ECE 470: Introduction to Robotics

Lecture 24

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Overview of Robot Vision

O. Introduction to Robot Vision
- What is Robot Vision?

I. Image Formation
- The science behind machine vision (+ represent as a form of signal)

II. Image Processing
- **Common techniques to manipulate, enhance & analyse images**

III. Robot Vision Applications
- 3D Vision; Photogrammetry; Vision-based techniques in robotics- visual servo, pose estimation, localization, mapping, navigation

Image Processing

- Thresholding & Histogram Processing
- Filtering
- Feature Detect & Extract
    - Edges & Corners
    - Lines, shapes, interest points

Overview of Robot Vision

Draft

Image Processing

- Thresholding & Histogram Processing
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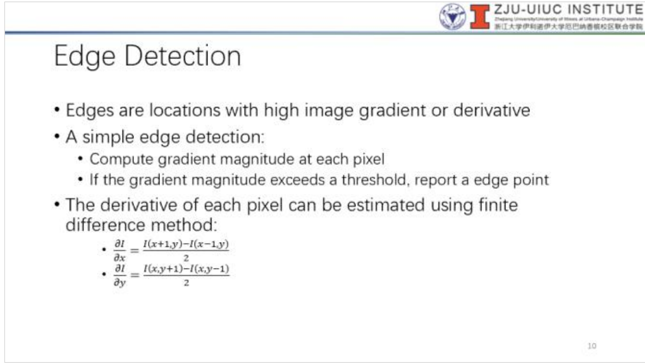
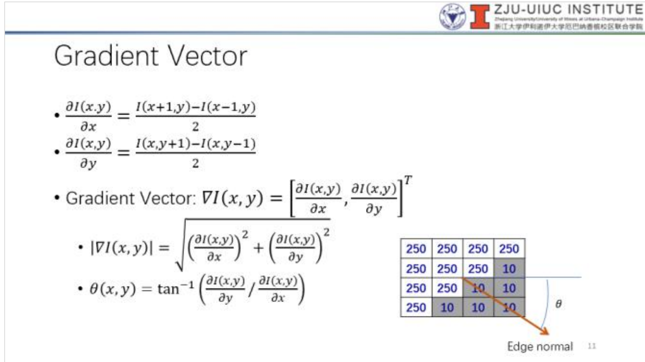
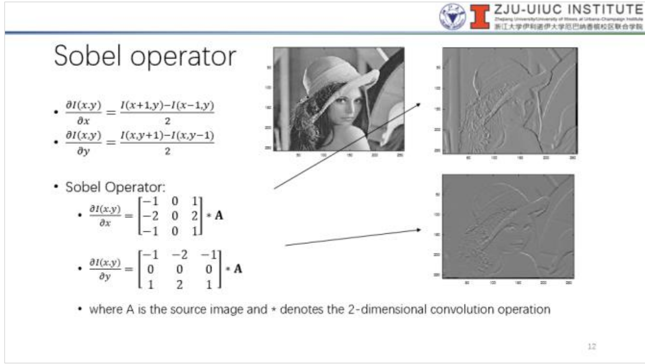






Canny Edge Detection (…… Last Lecture)

- Canny edge detection is probably the most used and taught edge detection algorithm
- Involves 5 steps:
  1. Apply Gaussian filter to smoothen the image in order to remove the noise
  2. Find the intensity gradients of the image
  3. Apply non-maximum suppression to get rid of spurious response to edge detection
  4. Apply edge detection using two threshold value
  5. Finalize edge detection by hysteresis
- J. Canny, “A Computational Approach to Edge Detection,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 8, no. 6, 1986.

Canny Edge Detection

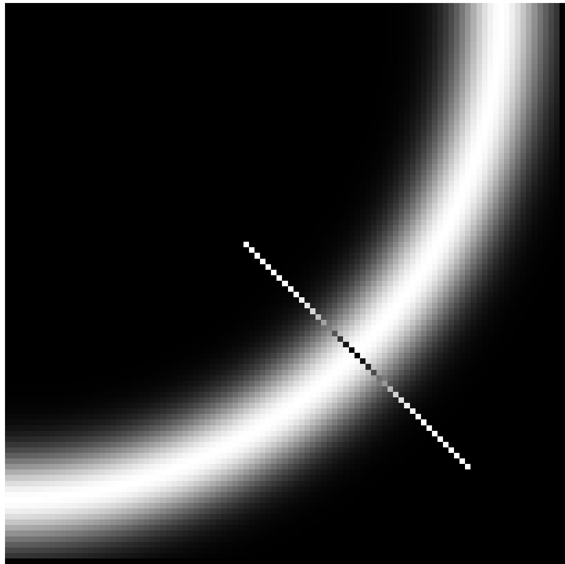
- Step (1): Apply Gaussian filter to smooth the image in order to remove the noise

Canny Edge Detection

- Step (2): Find the intensity gradients of the image

Canny Edge Detection

- How do we precisely localize the edge?



Canny Edge Detection

- Step (4): Apply edge detection using two threshold value K_H and K_L
- $Edge(x,y) = \begin{cases} E_{strong} & if\ \ |\nabla I(x,y)| > K_H \\ E_{average} & if\ \ K_L \leq |\nabla I(x,y)| \leq K_H \\ E_{weak} & if\ \ |\nabla I(x,y)| < K_L \end{cases}$

Canny Edge Detection

- Step (5): Finalize edge detection by hysteresis thresholding
  - Small K means more details
  - High K includes more noise
  - Hysteresis Thresholding allows us to apply both
    - Keep both high threshold K_H and low threshold K_L
    - Any edges with magnitude < K_L are discarded
    - Any edges with magnitude > K_H are kept
    - An edge with magnitude between the two threshold values is kept if there is a path of edges with magnitude > K_L connecting the edge to another edge with magnitude > K_H

Edge Detection

Original　　　　------------　　　　------------

Image Processing

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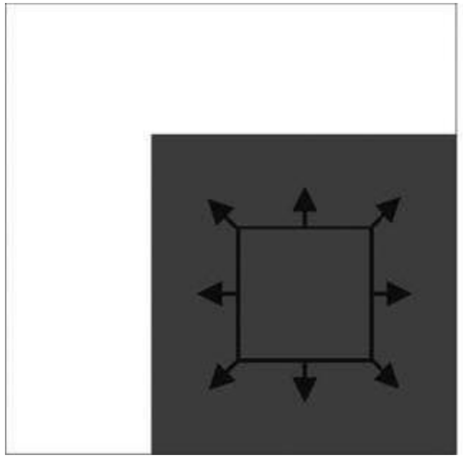
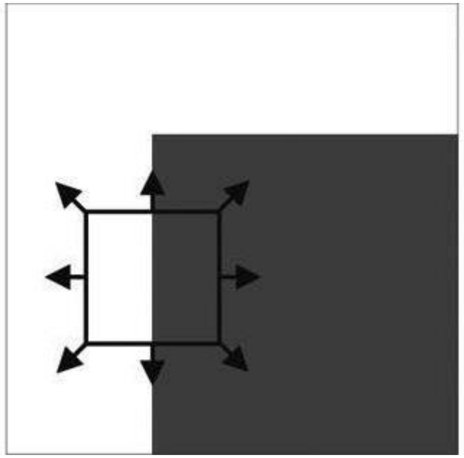
Corner Detection

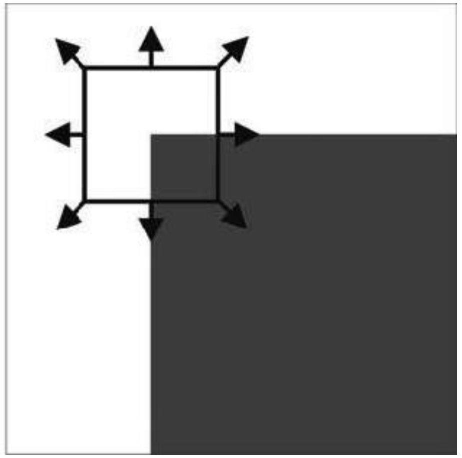
- Corner detection are used for many image feature extraction
  - Because corners are features with high repeatability



Flat region



Edge

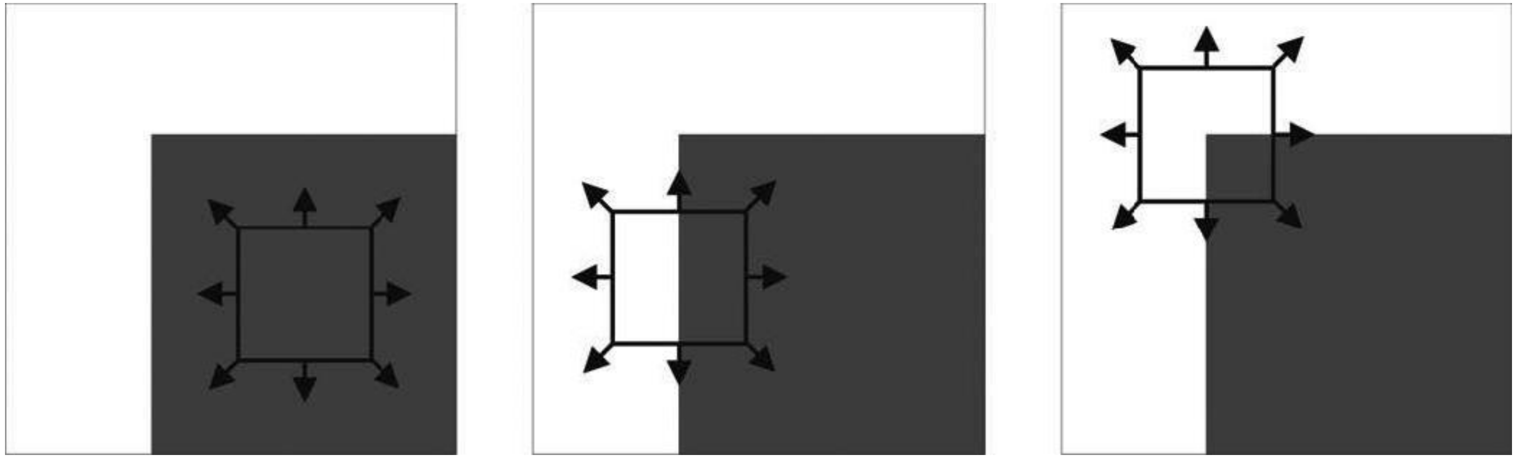


Corner

Images taken from Introduction to Autonomous Mobile Robot

Corner Detection

- Basic idea of corner detection: large change in appearance
  - Flat region: no change
  - Edge: no change along edge
  - Corner: significant change in all direction



Flat region Edge Corner

Images taken from Introduction to Autonomous Mobile Robot

Harris Corner Detector

- Consider taking an image patched centered on (u, v) and shifting it by (x, y), the sum of square differences SSD between these two patches is:

$$SSD(x, y) = \sum_u \sum_v [I(u, v) - I(u + x, v + y)]^2$$

- Using first-order Talyor expansion,

$$I(u + x, v + y) \approx I(u, v) + I_x(u, v)x + I_y(u, v)y$$

- Hence, SSD becomes

$$SSD(x, y) \approx \sum_u \sum_v \left[I_x(u, v)x + I_y(u, v)y\right]^2$$

$$= \sum_u \sum_v \left[I_x^2 x^2 + 2xyI_xI_y + I_y^2 y^2\right]^2$$

Harris Corner Detector

$$
\begin{aligned}
SSD(x,y) &= \sum_u \sum_v \left[I_x^2 x^2 + 2xyI_xI_y + I_y^2 y^2\right]^2 \\
&= \sum_u \sum_v [x \quad y] \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \\
&= [x \quad y] \sum_u \sum_v \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}
\end{aligned}
$$

- $SSD(x,y) = [x \quad y] M \begin{bmatrix} x \\ y \end{bmatrix}$
- Since M is symmetric, we can rewrite the matrix as:

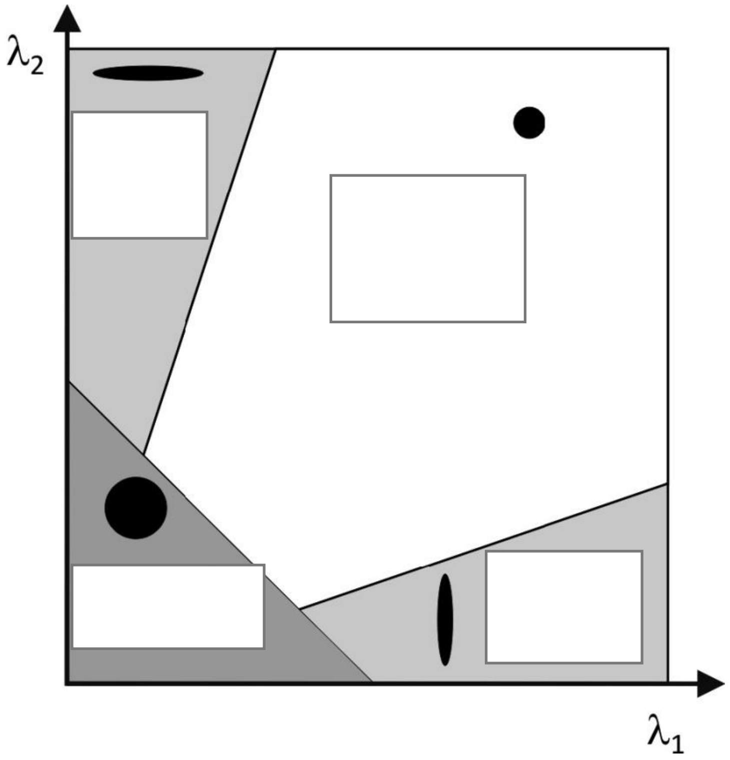
$$M = A^{-1} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} A$$

- where λ_1 and λ_2 are the eigenvalues of M

Harris Corner Detector

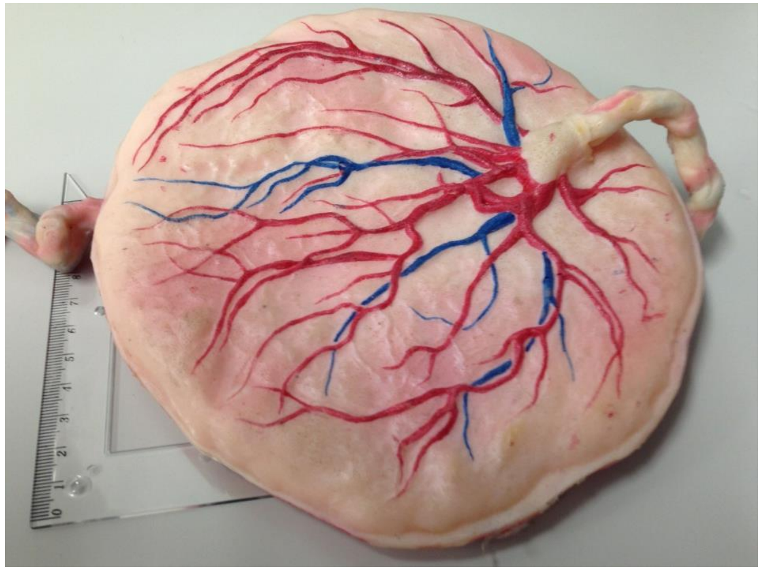
- As mentioned, a corner is characterized by a large variation of SSD in all direction, the larger the variation in that direction

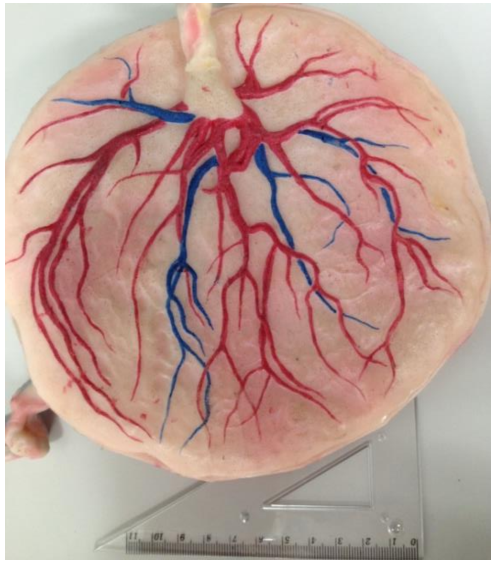
- Both λ are small means flat region
- One strong and one weak λ means edge
- Two strong λ means corner



Match two images

- Are these objects the same?
  - Pixel to pixel comparison might not work



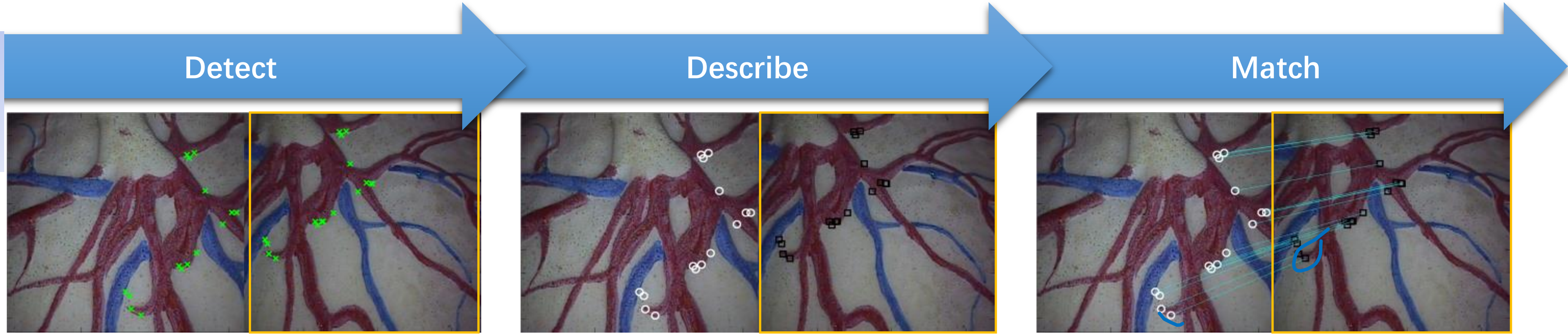


Match two images

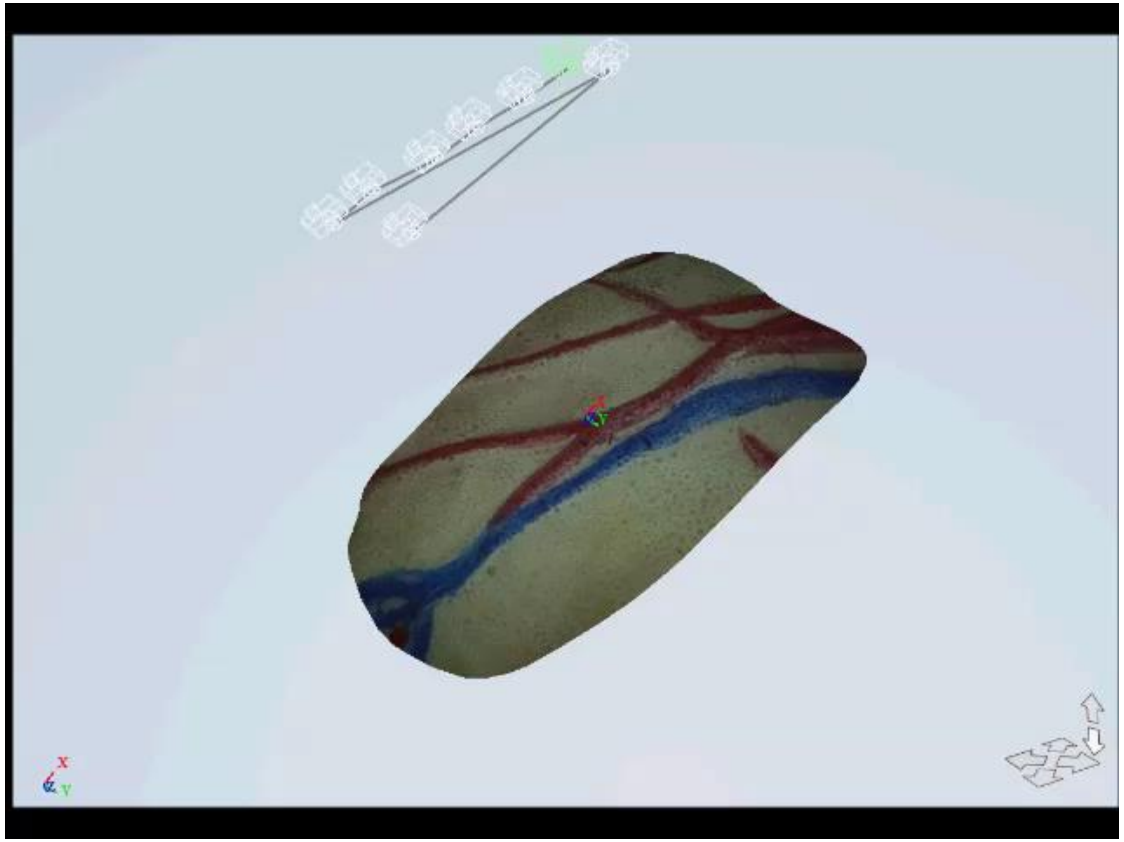
- Feature matching
- Detect; Describe; Match; Transform (for image mapping)

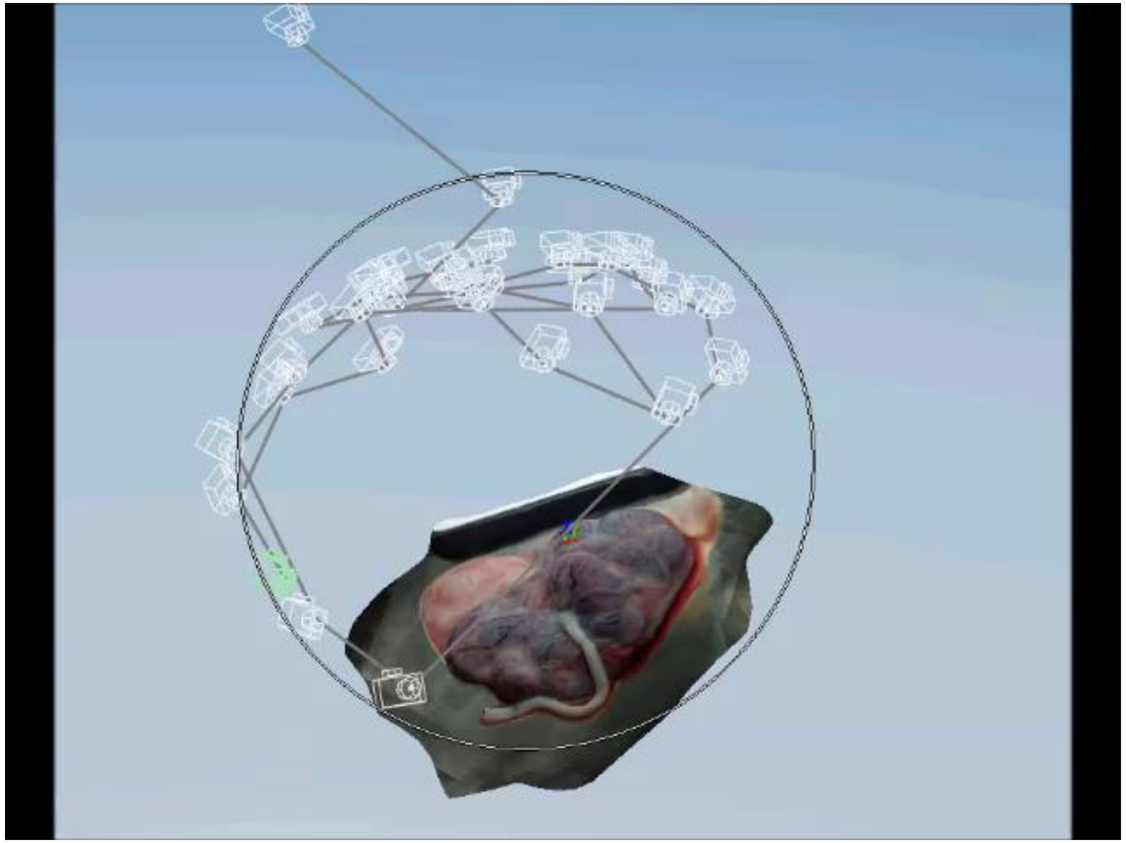
Feature Detection, Description, & Matching

Feature Matches



Example of Applications in Corner Detection





Example of Applications in Corner Detection

- Microsoft Photosynth

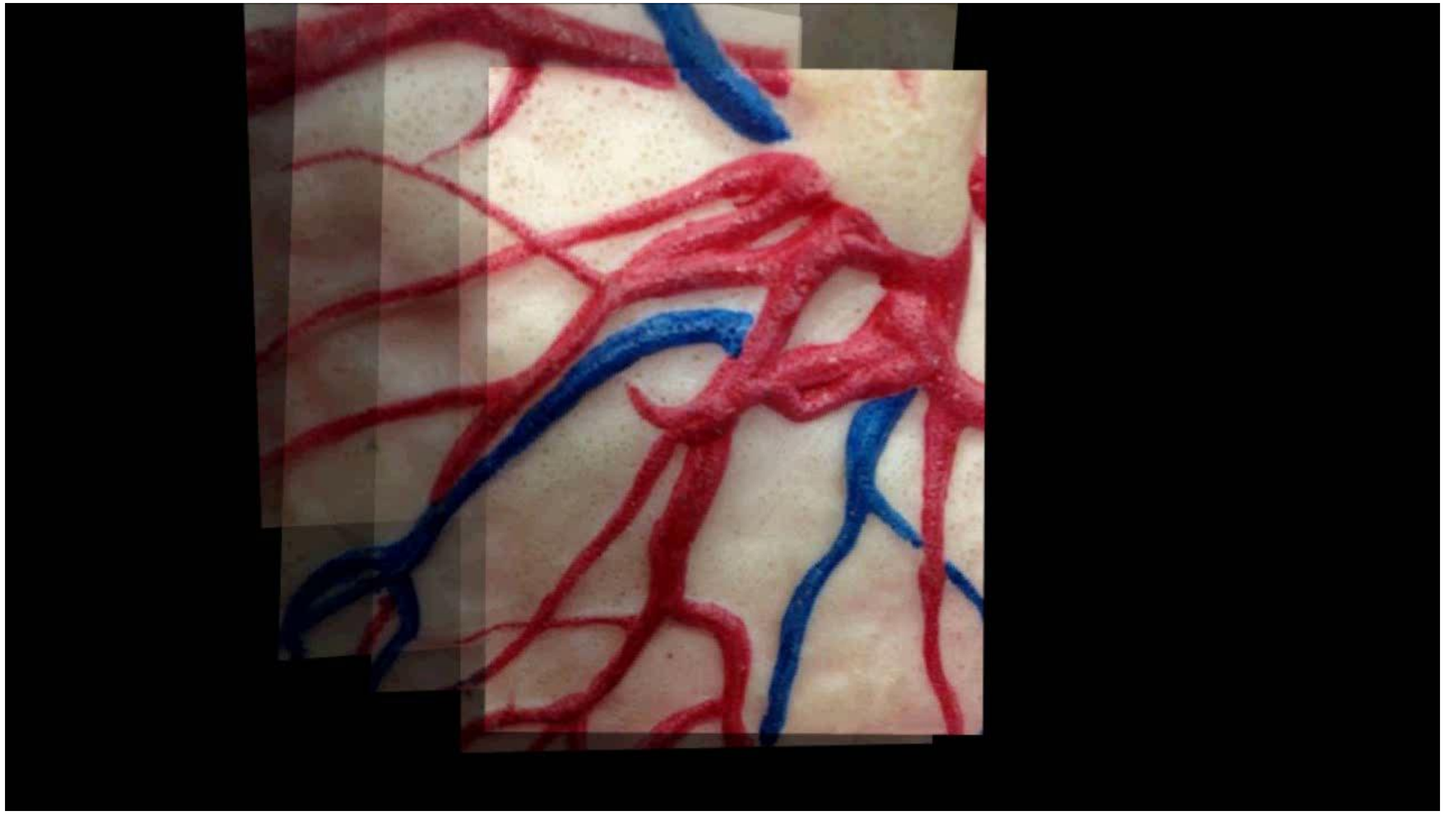


Image Processing

- Image Enhancement
  - ☑Thresholding & Histogram Processing
  - ☑ Filtering
- Image Analysis
  - ☑ Feature Detection
    - ☑ Edges
    - ☑ Interest points- Corners
    - Lines & Shapes
    - Target Tracking