COMPUTER VISION
Locating Interesting Points

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Why extract features?

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

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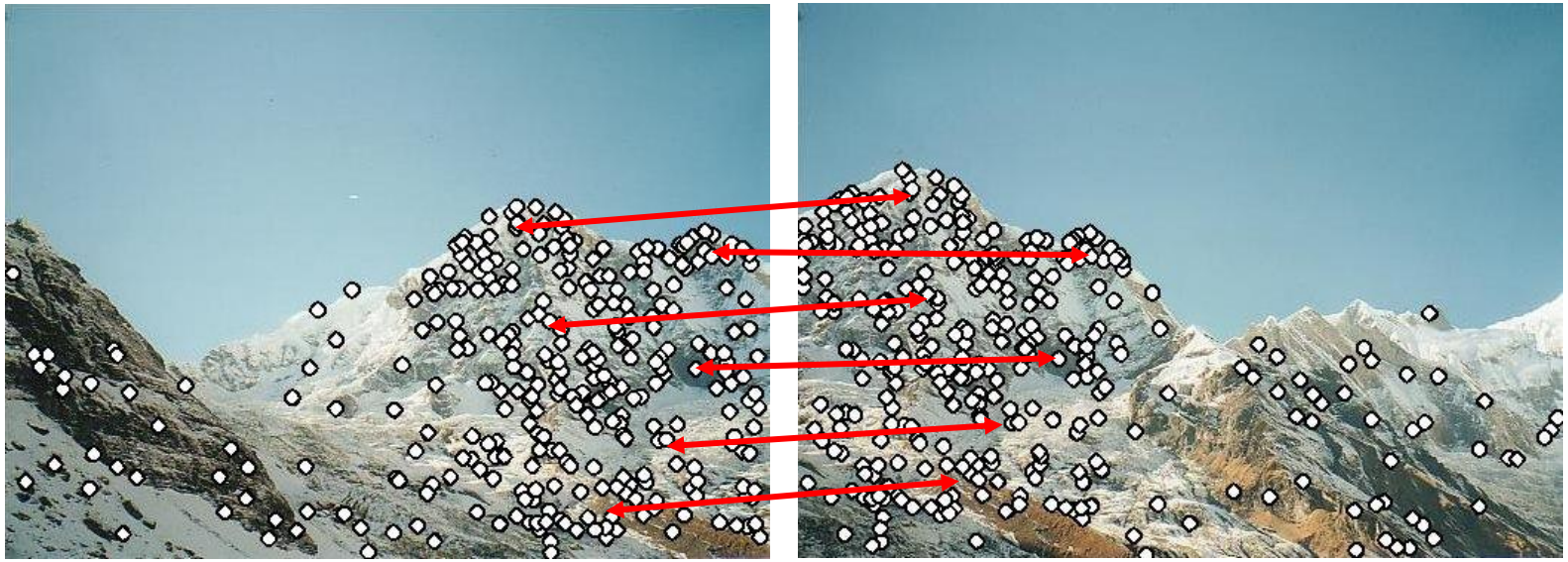


Step 1: extract features

Step 2: match features

Why extract features?

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

Step 1: extract features
Step 2: match features
Step 3: align images

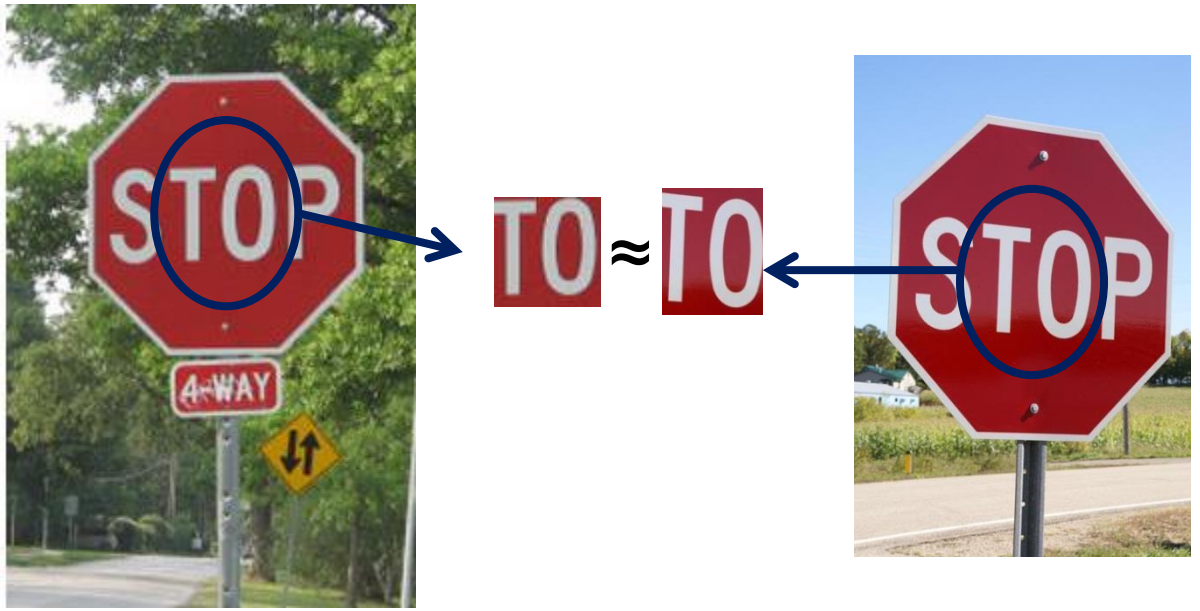
HMI
HUMAN MACHINE INTERACTION LABORATORY

- Overview of correspondence and alignment
- Interesting points
- Harris detector
- Hessian detector

TODAY LECTURE

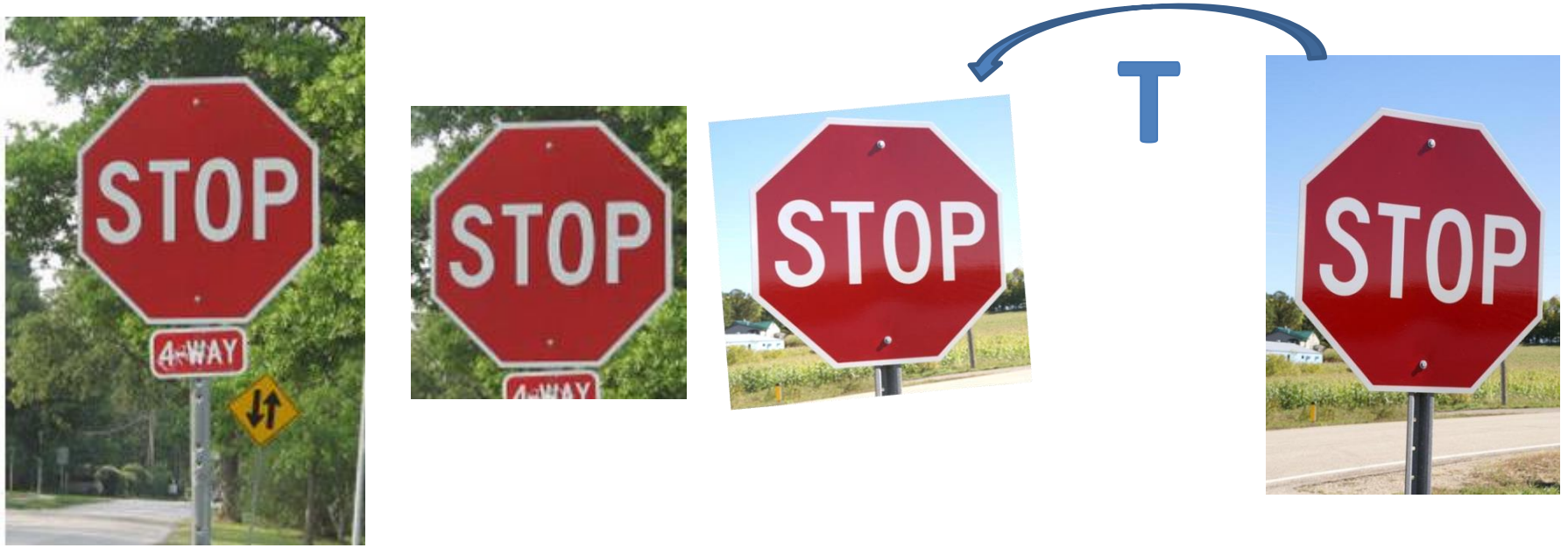
This section: correspondence and alignment

- Correspondence: matching points, patches, edges, or regions across images

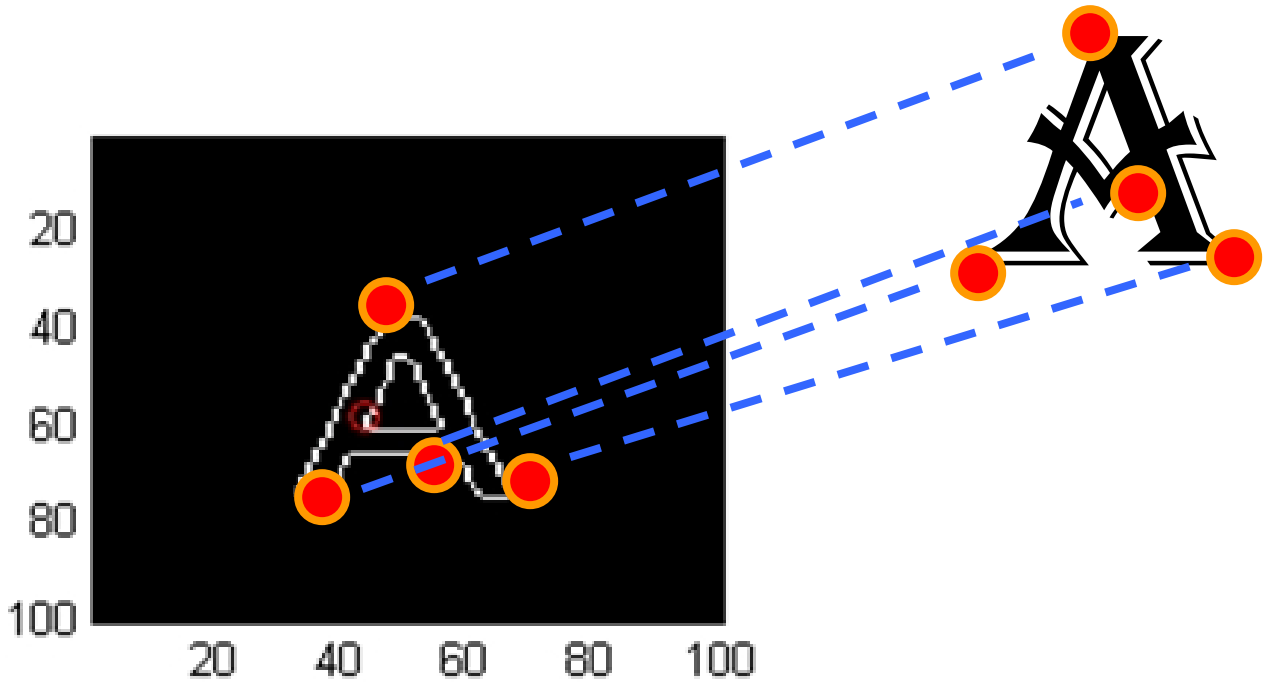


This section: correspondence and alignment

- Alignment: solving the transformation that makes two things match better

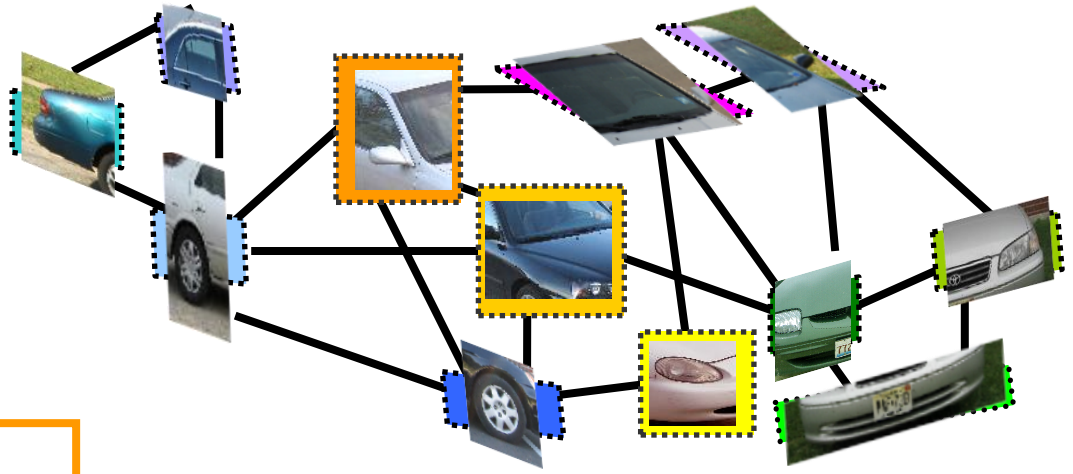


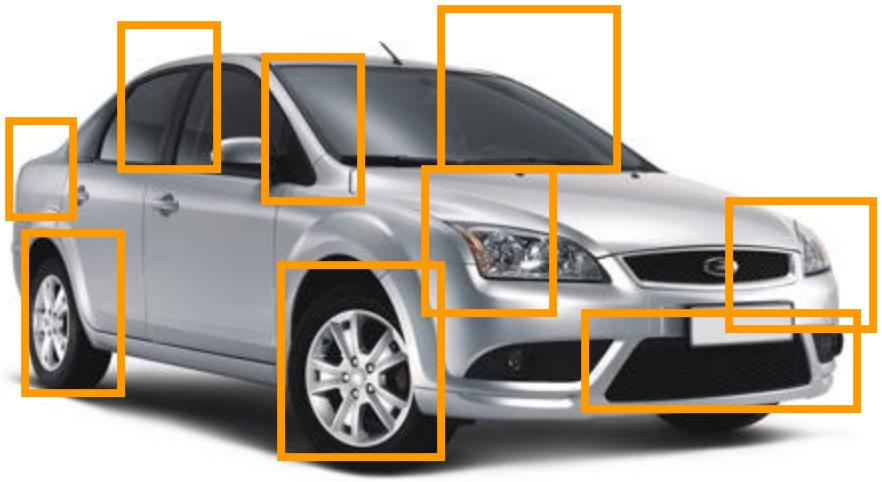
Example: fitting an 2D shape template



Slide from Silvio Savarese

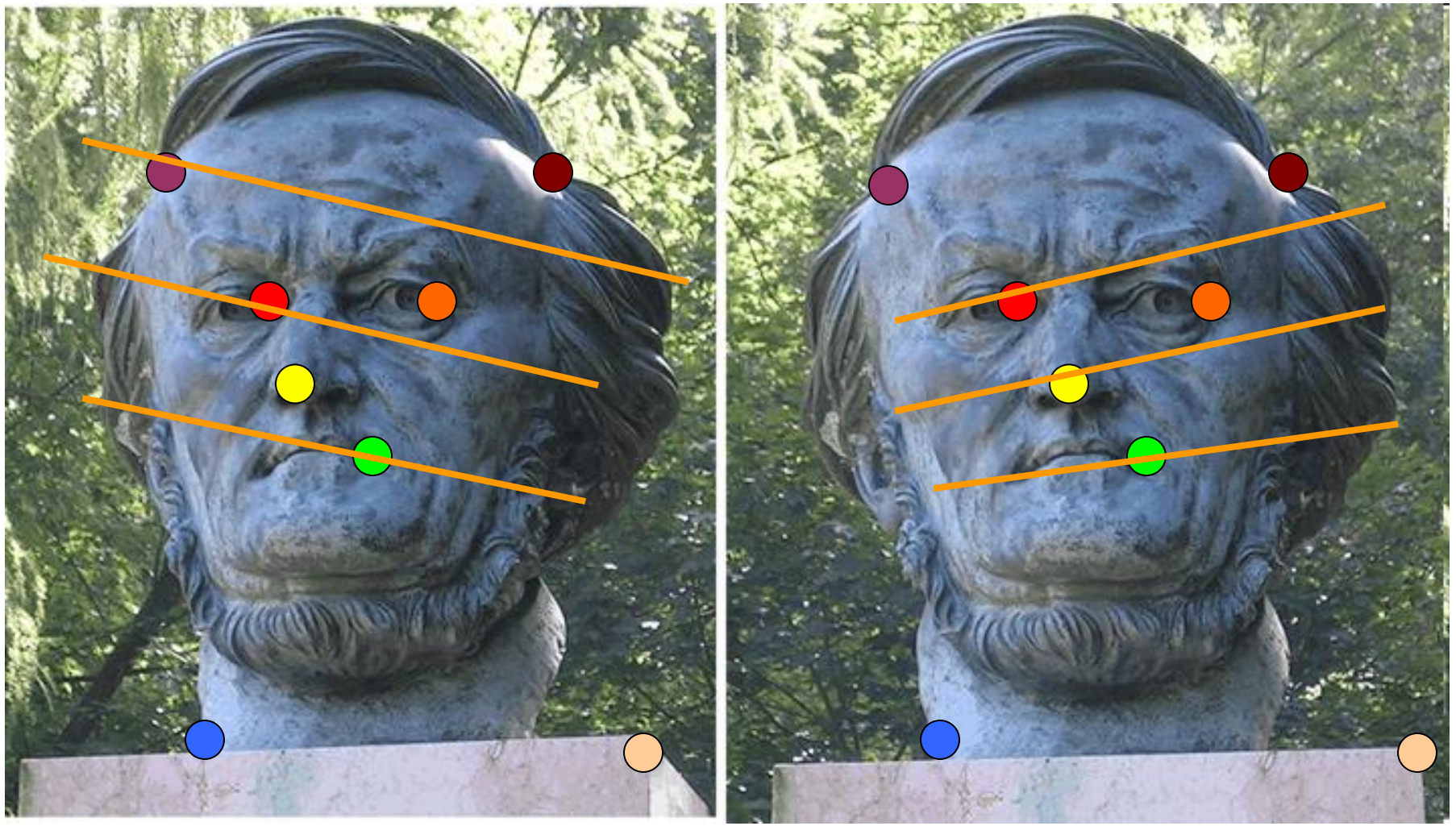
Example: fitting a 3D object model





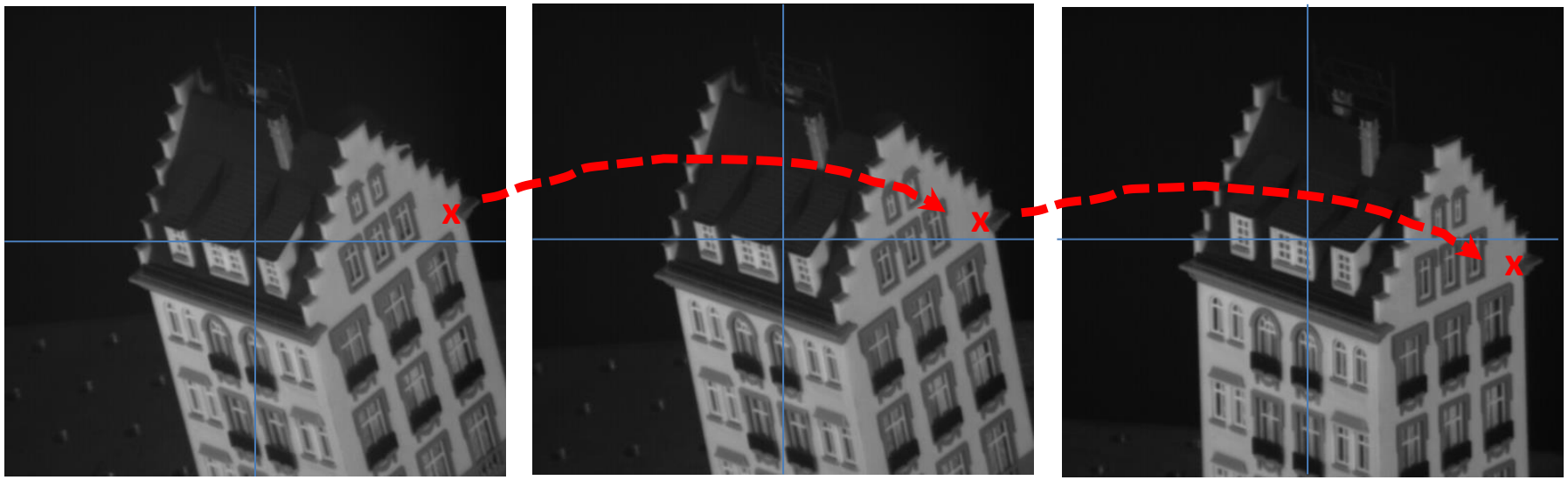
Slide from Silvio Savarese

Example: estimating “fundamental matrix” that corresponds two views



Slide from Silvio Savarese

Example: tracking points



frame 0 frame 22 frame 49

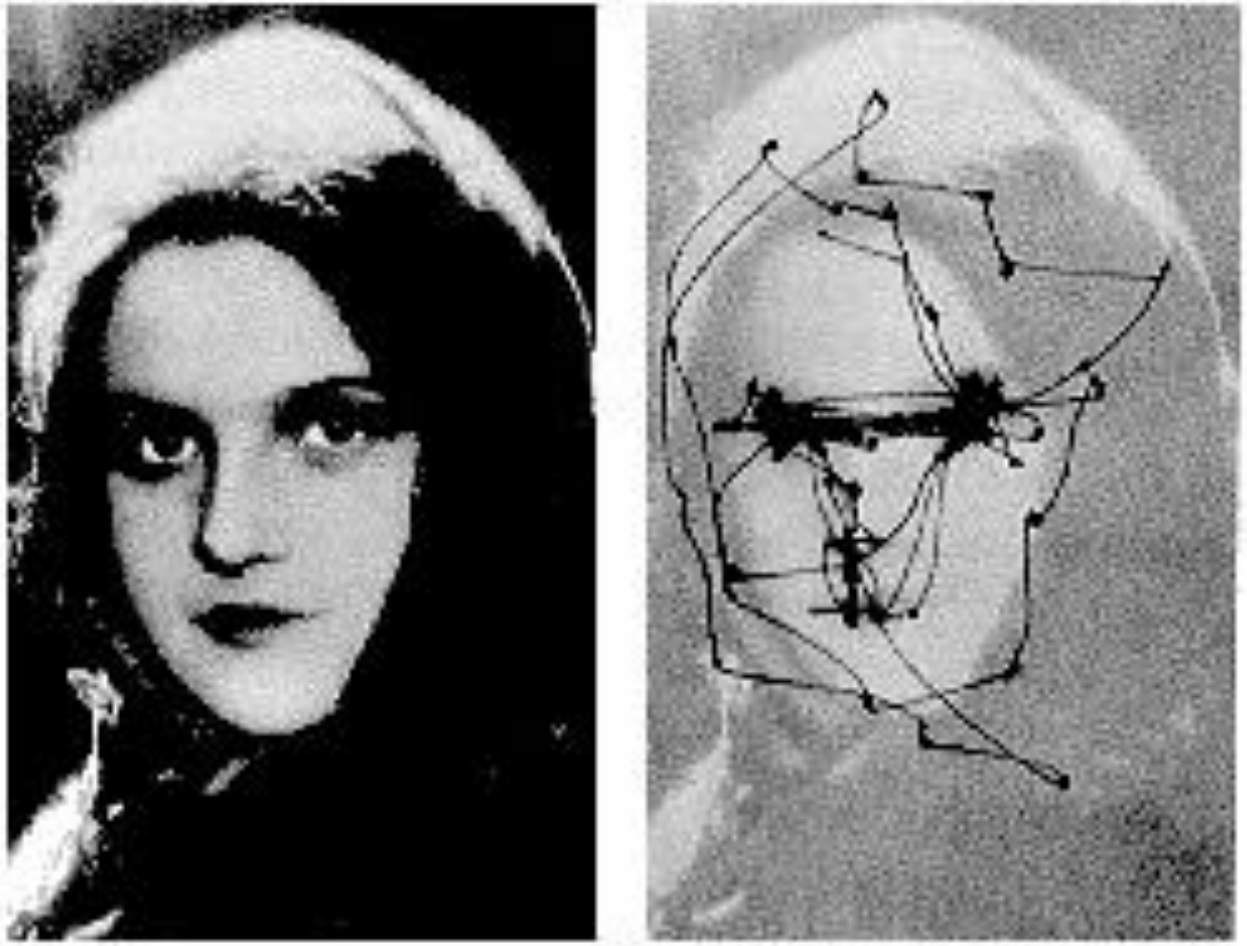
HMI
HUMAN MACHINE INTERACTION LABORATORY

Interest points

- Note: “interest points” = “keypoints”, also sometimes called “features”

- Many applications
  - tracking: which points are good to track?
  - recognition: find patches likely to tell us something about object category
  - 3D reconstruction: find correspondences across different views

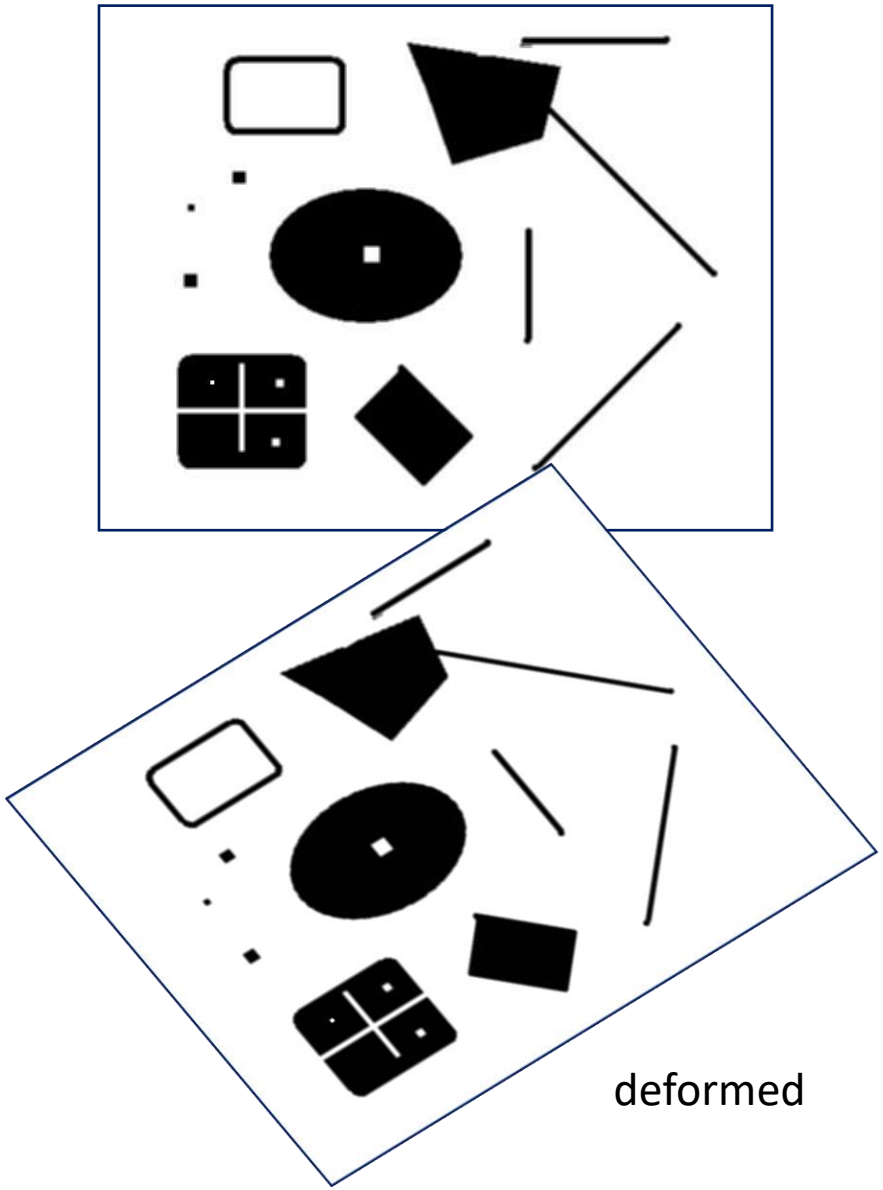
Human eye movements



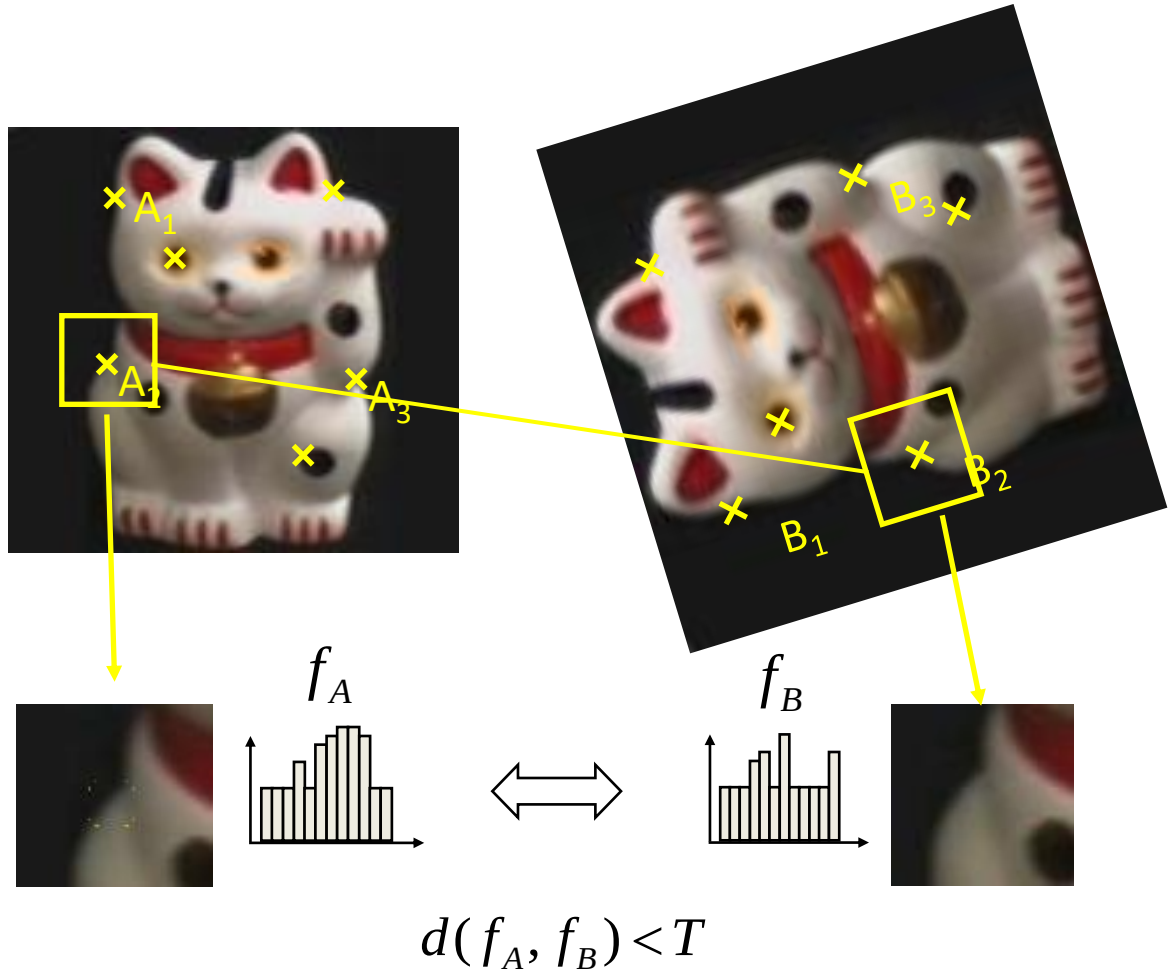
Yarbus eye tracking

This class: interest points

- Suppose you have to click on some point, go away and come back after I deform the image, and click on the same points again.
  - Which points would you choose?



Overview of Keypoint Matching



1. Find a set of distinctive key-points
2. Define a region around each keypoint
3. Extract and normalize the region content
4. Compute a local descriptor from the normalized region
5. Match local descriptors

Goals for Keypoints

Detect points that are *repeatable* and *distinctive*

Choosing interest points

Where would you tell your friend to meet you?

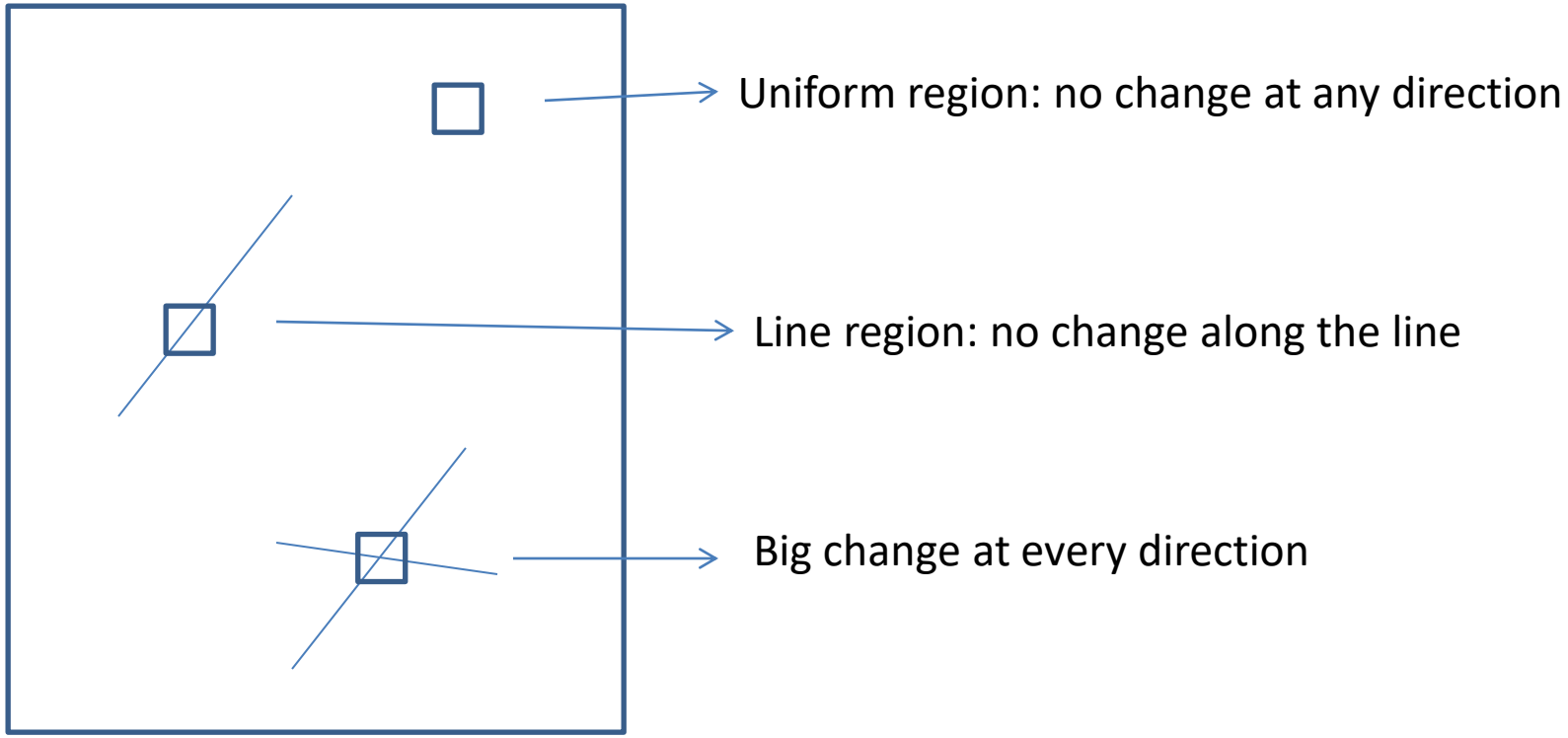
Choosing interest points

Where would you tell your friend to meet you?

Many Existing Detectors Available

Hessian & Harris	[Beaudet ‘78], [Harris ‘88]
Laplacian, DoG	[Lindeberg ‘98], [Lowe 1999]
Harris-/Hessian-Laplace	[Mikolajczyk & Schmid ‘01]
Harris-/Hessian-Affine	[Mikolajczyk & Schmid ‘04]
EBR and IBR	[Tuytelaars & Van Gool ‘04]
MSER	[Matas ‘02]
Salient Regions	[Kadir & Brady ‘01]
Others…	

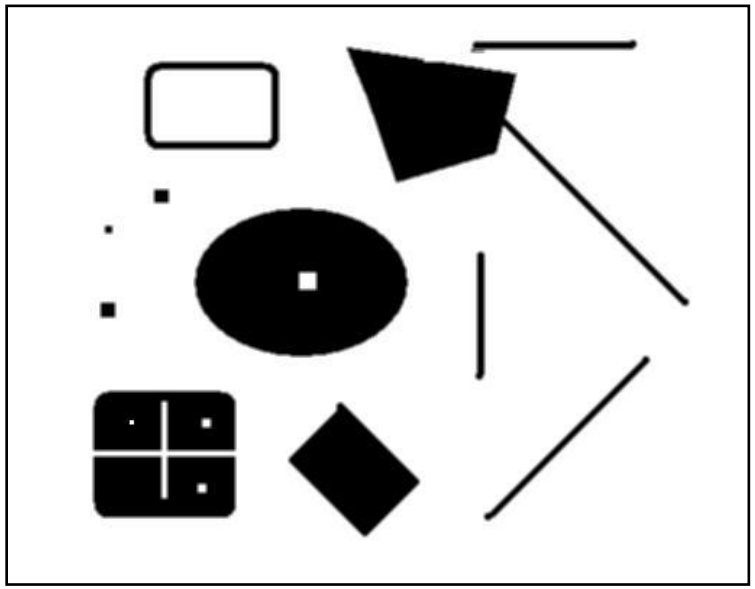
Interesting points detection



Harris Detector [Harris88]

- Second moment matrix

$$\mu(\sigma_I, \sigma_D) = g(\sigma_I) * \begin{bmatrix} I_x^2(\sigma_D) & I_x I_y(\sigma_D) \\ I_x I_y(\sigma_D) & I_y^2(\sigma_D) \end{bmatrix}$$

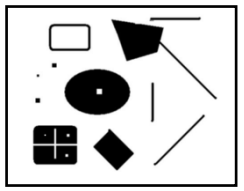


Intuition: **Search for local neighborhoods where the image content has two main directions (eigenvectors).**

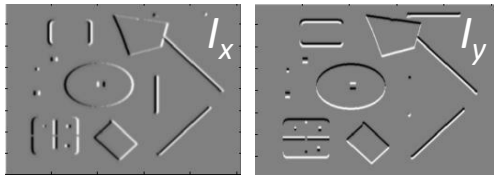
Harris Detector [Harris88]

- Second moment matrix

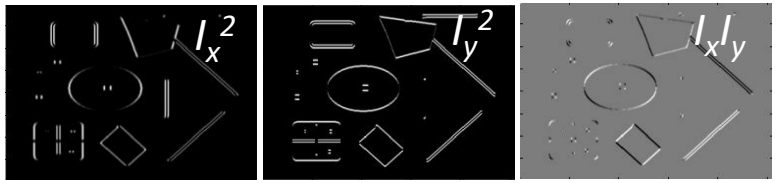
$$\mu(\sigma_I, \sigma_D) = g(\sigma_I) * \begin{bmatrix} I_x^2(\sigma_D) & I_x I_y(\sigma_D) \\ I_x I_y(\sigma_D) & I_y^2(\sigma_D) \end{bmatrix}$$



1. Image derivatives (optionally, blur first)



2. Square of derivatives

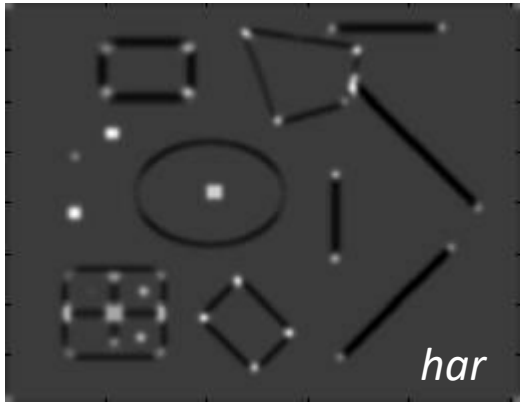


3. Gaussian filter $g(\sigma_I)$

$$\det M = \lambda_1 \lambda_2$$
$$\text{trace}\, M = \lambda_1 + \lambda_2$$

4. Cornerness function – both eigenvalues are strong

$$har = \det[\mu(\sigma_I, \sigma_D)] - \alpha[\text{trace}(\mu(\sigma_I, \sigma_D))^2] =$$
$$g(I_x^2)g(I_y^2) - [g(I_x I_y)]^2 - \alpha[g(I_x^2) + g(I_y^2)]^2$$



5. Non-maxima suppression

Harris Detector: Mathematics

$$M = g(\sigma_I) * \begin{bmatrix} I_x^2(\sigma_D) & I_x I_y(\sigma_D) \\ I_x I_y(\sigma_D) & I_y^2(\sigma_D) \end{bmatrix}$$

1. Want large eigenvalues, and small ratio $\frac{\lambda_1}{\lambda_2} < t$

2. We know

$$\det M = \lambda_1 \lambda_2$$

$$\text{trace}\, M = \lambda_1 + \lambda_2$$

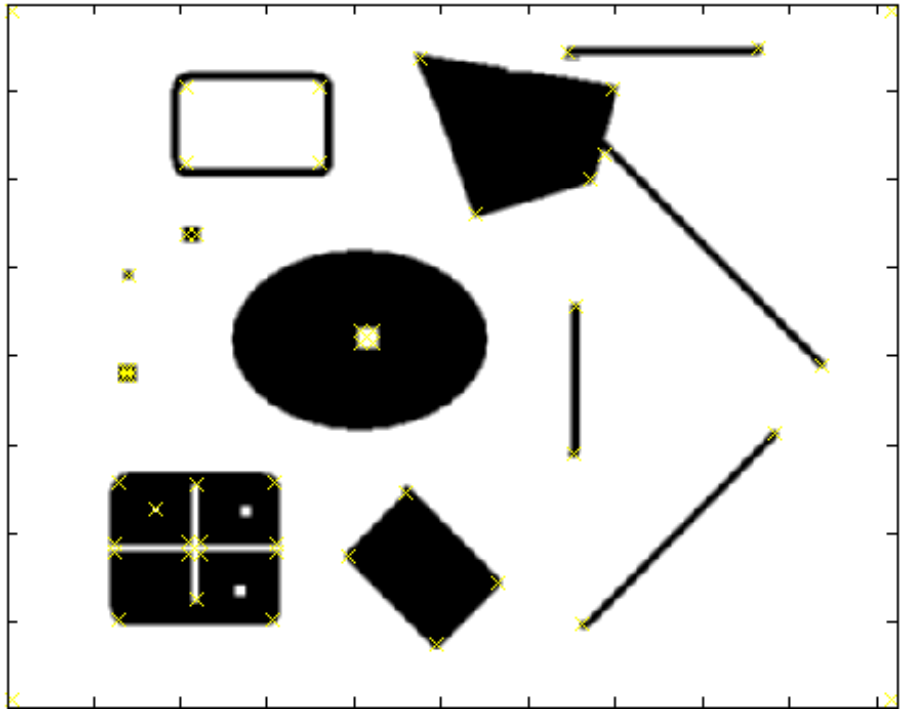
3. Leads to

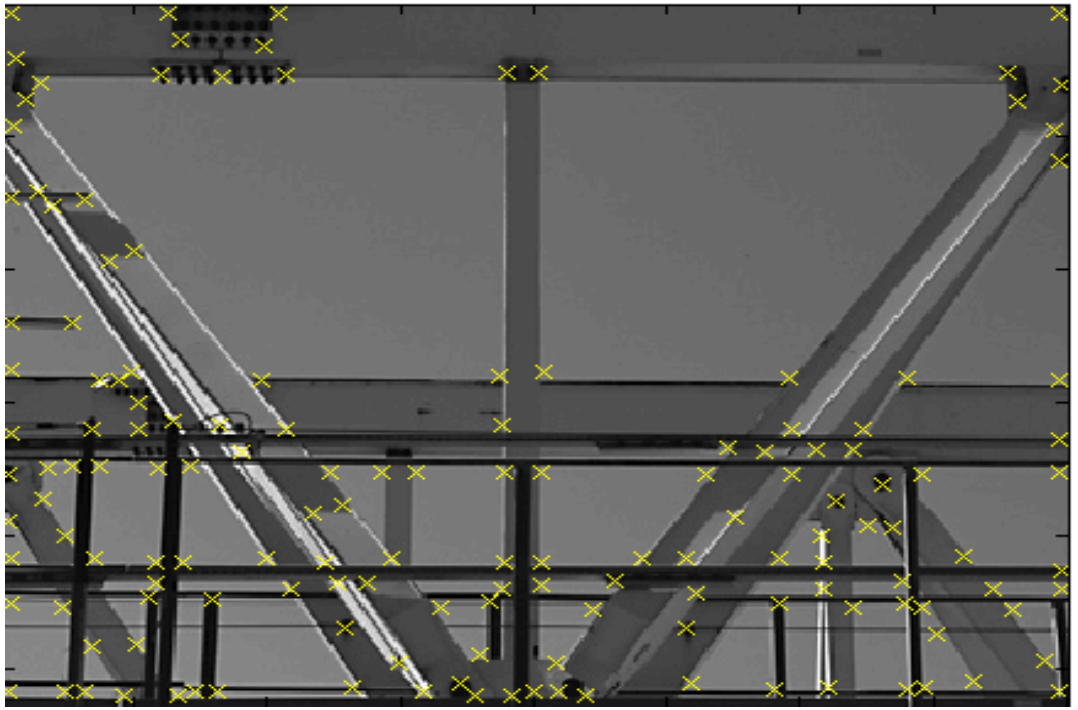
$$\det M - k \cdot \text{trace}^2(M) > t$$

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

Nice brief derivation on wikipedia

Harris Detector – Responses [Harris88]





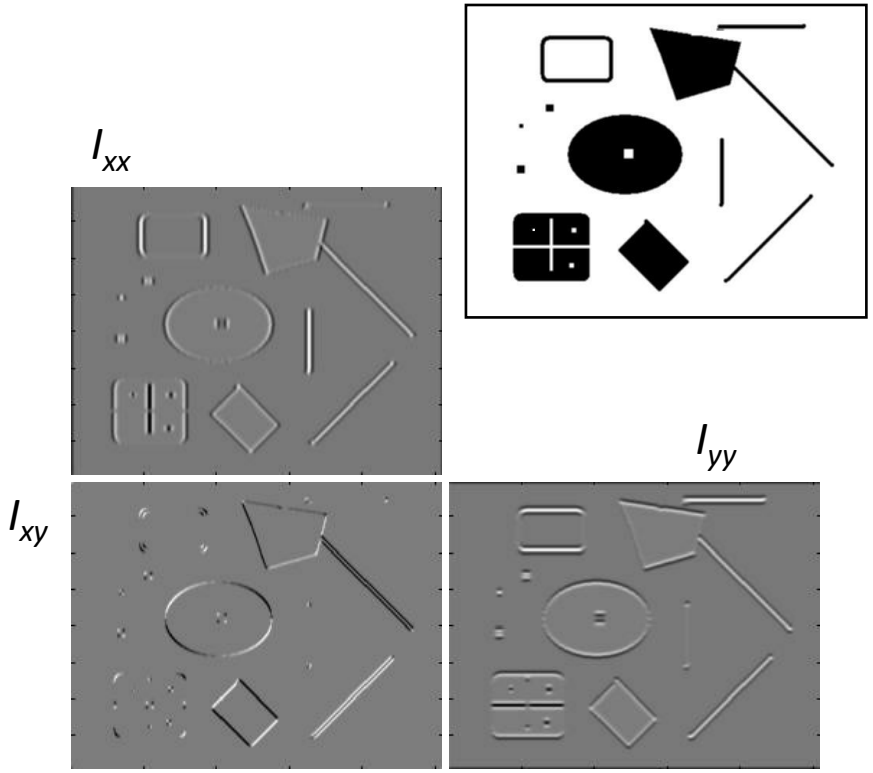
Effect: **A very precise corner detector.**

Harris Detector - Responses [Harris88]

Hessian Detector [Beaudet78]

- Hessian determinant

$$Hessian(I) = \begin{bmatrix} I_{xx} & I_{xy} \\ I_{xy} & I_{yy} \end{bmatrix}$$



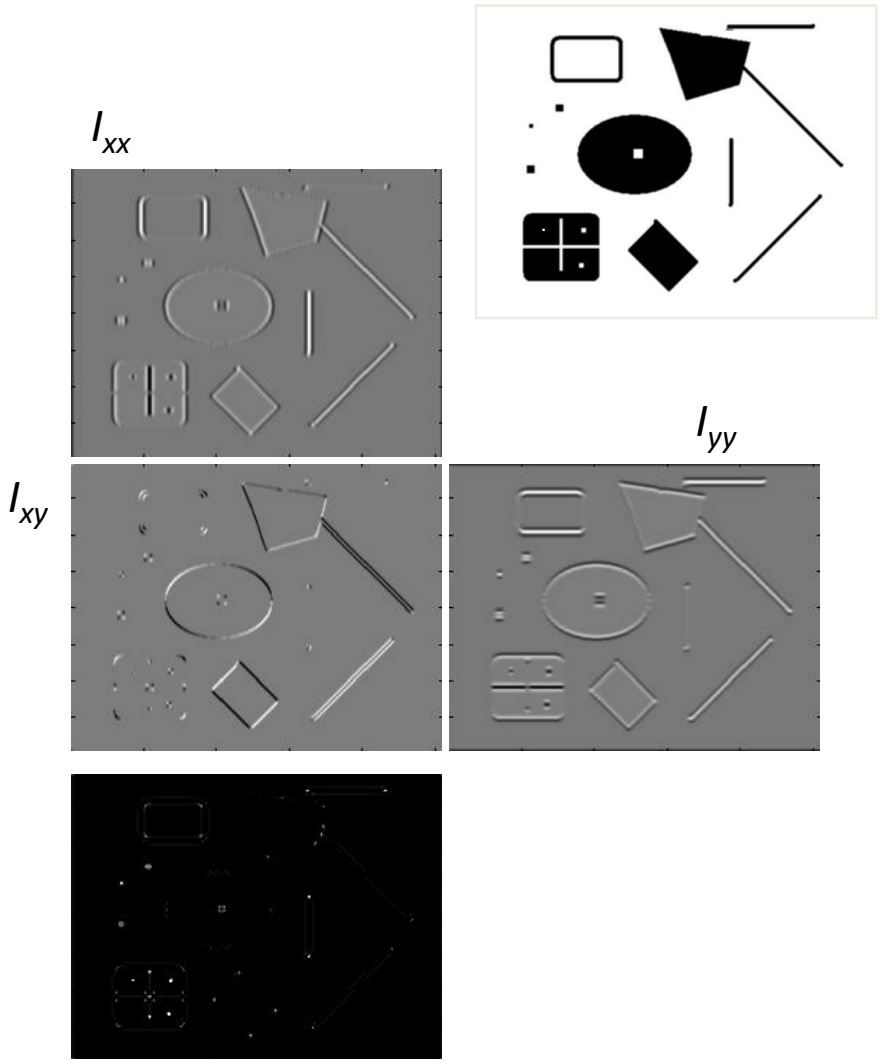
Intuition: **Search for strong curvature in two orthogonal directions**

Hessian Detector [Beaudet78]

- Hessian determinant

$$Hessian(I) = \begin{bmatrix} I_{xx} & I_{xy} \\ I_{xy} & I_{yy} \end{bmatrix}$$

$$\det M = \lambda_1 \lambda_2$$
$$\text{trace}\, M = \lambda_1 + \lambda_2$$

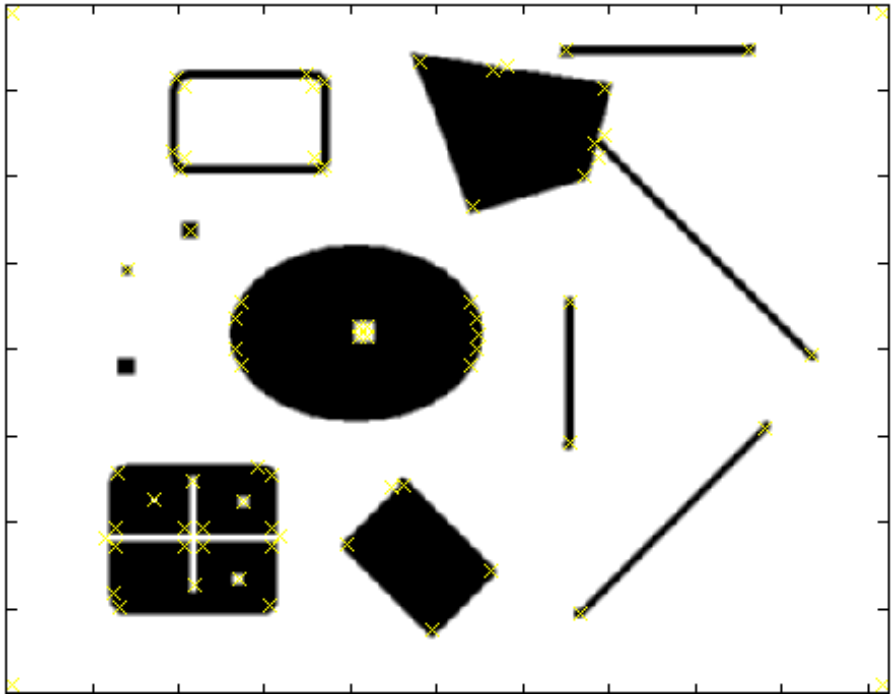


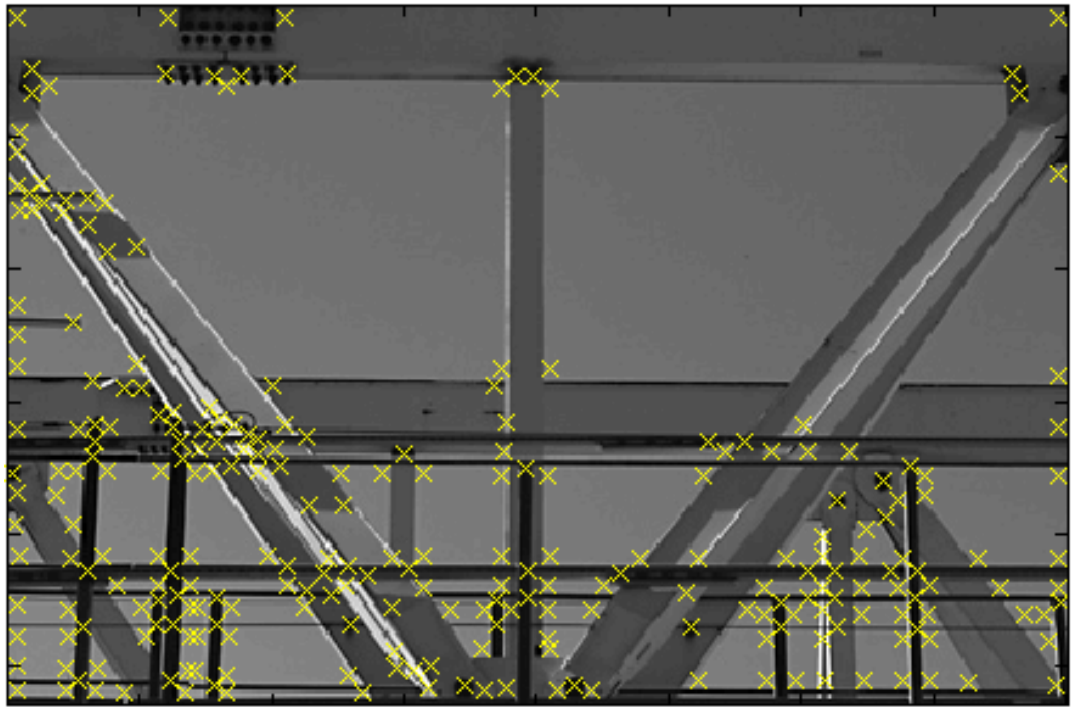
$$\det(Hessian(I)) = I_{xx} I_{yy} - I_{xy}^2$$

In Matlab:

$$I_{xx} .* I_{yy} - (I_{xy})\text{^}2$$

Hessian Detector – Responses [Beaudet78]





Effect: **Responses mainly on corners and strongly textured areas.**

Hessian Detector – Responses [Beaudet78]

So far: can localize in x-y, but not scale