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Review

What Are the Limitations of a Canny Edge Detector?

- It consumes a lot of time due to its complex computation.
- It is difficult to implement to reach the real-time response.

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Translation and rotation invariant feature detection
- Moravec corner
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Feature

A feature is a piece of information about the content of an image.
- Features may be specific structures in the image such as points, edges or objects.

The features can be classified into two main categories:
- Keypoint features (Corners) & Edges

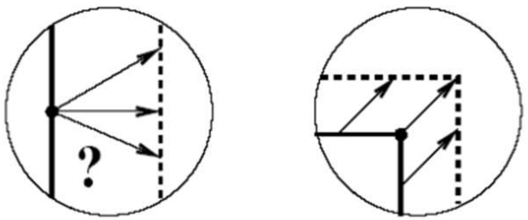
Corners vs Edges

Corners

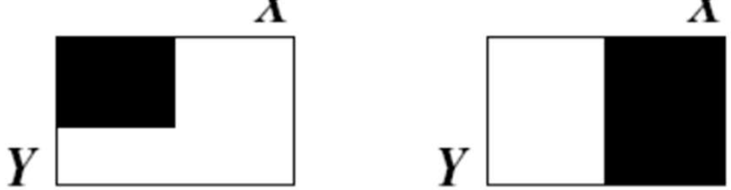
- Often described by the appearance of patches of pixels surrounding the point location.
- both partial derivatives f_x and f_y are large
- motion vectors are unambiguous at corner

Edges

- The features that can be matched based on their orientation and local appearance.
- partial derivatives in certain direction is high, while in the orthogonal direction is low
- motion vectors are ambiguous at edge



ambiguity unambiguity



Corner Edge

Properties of good features/detectors

Locality: should be local, robust to occlusion and clutter.

Accuracy: should be precisely localized.

Invariant: should be detected despite geometric or photometric changes in the image.

Repeatability: same feature will be detected in several images of the same scene.

Efficiency: close to real-time performance.

Feature Detection And Matching

Feature Detection : Identifying the Interest Point.

Feature Matching : Identifying similar features.

- For two images we may get a set of pairs (X, Y) ↔ (X’, Y’)
- (X, Y) is a feature in one image and (X’, Y’) its matching feature in the other image.

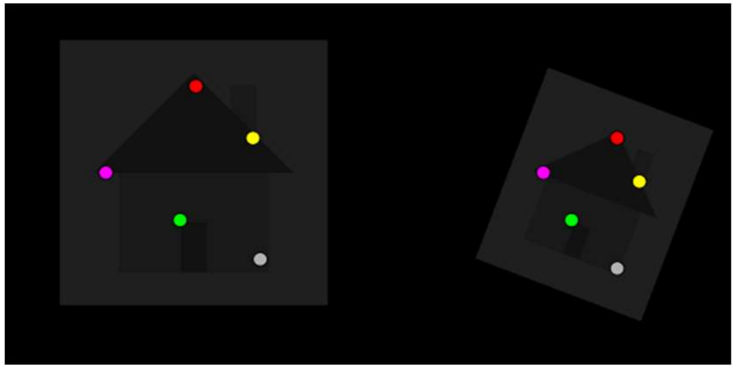
Interest Point(Corner)

The terms corners and interest points are used somewhat interchangeably.

Corner (Interest point):

- the point at which the various direction of the boundary of the object changes abruptly
- intersection point between two or more edge segments.

Corresponding points (or features) between images enable the estimation of parameters describing geometric transforms between the images.

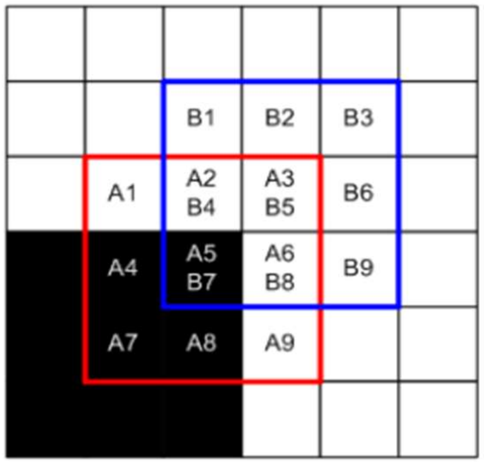


Moravec Corner Detection

Measure intensity variation at (x, y) by shifting a small window (3x3 or 5x5) by one pixel in each of the eight directions.

This variation is measured by the SSD (sum of square differences) between the two patches.

$$S_W(\Delta x, \Delta y) = \sum_{x_i \in W} \sum_{y_i \in W} \left(f(x_i, y_i) - f(x_i - \Delta x, y_i - \Delta y)\right)^2 .$$

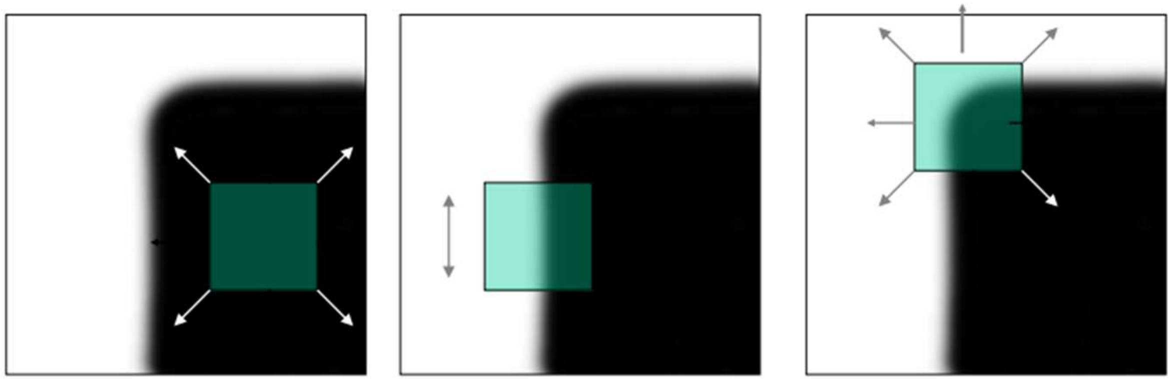


Moravec Corner Detection

region of uniform intensity: **low variation**
- nearby patches will result a small change.

on an edge: **high variation in certain direction**
- nearby patches in a direction parallel to the edge will result only in a small change.

on a corner: **high variation**
- all of the nearby patches will result a significant change.



Moravec Corner Detection

The corner strength is defined as the smallest SSD between the patch and its neighbors.

$$\mathrm{Cornerness}(x, y) = \min\{S(-1,-1), S(-1,0), \dots, S(1,1)\}$$

If this number is locally maximal, then a feature of interest is present.

X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	0	0	0	0	0	0	0	0	0	1	1	1	X	X
X	X	0	0	0	0	0	1	1	0	0	1	2	1	X	X
X	X	0	0	0	0	0	2	1	0	0	1	1	1	X	X
X	X	0	0	0	0	0	0	0	0	0	0	0	0	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Moravec Corner Detection

One of the main problems with this operator is that it is not isotropic:

=> not rotationally invariant

Original Image

Image Rotated 30°

Harris Corner Detection

Harris considered the differential of the corner score with respect to direction directly.

$$S(u,v) = \sum_{y,x} w(y,x)(f(y+v,x+u) - f(y,x))^2$$

$f(y+v,x+u)$ can be approximated by first-order Taylor expansion.

$$f(y+v,x+u) \cong f(y,x) + vd_y(y,x) + ud_x(y,x)$$

This produces the approximation $S(u,v) \cong \sum_{y,x} w(y,x)(vd_y + ud_x)^2$

Harris Corner Detection

which can be written in matrix form:

$$S(u, v) \cong \sum_{y,x} w(y, x)(v \quad u) \begin{bmatrix} {d_y}^2 & d_y d_x \\ d_y d_x & {d_x}^2 \end{bmatrix} \begin{pmatrix} v \\ u \end{pmatrix}$$

Angle brackets denote convolution (i.e. weighted summation over ***(x, y)***)

$$S(u, v) \cong (v \quad u) \begin{bmatrix} \langle {d_y}^2 \rangle & \langle d_y d_x \rangle \\ \langle d_y d_x \rangle & \langle {d_x}^2 \rangle \end{bmatrix} \begin{pmatrix} v \\ u \end{pmatrix}$$

w(u, v) denotes the type of window that slides over the image.
If a Gaussian is used, then the response will be isotropic.

Harris Corner Detection

We find the covariance of the partial derivative(= matrix A) of the image intensity d with respect to the x and y axis.

$$S(u,v) \cong (v \quad u)\begin{bmatrix} \langle {d_y}^2 \rangle & \langle d_y d_x \rangle \\ \langle d_y d_x \rangle & \langle {d_x}^2 \rangle \end{bmatrix}\begin{pmatrix} v \\ u \end{pmatrix}$$

$$A = \begin{bmatrix} \langle {d_y}^2 \rangle & \langle d_y d_x \rangle \\ \langle d_y d_x \rangle & \langle {d_x}^2 \rangle \end{bmatrix}$$

A is called auto-correlation matrix or second moment matrix.

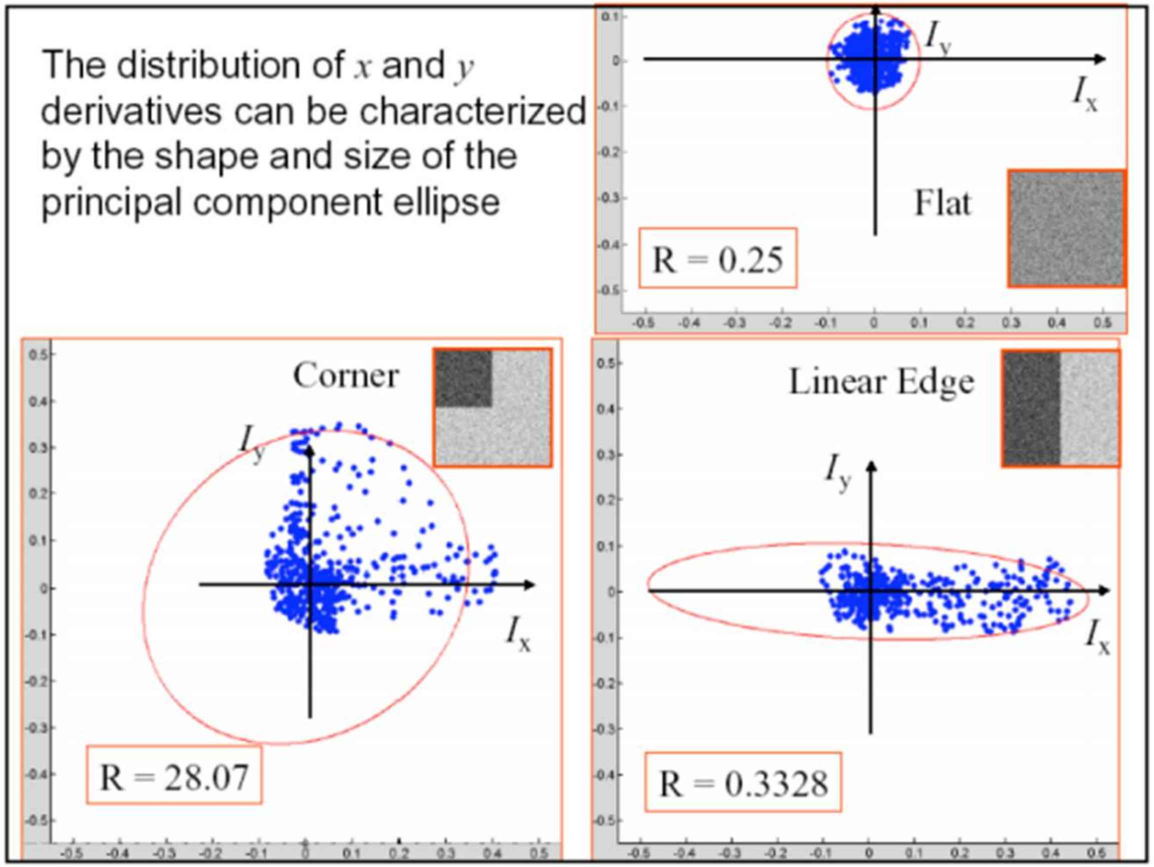
A corner is characterized by the value of S in all directions of the vector (u, v)

Harris Corner Detection

By analyzing the eigenvalues of A, this characterization can be expressed:
A should have two "large" eigenvalues for an interest point.

$$A = \begin{bmatrix} \langle {d_y}^2 \rangle & \langle d_y d_x \rangle \\ \langle d_y d_x \rangle & \langle {d_x}^2 \rangle \end{bmatrix}$$

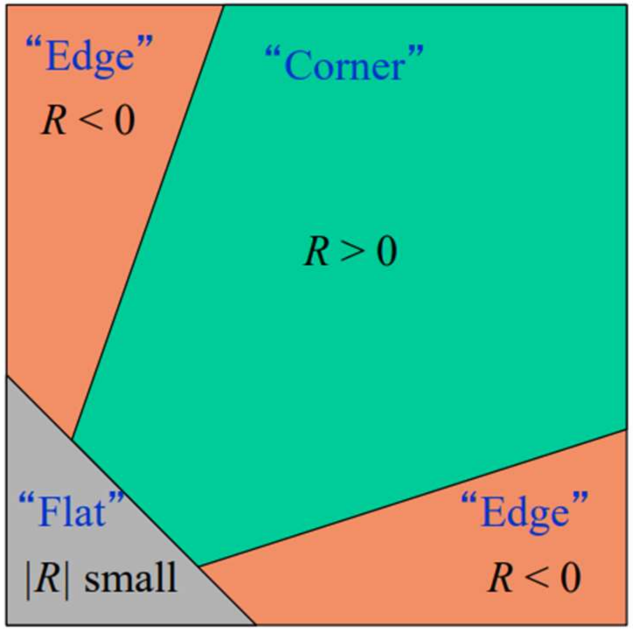
$$\begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix}$$



Harris Corner Detection

Exact computation of the eigenvalues is computationally expensive.
Instead, calculate the following function.

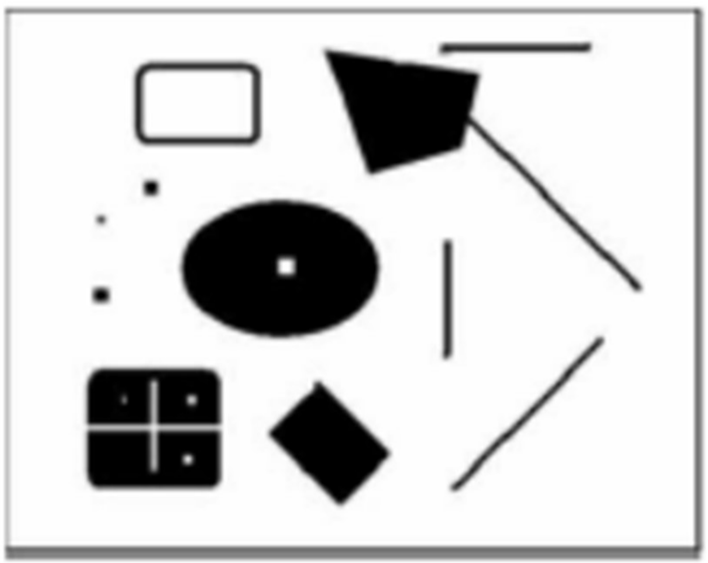
$$R = \lambda_1 \lambda_2 - \kappa (\lambda_1 + \lambda_2)^2 = \det(A) - \kappa \, \mathrm{trace}^2(A)$$



Harris Corner Detection

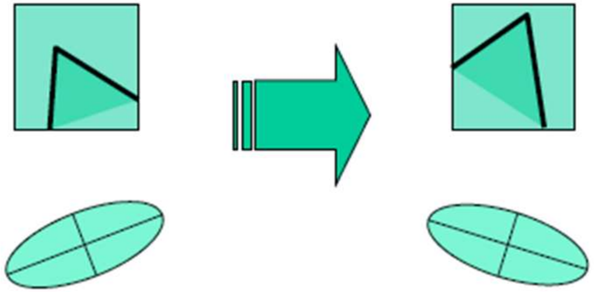
Find points with Harris Corner Detection response function R (R > threshold)

Take the points of local maxima of R

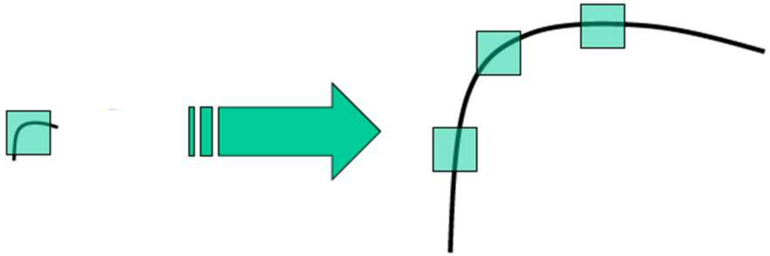


Harris Corner Detection

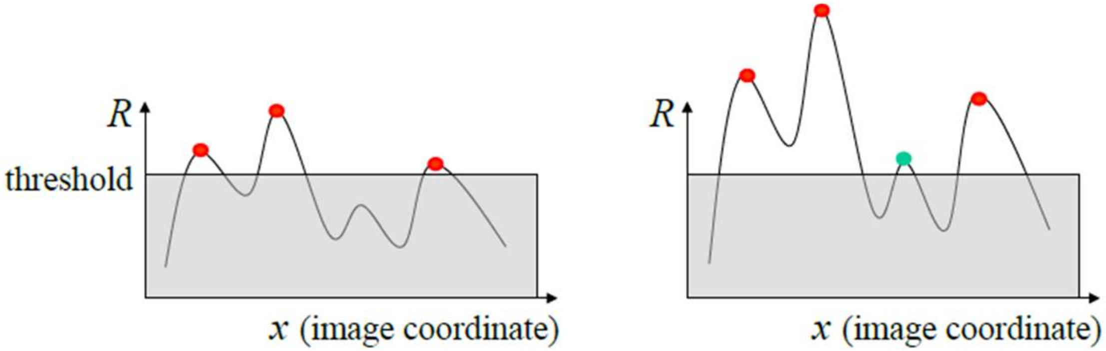
Invariant to rotation



Not invariant to scaling



Partially invariant to affine intensity change

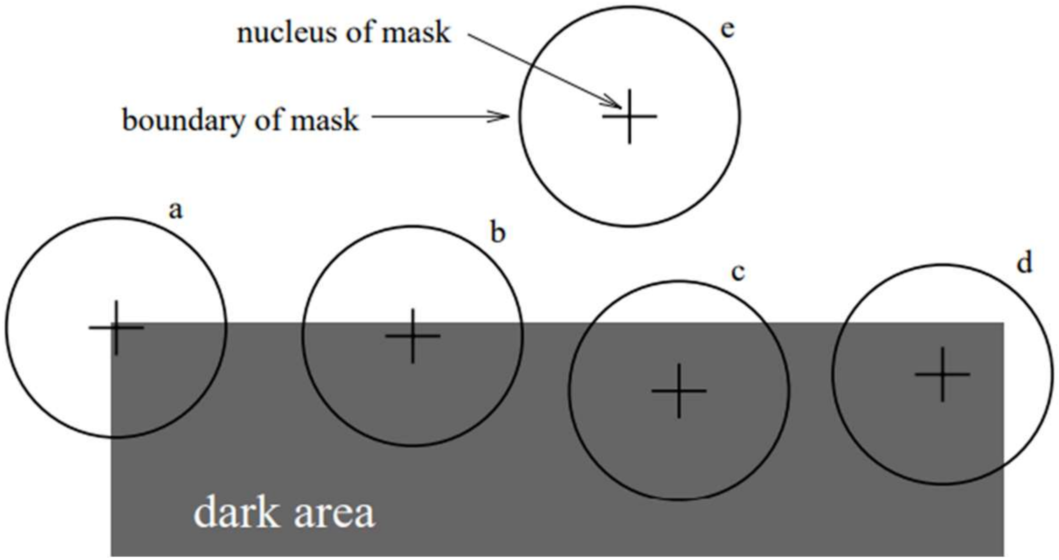


SUSAN

For feature detection, SUSAN places a circular mask over the pixel to be tested.

USAN is an area of the mask which has the same brightness as the nucleus.

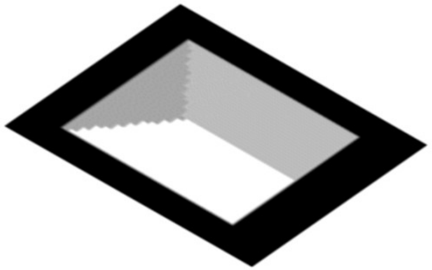
The area of an USAN conveys the most important information about the structure.

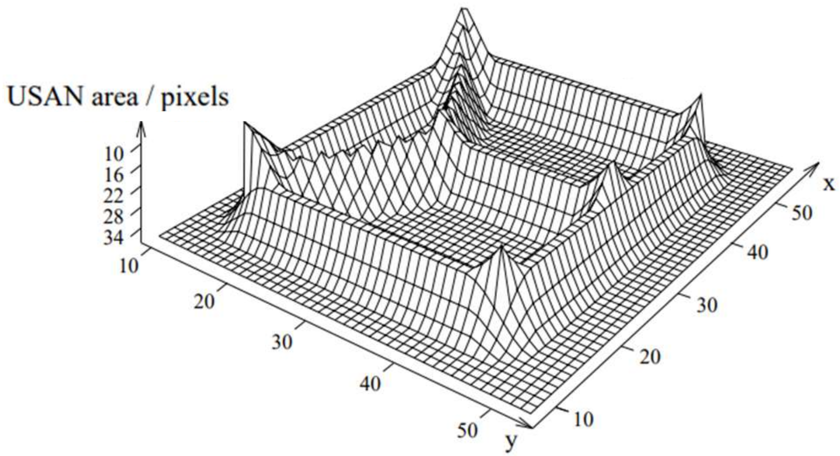


SUSAN

USAN area is
maximum when the mask lies in a flat region of the image surface,
half of this maximum very near a straight edge,
smaller than half of this maximum when inside a corner.

USAN's area is used as the main determinant of the presence of corners and 2D features.





SUSAN

The SUSAN edge finder uses circular masks to give isotropic responses.

The brightness of each pixel within the mask is compared with that of the nucleus.

$$c(\vec{r}, \vec{r_0}) = \begin{cases} 1 & \text{if } |I(\vec{r}) - I(\vec{r_0})| \le t \\ 0 & \text{if } |I(\vec{r}) - I(\vec{r_0})| > t, \end{cases}$$

$\vec{r_0}$ is the position of the nucleus, $\vec{r}$ is the position of any other point.

SUSAN

This comparison is done for each pixel within the mask.

$$n(\vec{r_0}) = \sum_{\vec{r}} c(\vec{r}, \vec{r_0}).$$

This total n gives the USAN's area.

Next, n is compared with a fixed threshold g, which is set to ½ of the mask's area.

$$R(\vec{r_0}) = \begin{cases} g - n(\vec{r_0}) & \text{if } n(\vec{r_0}) < g \\ 0 & \text{otherwise,} \end{cases}$$

SUSAN

This non-linear response gives strong noise rejection.

And other strength of the SUSAN edge detector is that the use of controlling parameters is much simpler and less arbitrary.