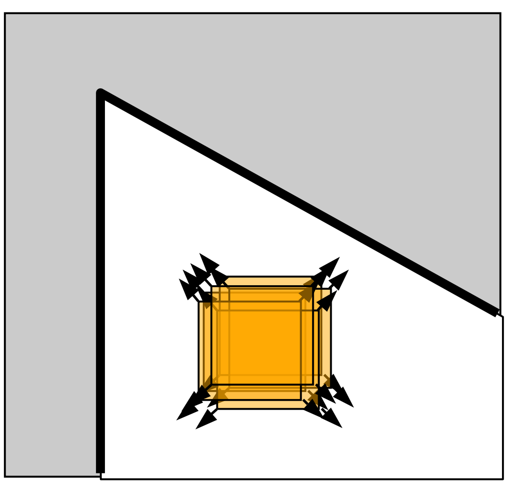
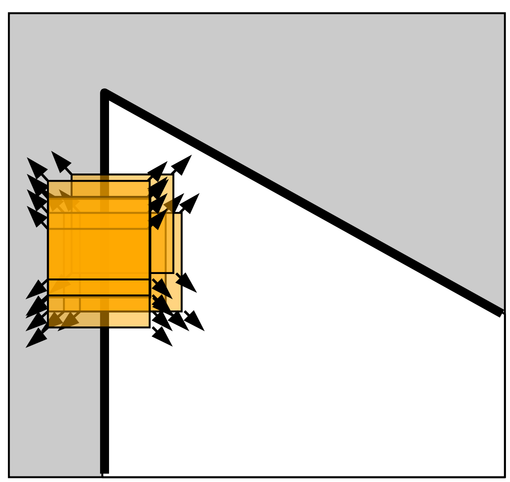
Corner detection: the basic idea

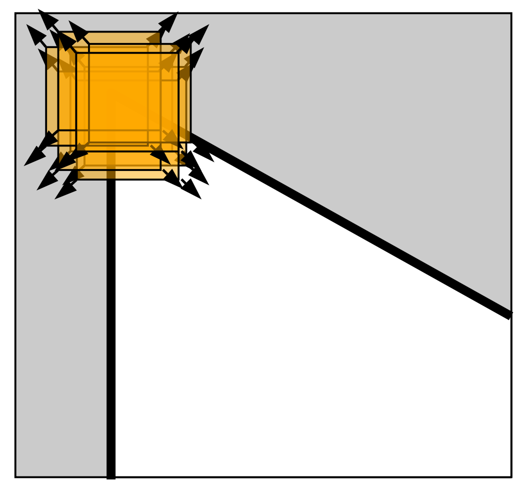
- At a corner, shifting a window in any direction should give a large change in intensity



"flat" region:
no change in
all directions



"edge":
no change along
the edge direction



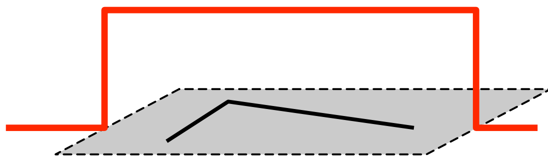
"corner":
significant change
in all directions

A simple corner detector

- Define the sum squared difference (SSD) between an image patch and a patch shifted by offset (x,y):

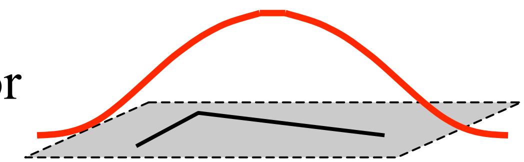
$$S(x,y) = \sum_u \sum_v w(u,v) \left(I(u,v) - I(u-x, v-y) \right)^2$$

where *w(u,v)* =



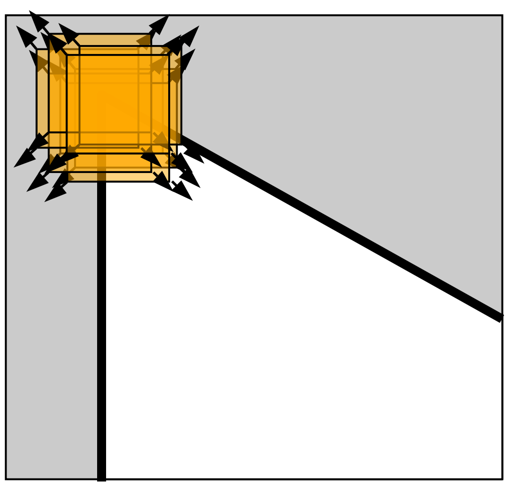
1 in window, 0 outside

or



Gaussian

- If s(x,y) is high for shifts in all 8 directions, declare a corner.
  - Problem: not isotropic



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

Harris corner detector derivation

- First -order Taylor series approximation:

$$S(x,y) = \sum_u \sum_v w(u,v) \; \left(I(u,v) - I(u-x, v-y) \right)^2$$

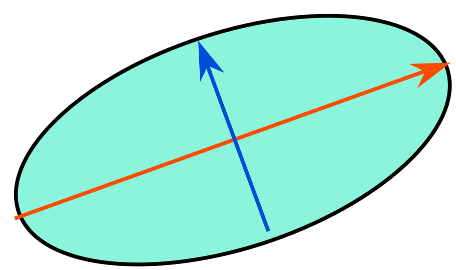
w(u,v) [x delta I/delta x + y delta I/delta y]^2
u = x v = y in partial derivatives

$$S(x,y) \approx (x \quad y) A \begin{pmatrix} x \\ y \end{pmatrix}$$

  - where A is defined in terms of partial derivatives $I_x = \partial I / \partial x$ and $I_y = \partial I / \partial y$ summed over (u,v):

$$A = \sum_u \sum_v w(u,v) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$$

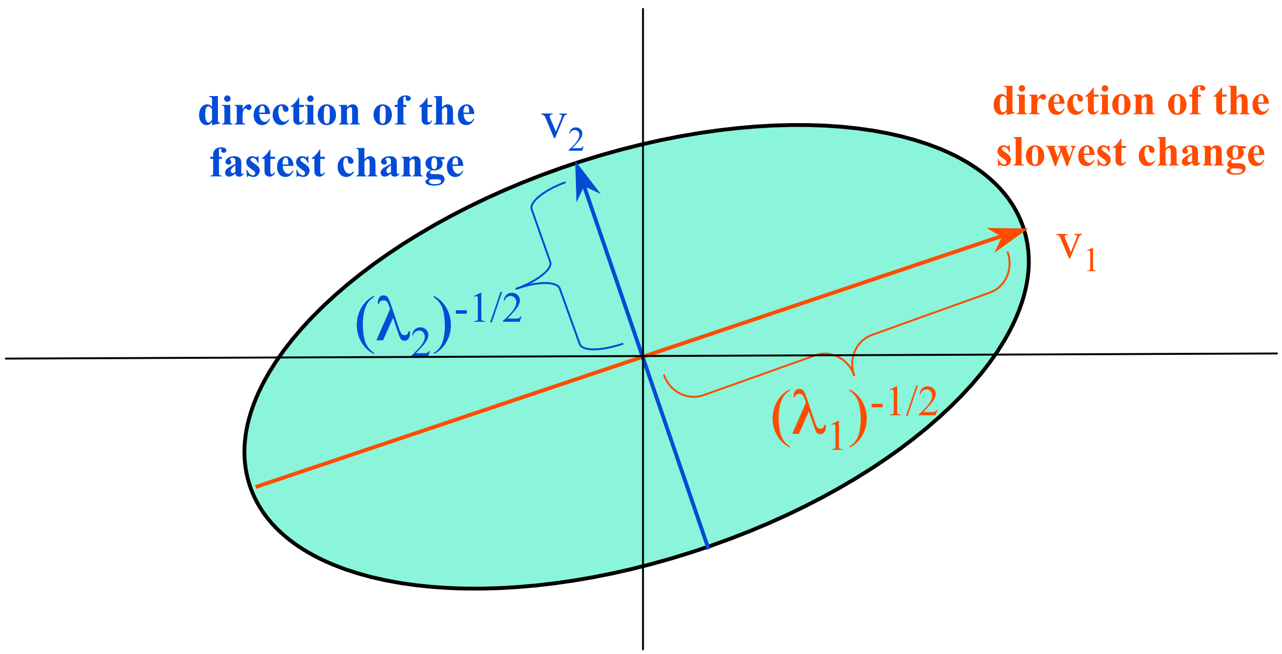
  - For constant t, S(x,y) < t is an ellipse



ellipse is the shape, the noise is not necessarily Gaussian

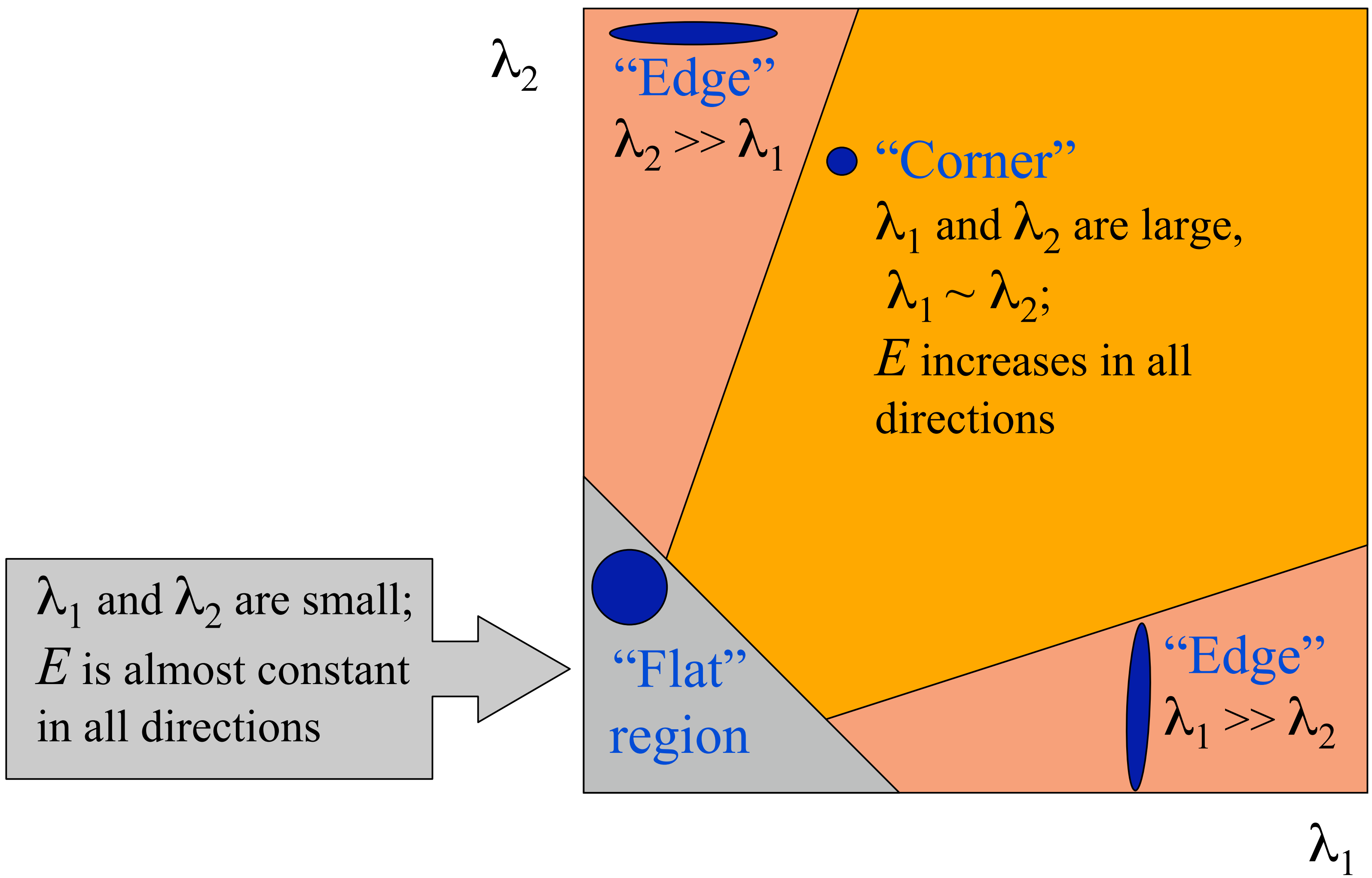
Eigenvector analysis

- The eigenvectors v_1, v_2 of A give an orthogonal basis for the ellipse
  - I.e. directions of fastest and slowest change
  - for $\lambda_2 > \lambda_1$, v_2 is the direction of fastest change (minor axis of ellipse) and v_1 is the direction of slowest change (major axis)



Classify points based on eigenvalues

- Classification of image points using eigenvalues of A:



Harris corner detection

- But square roots are expensive
  - Approximate corner response function that avoids square roots:

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

k = 0.04 -- 0.06

R = determinant - k * trace^2

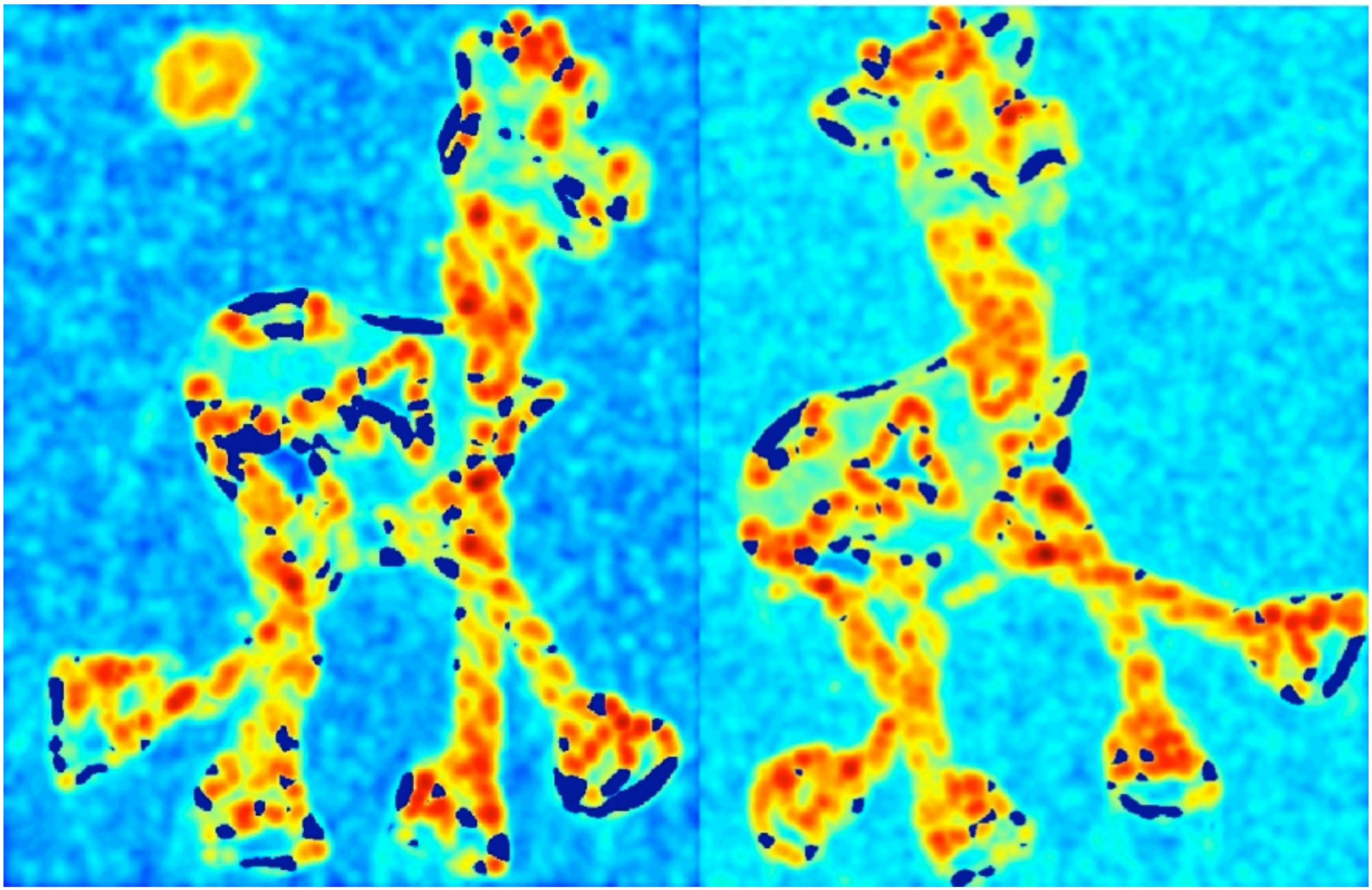
with *k* is set empirically

- After thresholding, keep only local maxima of *R* as corners
  - prevents multiple detections of the same corner

Harris detector, step-by-step

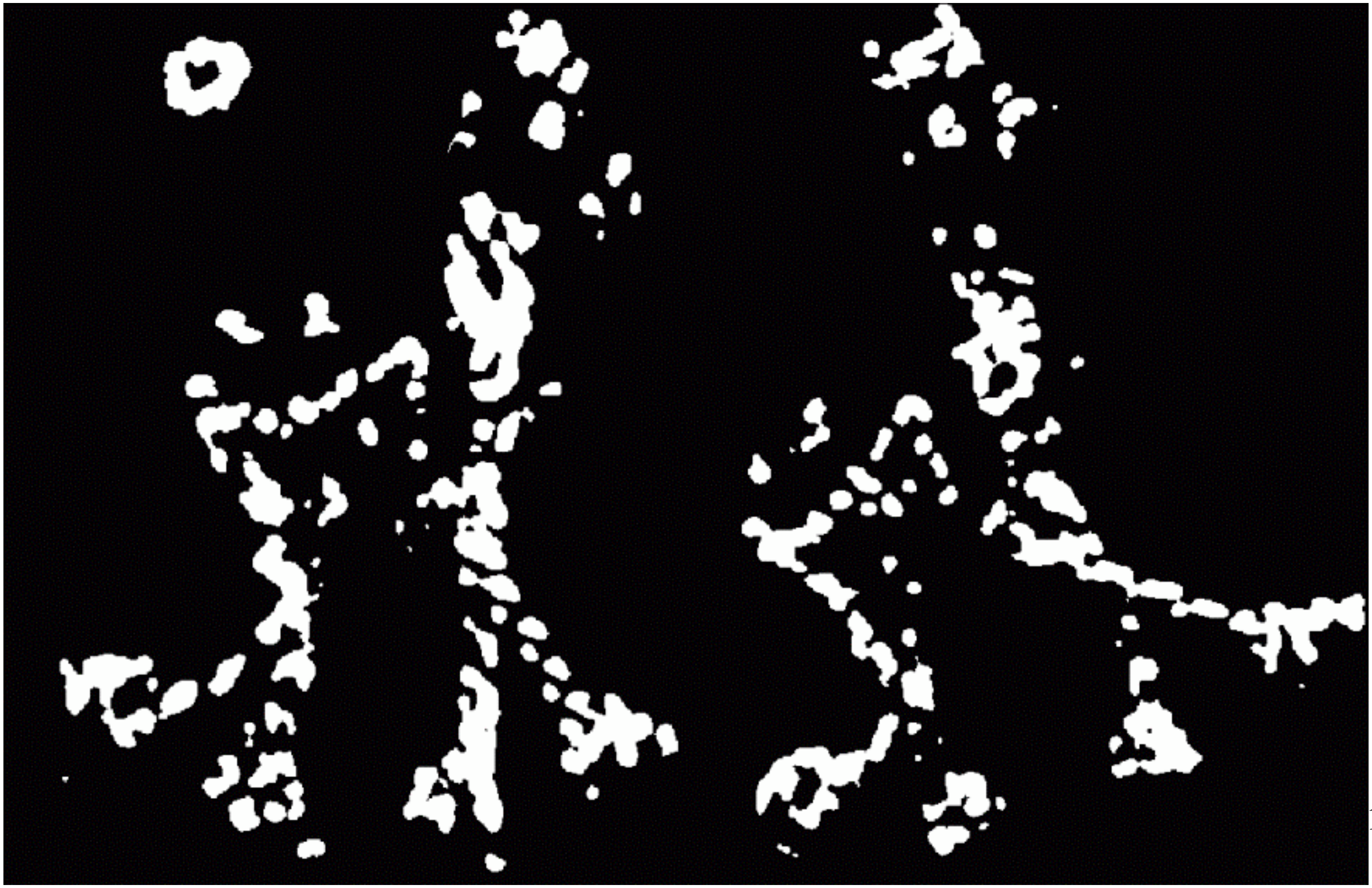
Harris detector, step-by-step

- Compute corner response R



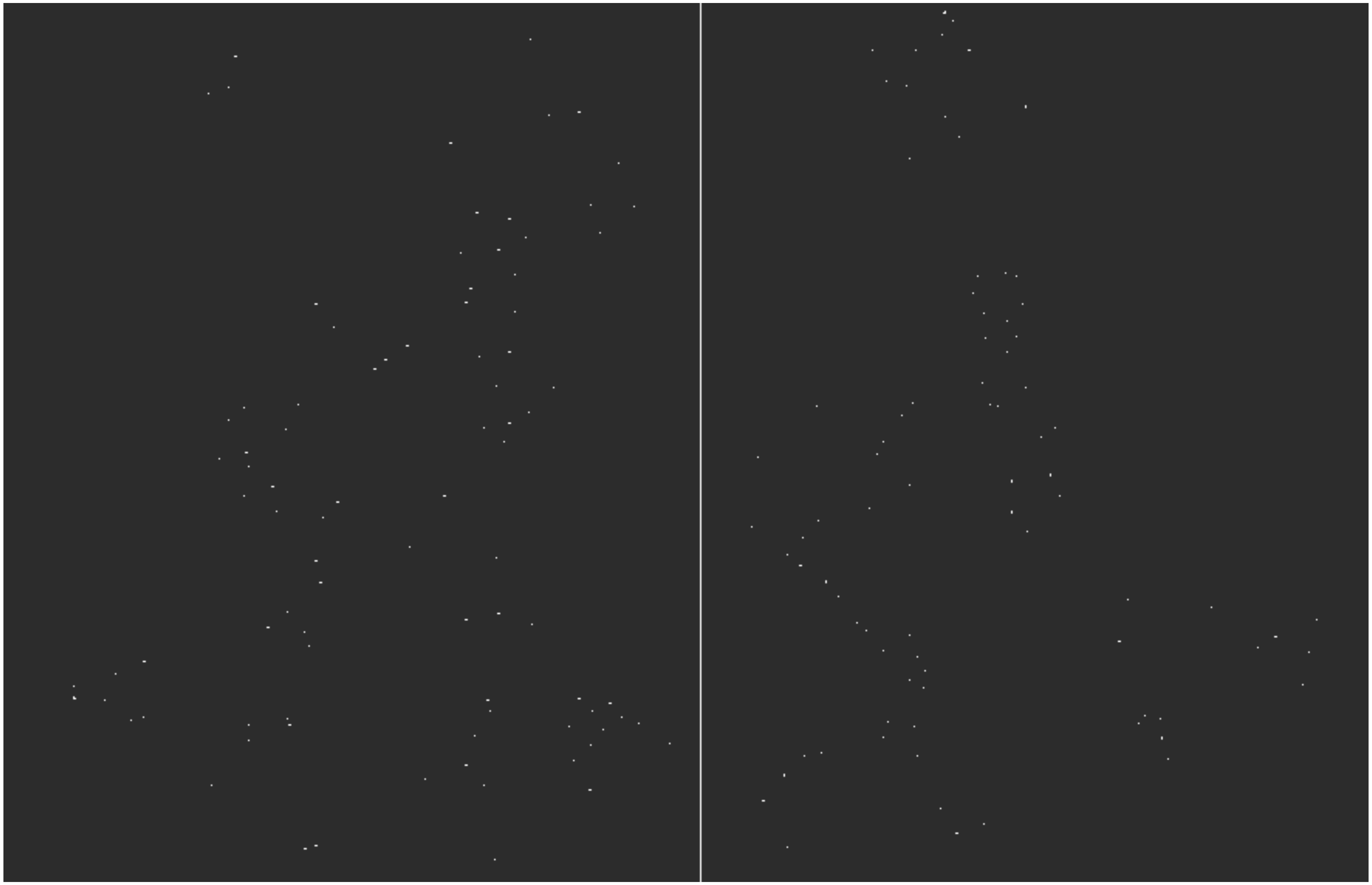
Harris detector, step-by-step

- Threshold on corner response *R*



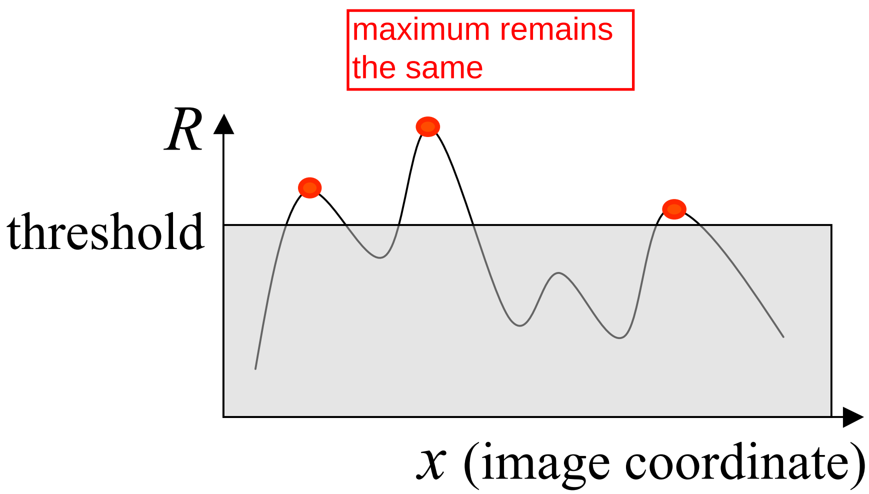
Harris detector, step-by-step

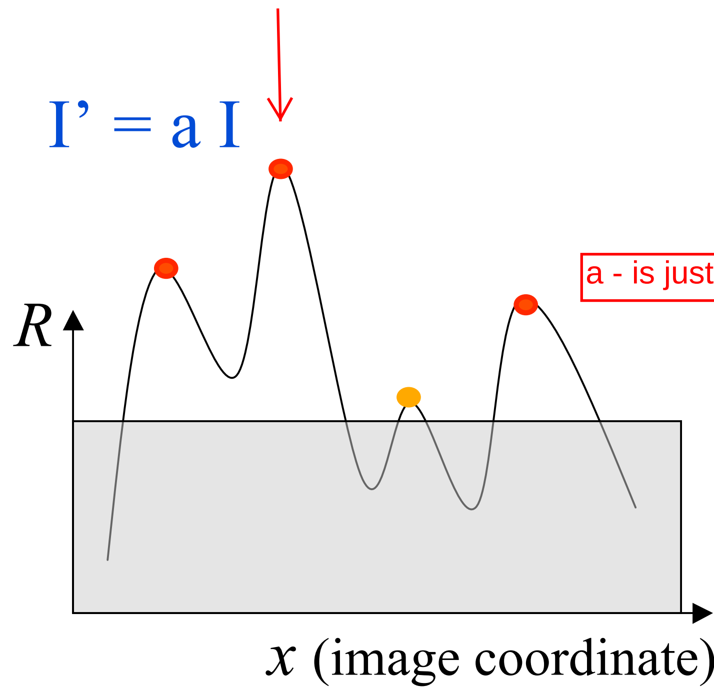
- Take only local maxima of *R*



Harris detector properties

- Invariant to intensity shift: $I' = I + b$
  - only derivatives are used, not original intensity values
- Insensitive to intensity scaling: $I' = a I$

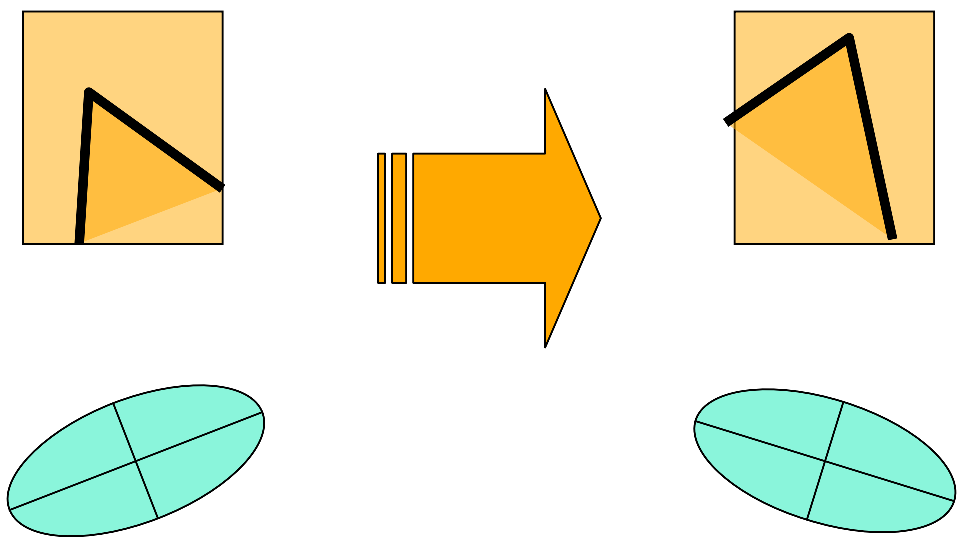




- So Harris is insensitive to affine intensity changes
  - I.e. linear scaling plus a constant offset, $I' = a I + b$

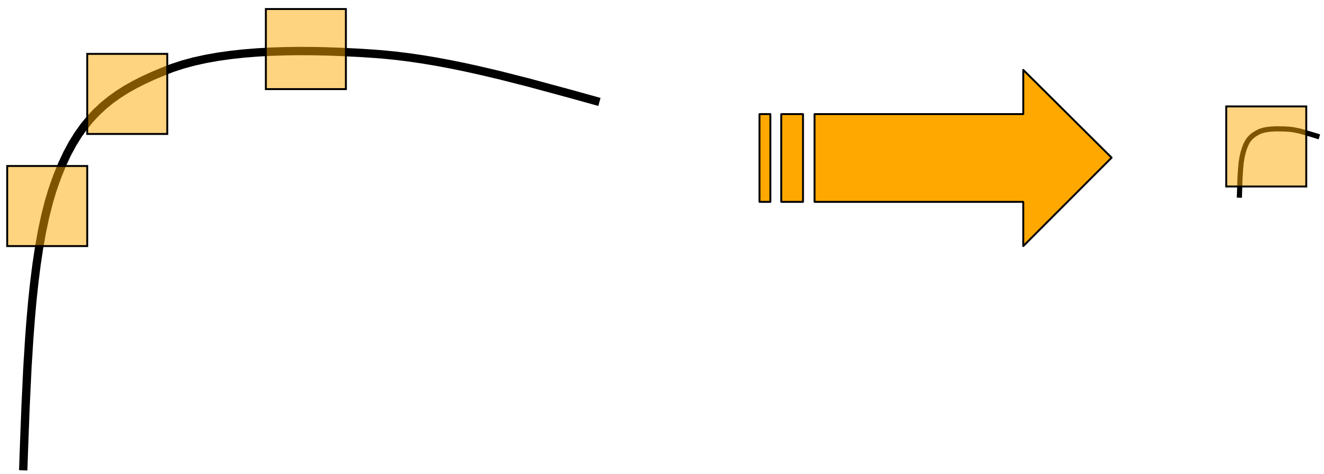
Harris detector properties

- Rotation invariance
  - Ellipse (eigenvectors) rotate but shape (eigenvalues) remain the same
  - Corner response *R* is invariant to image rotation upto sampling



Harris detector properties

- But Harris is *not* invariant to image scale



All points will be classified as edges

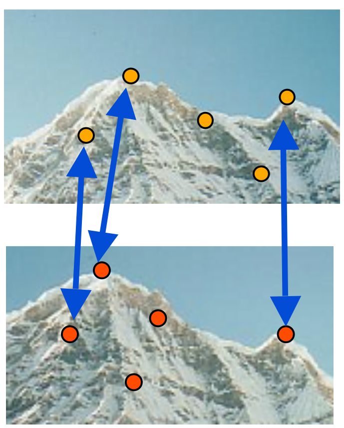
Corner !

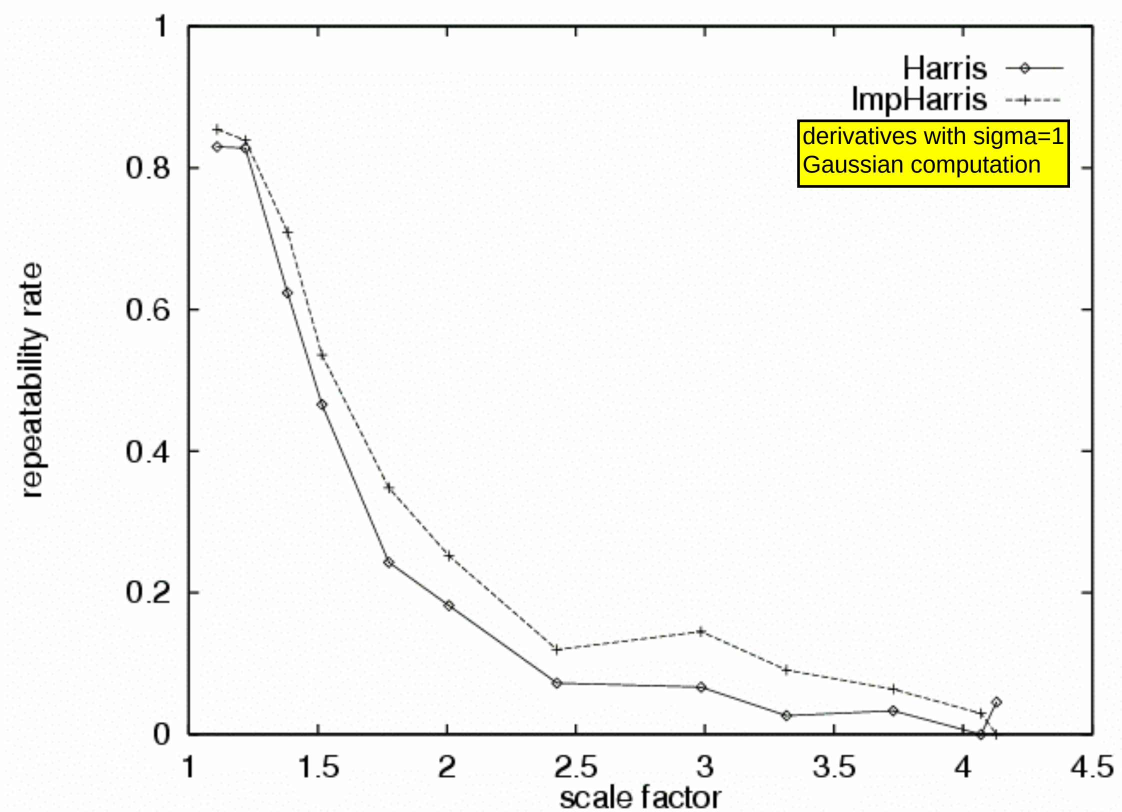
Experimental evaluation

- Quality of Harris detector for different scale changes

Repeatability rate:

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



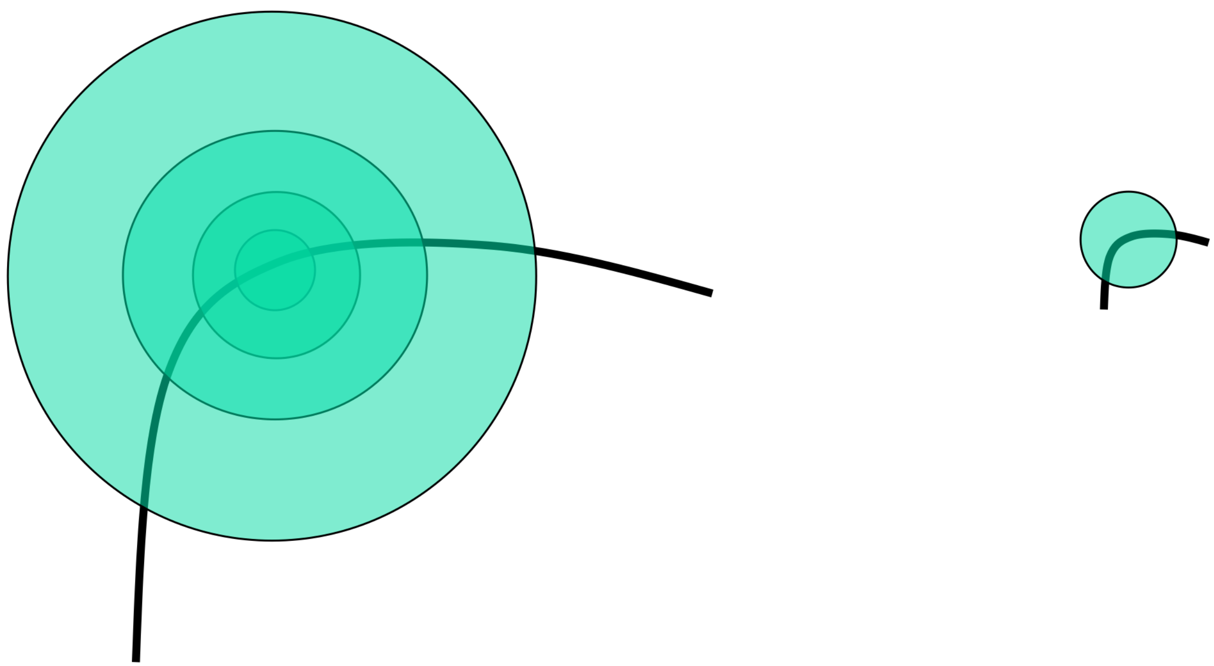


the image is Van Gogh's sower painting

C.Schmid et.al. "Evaluation of Interest Point Detectors". IJCV 2000 37(2), 151-172

Scale invariant interest point detection

- Consider regions (e.g. circles) of different sizes around a point
- Regions of corresponding sizes will look the same in both images



Scale invariant detection

- The problem: how do we choose corresponding circles ***independently*** in each image?

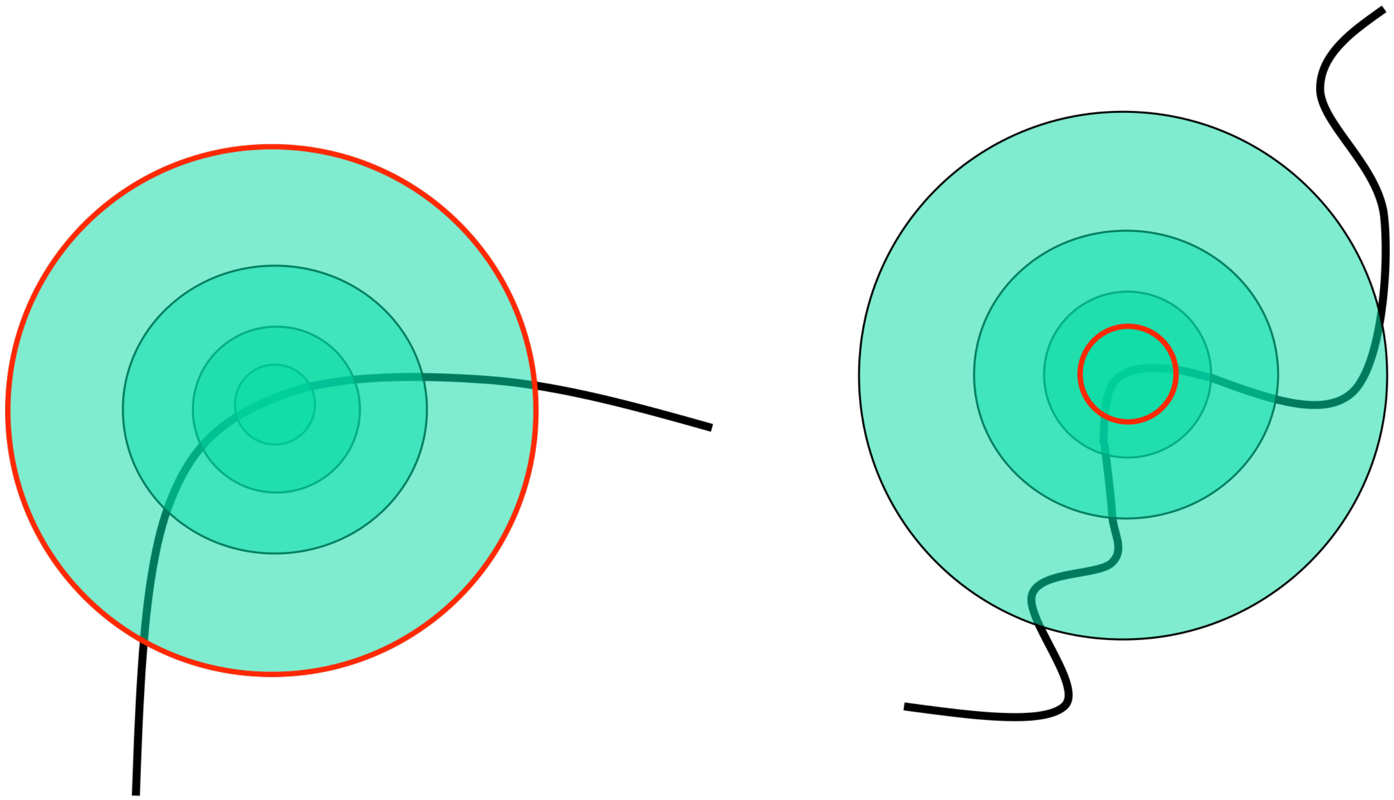
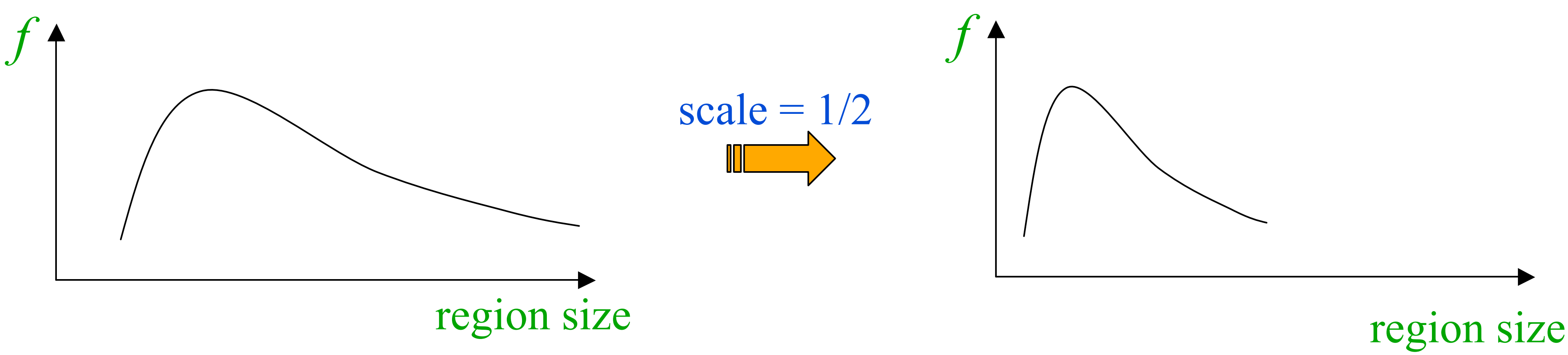


IMAGE PYRAMID

A solution

- Design a function which is “scale invariant”
  - I.e. value is the same for two corresponding regions, even if they are at different scales
  - Example: average intensity is the same for corresponding regions, even of different sizes

- For a given point in an image, consider the value of f as a function of region size (circle radius)

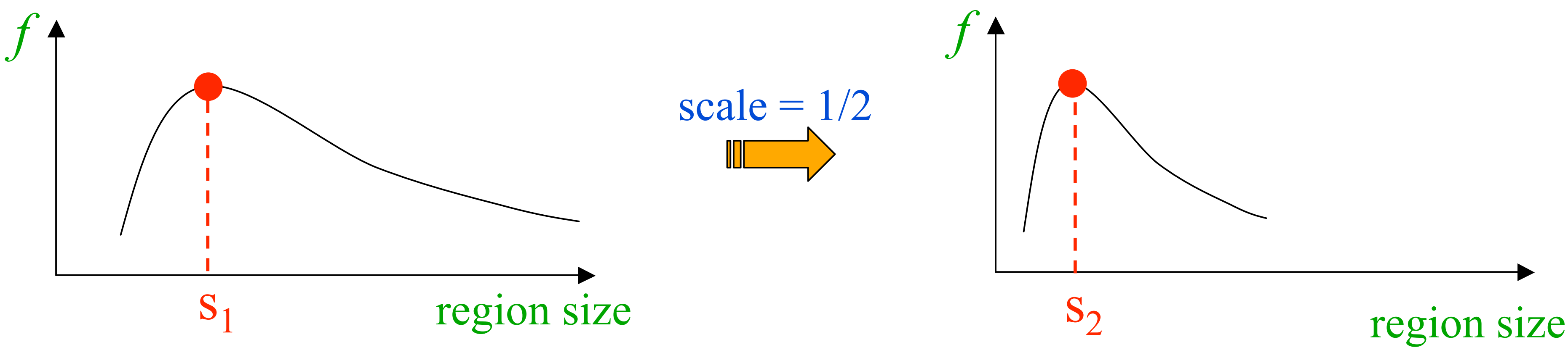


A solution

- Take a local maximum of this function
  - The region size at which maximum is achieved should be invariant to image scale

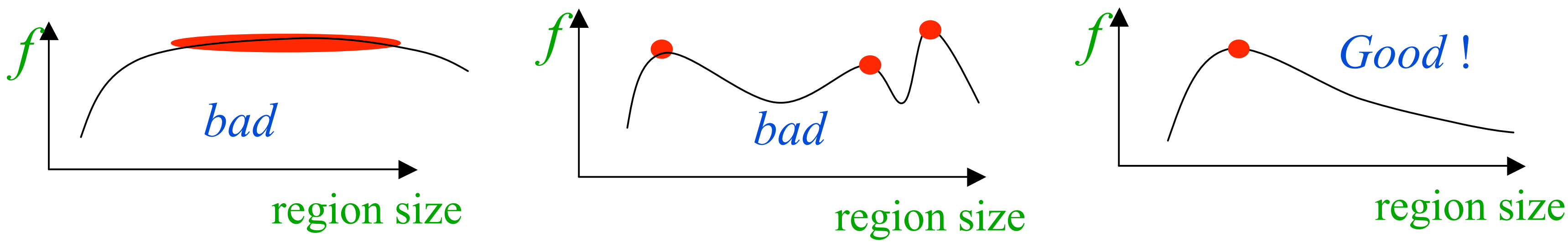
- This scale invariant region size is determined independently in each image

in reality you don't have a good theoretically valid solution just a generally good approximation



Choosing a function

- A good function for scale detection has one sharp peak



- A function that responds to image contrast is a good choice
  - e.g. convolve with a kernel like the Laplacian or the Difference of Gaussians (almost the same)