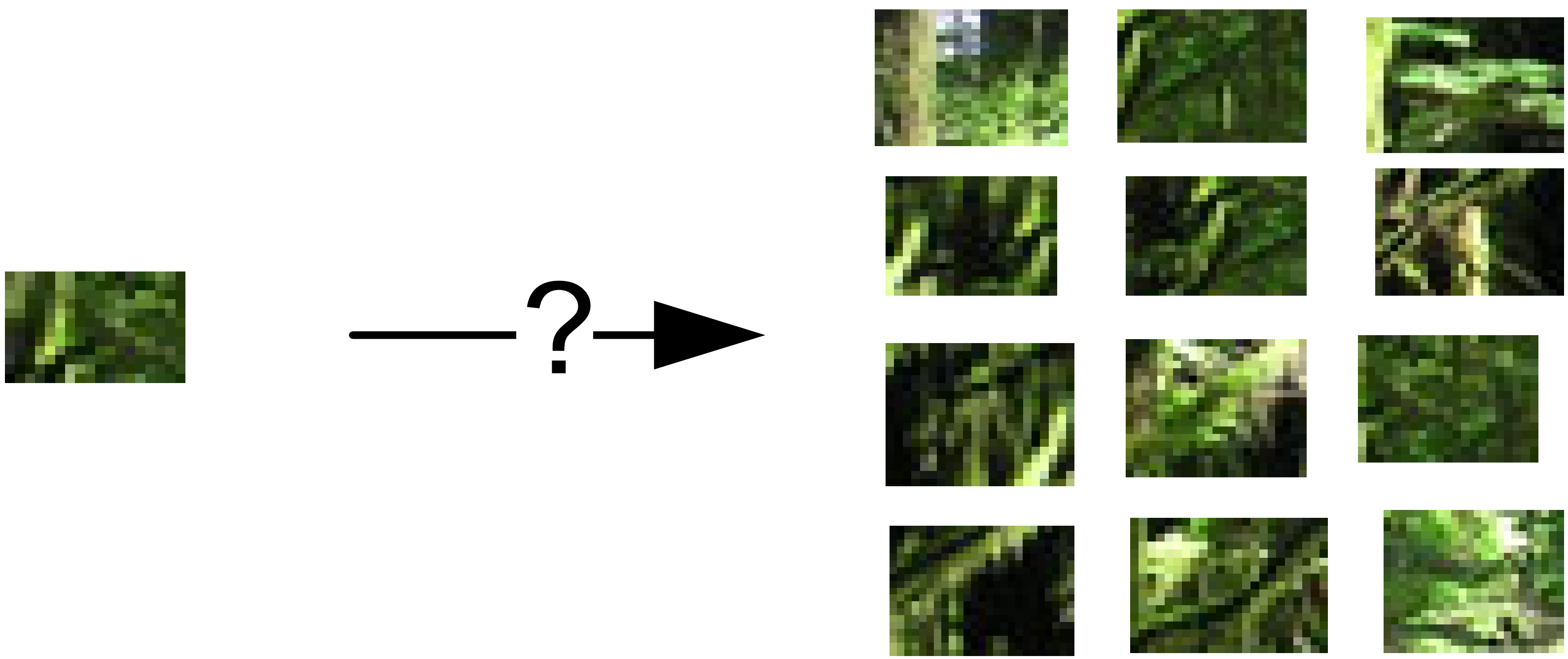


Existing packages in MATLAB, OpenCV, etc

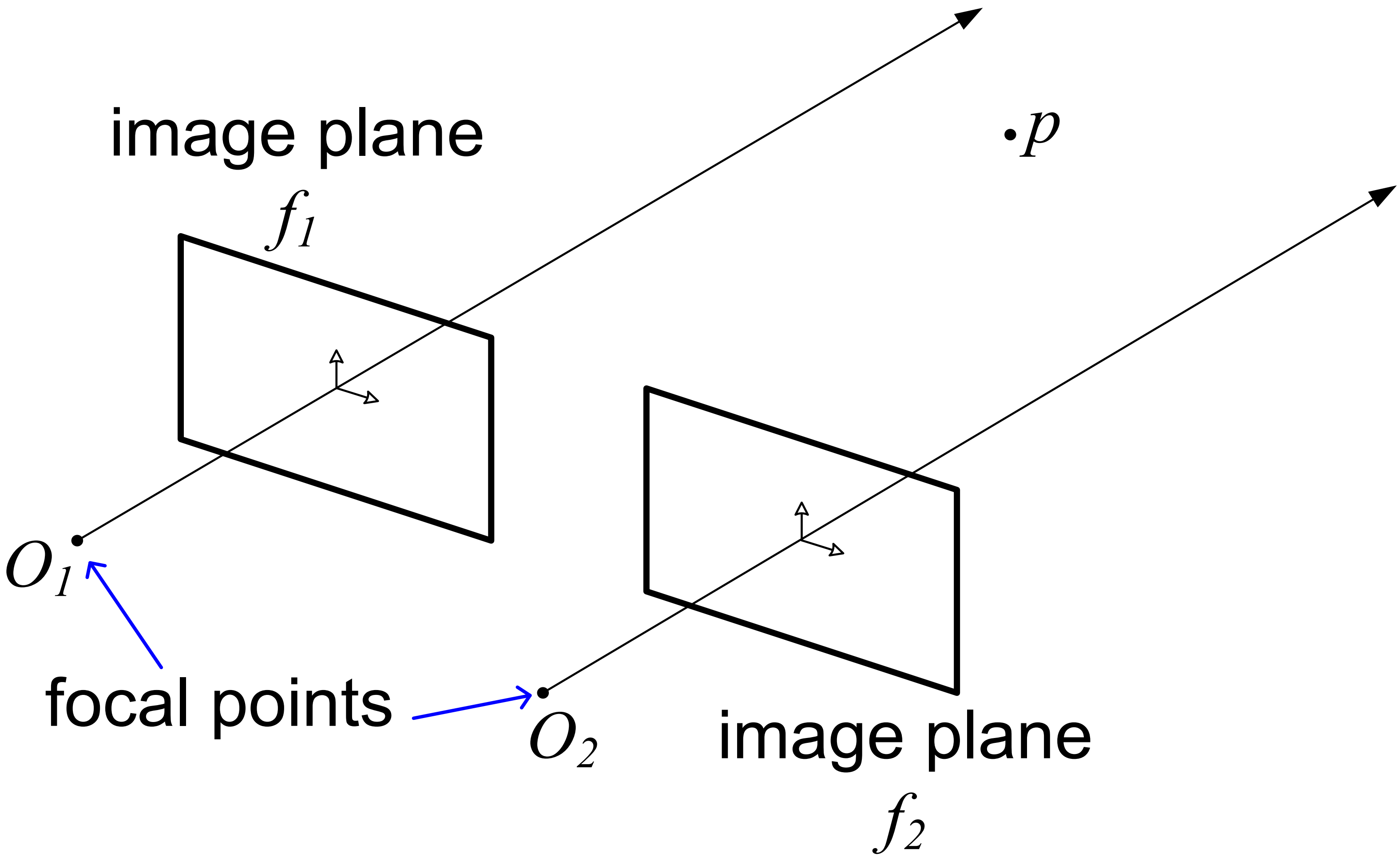
Correspondence Problem

Correspondence

From I_1 From I_2



Stereo Vision: Pinhole Camera



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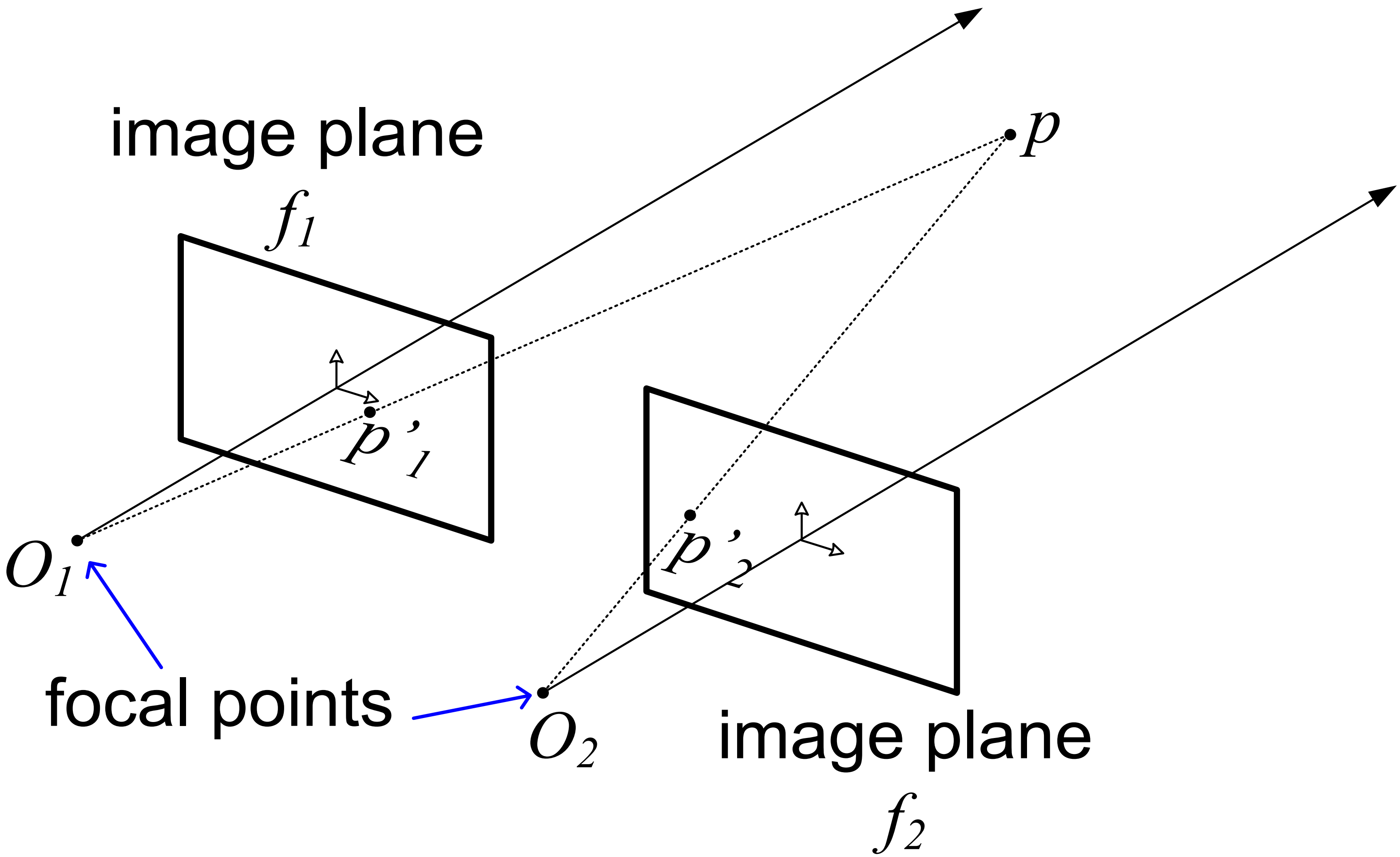
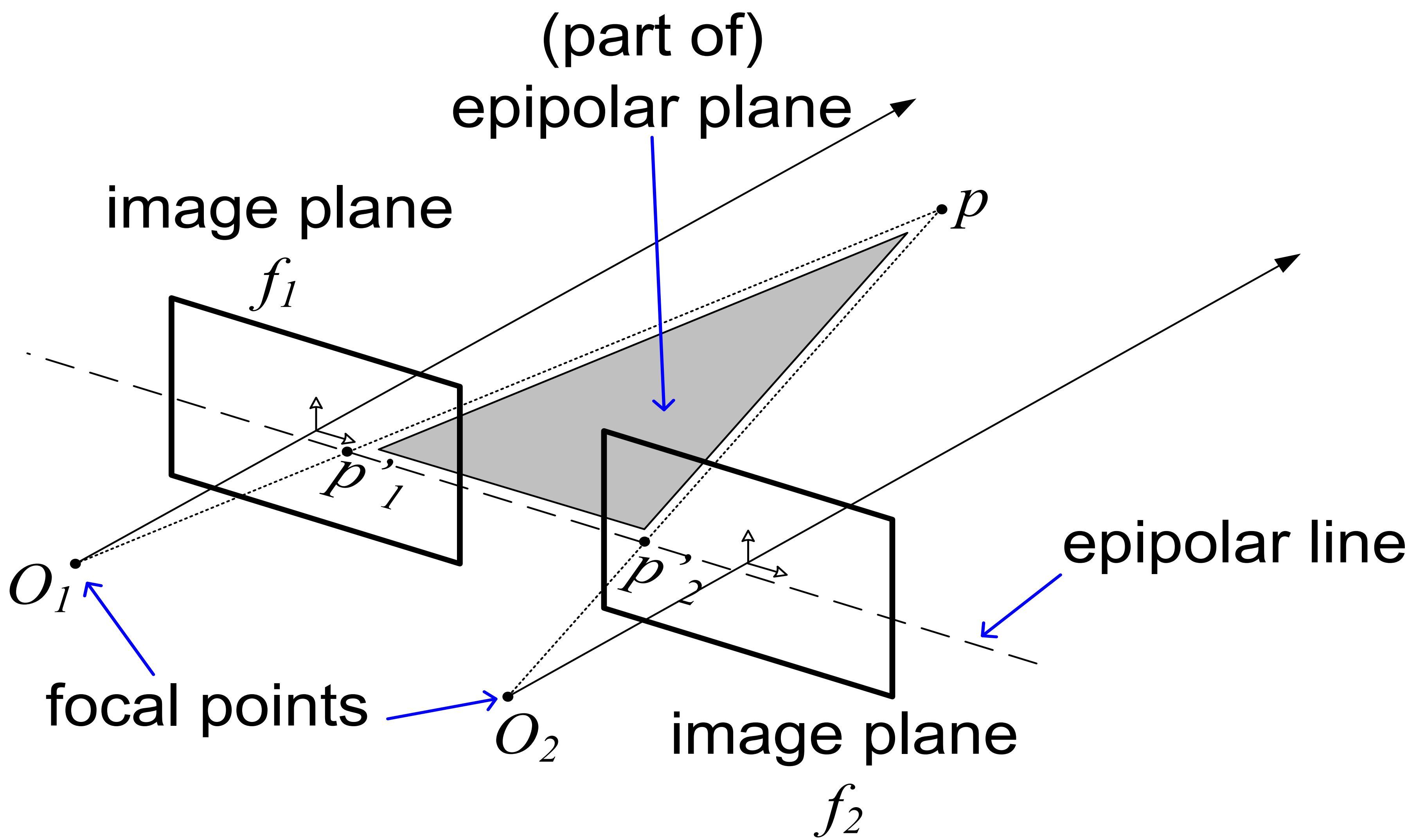
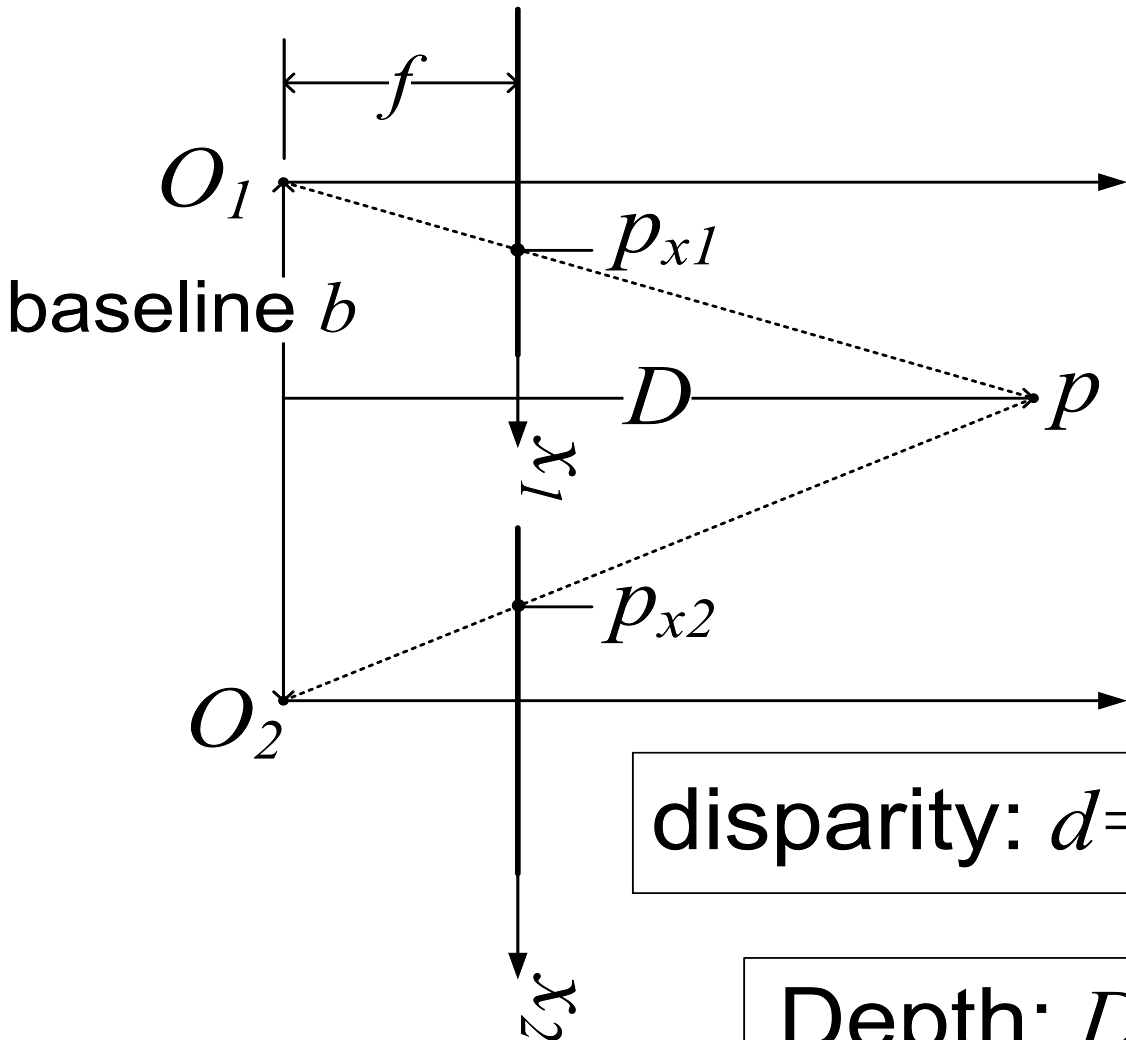


Stereo Vision: Pinhole Camera



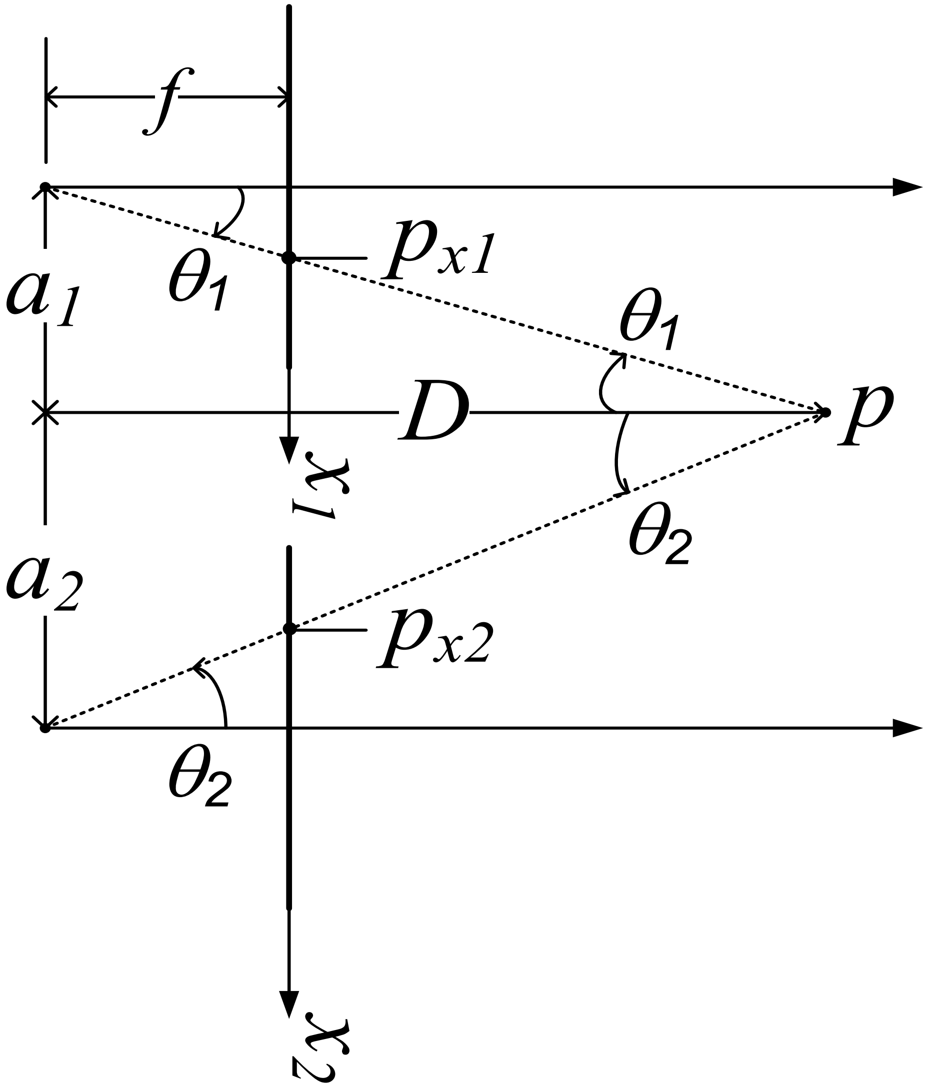
Stereo Vision: Pinhole



disparity: $d = p_{x1} - p_{x2}$

Depth: $D = fb/d$

Stereo Vision: Pinhole



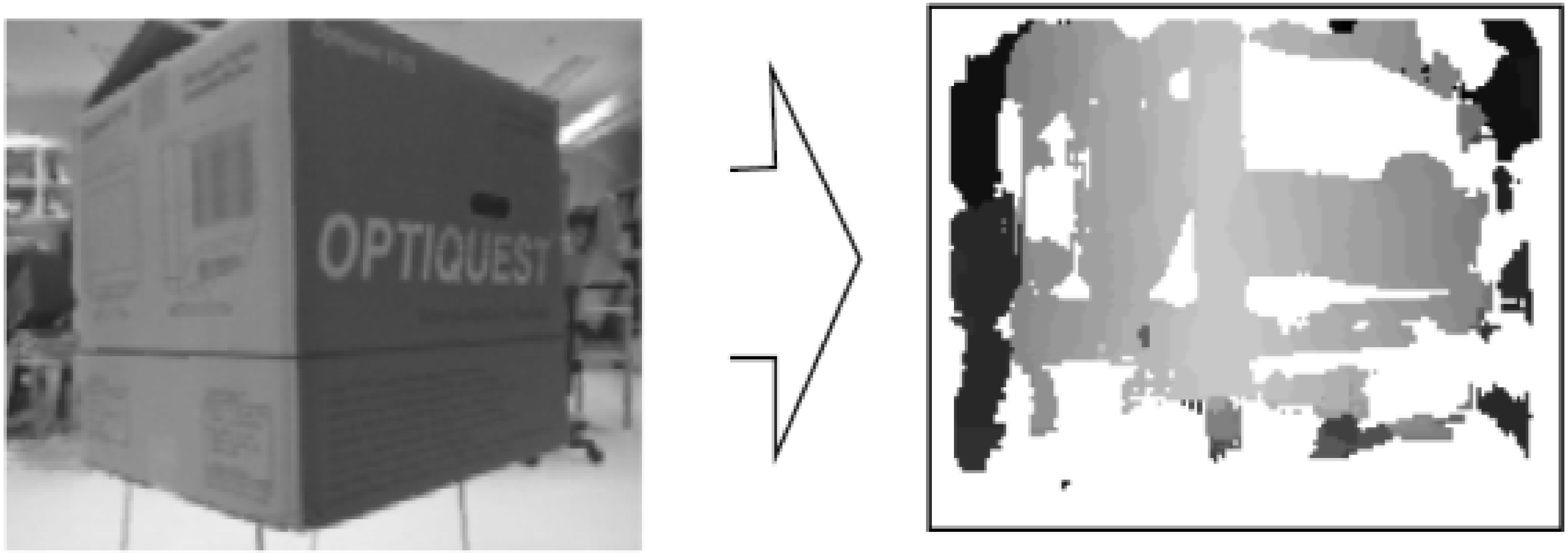
$$\frac{p_{x1}}{f} = \frac{a_1}{D}$$

$$\frac{p_{x2}}{f} = \frac{a_2}{D}$$

$$a_1 + a_2 = b$$

Large Baseline

Stereo: Disparity Map

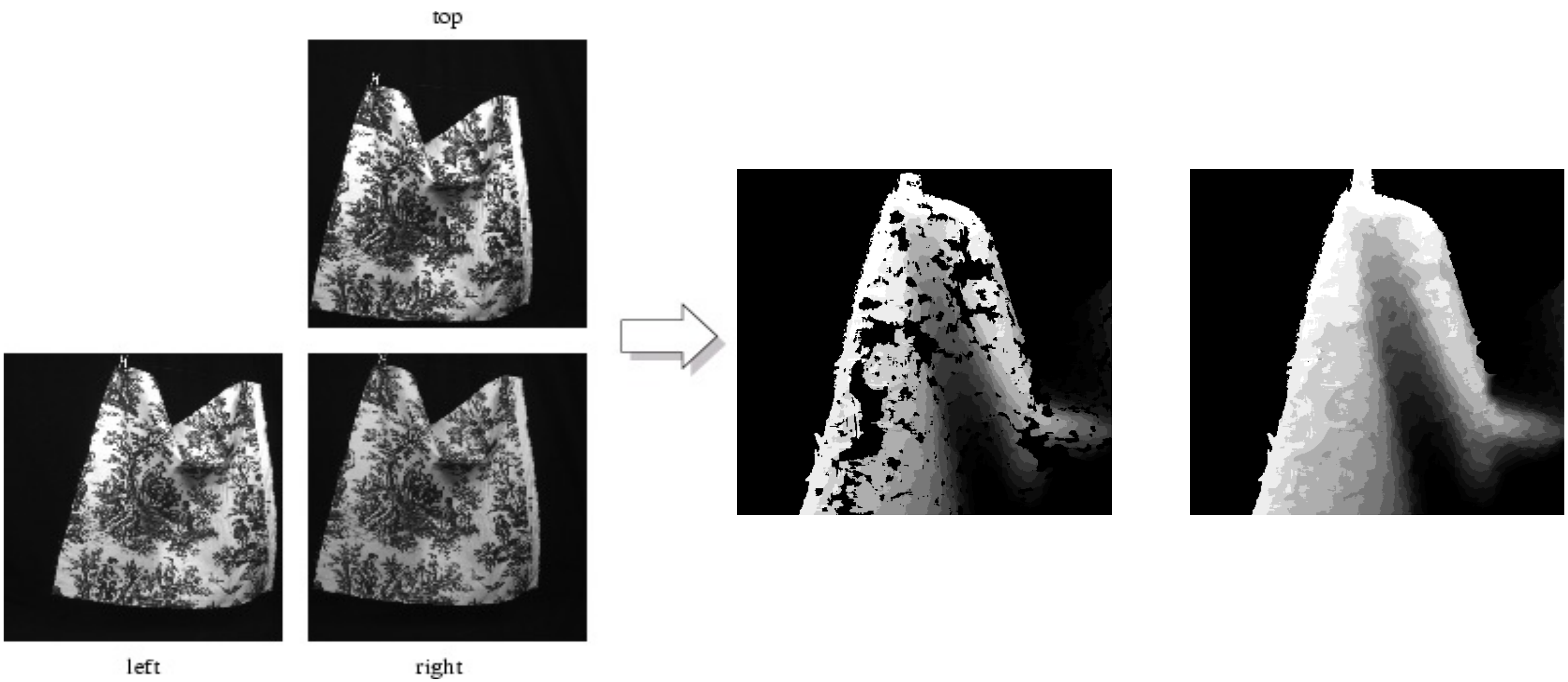


Using real-time stereo vision for mobile robot navigation

Don Murray Jim Little

Computer Science Dept.
University of British Columbia
Vancouver, BC, Canada V6T 1Z4

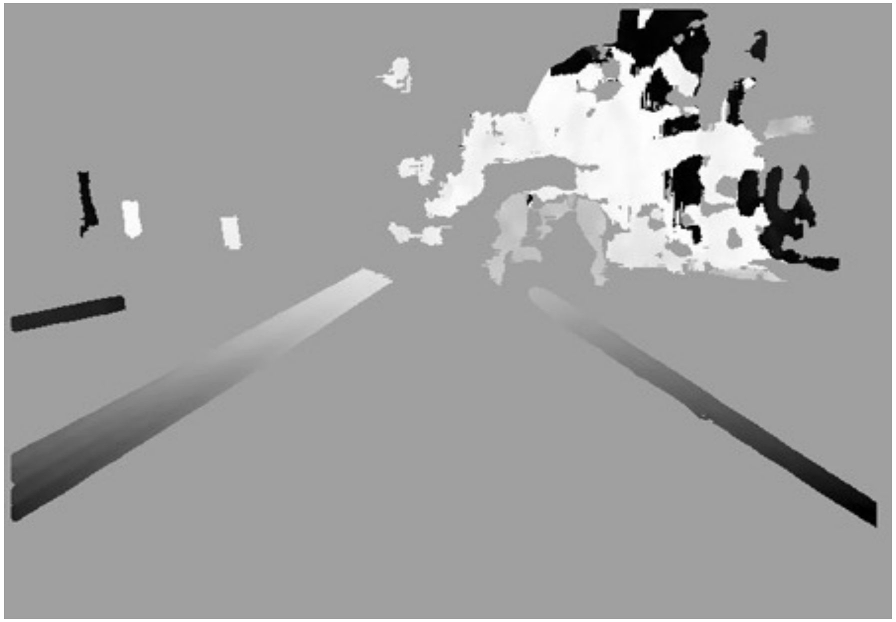
Another Example (Hole Filling)



Cloth Parameters and Motion Capture by David Pritchard

B.A.Sc., University of Waterloo, 2001

Depth Map in a City



Good Feature

- High Recall
- Good Precision
- Feature Detection
- Feature Matching
- Several Alternatives:
  - Harris Corners (OpenCV)
  - SURF (OpenCV)
  - SIFT
  - etc