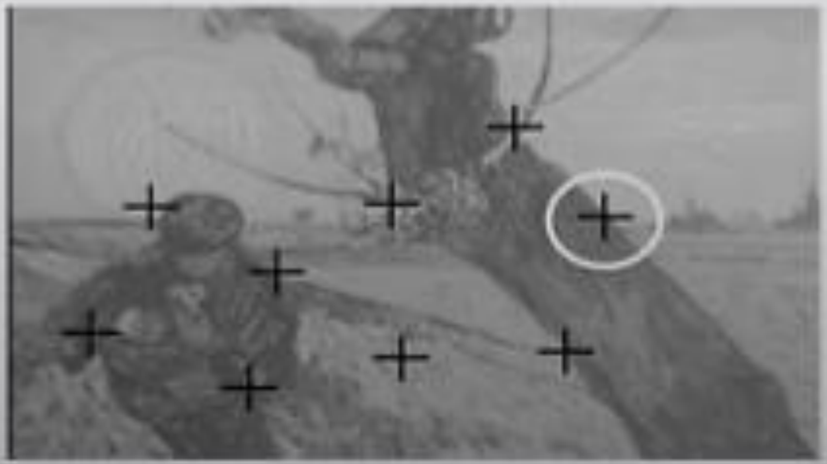
CVFA (Interest point detector)

What is an Interest Point?

- A point in an image which has a well-defined position and can be robustly detected.
- Typically associated with a significant change of one or more image properties simultaneously (e.g., intensity, color, texture).



Why are interest points useful?

- Could be used to find corresponding points between images which is very useful for numerous applications!

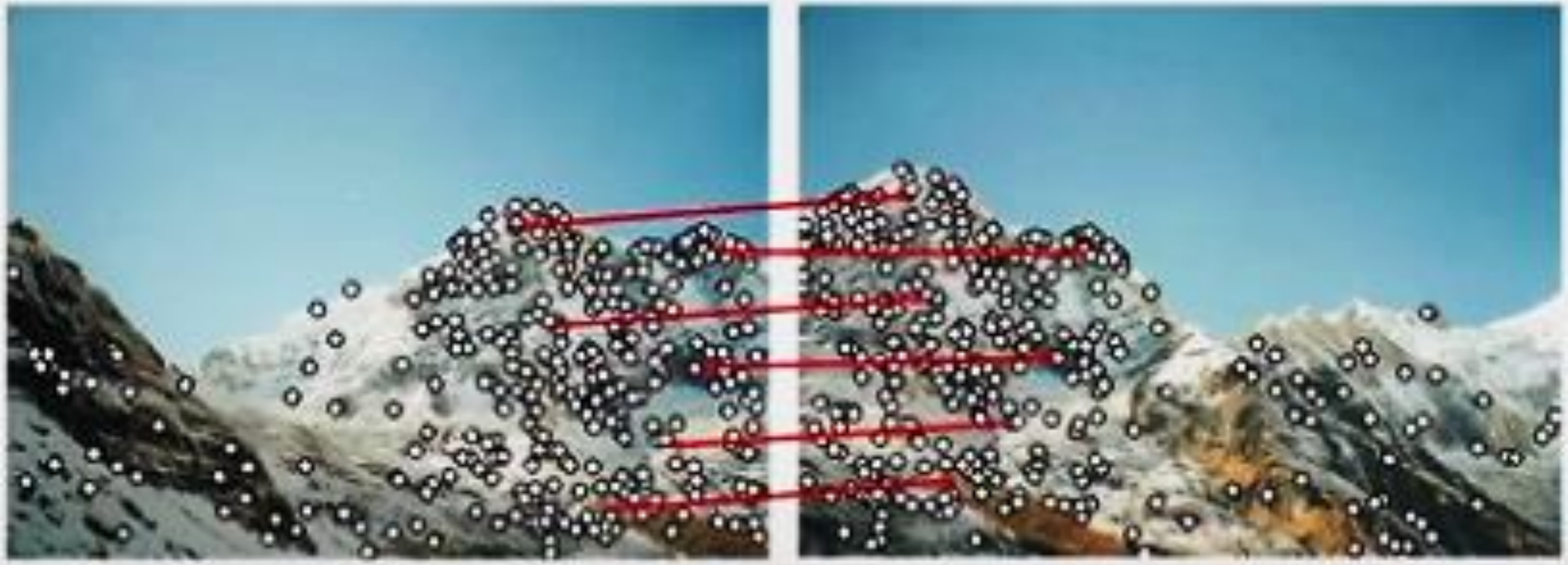
stereo matching

left camera right camera

panorama stitching

- Application: panorama stitching
  - We have two images – how do we combine them?

Step 1: extract features



Step 1: extract features

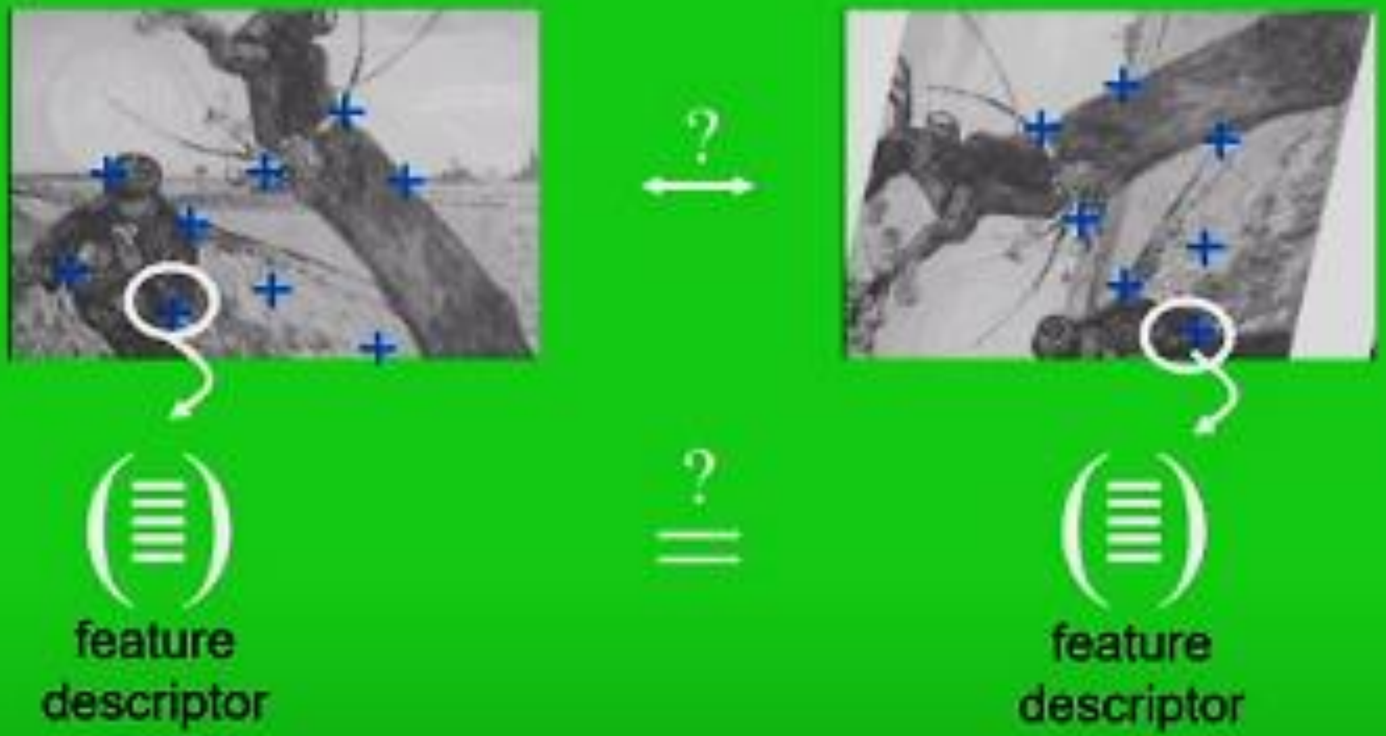
Step 2: match features

Step 1: extract features

Step 2: match features

Step 3: align images

How to find corresponding points?



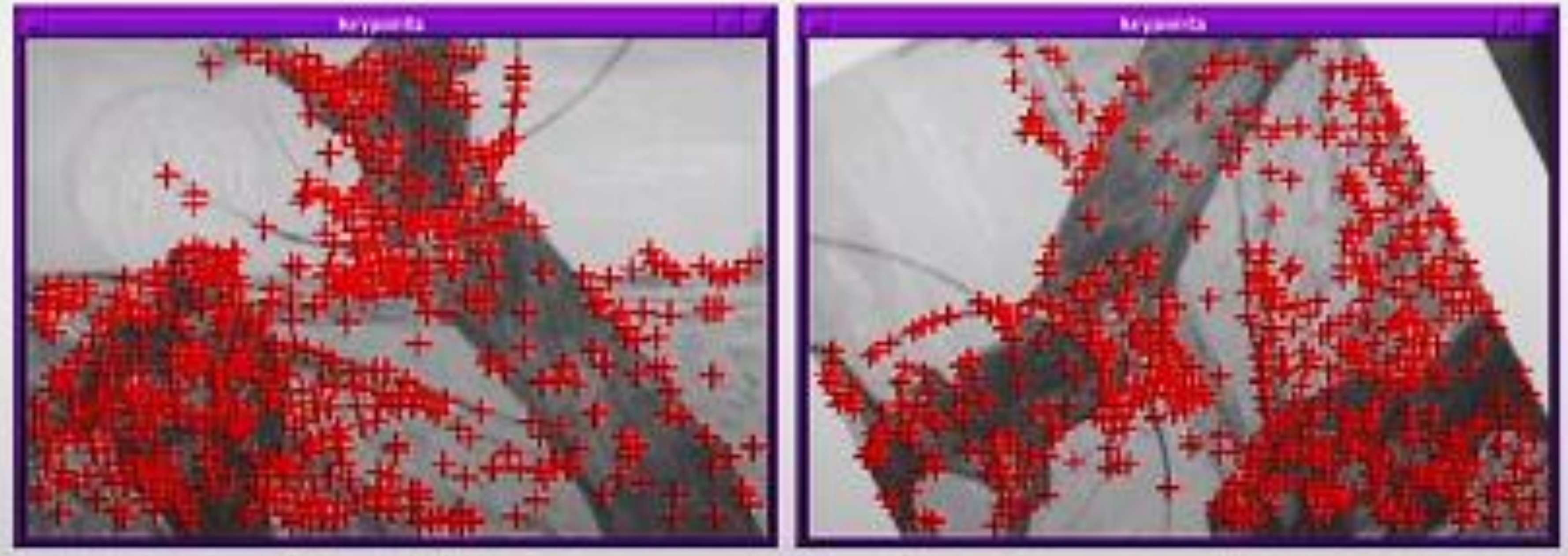
- Need to define local patches surrounding the interest points and extract feature **descriptors** from every patch.
- Match feature descriptors to find corresponding points.

Characteristics of good features

- Repeatability
  - The same feature can be found in several images despite geometric and photometric transformations
- Saliency
  - Each feature is distinctive
- Compactness and efficiency
  - Many fewer features than image pixels
- Locality
  - A feature occupies a relatively small area of the image; robust to clutter and occlusion
- Efficient: close to real-time performance
- Covariant

Interest point detectors should be covariant

- Features should be detected in corresponding locations despite <u>geometric</u> or <u>photometric</u> changes.

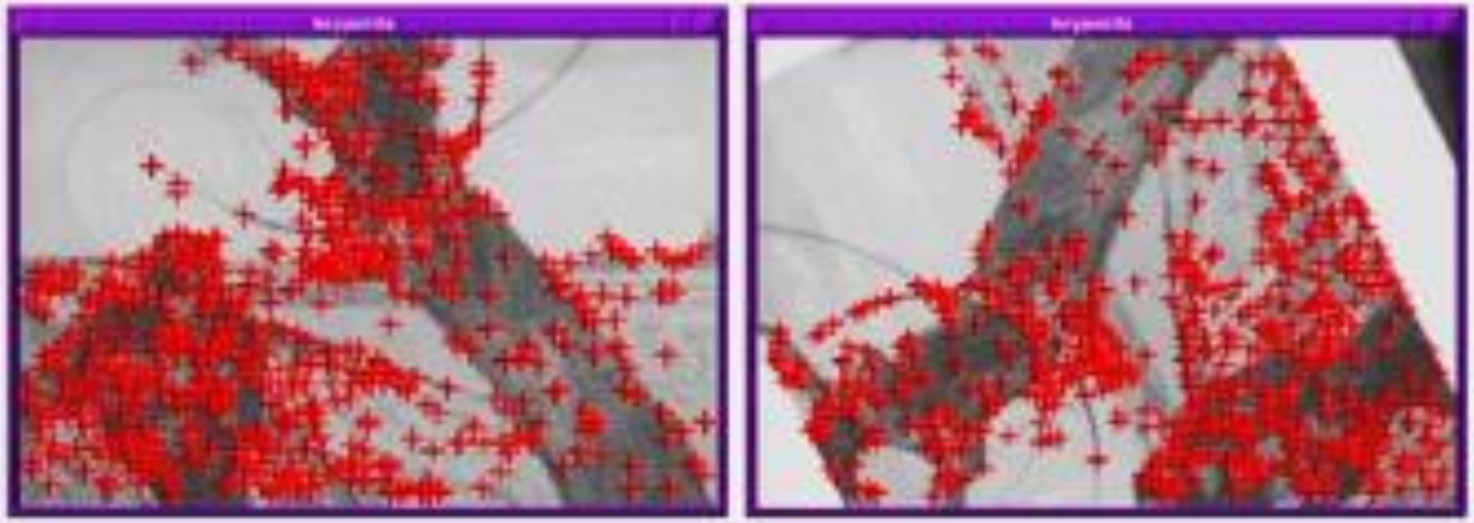


Applications

Feature points are used for:

- Image alignment
- 3D reconstruction
- Motion tracking
- Indexing and database retrieval
- Object recognition

Finding Corners



- Key property: in the region around a corner, image gradient has two dominant directions
- Corners are repeatable and distinctive

Method 1

SUSAN

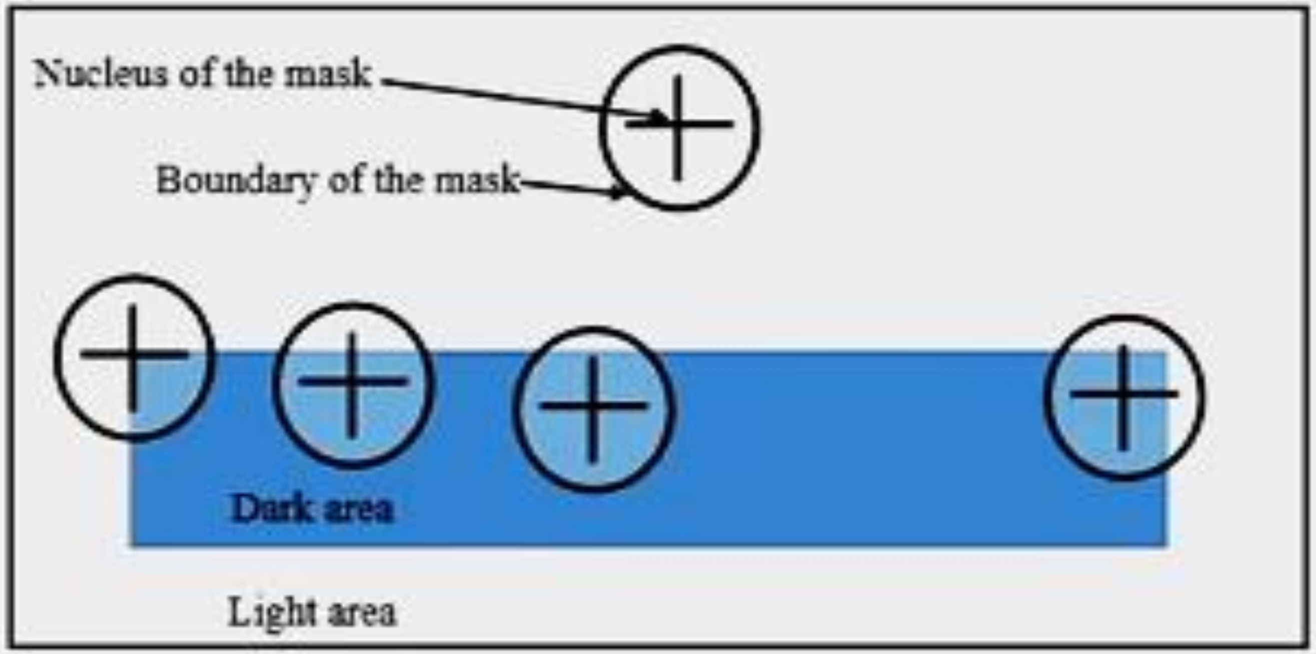
- Method for edge and corner detection
- No image derivatives
- Insensitive to noise

The SUSAN edge detector is implemented using circular masks (known as windows or kernels) to get isotropic responses.

USAN

"Univalue Segment Assimilating Nucleus"

It is the portion of the template with intensity within a threshold of the "nucleus".

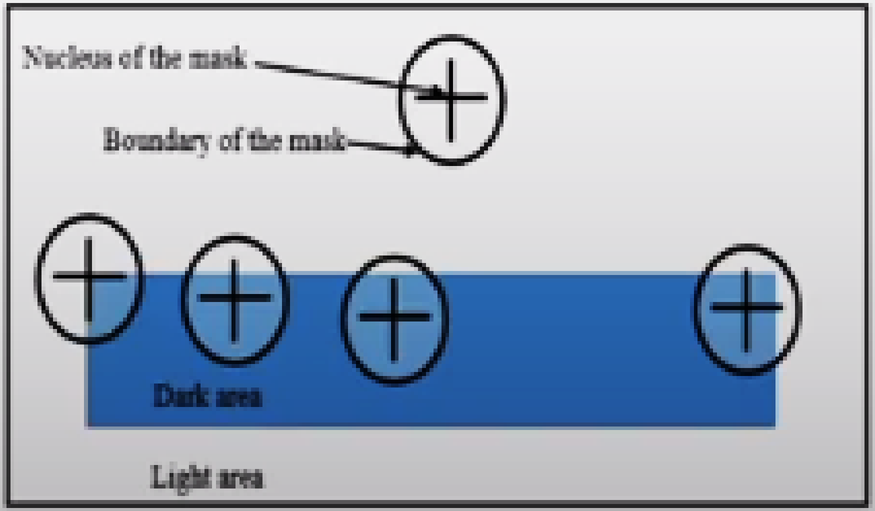


USAN area is at its maximum when its nucleus lies in the homogeneous region of the image, becomes less when it encounters an edge and even decreases when a corner point is approached.

The center pixel of the mask is known as the nucleus. If the pixels lying within the mask have similar brightness as that of the nucleus, then such areas are defined as USAN (Univalue Segment Assimilating Nucleus).

Edges and Corners

- In flat regions the USAN has similar area to the template
- At edges the USAN area is about half the template area
- At corners the USAN area is smaller than half the template area.
- "SUSAN" = Smallest USAN



Implementation

```
  0011100
  0111110
  1111111
C=1111111
  1111111
  0111110
  0011100
```

- Circular mask C with radius 3.4 ($|C| = 37$ pixels).
- The nucleus is the centre pixel r_0.

$$u(r,r_0) = \begin{cases} 1 & |I(r) - I(r_0)| < t \\ 0 & \text{otherwise} \end{cases}$$

$$n = \sum_{r \in C(r_0)} u(r,r_0)$$

$$A(r_0) = \begin{cases} |C| - n & n < T \\ 0 & \text{otherwise} \end{cases}$$

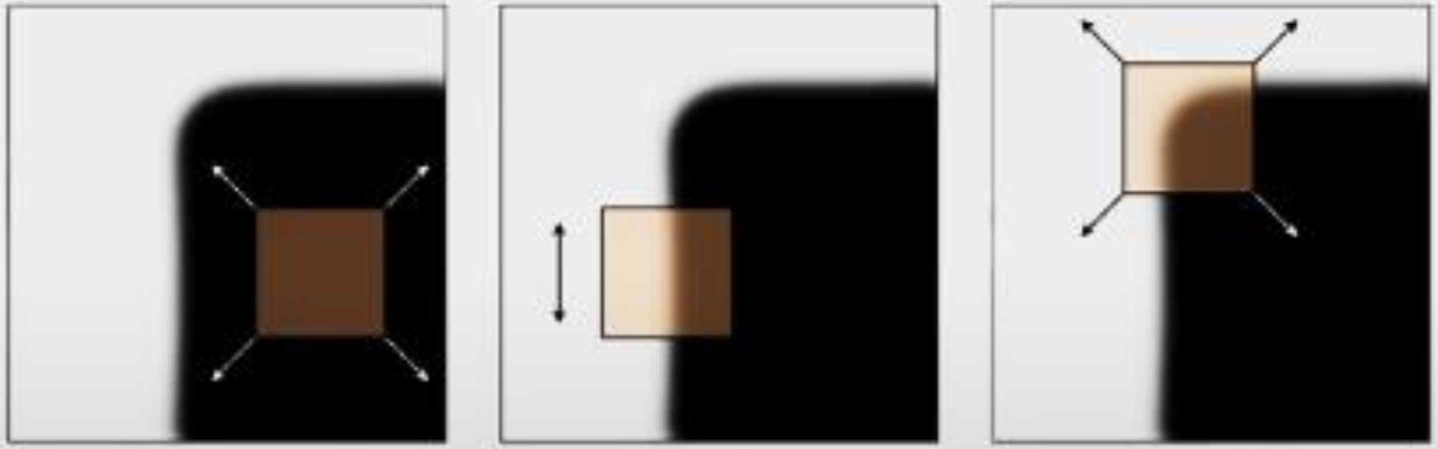
T=3|C|/4 for edge detection

T=|C|/2 for corner detection

Select t by considering image noise level.

Corner detection: basic idea

- We should easily recognize the point by looking through a small window
- Shifting a window in *any direction* should give *a large change* in intensity



"flat" region: no change in all directions

"edge": no change along the edge direction

"corner": significant change in all directions

Method 2: Window based

Moravec Corner Detector

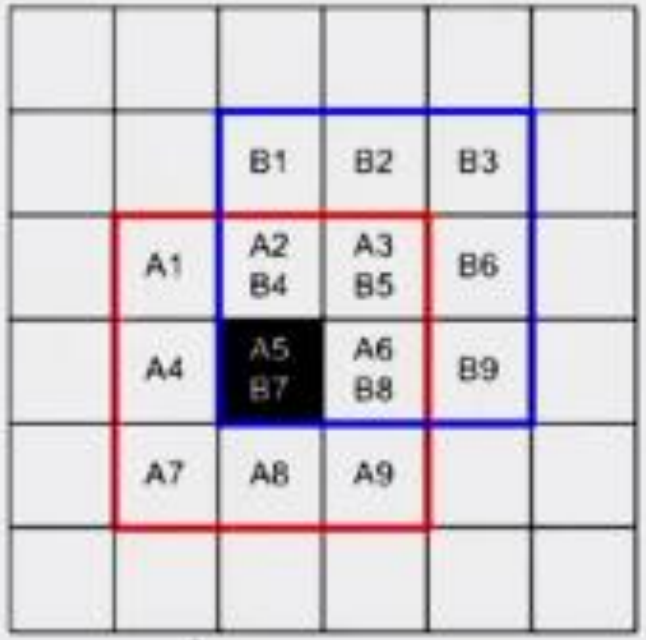
- The earliest corner detector
- Measures the grey value differences between a window and windows shifted in eight principle directions.
- The intensity variation for a given shift is calculated by taking the sum of squares of intensity differences of corresponding pixels in these two windows.
- If the minimum of these differences > Threshold =>Interest point

Moravec Corner Detector

SSD (Patch A, Patch B)

$$= \sum_{i=1}^{9} (A_i - B_i)^2$$

In a similar way, SSD is computed in 8 possible directions



Note:

For patch sizes of 5 *5 ,
SSD (Patch A, Patch B) $= \sum_{i=1}^{25} (A_i - B_i)^2$

The SSD $E(u,v)$ is computed in 8 possible directions

$$E(u,v) = \sum_{x,y \in W} (I(x+u, y+v) - I(x,y))^2$$

$$R = \min_{-1 \le u,v \le 1} E(u,v)$$

W is a window centered at (x_c, y_c)

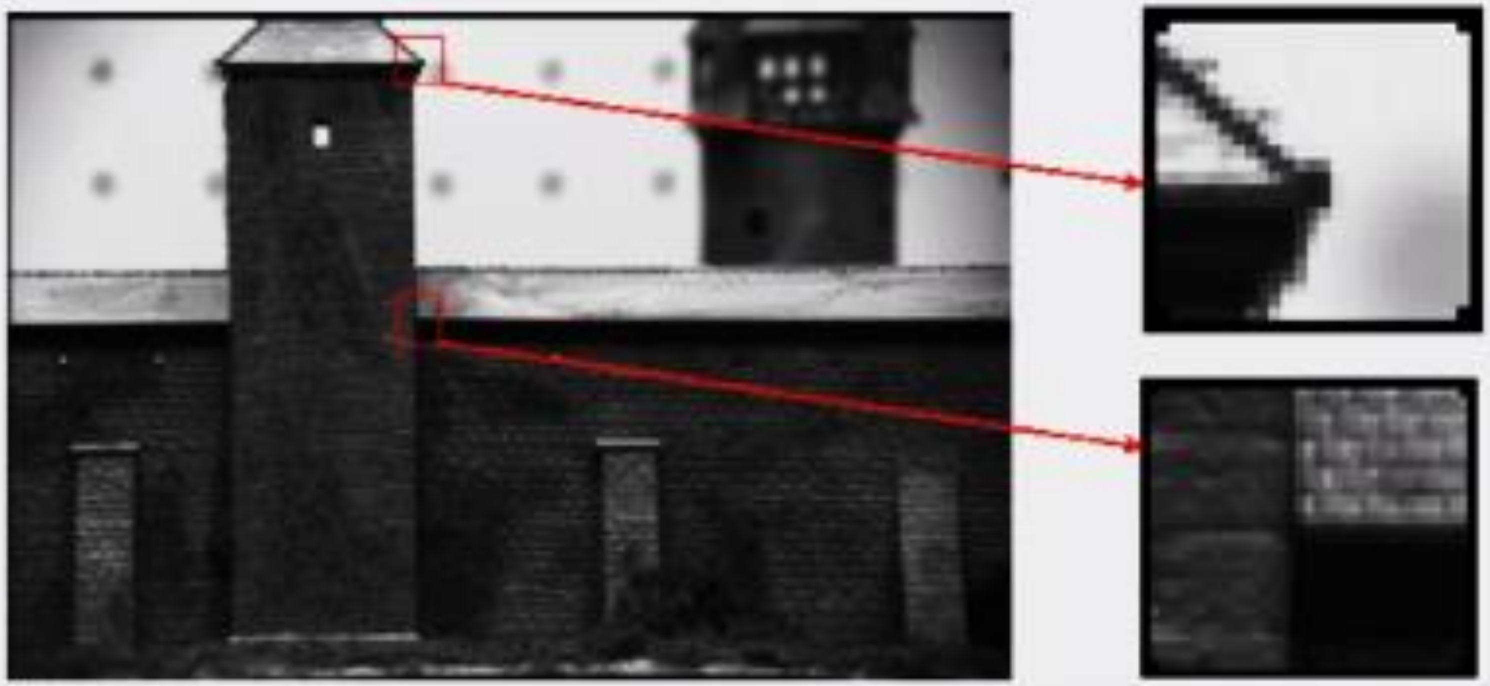
If the minimum SSD is greater than a threshold, declare pixel as a 'corner'

$$R > T \Rightarrow (x_c, y_c) \text{ is corner}$$

- Moravec detector works reasonably well on detecting corners.
- However, at times, edges do get classified as corners : quite undesirable.
- Harris corner detector alleviates this drawback of the Moravec detector.

Harris Corner Detector

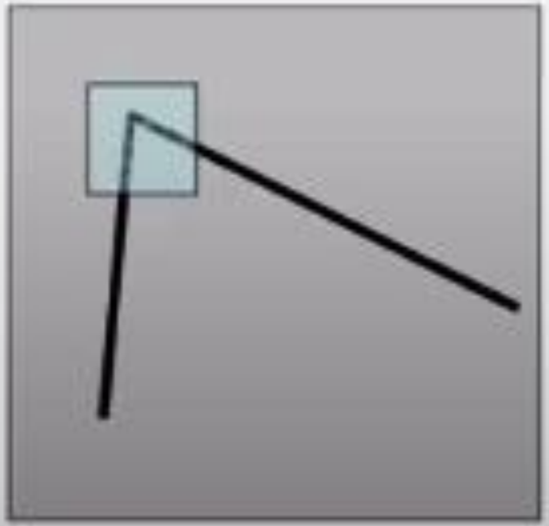
What are Corners?



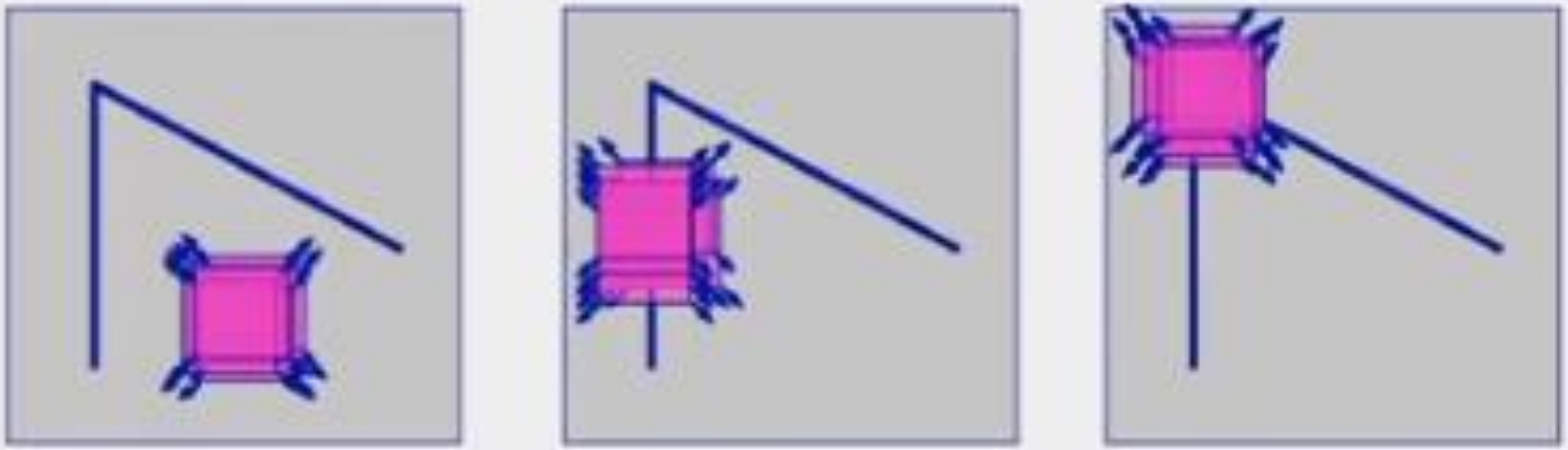
- Intuitively, junctions of contours.
- Generally more stable features over changes of viewpoint
- Intuitively, large variations in the neighborhood of the point in all directions
- They are good features to match!

The Basic Idea

- We should easily recognize the point by looking through a small window
- Shifting a window in *any direction* should give *a large change* in intensity



Harris Corner Detector: Basic Idea



"flat" region:
no change in
all directions

"edge":
no change along
the edge direction

"corner":
significant change
in all directions

Harris corner detector gives a mathematical approach for determining which case holds.

Harris Detector: Mathematics

Change of intensity for the shift $[u,v]$:

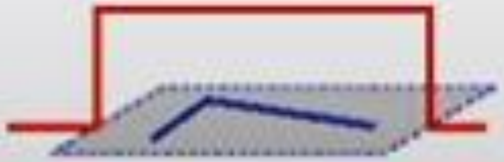
$$E(u,v) = \sum_{x,y} w(x,y)\left[I(x+u, y+v) - I(x,y)\right]^2$$

Window function

Shifted intensity

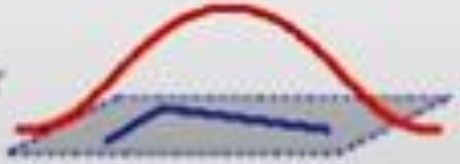
Intensity

Window function $w(x,y)$ =



1 in window, 0 outside

or



Gaussian

Harris Detector: Intuition

Change of intensity for the shift $[u,v]$:

$$E(u,v) = \sum_{x,y} w(x,y)\left[I(x+u,y+v) - I(x,y)\right]^2$$

Window function

Shifted intensity

Intensity

For nearly constant patches, this will be near 0.
For very distinctive patches, this will be larger.
Hence... we want patches where E(u,v) is LARGE.

Taylor Series for 2D Functions

$$f(x+u,y+v)=f(x,y)+uf_x(x,y)+vf_y(x,y)+$$

First partial derivatives

$$\frac{1}{2!}\left[u^2 f_{xx}(x,y)+uvf_{xy}x,y+v^2 f_{yy}(x,y)\right]+$$

Second partial derivatives

$$\frac{1}{3!}\left[u^3 f_{xxx}(x,y)+u^2 v f_{xxy}(x,y)+uv^2 f_{xyy}(x,y)+v^3 f_{yyy}(x,y)\right]$$

Third partial derivatives

$+ \ldots$ (Higher order terms)

First order approx

$$f(x+u,y+v)\approx f(x,y)+uf_x(x,y)+vf_y(x,y)$$

Harris Corner Derivation

$$\sum [I(x+u, y+v) - I(x,y)]^2$$

$$\approx \sum [I(x,y) + uI_x + vI_y - I(x,y)]^2 \quad \text{First order approx}$$

$$= \sum u^2 I_x^2 + 2uvI_xI_y + v^2 I_y^2$$

$$= \sum \begin{bmatrix} u & v \end{bmatrix} \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} \quad \text{Rewrite as matrix equation}$$

$$= \begin{bmatrix} u & v \end{bmatrix} \left(\sum \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} \right) \begin{bmatrix} u \\ v \end{bmatrix}$$

Harris Detector: Mathematics

For small shifts $[u,v]$ we have a *bilinear* approximation:

$$E(u,v) \cong [u,v] \; M \begin{bmatrix} u \\ v \end{bmatrix}$$

where M is a 2×2 matrix computed from image derivatives:

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$$

Windowing function - computing a weighted sum (simplest case, w=1)

Note: these are just products of components of the gradient, Ix, Iy

Intuitive Way to Understand Harris

Treat gradient vectors as a set of (dx,dy) points with a center of mass defined as being at (0,0).

Fit an ellipse to that set of points via scatter matrix

Analyze ellipse parameters for varying cases…

Example: Cases and 2D Derivatives