Visual Features: Keypoints

(Harris, Shi-Tomasi, Förstner, DoG)

Visual features

Keypoint | Descriptors

{Locally distinct location in an image}

{Summary of the local structures around the Keypoint}

- Harris corners
- Shi-Tomasi corner detector
- Förstner operator
- Difference of Gaussians (DoG)

- SIFT (Scale Invariant Feature Transform)
- BRIEF (Binary Robust Independent Elementary Features)
- ORB (Oriented FAST rotated BRIEF)

Corners

⇒ Corners are often highly distinct points.

⇒ Corners are invariant to translation, rotation and illumination.

⇒ Corner ⇒ Two edges in roughly orthogonal directions.

⇒ Edge ⇒ A sudden brightness change.

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* Finding Corners

⇒ To find corners we need to search for intensity changes in two directions.

⇒ Compute the Sum of Squared difference of neighbor pixels around (X,Y).

$$f(X,Y) = \sum_{(u,v)\in W_{xy}} \left(I(u,v) - I(u+\delta u, v+\delta v) \right)^2$$

Local patch around (x,y)

⇒ Using taylor expansion, we obtain:

$$I(u+\delta u, v, \delta v) \approx I(u,v) + [J_x \; J_y] \begin{bmatrix} \delta u \\ \delta v \end{bmatrix}$$

$$\Rightarrow f(X,Y) \approx \sum_{(u,v)\in W_{xy}} \left([J_x \; J_y] \begin{bmatrix} \delta u \\ \delta v \end{bmatrix} \right)^2$$

$$\boxed{f(X,Y) \approx \sum_{(u,v)\in W_{xy}} \begin{bmatrix} \delta u \\ \delta v \end{bmatrix}^T \begin{bmatrix} J_x^2 & J_x J_y \\ J_x J_y & J_y^2 \end{bmatrix} \begin{bmatrix} \delta u \\ \delta v \end{bmatrix}}$$

$$f(x,y) = \begin{bmatrix} \delta u \\ \delta v \end{bmatrix}^T \begin{bmatrix} \sum_w J_x^2 & \sum_w J_x J_y \\ \sum_w J_y J_x & \sum_w J_y^2 \end{bmatrix} \begin{bmatrix} \delta u \\ \delta v \end{bmatrix}$$

Structure matrix

* Structure Matrix

⇒ Key to finding edges and corners

⇒ It encodes the changes in image intensity in a local area.

$$M = \begin{bmatrix} \sum_w J_x^2 & \sum_w J_x J_y \\ \sum_w J_y J_x & \sum_w J_y^2 \end{bmatrix}$$

⇒ Jacobians computed via a convolution with a gradient kernel such as Scharr or Sobel:

$$J_x^2 = (D_x * I)^2$$

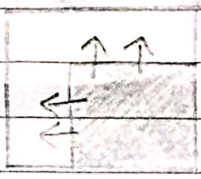
$$J_x J_y = (D_x * I)(D_y * I)$$

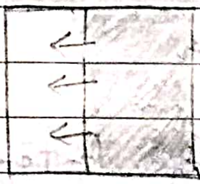
$$J_y^2 = (D_y * I)^2$$

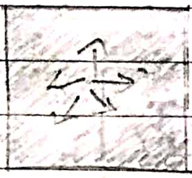
$$D_x^{Scharr} = \frac{1}{32}\begin{bmatrix} 3 & 10 & 3 \\ 0 & 0 & 0 \\ -3 & -10 & -3 \end{bmatrix} \qquad D_x^{Sobel} = \frac{1}{8}\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

$$D_y^{Scharr} = \frac{1}{32}\begin{bmatrix} 3 & 0 & -3 \\ 10 & 0 & -10 \\ 3 & 0 & -3 \end{bmatrix} \qquad D_y^{Sobel} = \frac{1}{8}\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

⇒ Structure matrix summarizes the dominant directions of the gradient around a point

 ⇒ $M = \begin{bmatrix} \gg 1 & \sim 0 \\ \sim 0 & \gg 1 \end{bmatrix}$ ✓

 ⇒ $M = \begin{bmatrix} \sim 0 & \sim 0 \\ \sim 0 & \gg 1 \end{bmatrix}$ ✗

 ⇒ $M = \begin{bmatrix} \sim 0 & \sim 0 \\ \sim 0 & \sim 0 \end{bmatrix}$ ✗

⇒ Key Idea: Considers points as corners if their structure matrix has two large Eigenvalues.

⇒ Three similar approaches proposed in:

- Förstner (1987)
- Harris (1988)
- Shi-Tomasi (1994)

⇒ All rely on the structure matrix.

⇒ Use different criterion for deciding if a point is a corner or not.

⇒ Förstner offers subpixel estimation.

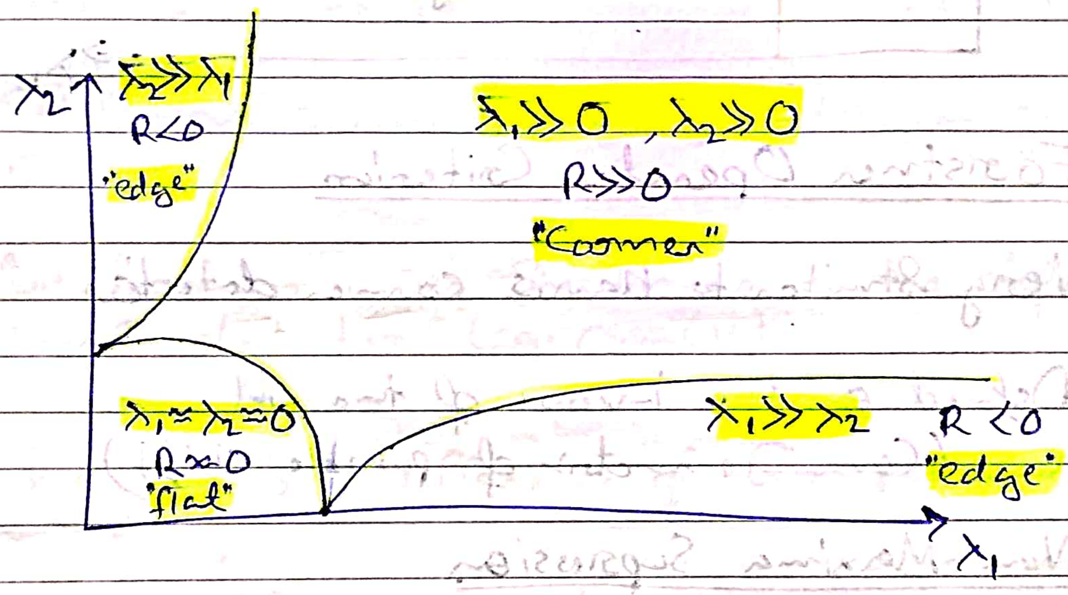
★ Harris Corner Criterion

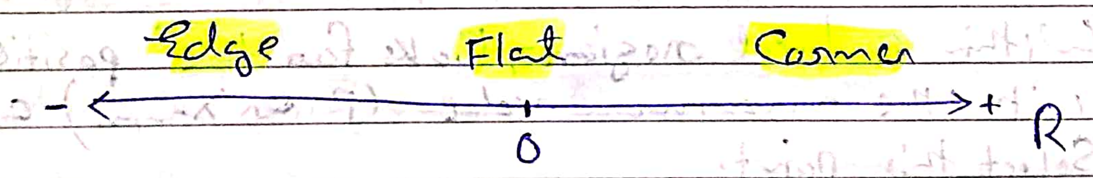
⇒ Criterion:

$$R = \det(M) - k(\text{trace}(M))^2$$

$$= \lambda_1 \lambda_2 - k(\lambda_1 + \lambda_2)^2$$

$\rightarrow k \in [0.04, 0.06]$



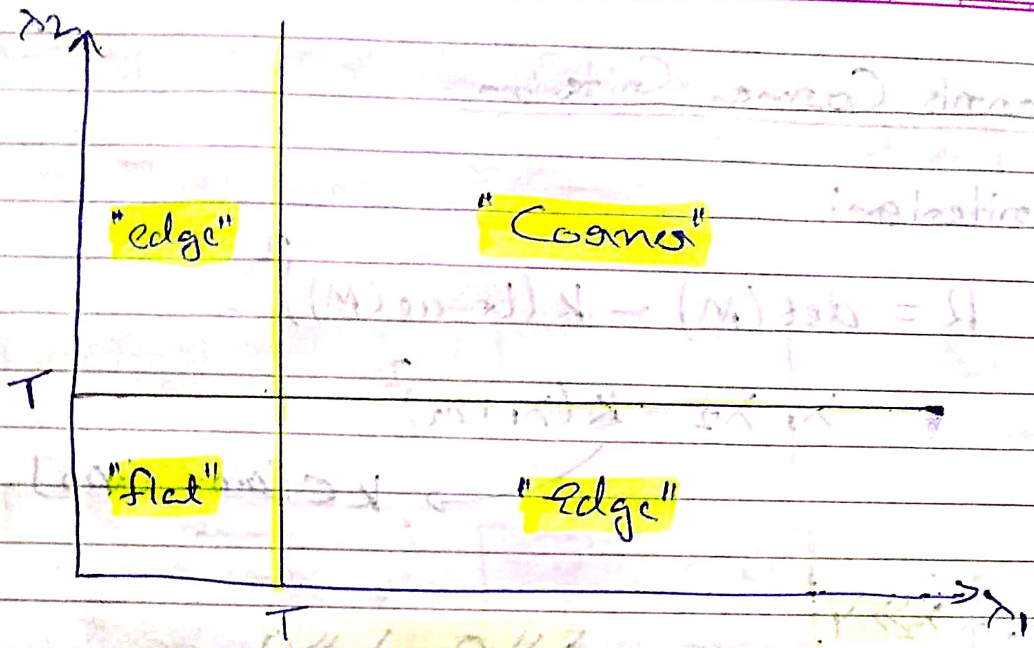


★ Shi-Tomasi Corner Detector

⇒ Criterion: Threshold smallest Eigenvalue

$$\lambda_{min}(M) = \frac{\text{trace}(M)}{2} - \frac{1}{2}\sqrt{\text{trace}(M)^2 - 4\det(M)}$$

$$\lambda_{min}(M) \geq T \Rightarrow \text{Corner.}$$



★ Förstner Operator Criterion

⇒ Very similar to Harris corner detection

⇒ Defined on the inverse of the M
(Covariance matrix of possible shift)

★ Non-Maxima Supression

⇒ Within a local region, looks for the position with the maximum value (R or λ_{min}) and select this point.

★ Implementation Remarks

⇒ RGB to gray-scale conversion first.

⇒ Real images are affected by noise, smoothing of the input is suggested.

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★ Corner Detectors Comparison

⇒ All three detectors perform similarly.

⇒ Forstner was the first one and additionally described subpixel estim.

⇒ Harris became the most famous corner detector in the past

⇒ Shi-Tomasi seems to slightly outperform Harris corners.

⇒ Most libraries uses Shi-Tomasi as the default corner detector. (eg. OpenCV)

Keypoints: Difference of Gaussians

⇒ A variant of corner detection

⇒ Provides responses at:

Corners, edges & blobs

{ Mainly constant region but different to its surrounding. }

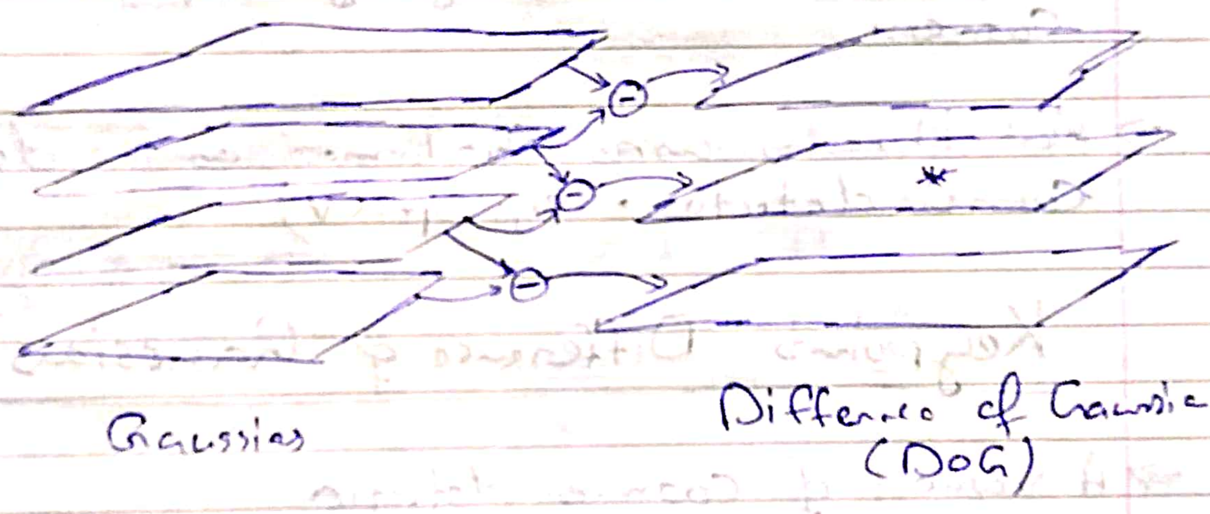
⇒ Difference of Gaussians over scale-Space pyramid

⇒ Procedure: (over different image pyramid levels)

① Gaussian Smoothing (differently blurred images)

② Difference of Gaussians: find extrema

③ Maxima suppression at edges.



★ Extrema Suppression

⇒ The DOG finds blob-like and corner like image structures but also leads to strong responses along edges.

⇒ Edges are bad for matching.

⇒ Eliminate edges via Eigenvalue test.