A large field of sunflowers stretches across the foreground and middle ground, with a clear blue sky above. The sunflowers are in various stages of bloom, with bright yellow petals and dark brown centers. The text is overlaid on this background.

T13 - Local features: detection and description

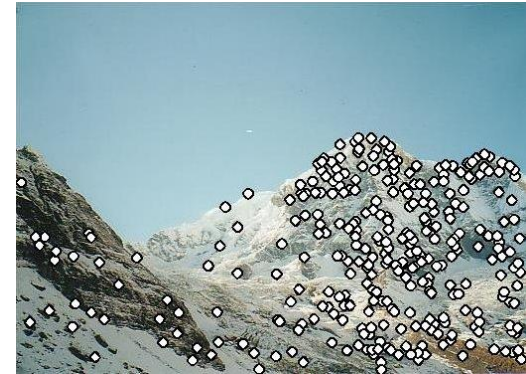
Computer Vision, FCUP, 2013
Miguel Coimbra
Slides by Prof. Kristen Grauman

Today

- Local invariant features
 - Detection of interest points
 - (Harris corner detection)
 - Scale invariant blob detection: LoG
 - Description of local patches
 - SIFT : Histograms of oriented gradients

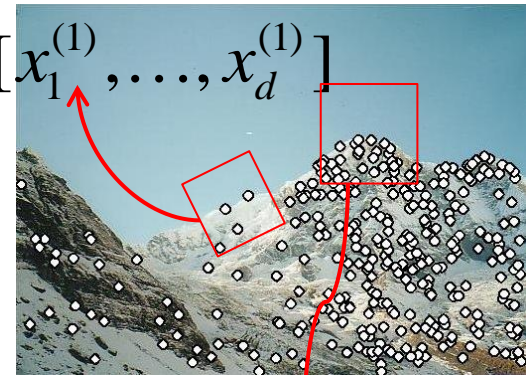
Local features: main components

1) Detection: Identify the interest points



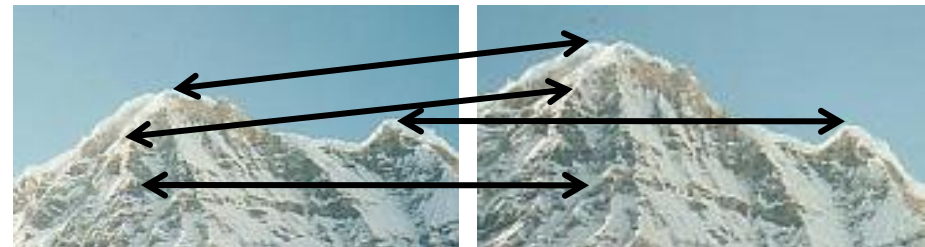
2) Description: Extract vector feature descriptor surrounding each interest point.

$$\mathbf{x}_1 = [x_1^{(1)}, \dots, x_d^{(1)}]$$



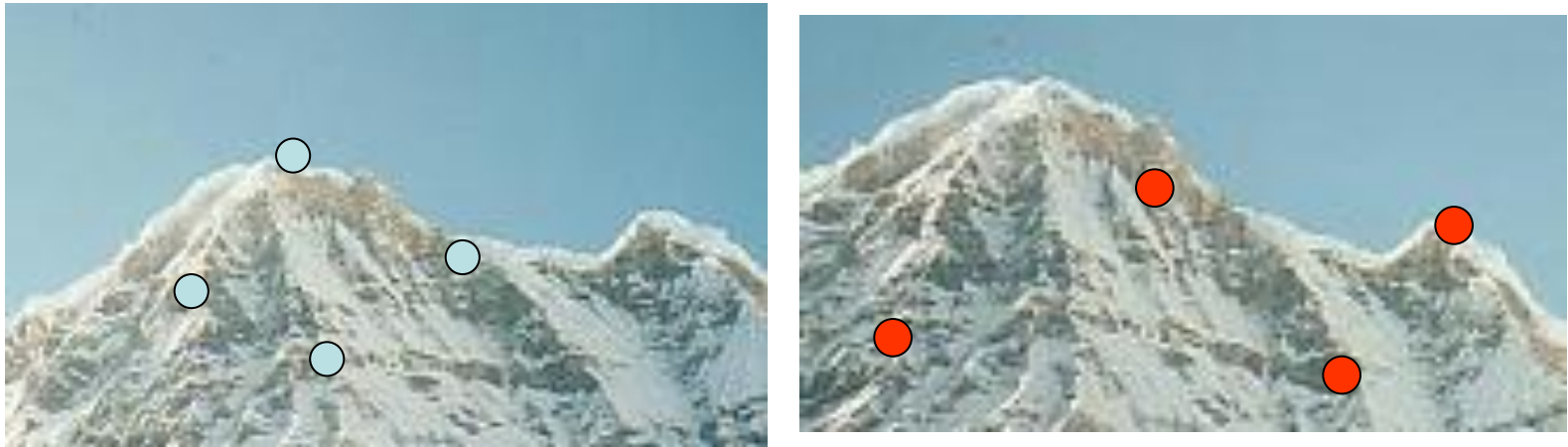
$$\mathbf{x}_2 = [x_1^{(2)}, \dots, x_d^{(2)}]$$

3) Matching: Determine correspondence between descriptors in two views



Goal: interest operator repeatability

- We want to detect (at least some of) the same points in both images.

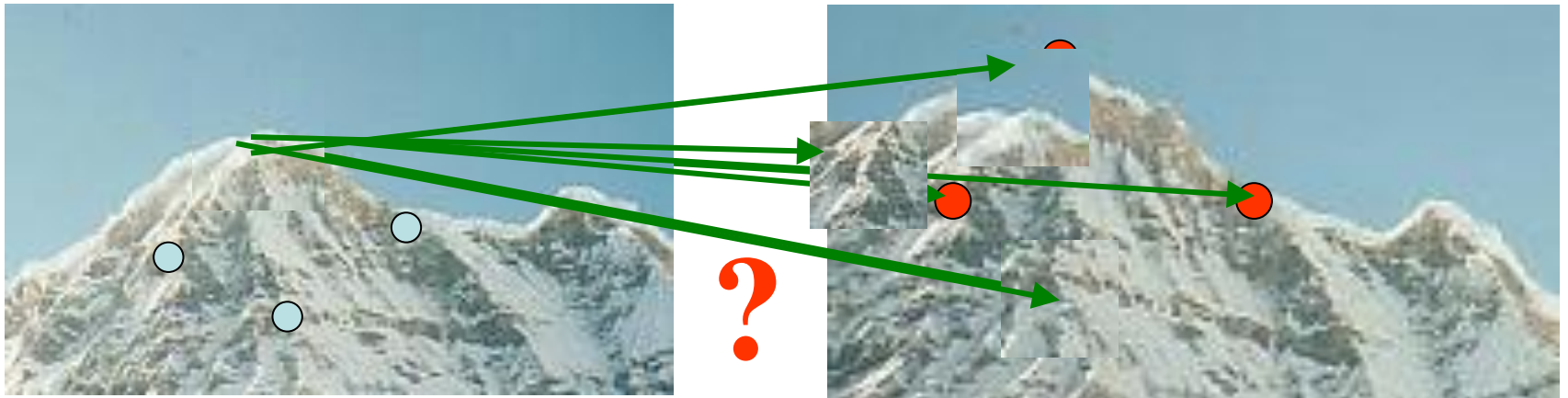


No chance to find true matches!

- Yet we have to be able to run the detection procedure *independently* per image.

Goal: descriptor distinctiveness

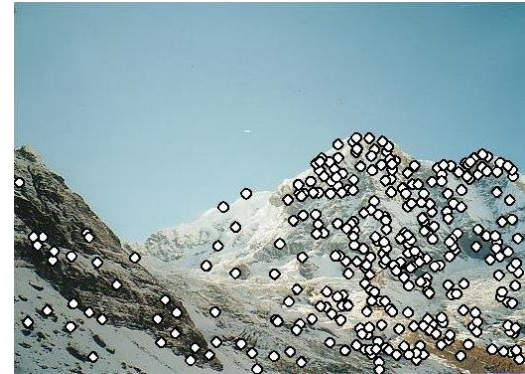
- We want to be able to reliably determine which point goes with which.



- Must provide some invariance to geometric and photometric differences between the two views.

Local features: main components

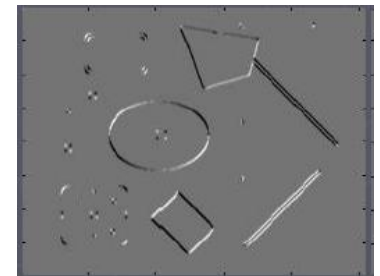
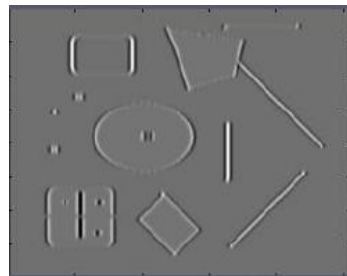
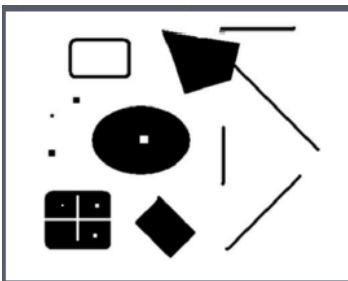
- 1) Detection: Identify the interest points
- 2) Description: Extract vector feature descriptor surrounding each interest point.
- 3) Matching: Determine correspondence between descriptors in two views



Recall: Corners as distinctive interest points

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

2 x 2 matrix of image derivatives (averaged in neighborhood of a point).



Notation:

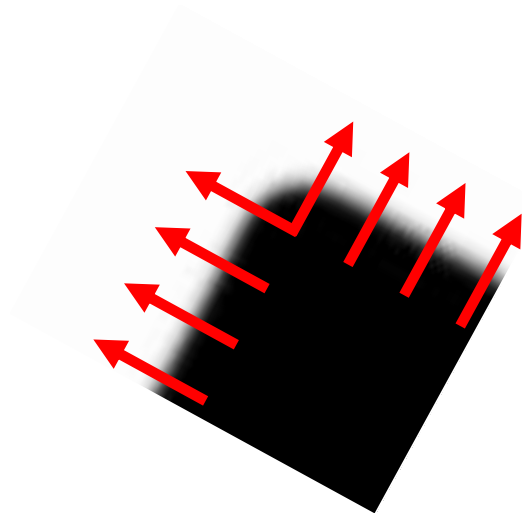
$$I_x \Leftrightarrow \frac{\partial I}{\partial x}$$

$$I_y \Leftrightarrow \frac{\partial I}{\partial y}$$

$$I_x I_y \Leftrightarrow \frac{\partial I}{\partial x} \frac{\partial I}{\partial y}$$

Recall: Corners as distinctive interest points

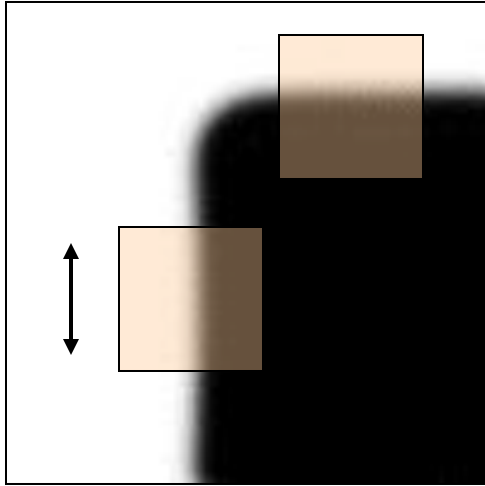
Since M is symmetric, we have $M = X \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} X^T$



$$Mx_i = \lambda_i x_i$$

The *eigenvalues* of M reveal the amount of intensity change in the two principal orthogonal gradient directions in the window.

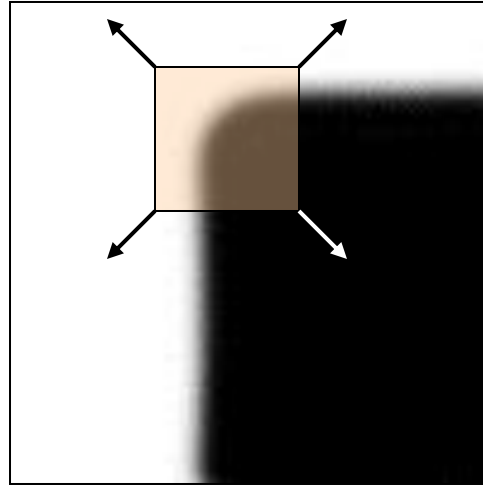
Recall: Corners as distinctive interest points



“edge”:

$$\lambda_1 \gg \lambda_2$$

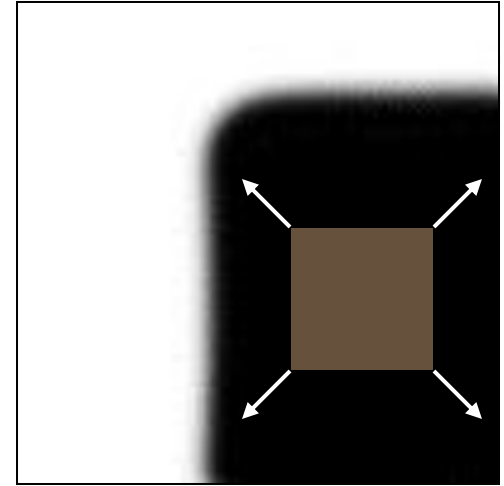
$$\lambda_2 \gg \lambda_1$$



“corner”:

λ_1 and λ_2 are large,

$$\lambda_1 \sim \lambda_2;$$



“flat” region

λ_1 and λ_2 are

small;

One way to score
the cornerness:

$$f = \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2}$$

Harris corner detector

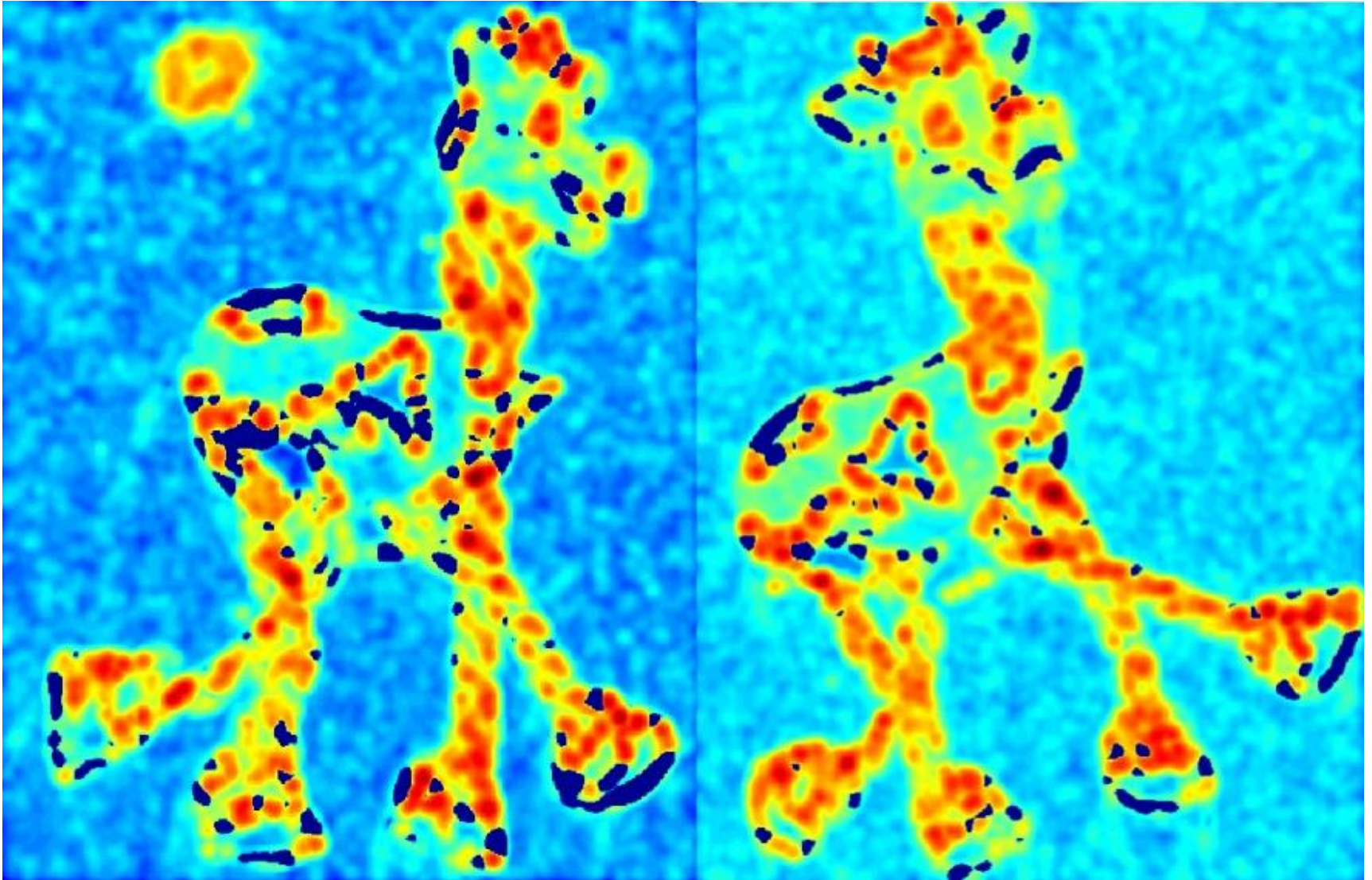
- 1) Compute M matrix for image window surrounding each pixel to get its *cornerness* score.
- 2) Find points with large corner response ($f >$ threshold)
- 3) Take the points of local maxima, i.e., perform non-maximum suppression

Harris Detector: Steps



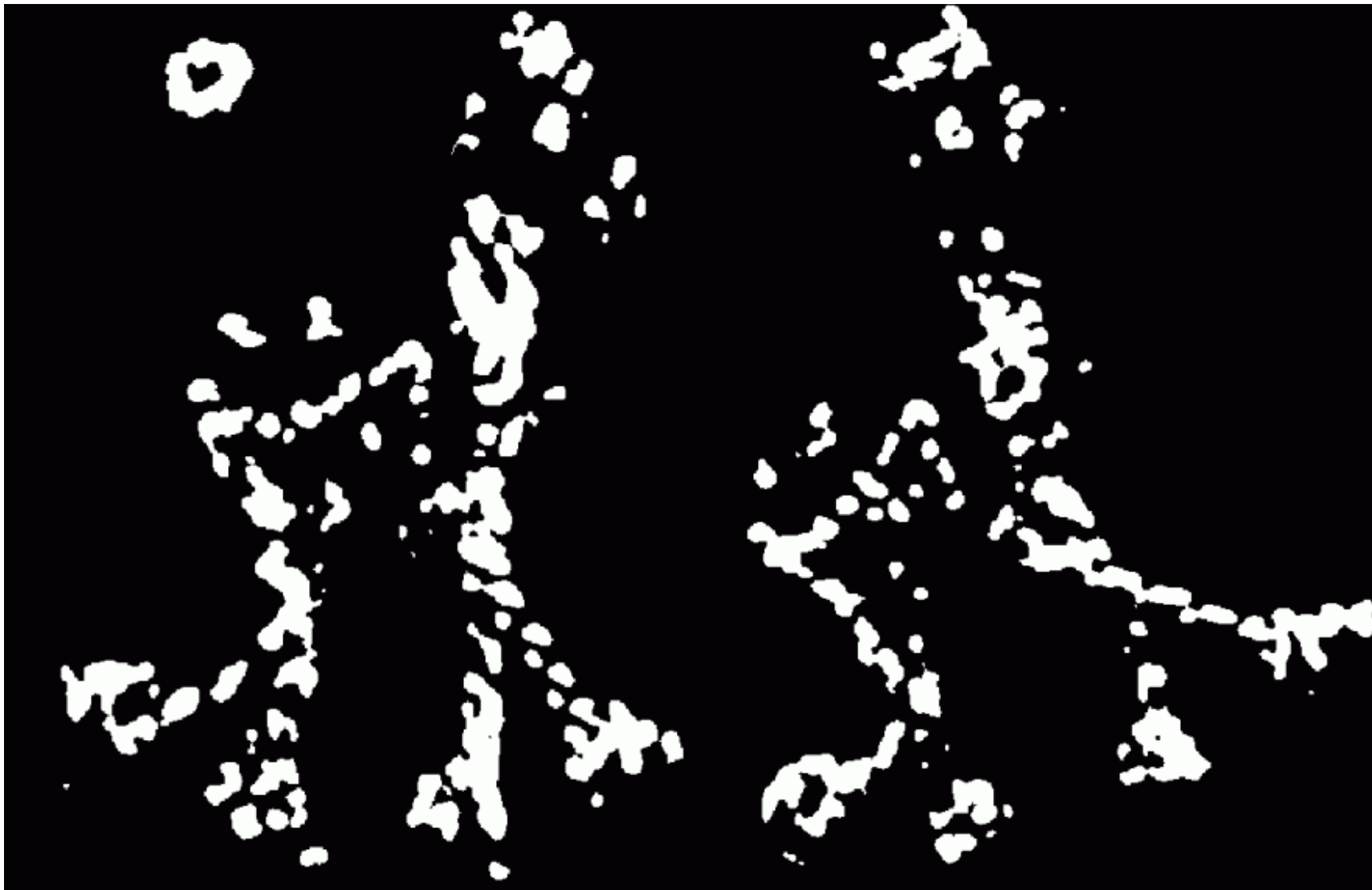
Harris Detector: Steps

Compute corner response f



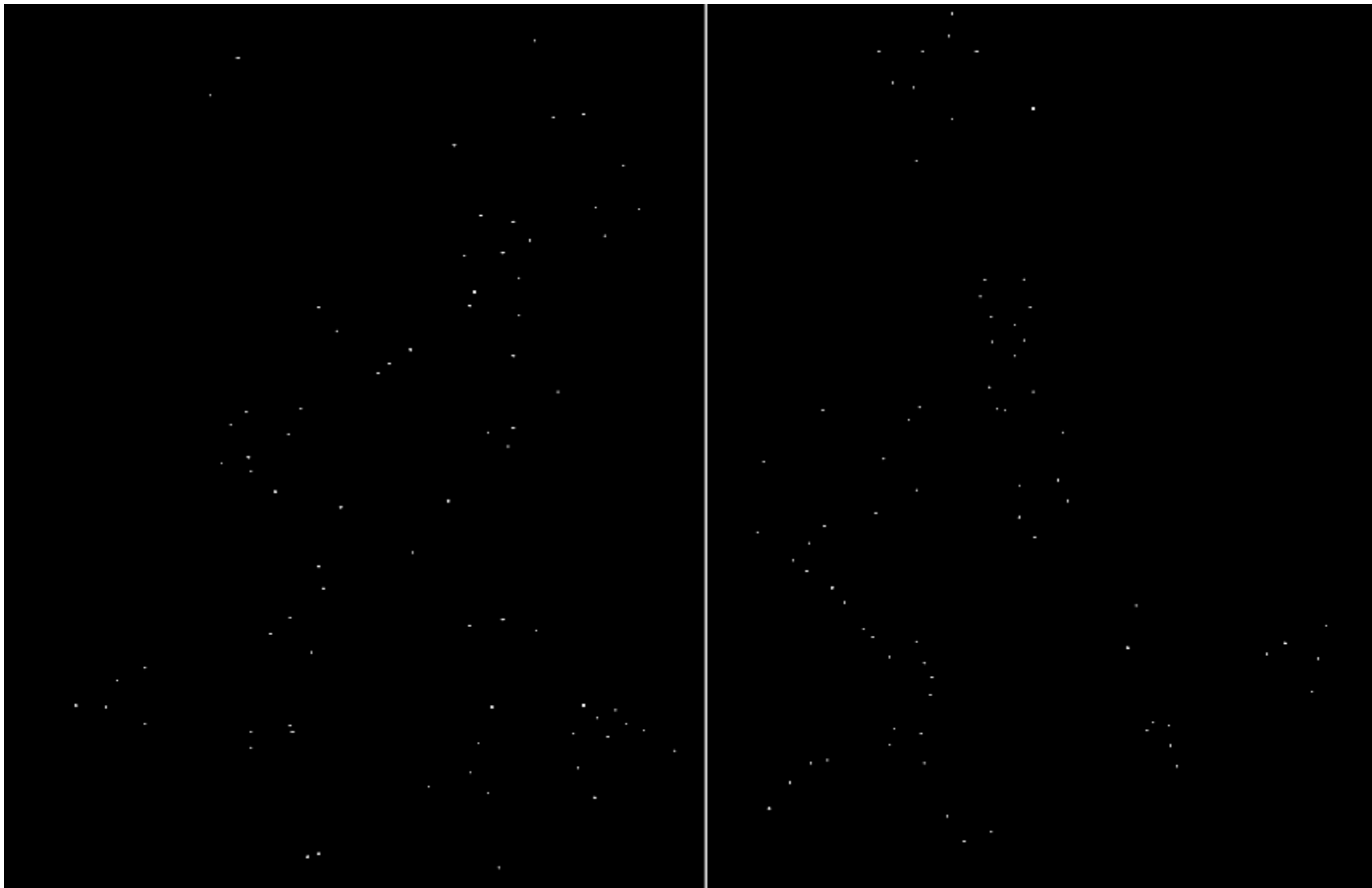
Harris Detector: Steps

Find points with large corner response: $f > \text{threshold}$

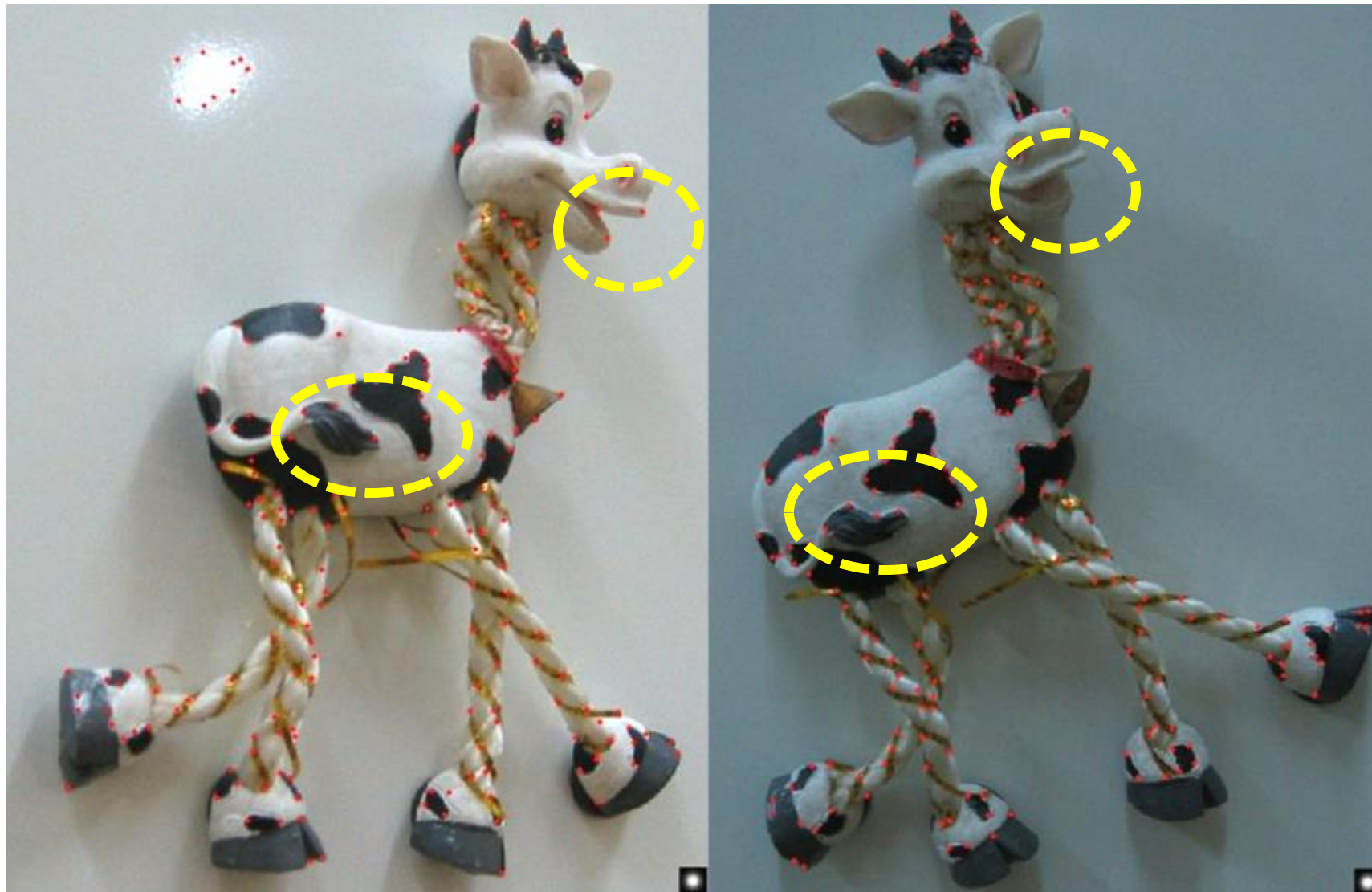


Harris Detector: Steps

Take only the points of local maxima of f



Harris Detector: Steps



Properties of the Harris corner detector

Rotation invariant? Yes

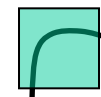
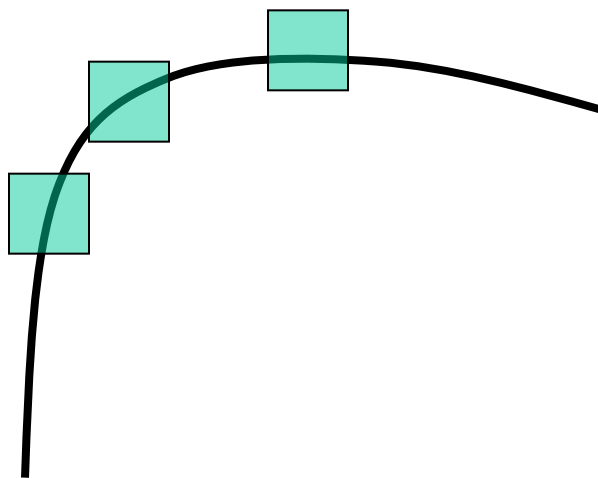
$$M = X \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} X^T$$

Scale invariant?

Properties of the Harris corner detector

Rotation invariant? Yes

Scale invariant? No



All points will be classified as **edges**

Corner !

Scale invariant interest points

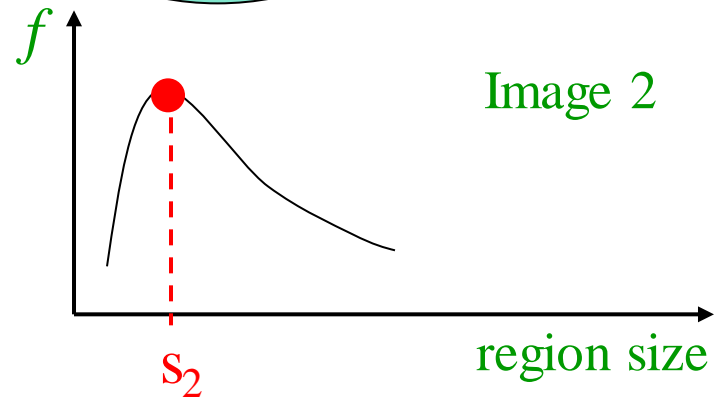
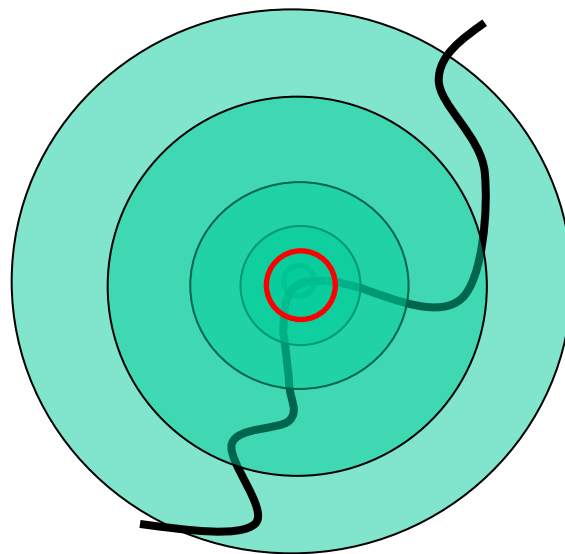
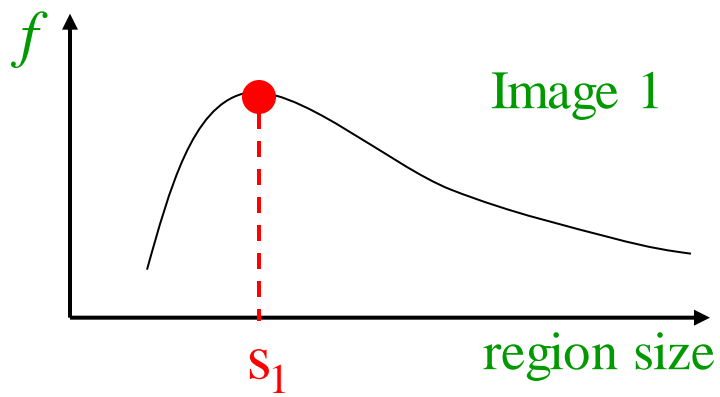
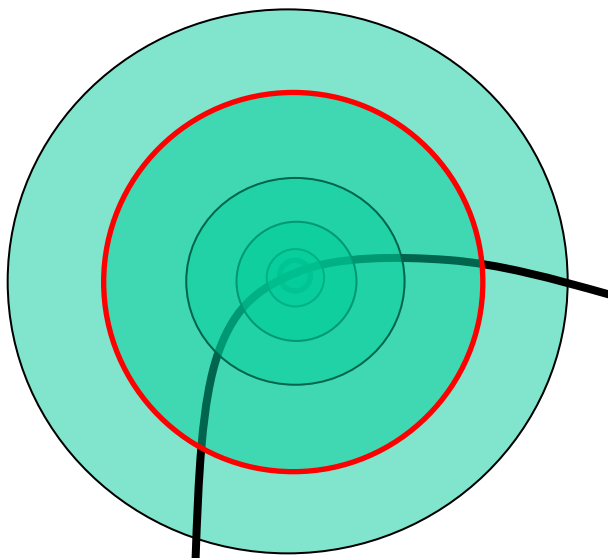
How can we independently select interest points in each image, such that the detections are repeatable across different scales?



Automatic scale selection

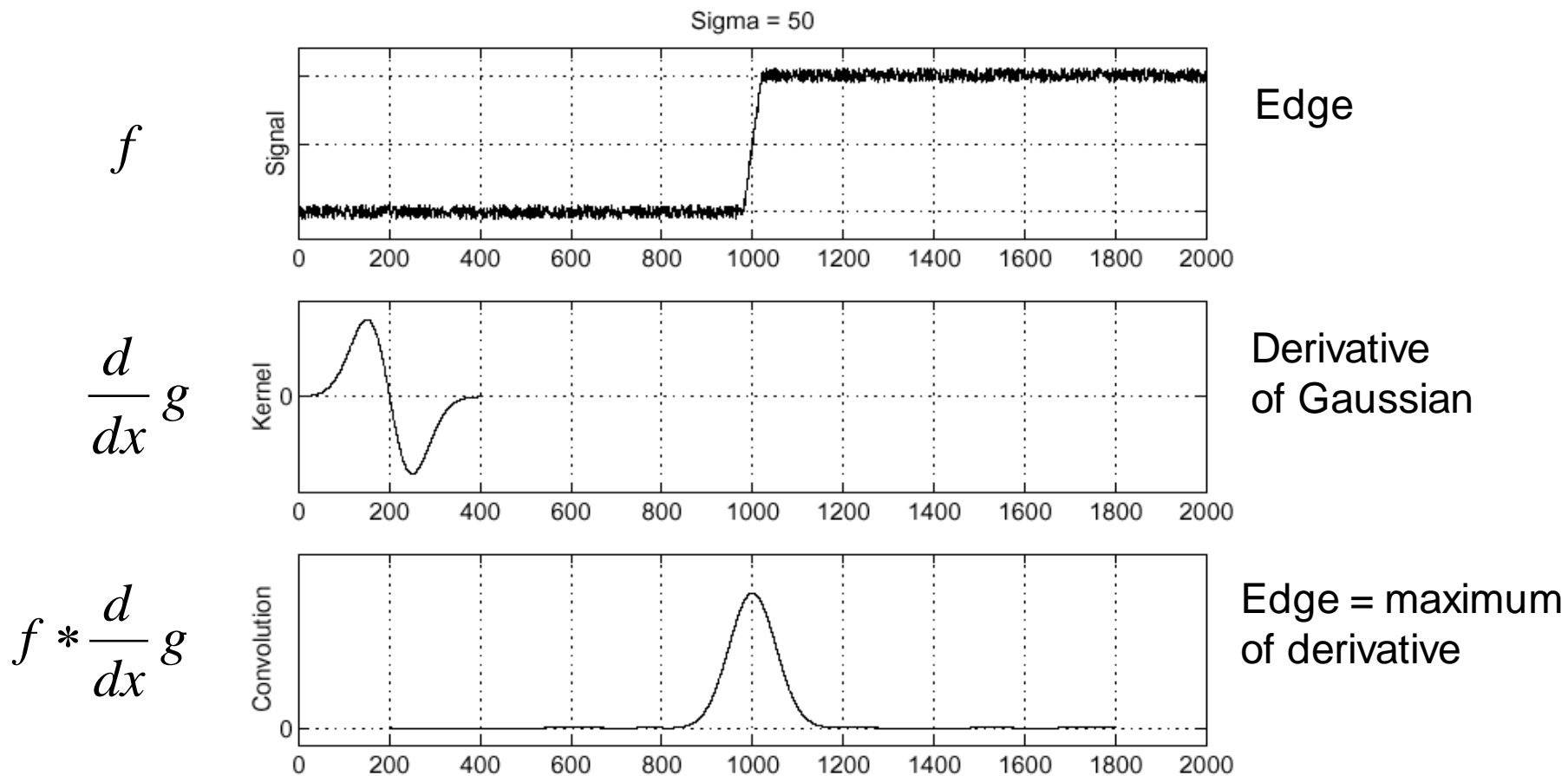
Intuition:

- Find scale that gives local maxima of some function f in both position and scale.



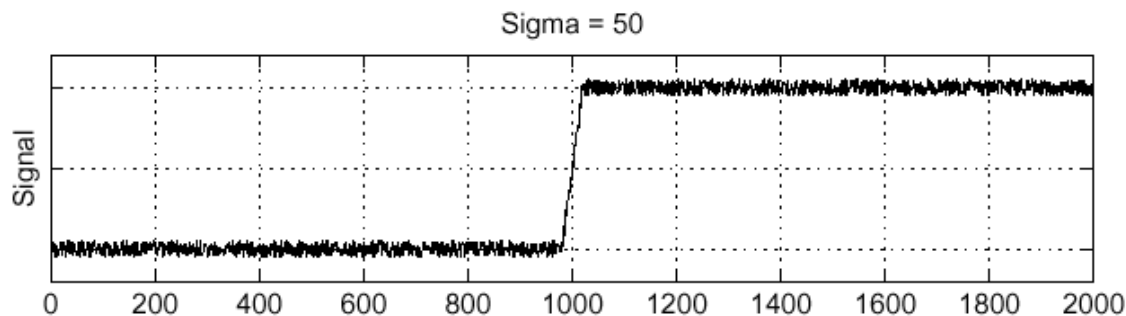
What can be the “signature” function?

Recall: Edge detection



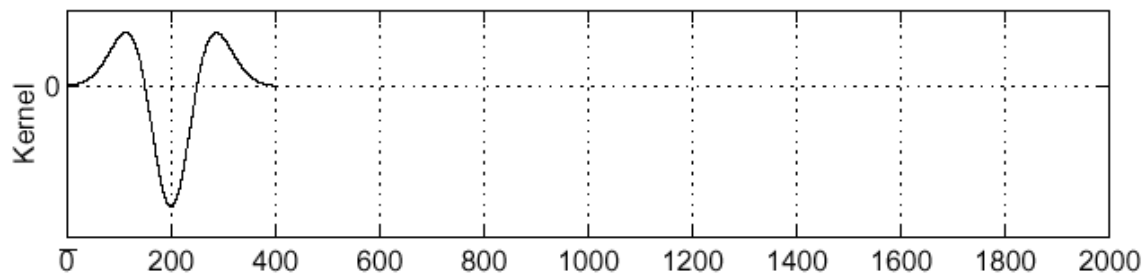
Recall: Edge detection

f



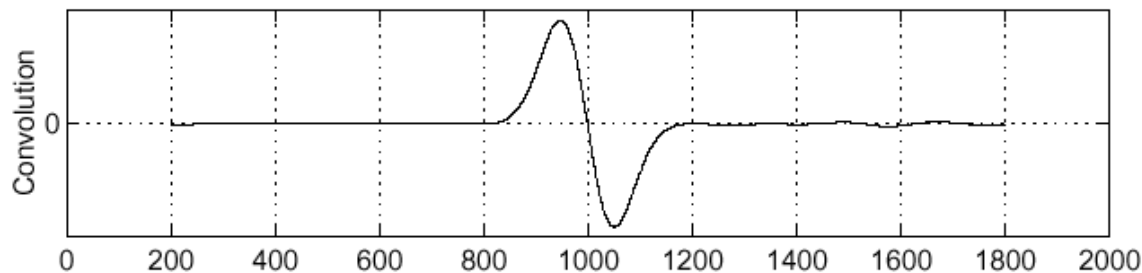
Edge

$\frac{d^2}{dx^2} g$



Second derivative
of Gaussian
(Laplacian)

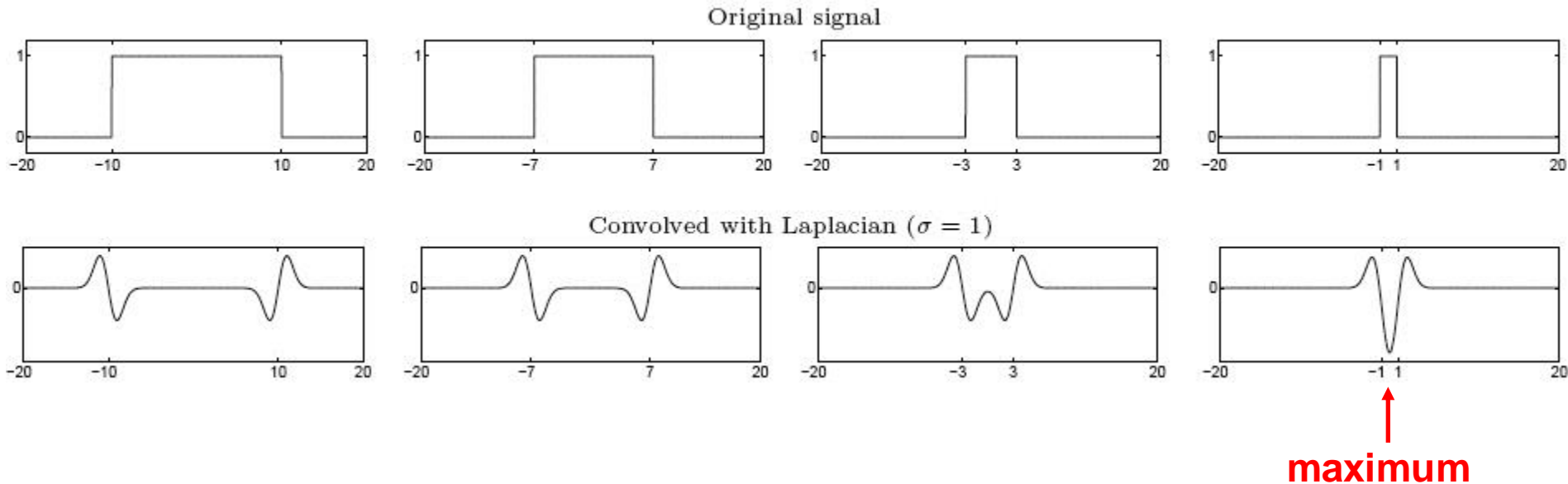
$f * \frac{d^2}{dx^2} g$



Edge = zero crossing
of second derivative

From edges to blobs

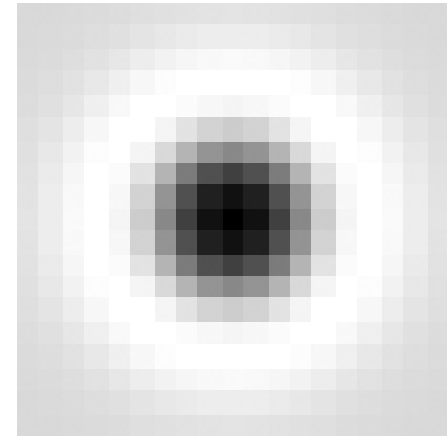
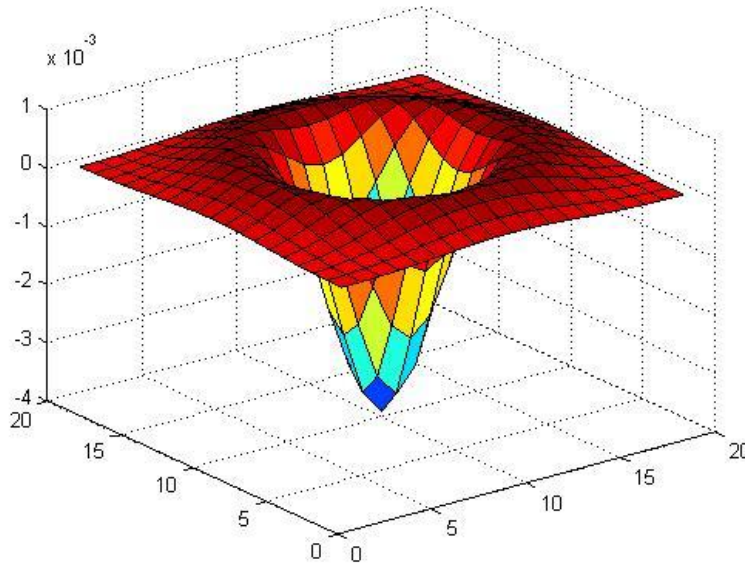
- Edge = ripple
- Blob = superposition of two ripples



Spatial selection: the **magnitude** of the Laplacian response will achieve a maximum at the center of the blob, provided the scale of the Laplacian is “matched” to the scale of the blob

Blob detection in 2D

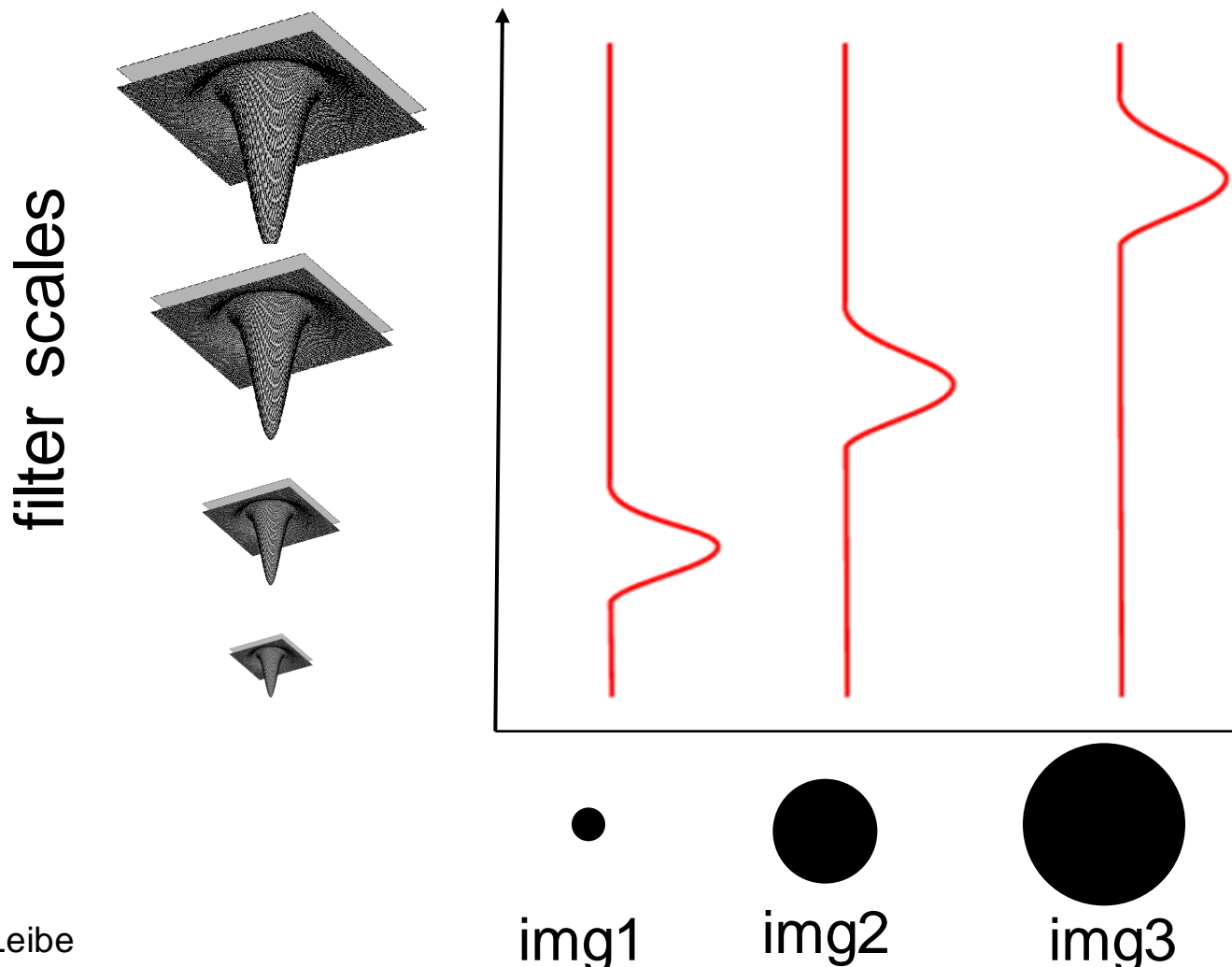
Laplacian of Gaussian: Circularly symmetric operator for blob detection in 2D



$$\nabla^2 g = \frac{\partial^2 g}{\partial x^2} + \frac{\partial^2 g}{\partial y^2}$$

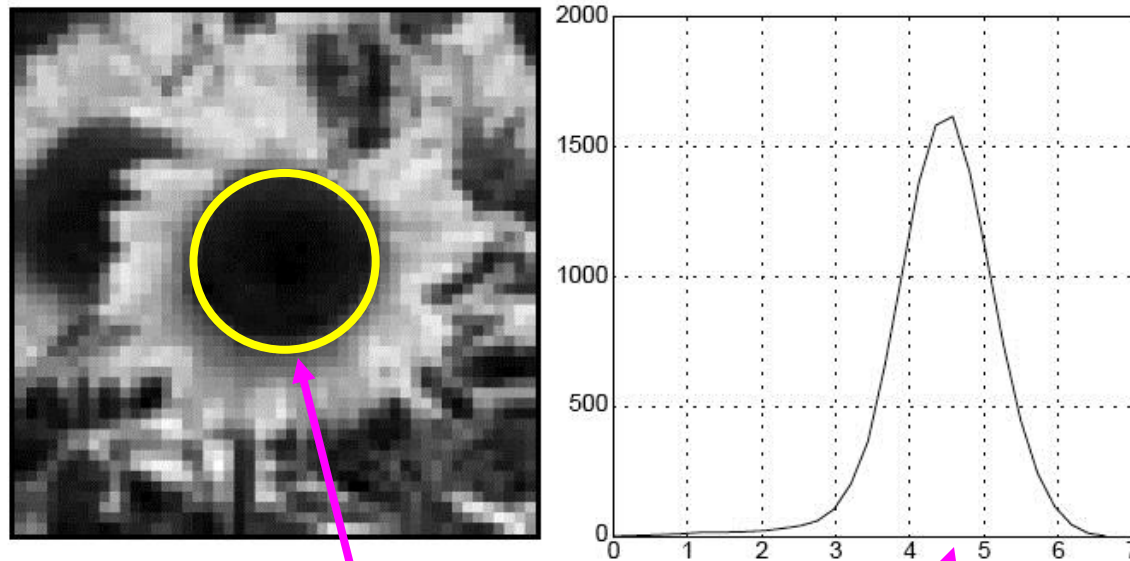
Blob detection in 2D: scale selection

Laplacian-of-Gaussian = “blob” detector $\nabla^2 g = \frac{\partial^2 g}{\partial x^2} + \frac{\partial^2 g}{\partial y^2}$



Blob detection in 2D

We define the *characteristic scale* as the scale that produces peak of Laplacian response



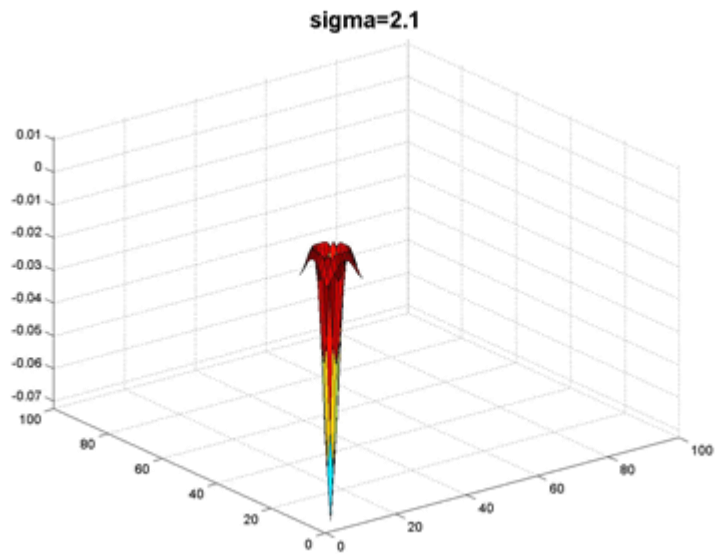
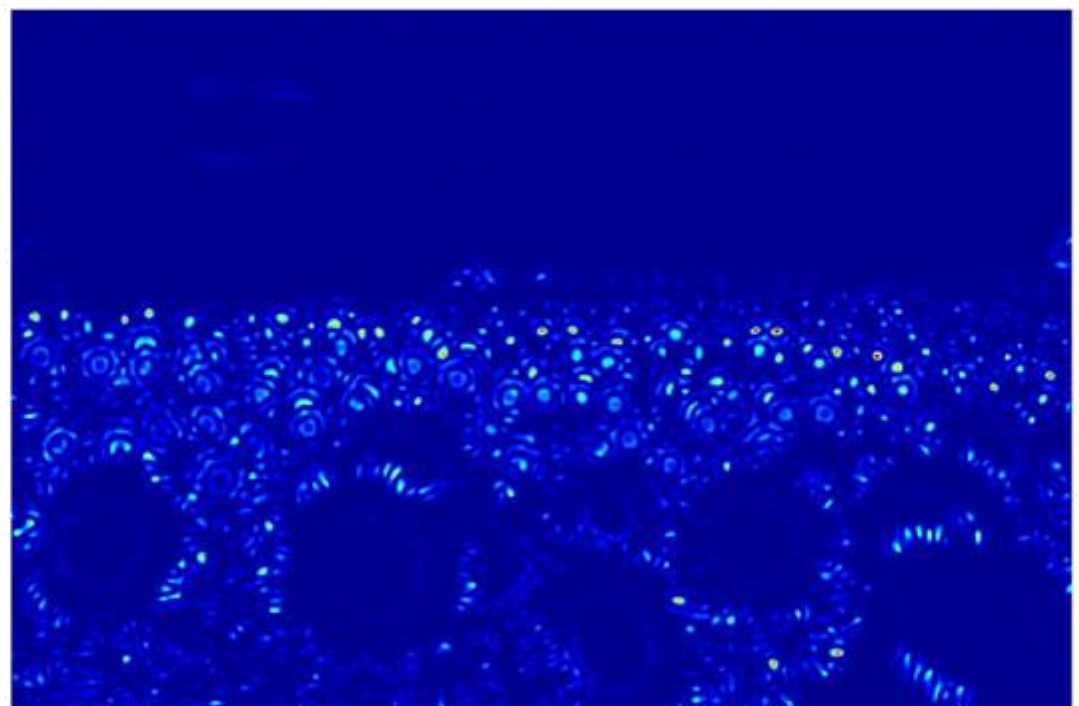
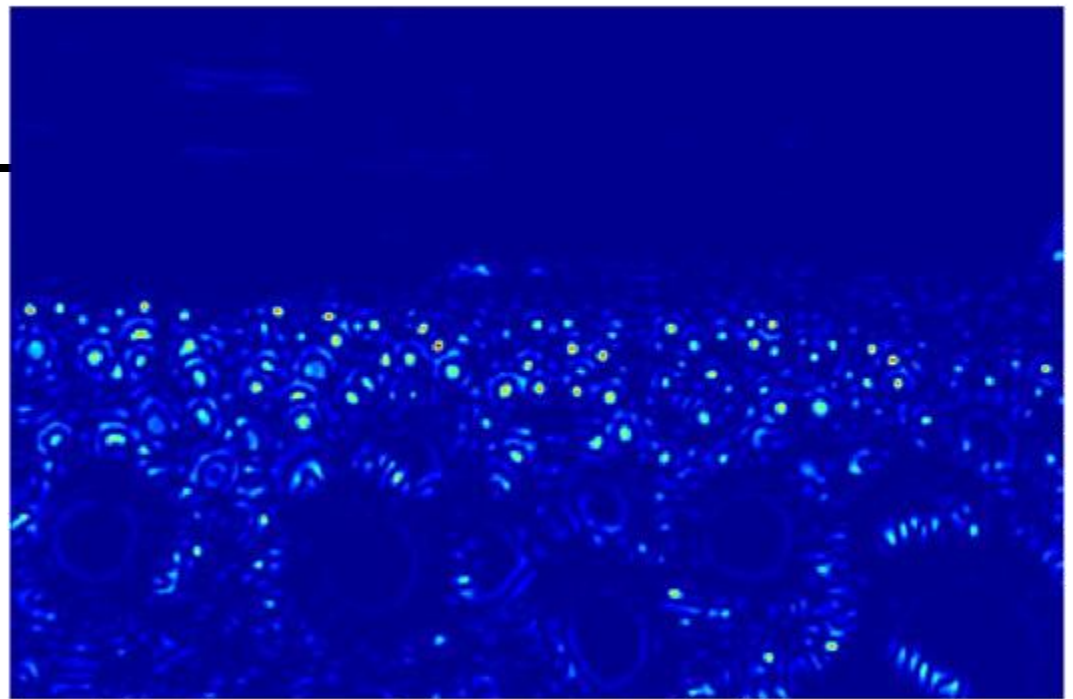
characteristic scale

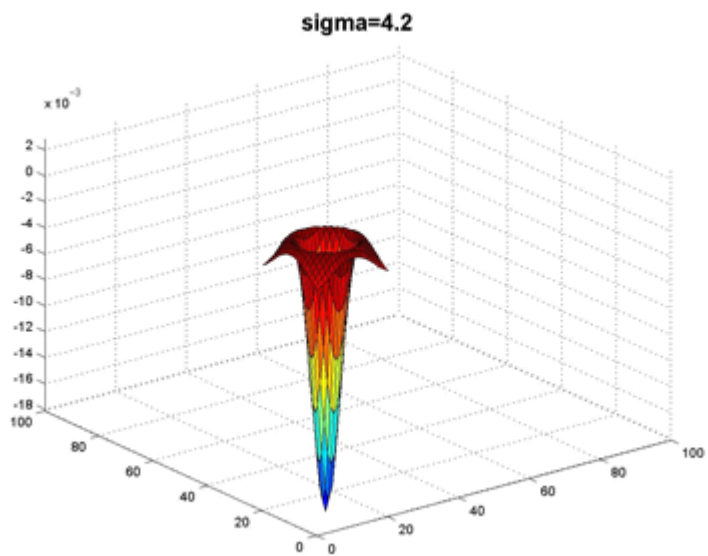
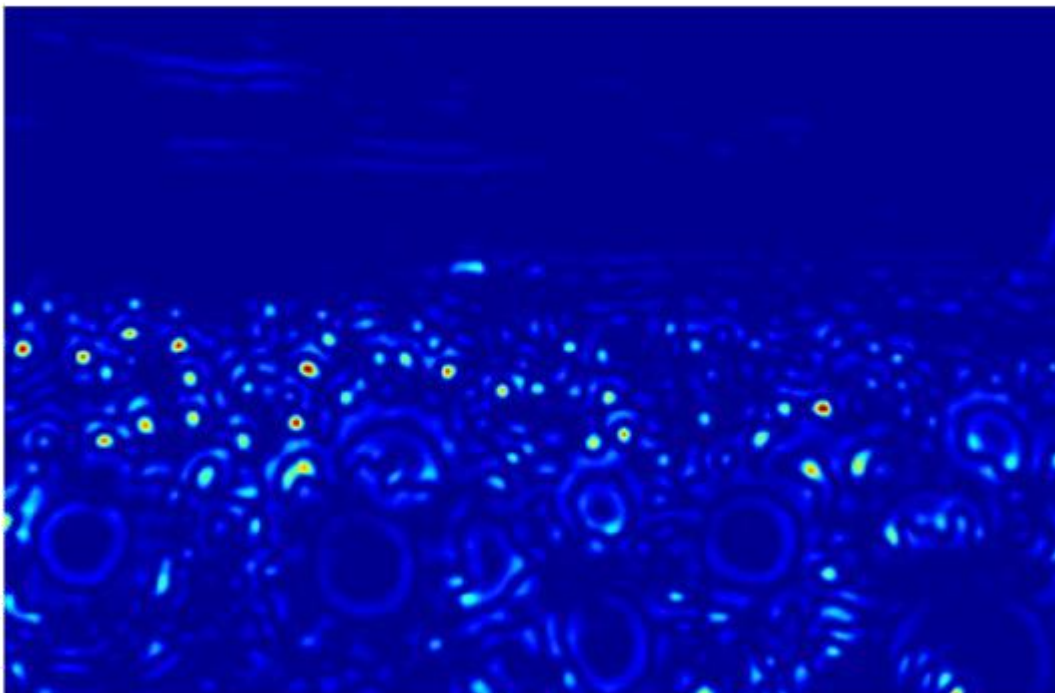
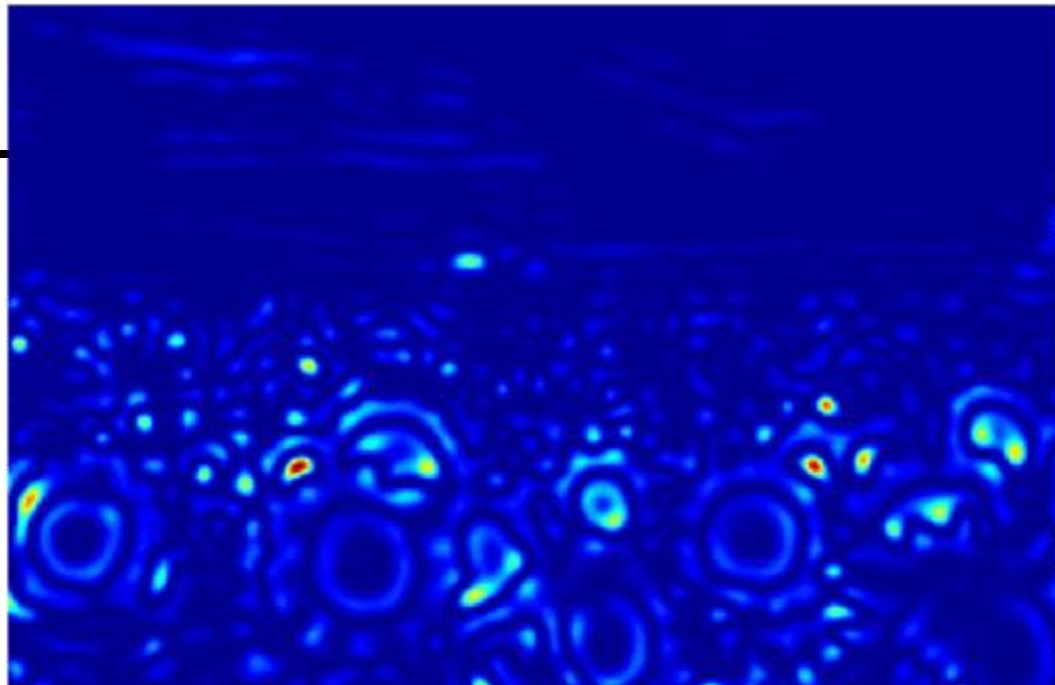
Example

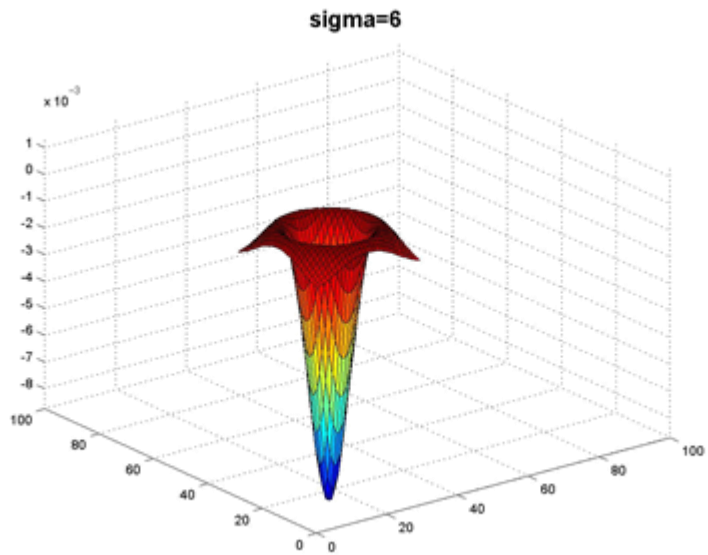
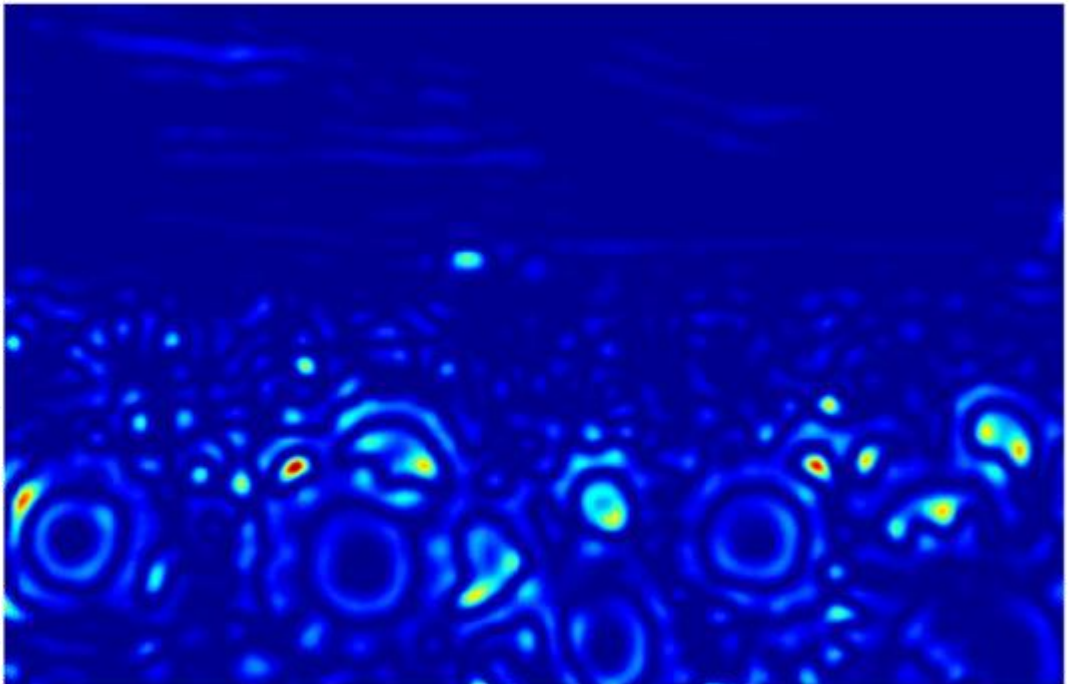
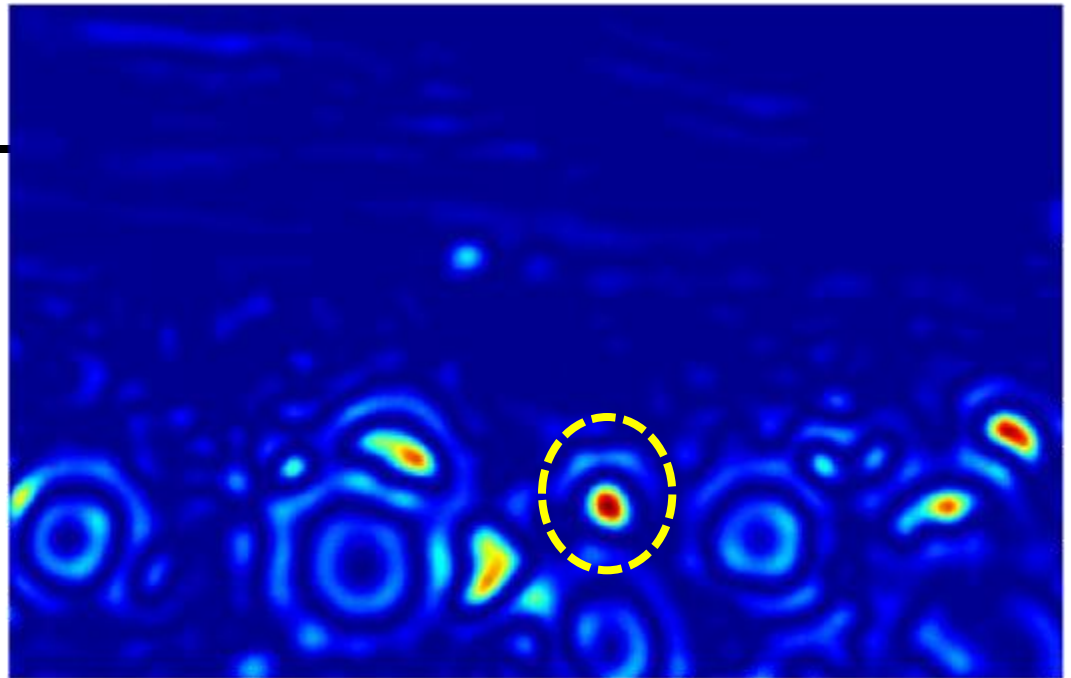
Original image
at $\frac{3}{4}$ the size

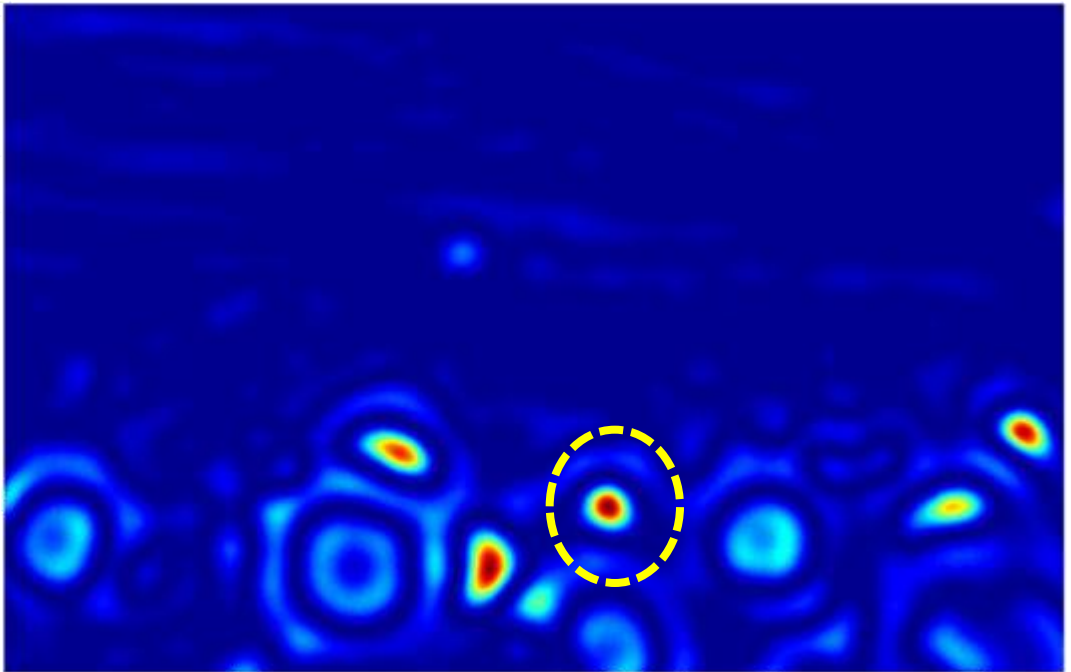
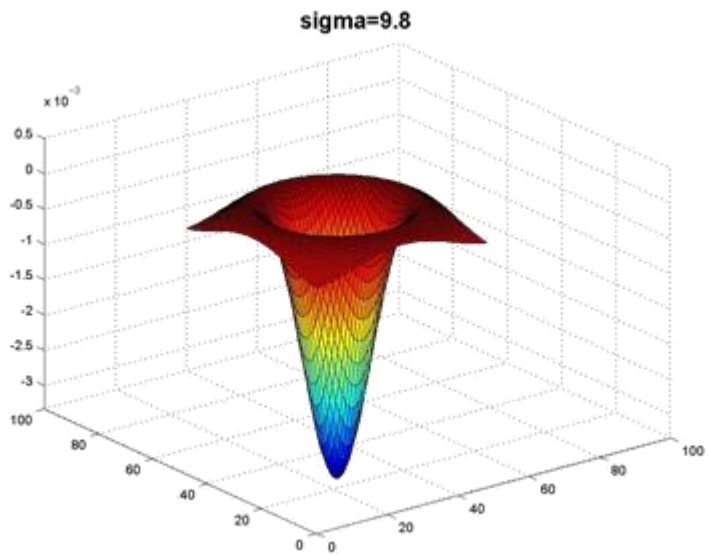
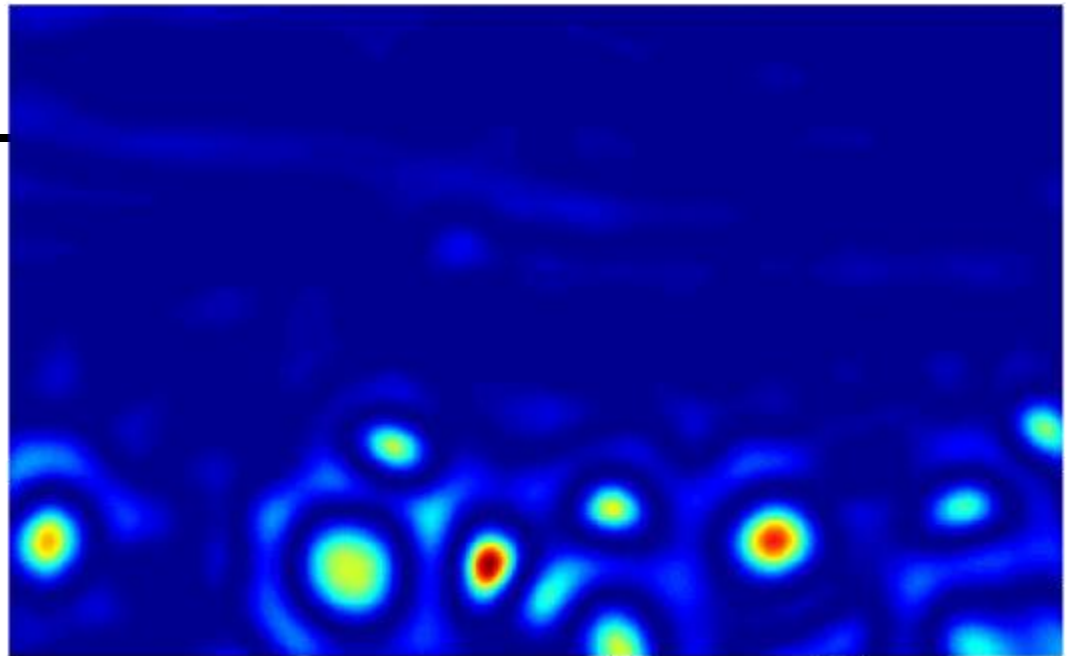


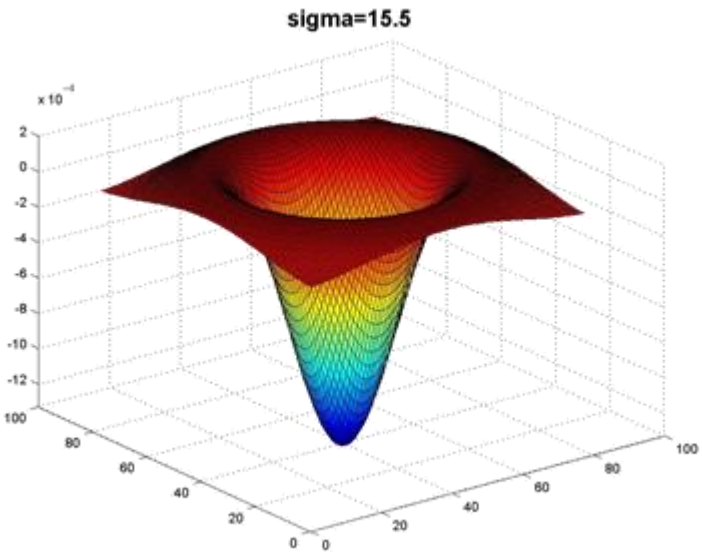
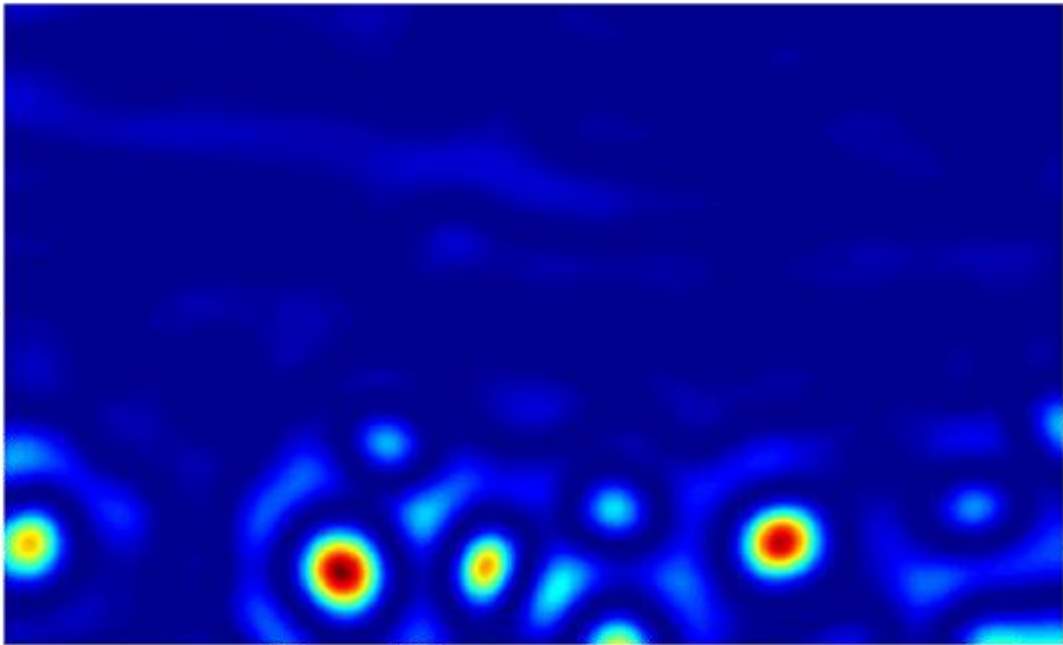
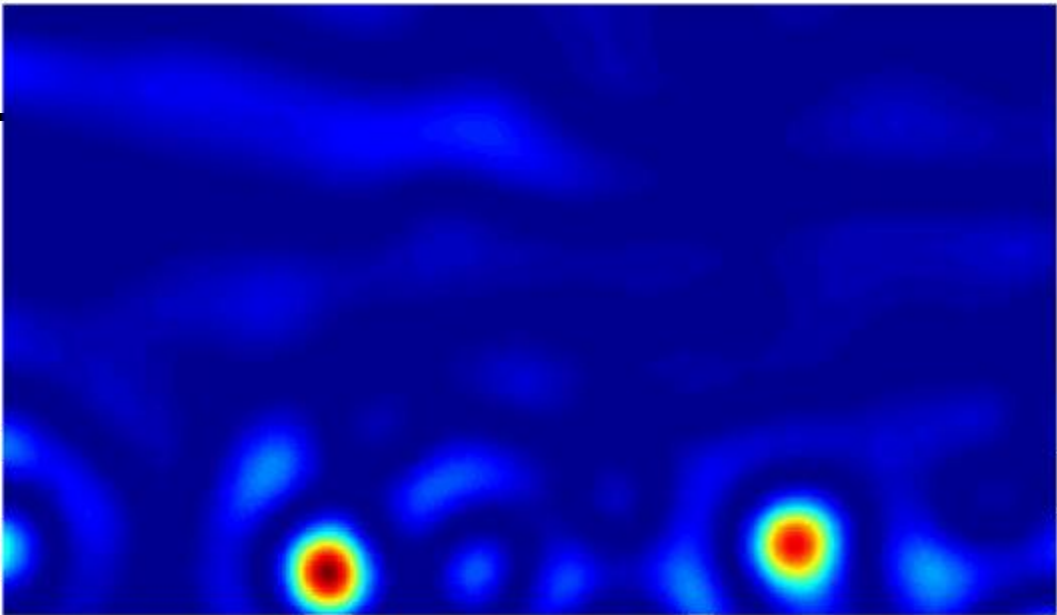
Original image
at $\frac{3}{4}$ the size

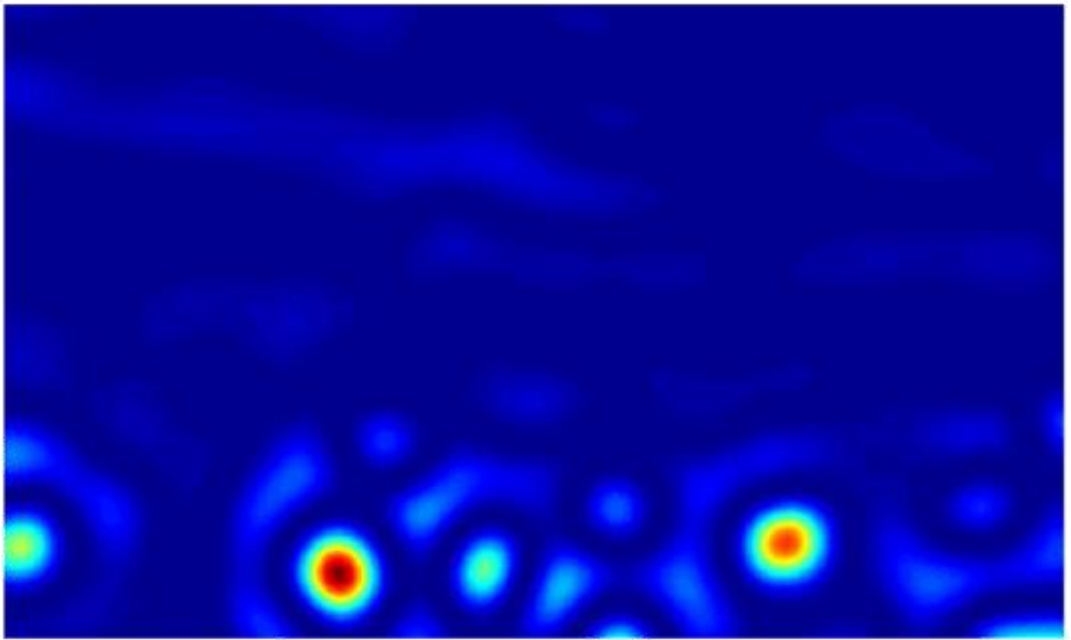
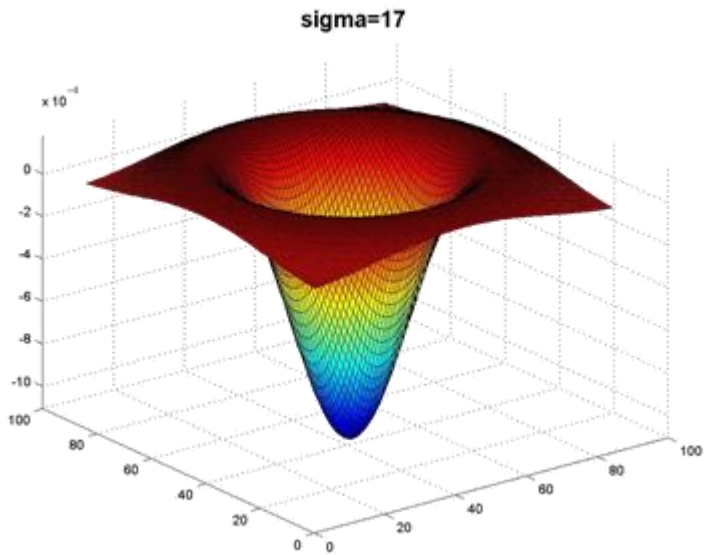
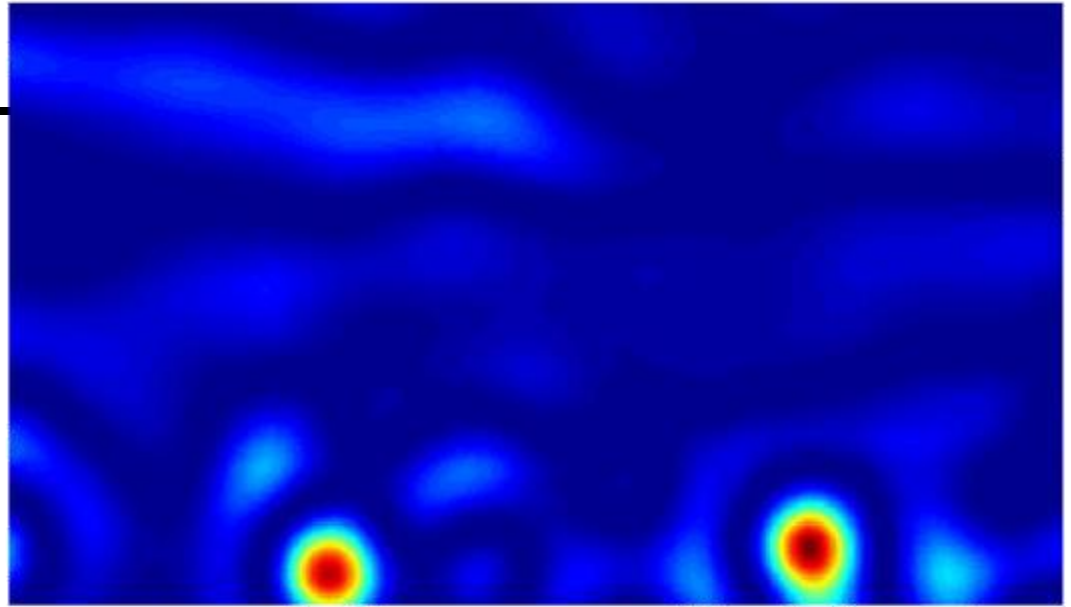






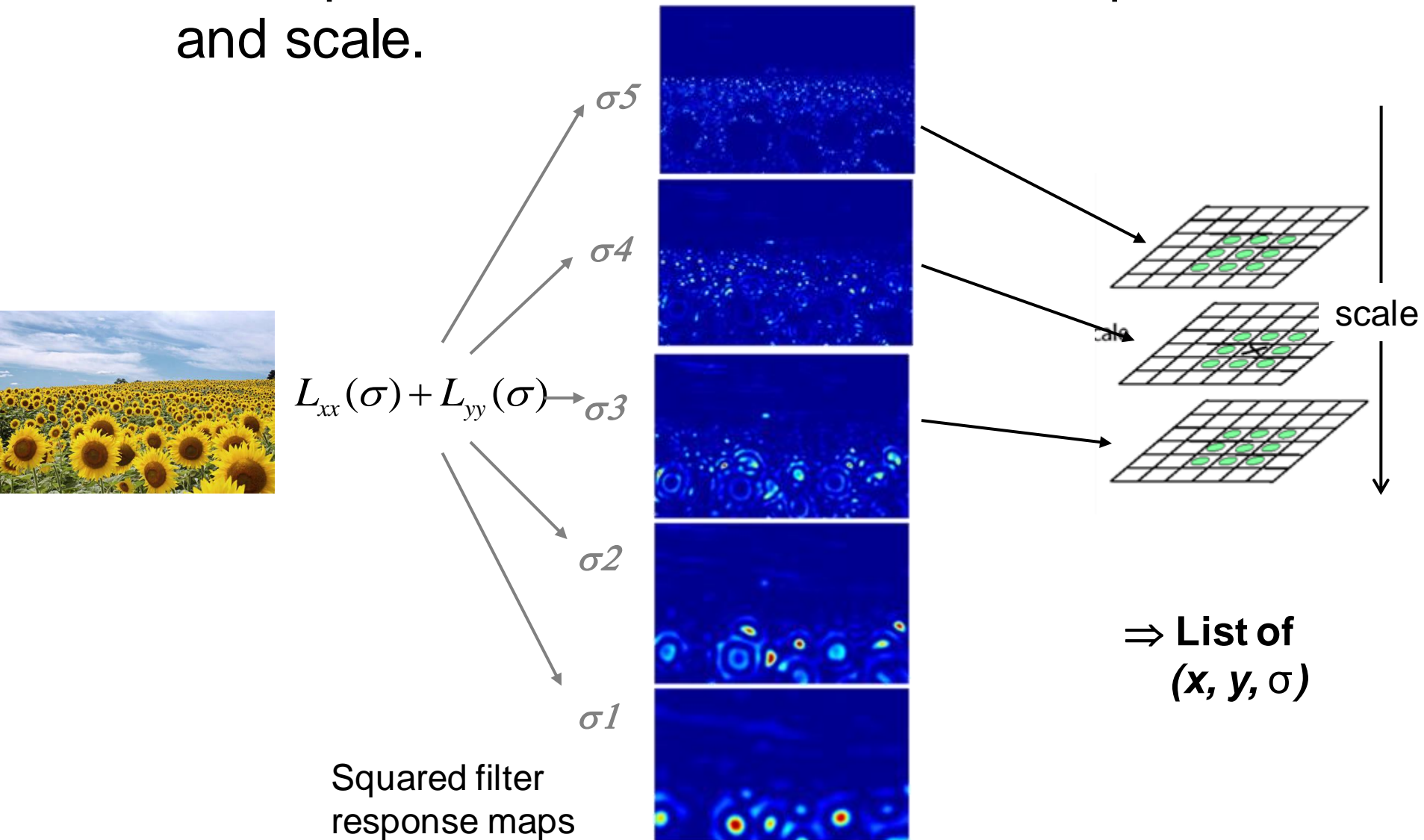




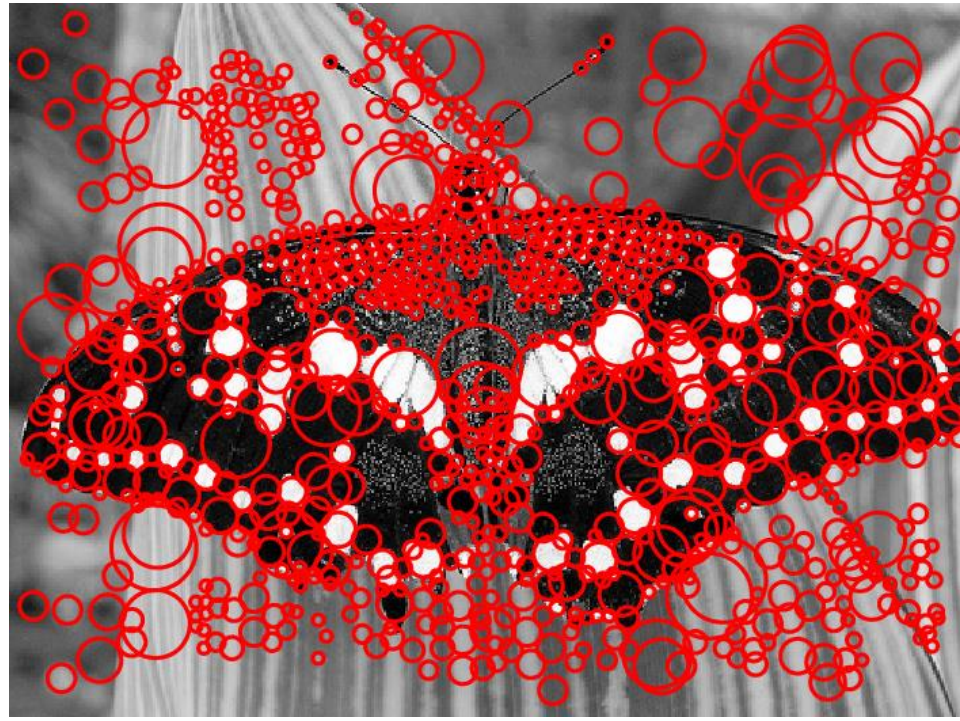


Scale invariant interest points

Interest points are local maxima in both position and scale.



Scale-space blob detector: Example



Technical detail

We can approximate the Laplacian with a difference of Gaussians; more efficient to implement.

$$L = \sigma^2 \left(G_{xx}(x, y, \sigma) + G_{yy}(x, y, \sigma) \right)$$

(Laplacian)

$$DoG = G(x, y, k\sigma) - G(x, y, \sigma)$$

(Difference of Gaussians)

$I(k\sigma)$

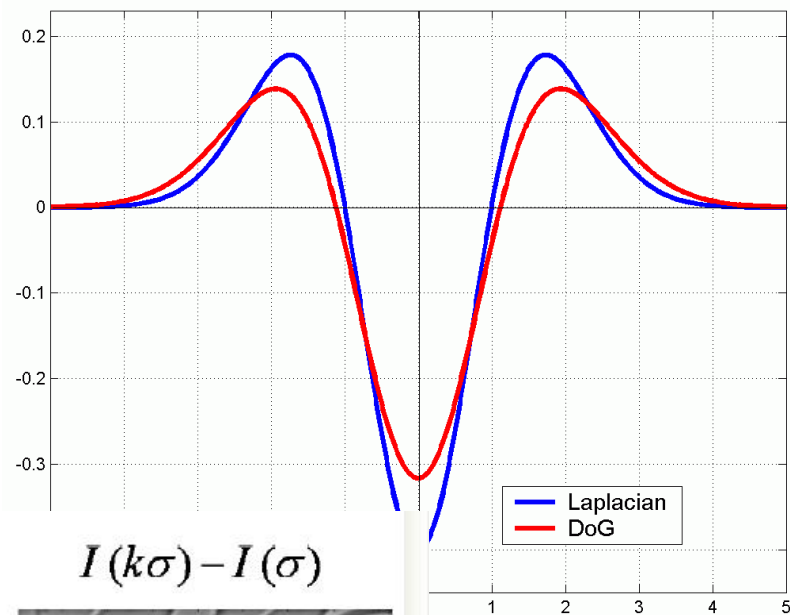
$I(\sigma)$



-

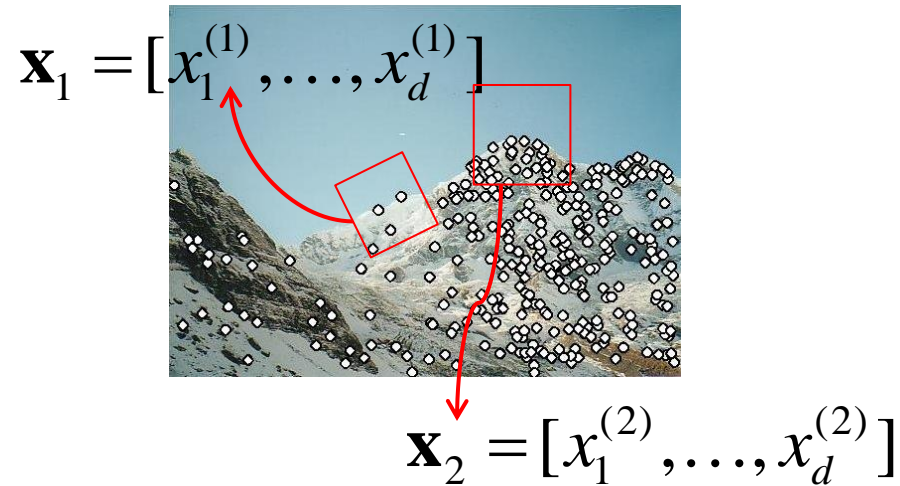


=

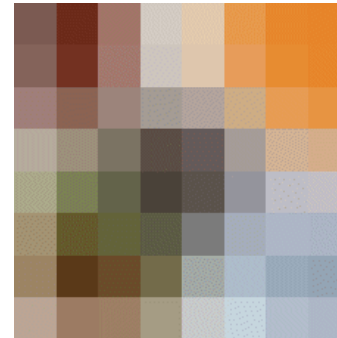
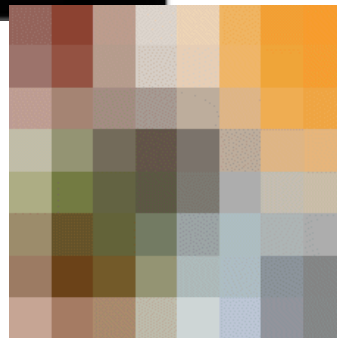
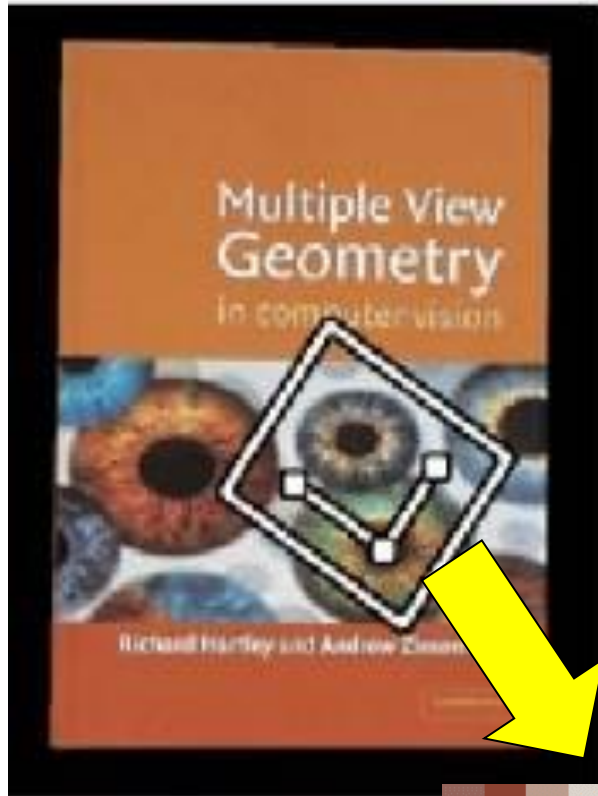


Local features: main components

- 1) Detection: Identify the interest points
- 2) Description: Extract vector feature descriptor surrounding each interest point.
- 3) Matching: Determine correspondence between descriptors in two views



Geometric transformations



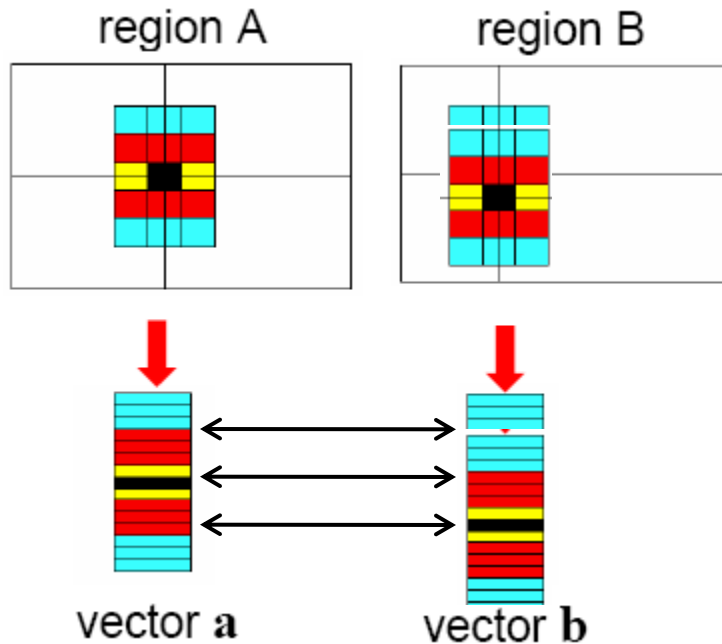
e.g. scale,
translation,
rotation

Photometric transformations



Figure from T. Tuytelaars ECCV 2006 tutorial

Raw patches as local descriptors

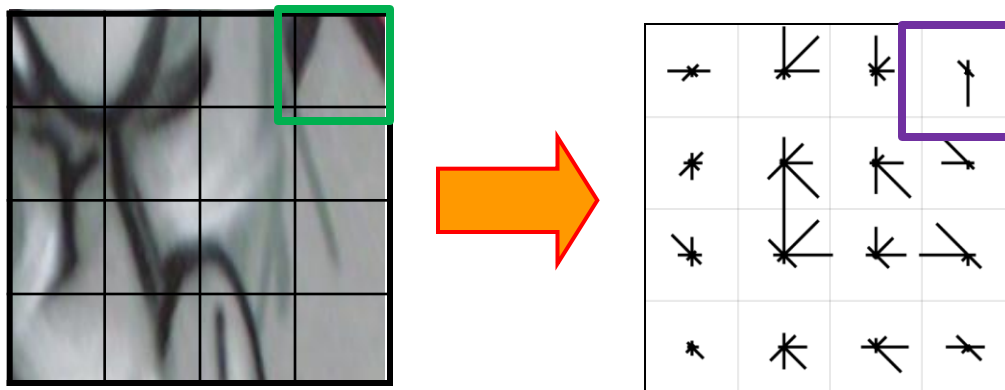
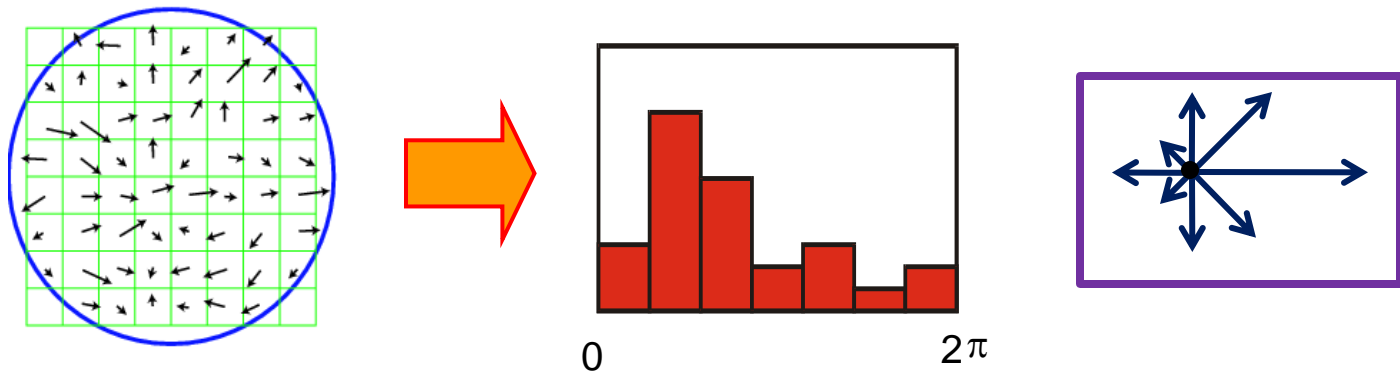


The simplest way to describe the neighborhood around an interest point is to write down the list of intensities to form a feature vector.

But this is very sensitive to even small shifts, rotations.

SIFT descriptor [Lowe 2004]

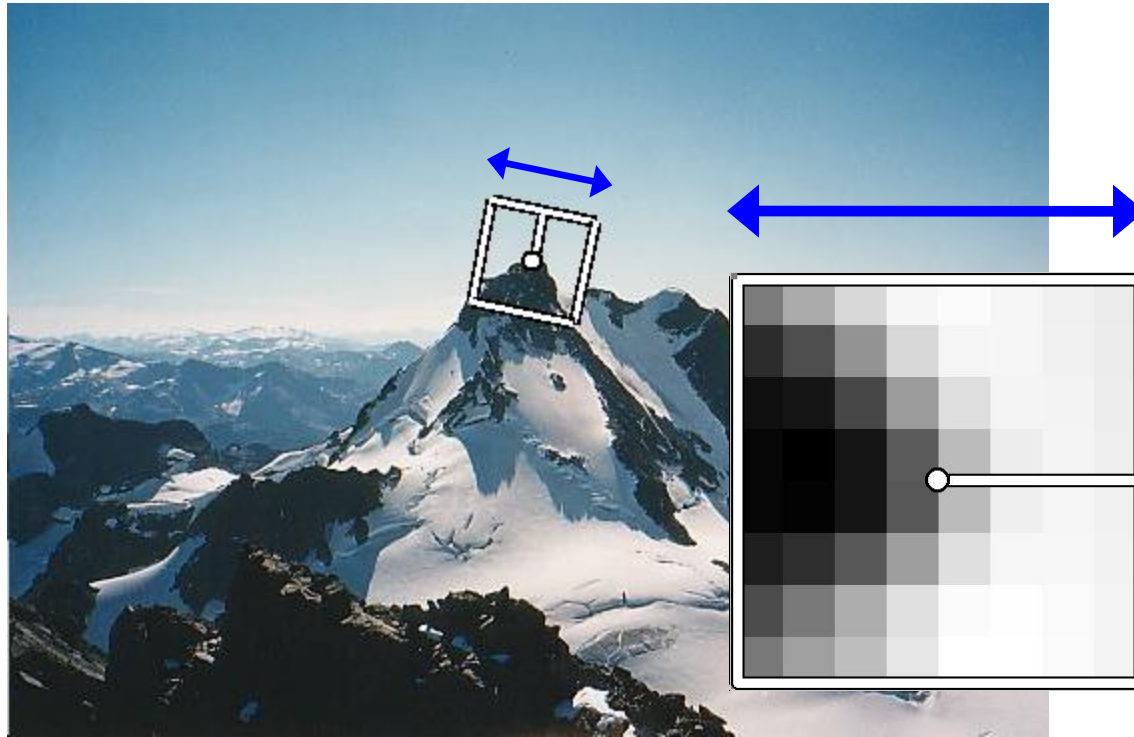
- Use histograms to bin pixels within sub-patches according to their orientation.



Why subpatches?

Why does SIFT have some illumination invariance?

Making descriptor rotation invariant



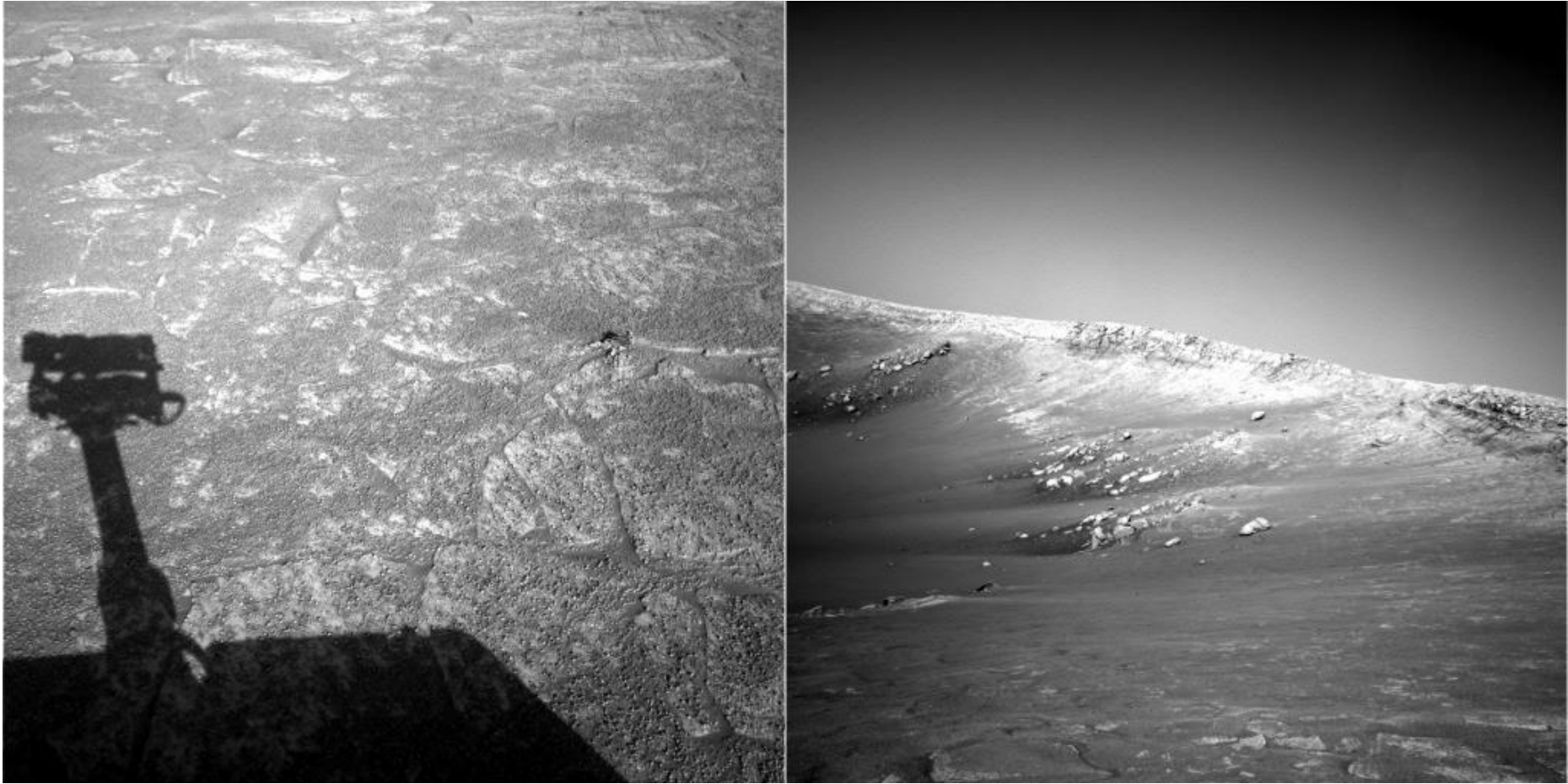
- Rotate patch according to its dominant gradient orientation
- This puts the patches into a canonical orientation.

SIFT descriptor [Lowe 2004]

- Extraordinarily robust matching technique
 - Can handle changes in viewpoint
 - Up to about 60 degree out of plane rotation
 - Can handle significant changes in illumination
 - Sometimes even day vs. night (below)
 - Fast and efficient—can run in real time
 - Lots of code available
 - http://people.csail.mit.edu/albert/ladypack/wiki/index.php/Known_implementations_of_SIFT

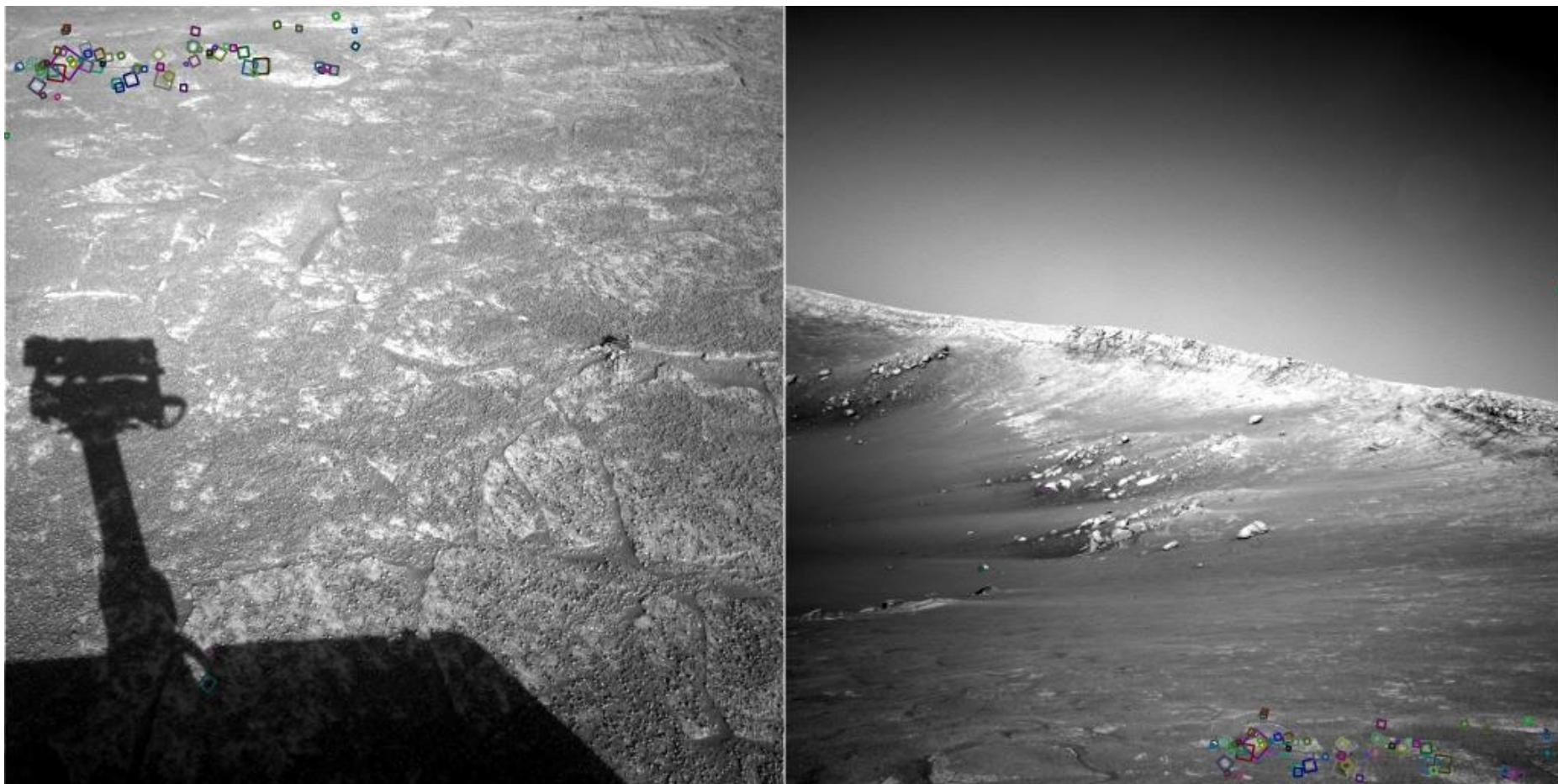


Example



NASA Mars Rover images

Example



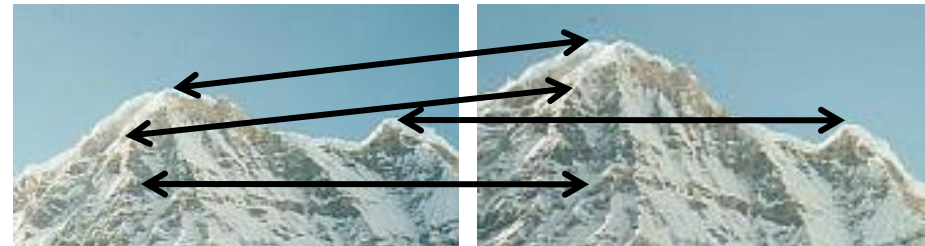
NASA Mars Rover images
with SIFT feature matches
Figure by Noah Snavely

SIFT properties

- Invariant to
 - Scale
 - Rotation
- Partially invariant to
 - Illumination changes
 - Camera viewpoint
 - Occlusion, clutter

Local features: main components

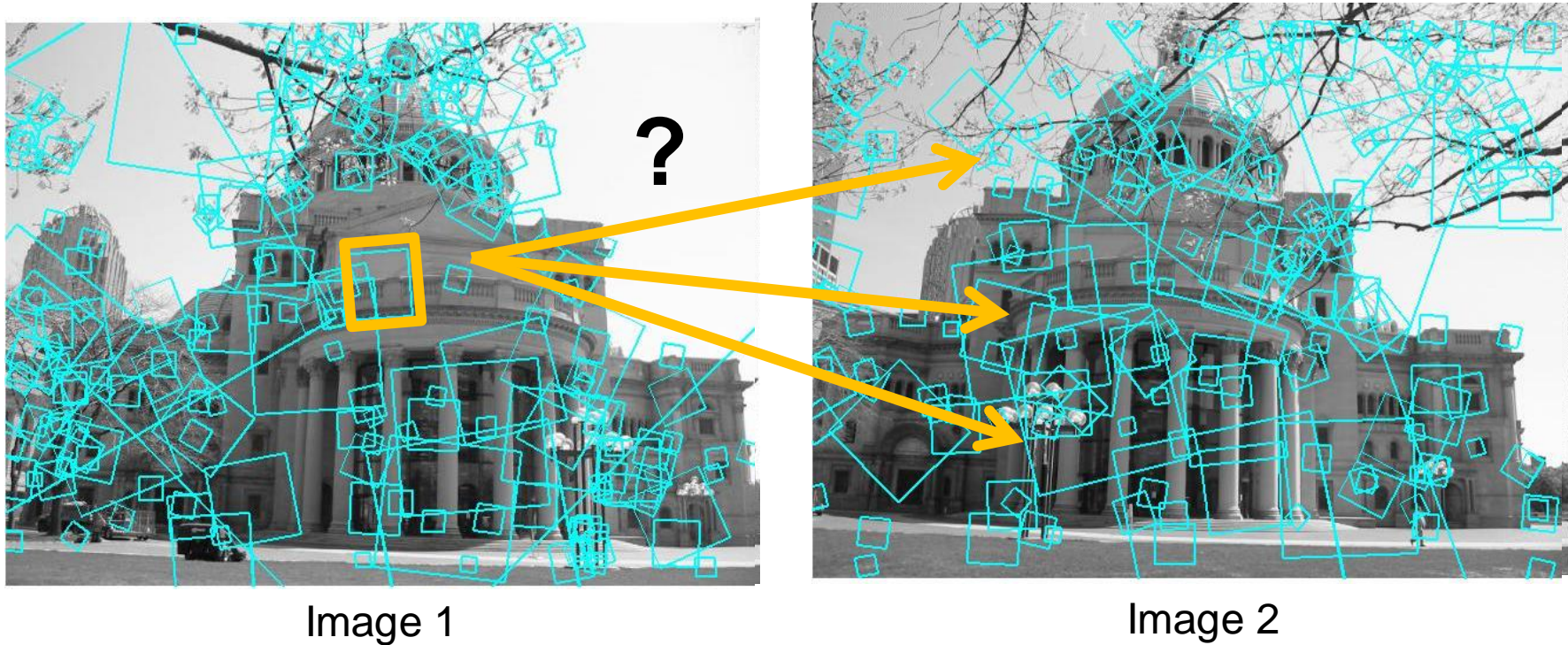
- 1) Detection: Identify the interest points
- 2) Description: Extract vector feature descriptor surrounding each interest point.
- 3) Matching: Determine correspondence between descriptors in two views



Matching local features



Matching local features



To generate **candidate matches**, find patches that have the most similar appearance (e.g., lowest SSD)

Simplest approach: compare them all, take the closest (or closest k , or within a thresholded distance)

Ambiguous matches



Image 1



Image 2

At what SSD value do we have a good match?

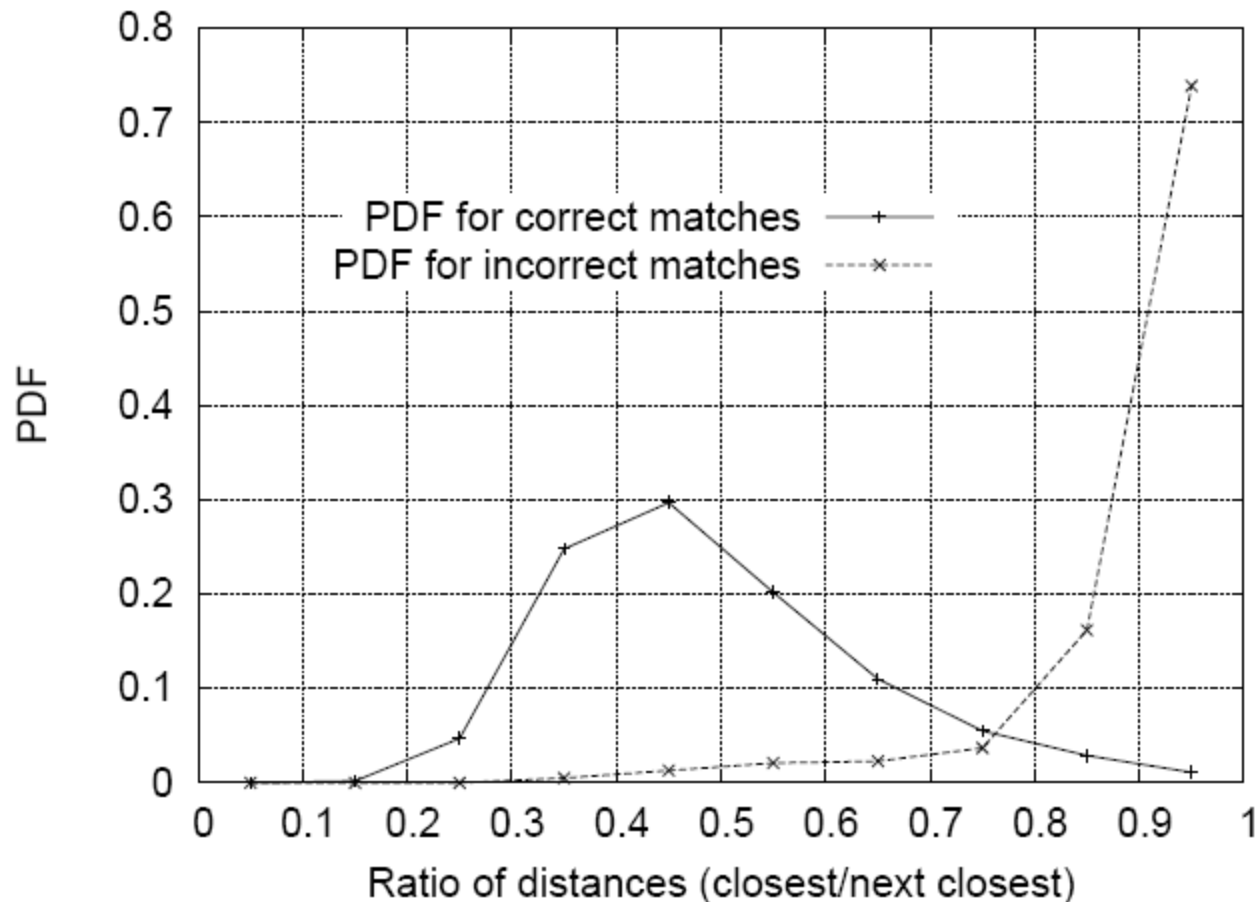
To add robustness to matching, can consider **ratio** :
distance to best match / distance to second best match

If low, first match looks good.

If high, could be ambiguous match.

Matching SIFT Descriptors

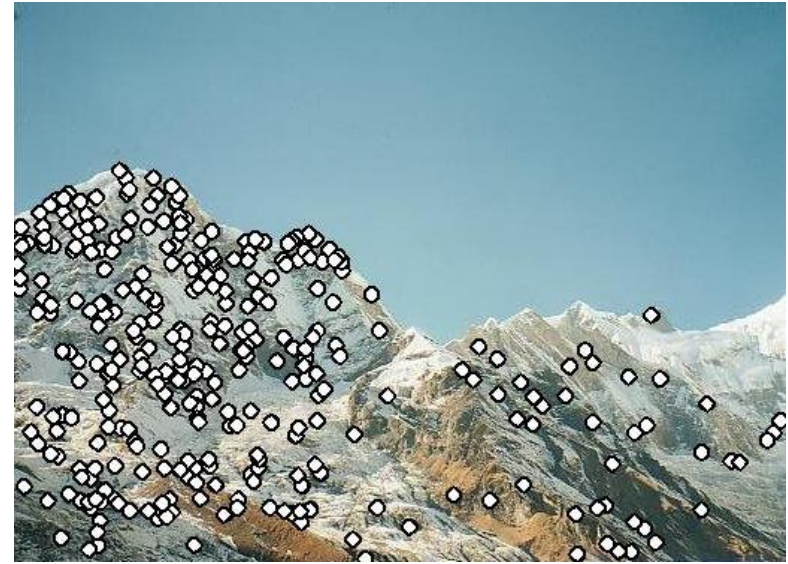
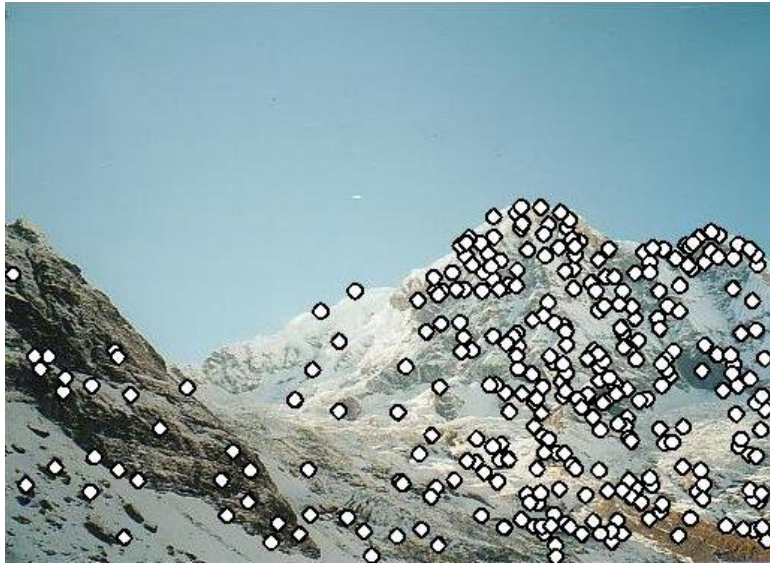
- Nearest neighbor (Euclidean distance)
- Threshold ratio of nearest to 2nd nearest descriptor



Recap: robust feature-based alignment

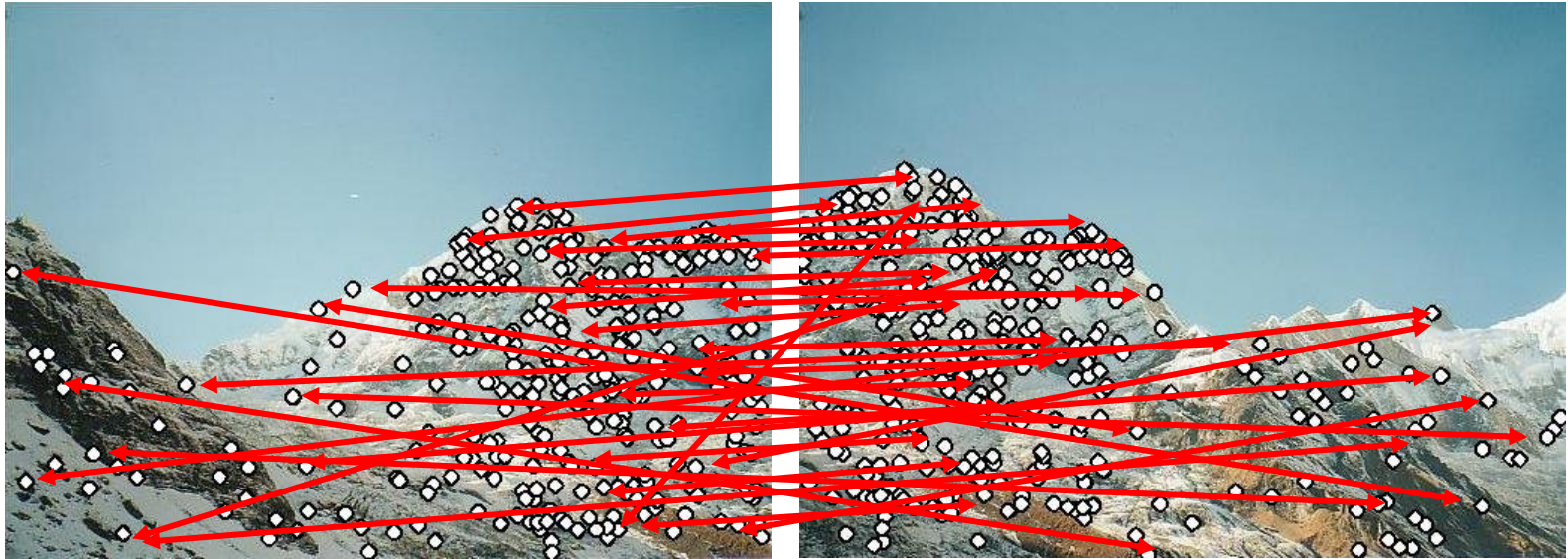


Recap: robust feature-based alignment



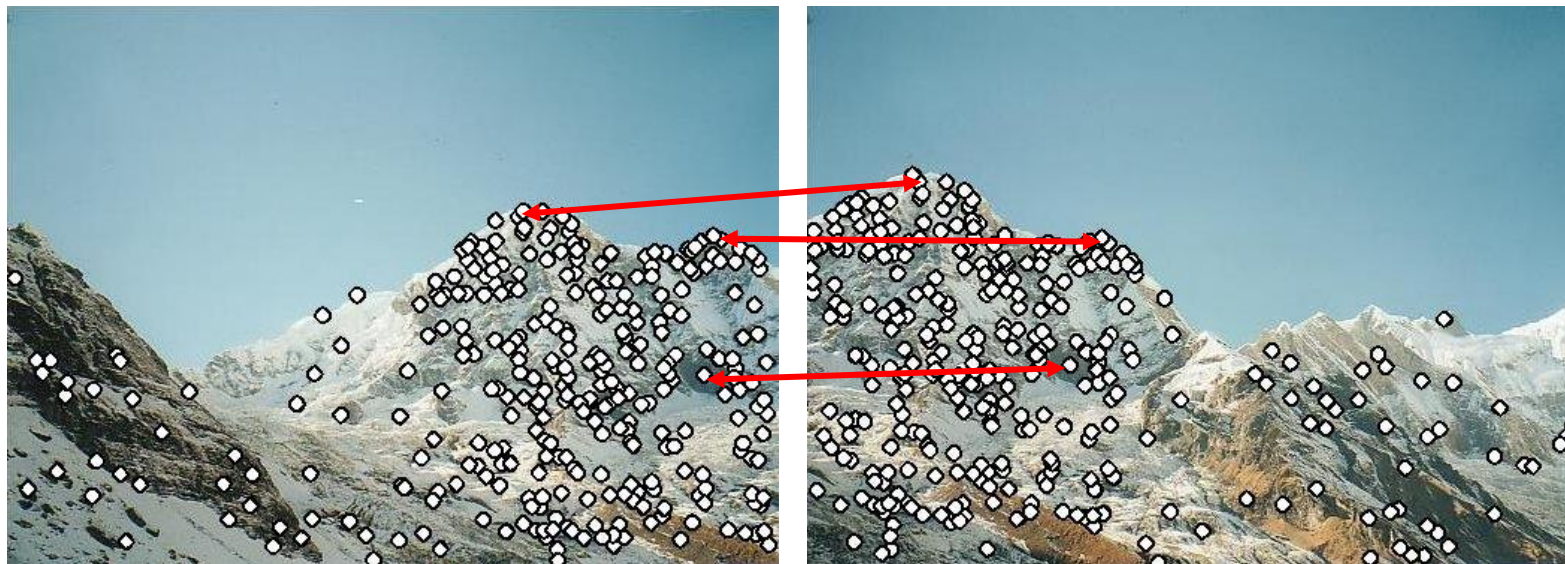
- Extract features

Recap: robust feature-based alignment



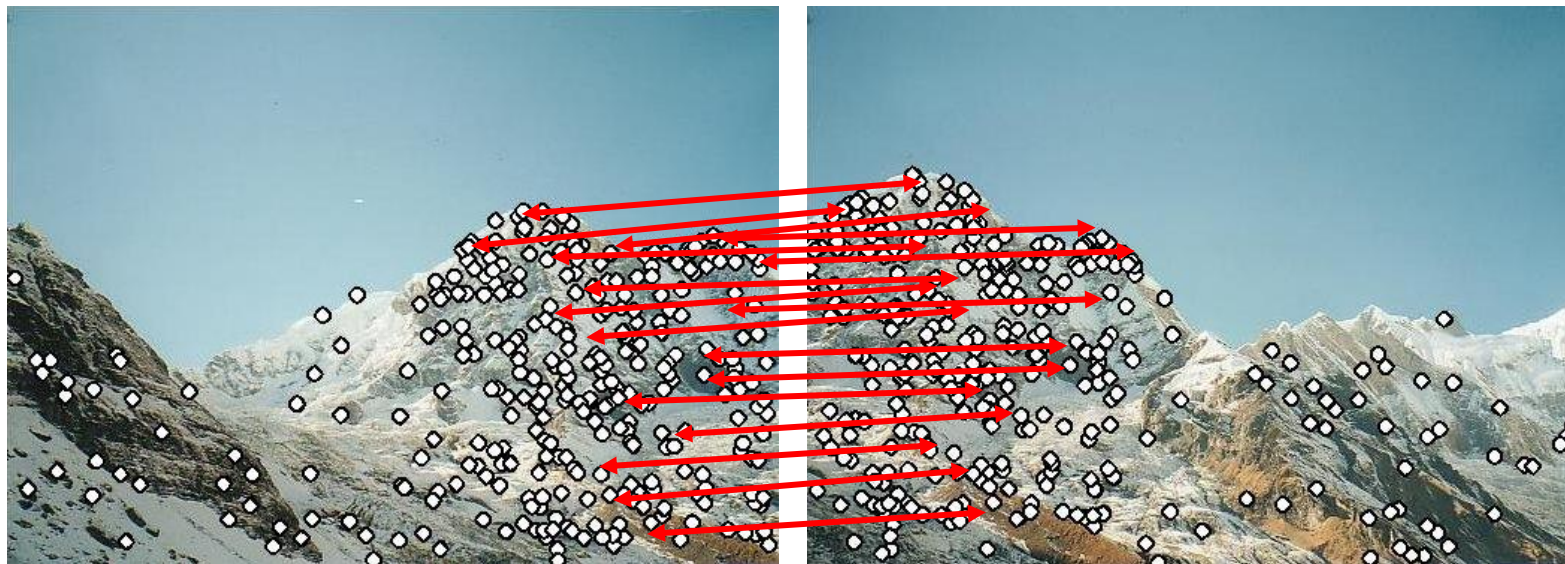
- Extract features
- Compute *putative matches*

Recap: robust feature-based alignment



- Extract features
- Compute *putative matches*
- Loop:
 - *Hypothesize* transformation T (small group of putative matches that are related by T)

Recap: robust feature-based alignment



- Extract features
- Compute *putative matches*
- Loop:
 - *Hypothesize* transformation T (small group of putative matches that are related by T)
 - *Verify* transformation (search for other matches consistent with T)

Recap: robust feature-based alignment

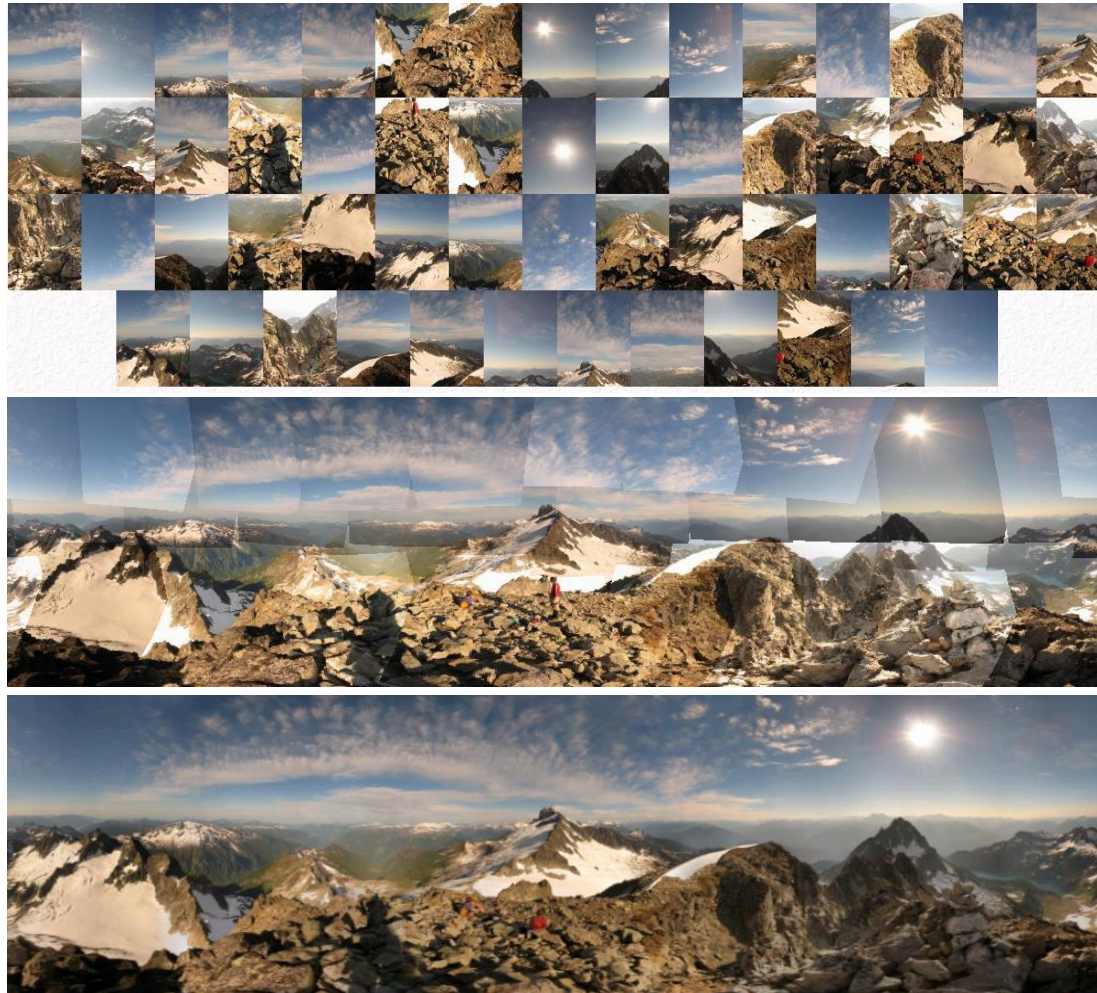


- Extract features
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 - *Hypothesize* transformation T (small group of putative matches that are related by T)
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Applications of local invariant features

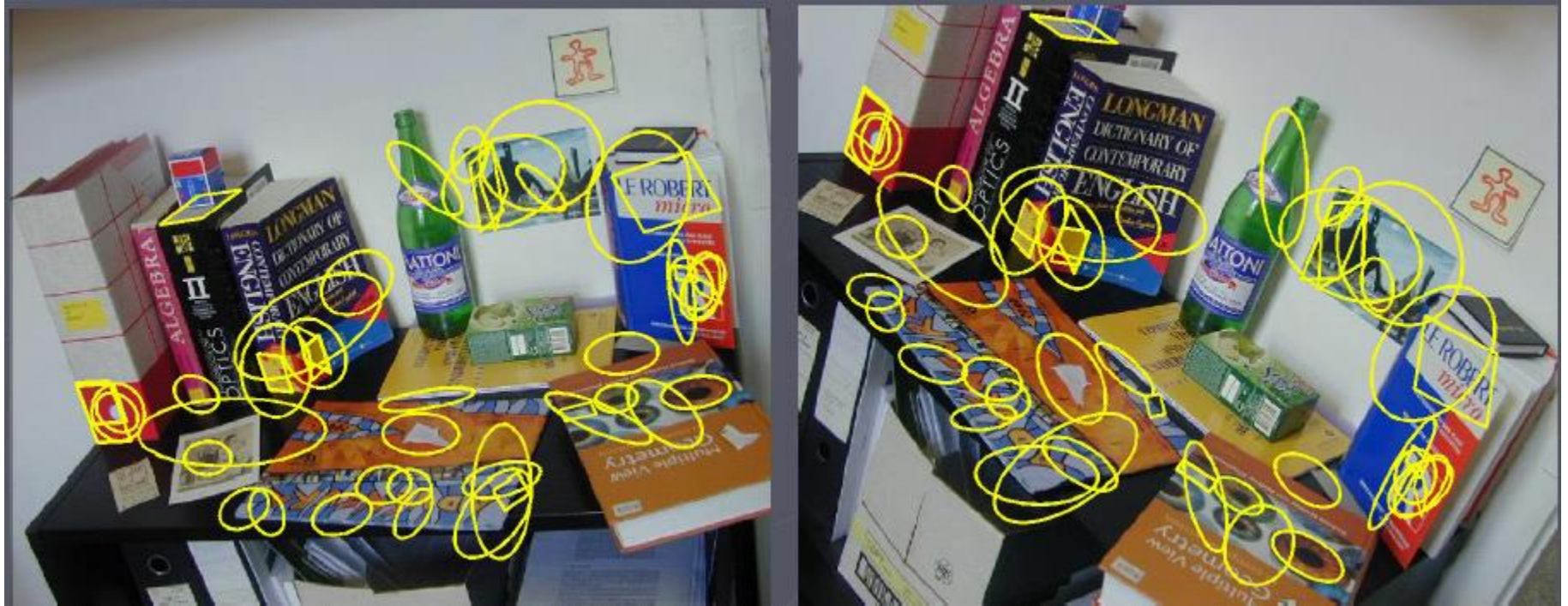
- Wide baseline stereo
- Motion tracking
- Panoramas
- Mobile robot navigation
- 3D reconstruction
- Recognition
- ...

Automatic mosaicing



<http://www.cs.ubc.ca/~mbrown/autostitch/autostitch.html>

Wide baseline stereo



[Image from T. Tuytelaars ECCV 2006 tutorial]

Recognition of specific objects, scenes



Schmid and Mohr 1997



Sivic and Zisserman, 2003



Rothganger et al. 2003



Lowe 2002

Summary

- Interest point detection
 - Harris corner detector
 - Laplacian of Gaussian, automatic scale selection
- Invariant descriptors
 - Rotation according to dominant gradient direction
 - Histograms for robustness to small shifts and translations (SIFT descriptor)