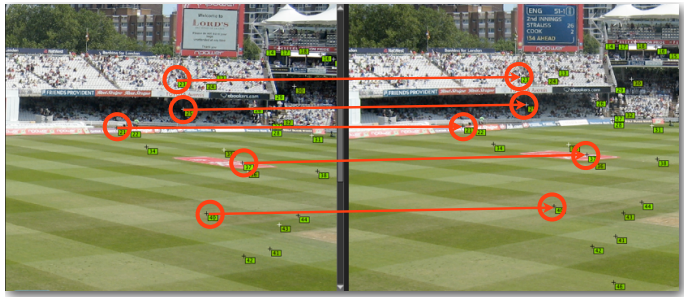
Corner Detection

Based on Richard Szeliski Notes
(textbook author)

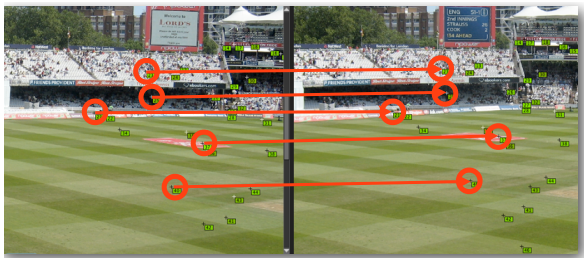
Combining Images

- Combining Images
  - Blending
  - Seam Carving
- Today: Use “similar” features



Courtesy: Irfan Essa

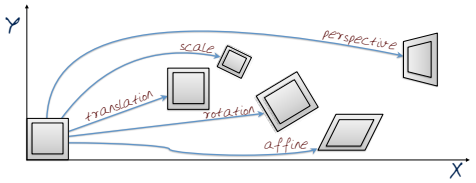
Challenge: Detect feature points in both Images



- Goal - Find points in an image that can be:
- Found in other images
- Found precisely - well localized
- Found reliably - well matched

What are Good Features?

- Distinctive
- Invariant to different acquisition conditions
  - Different view-points,
  - different illuminations,
  - different cameras (wide angle, different looking perspective)



Shi and C. Tomasi (June 1994). "Good Features to Track, ” (citeseer)

Find Corners

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

Corner Detection: Basic Idea

"flat" region: no change in all directions

"edge": no change along the edge direction

"corner": significant change in all directions

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

Basic Idea

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

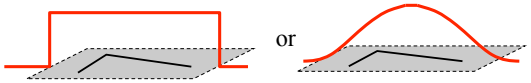
$$E(u,v) = \sum_{x,y} w(x,y)\left[I(x+u,y+v) - I(x,y)\right]^2$$

Window function

Shifted intensity

Intensity

Window function $w(x,y)$ =



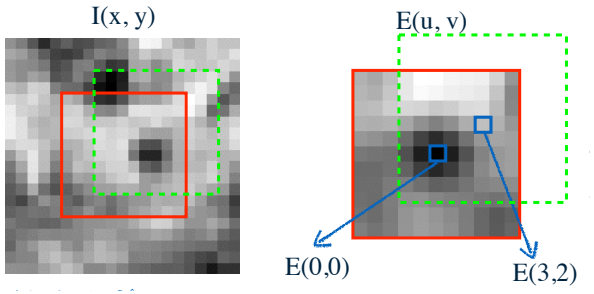
1 in window, 0 outside

or

Gaussian

H. Moravec (1980). "Obstacle Avoidance and Navigation in the Real World by a Seeing Robot Rover"

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



- Computation of the change in appearance by shifting the window by u,v:

Intuition

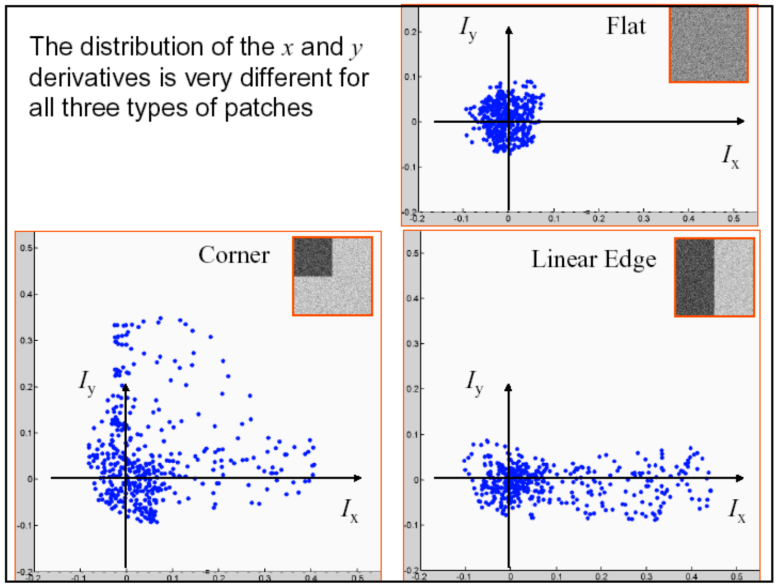
- Convert the above formula (uses Taylor Series expansion) –

$$E(u,v) \approx \begin{bmatrix} u & v \end{bmatrix} M \begin{bmatrix} u \\ v \end{bmatrix}$$

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

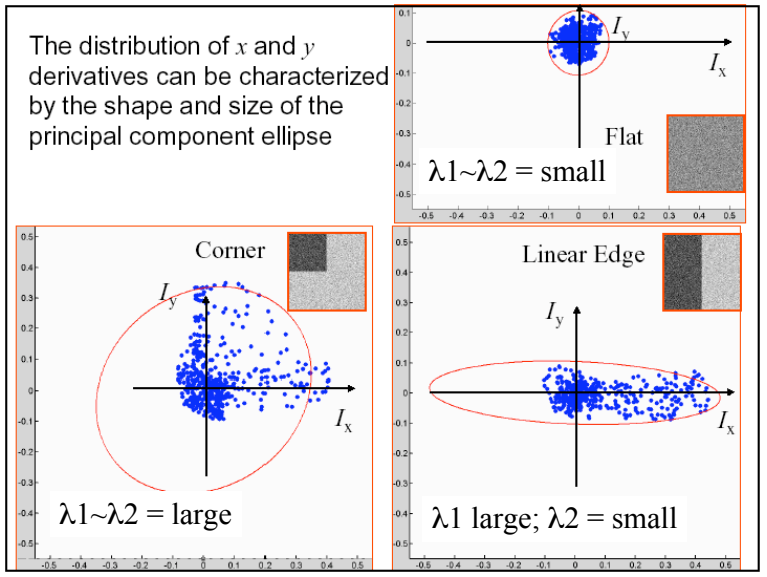
Familiar? These are just products of Component of the **gradients** I_x, I_y,

- M is matrix computed from image derivatives – M is also called structure tensor



Courtesy: R. Collins, Penn State University

- 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 case.



Courtesy: R. Collins, Penn State University

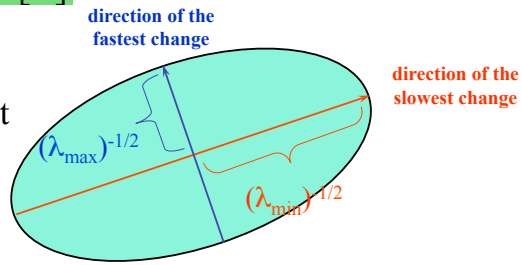
Harris Detector: Mathematics

Intensity change in shifting window: eigenvalue analysis

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

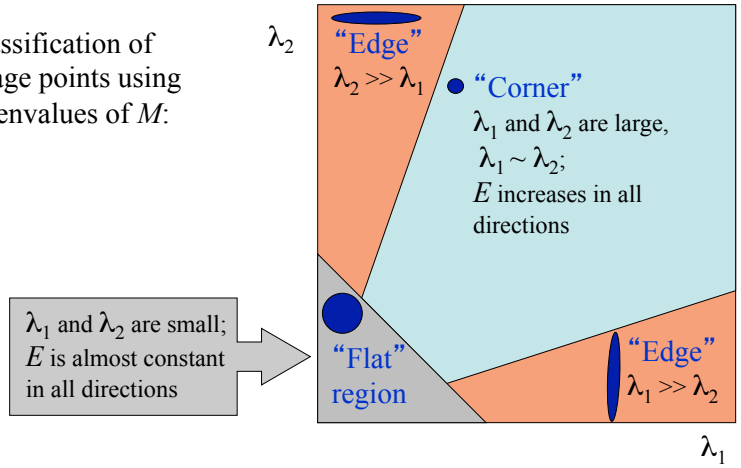
λ_1, λ_2 – eigenvalues of M

Ellipse $E(u,v)$ = const



Harris Detector: Mathematics

Classification of image points using eigenvalues of M:



Harris Detector: Mathematics

Measure of corner response:

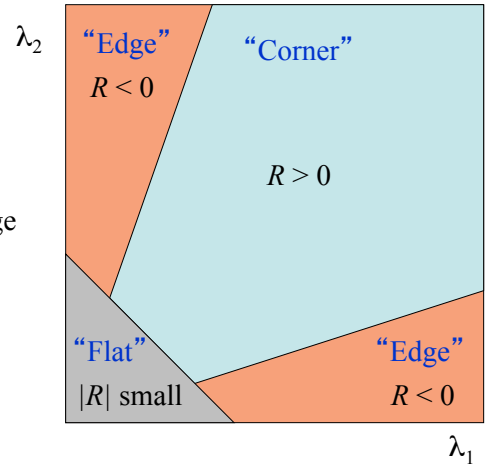
$$R = \det M - k\left(\operatorname{trace} M\right)^2$$

$$\det M = \lambda_1 \lambda_2$$
$$\operatorname{trace} M = \lambda_1 + \lambda_2$$

(k – empirical constant, k = 0.04-0.06)

Harris Detector: Mathematics

- R depends only on eigenvalues of M
- R is large for a corner
- R is negative with large magnitude for an edge
- $|R|$ is small for a flat region



Harris Detector (Preview)
`Detect Corners'

- The Algorithm:
  - Compute Gaussian derivatives at each pixel
  - Compute matrix M in a ga
  - Find points with large corner response function R (R > threshold)
  - Take the points of local maxima of R

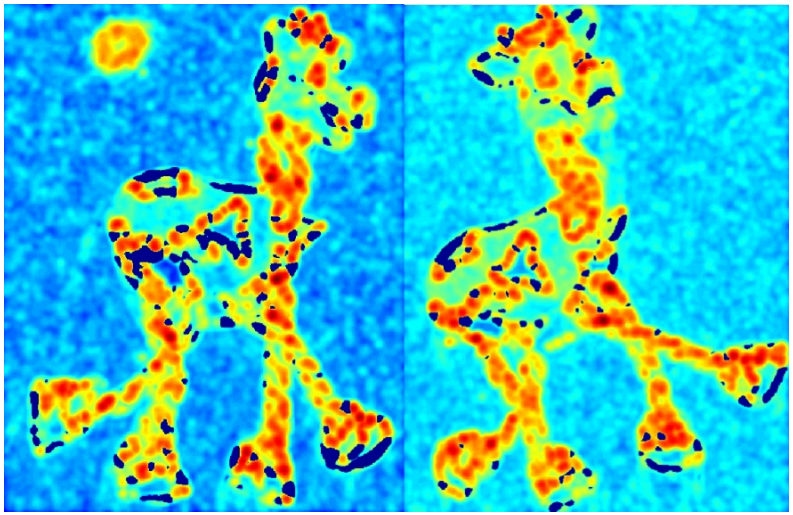
(we are not matching corner to 'another' image's corner Yet)

C. Harris and M. Stephens (1988). "A combined corner and edge detector"
Proceedings of the 4th Alvey Vision Conference. pp 147--151

Harris Detector: Workflow

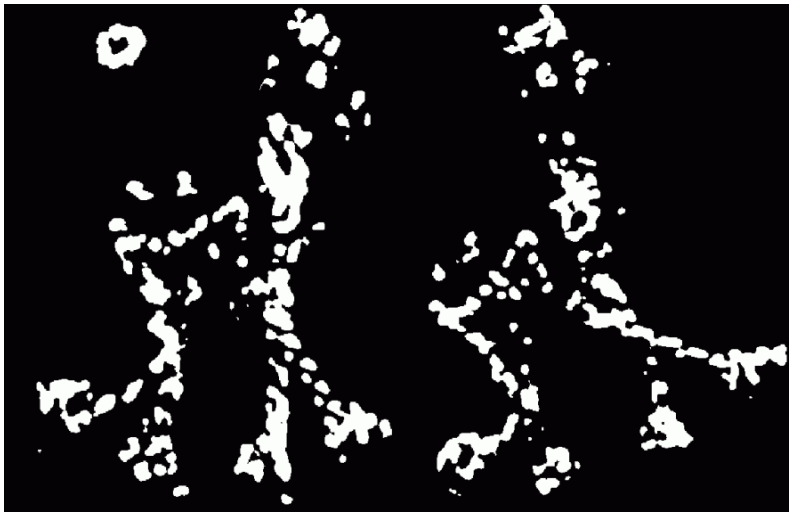
Harris Detector: Workflow

Compute corner response R



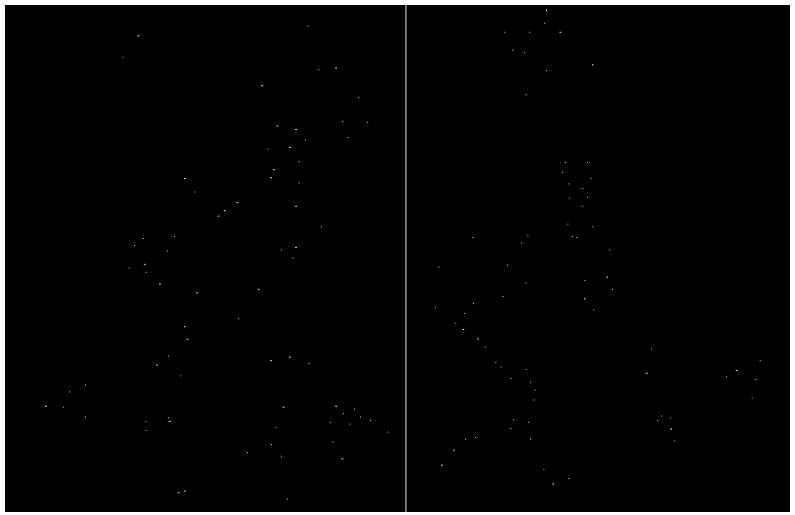
Harris Detector: Workflow

Find points with large corner response: R>threshold



Harris Detector: Workflow

Take only the points of local maxima of R



Harris Detector: Workflow

Harris Detector: Summary

- Average intensity change in direction $[u,v]$ can be expressed as a bilinear form:

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

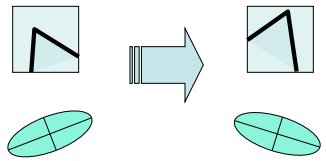
- Describe a point in terms of eigenvalues of M: *measure of corner response*

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

- A good (corner) point should have a *large intensity change* in *all directions*, i.e. R should be large positive

Harris Detector: Some Properties

- Rotation invariance

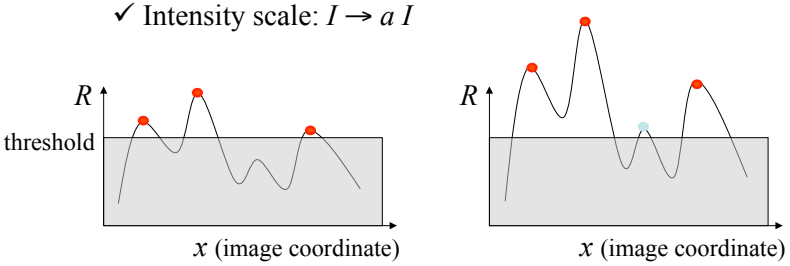


Ellipse rotates but its shape (i.e. eigenvalues) remains the same

Corner response R is invariant to image rotation

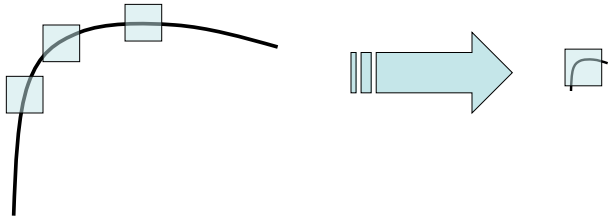
Harris Detector: Some Properties

- Partial invariance to *affine intensity* change
  - ✓ Only derivatives are used => invariance to intensity shift $I \rightarrow I + b$
  - ✓ Intensity scale: $I \rightarrow a\, I$



Harris Detector: Some Properties

- But: non-invariant to *image scale*!



All points will be classified as edges

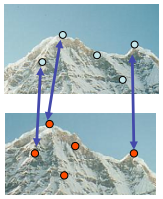
Corner !

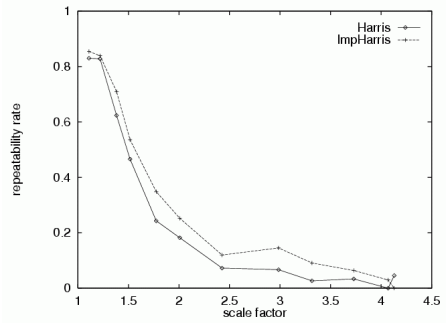
Harris Detector: Some Properties

- Quality of Harris detector for different scale changes

Repeatability rate:

$$\frac{\text{\# correspondences}}{\text{\# possible correspondences}}$$

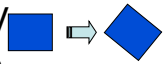


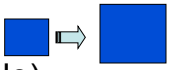


C.Schmid et.al. "Evaluation of Interest Point Detectors". IJCV 2000

Models of Image Change

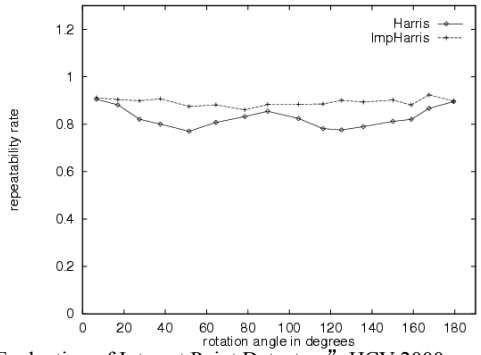
- Geometry
  - Rotation
  - Similarity (rotation + uniform scale)
  - Affine (scale dependent on direction) valid for: orthographic camera, locally planar object
- Photometry
  - Affine intensity change ($I \rightarrow a\, I + b$)





Rotation Invariant Detection

- Harris Corner Detector



C.Schmid et.al. "Evaluation of Interest Point Detectors". IJCV 2000

Reading

https://en.wikipedia.org/wiki/Corner_detection
- See bibliography for additional resources

Shi and C. Tomasi (1994). Good Features to Track
- http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.135.7147

Moravec (1980) Corner Detector (Ch 5-6) (here).

Harris & Stephens (1998), A Corner & Edge Detector
- http://www.bmva.org/bmvc/1988/avc-88-023.pdf
- Very readable.

Mikolajczyk and Schmid (2001). "Indexing Based on Scale Invariant Interest Points"
- http://www.ee.surrey.ac.uk/CVSSP/Publications/papers/Mikolajczyk-ICCV-2001.pdf

Lowe (2004) "Distinctive Image Features from Scale-Invariant Keypoints". IJCV 2004
- http://people.eecs.berkeley.edu/~malik/cs294/lowe-ijcv04.pdf

Search for "Features" on OpenCV site