Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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Feature Detection and Matching

* More details on Harris and SIFT Features

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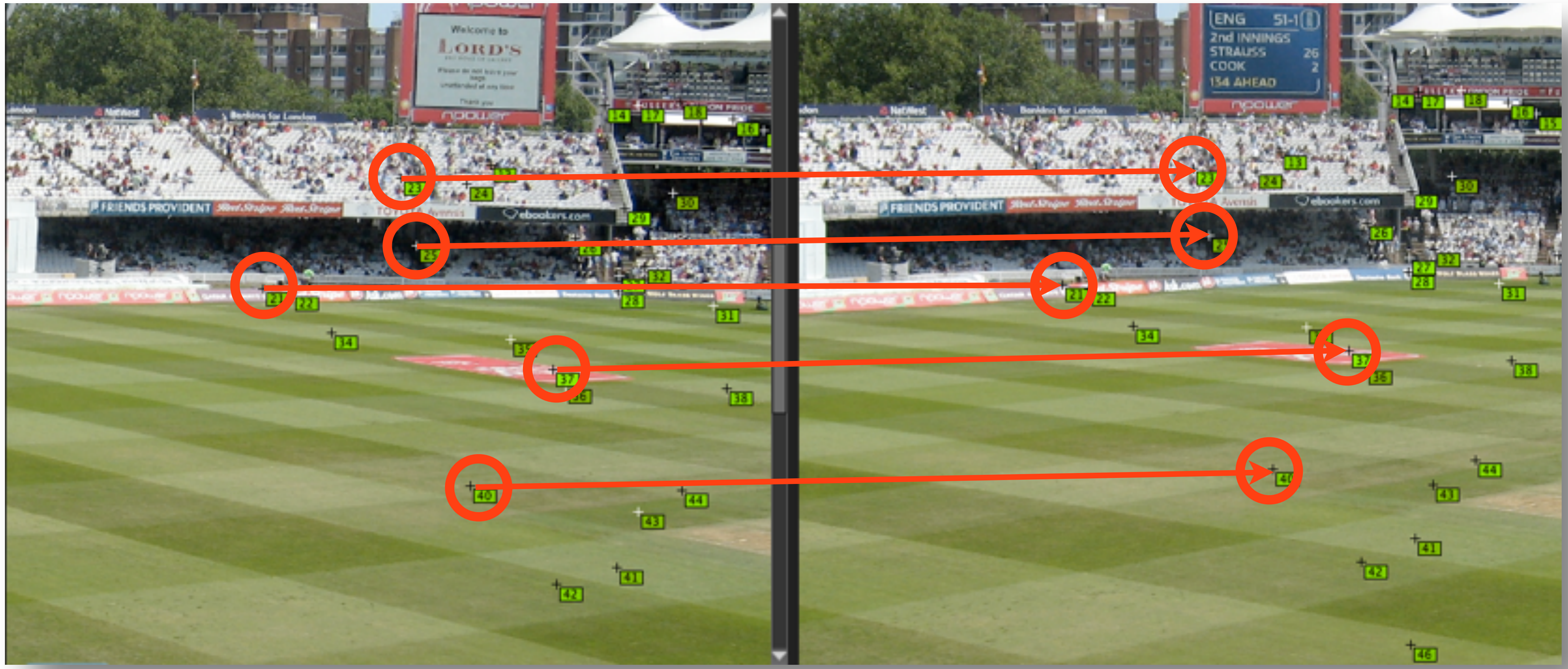
1. Harris Corner Detector Algorithm
2. SIFT

Recall: Detection and Matching



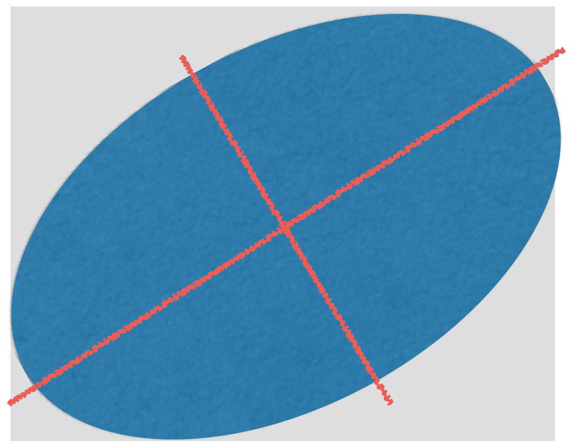
Recall: Corner Detection: Mathematics

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

The quadratic approximation, following Taylor Expansion, simplifies to:

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

where ***M*** is a second moment matrix computed from image derivatives $\mathbf{I}_x$ and $\mathbf{I}_y$:



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

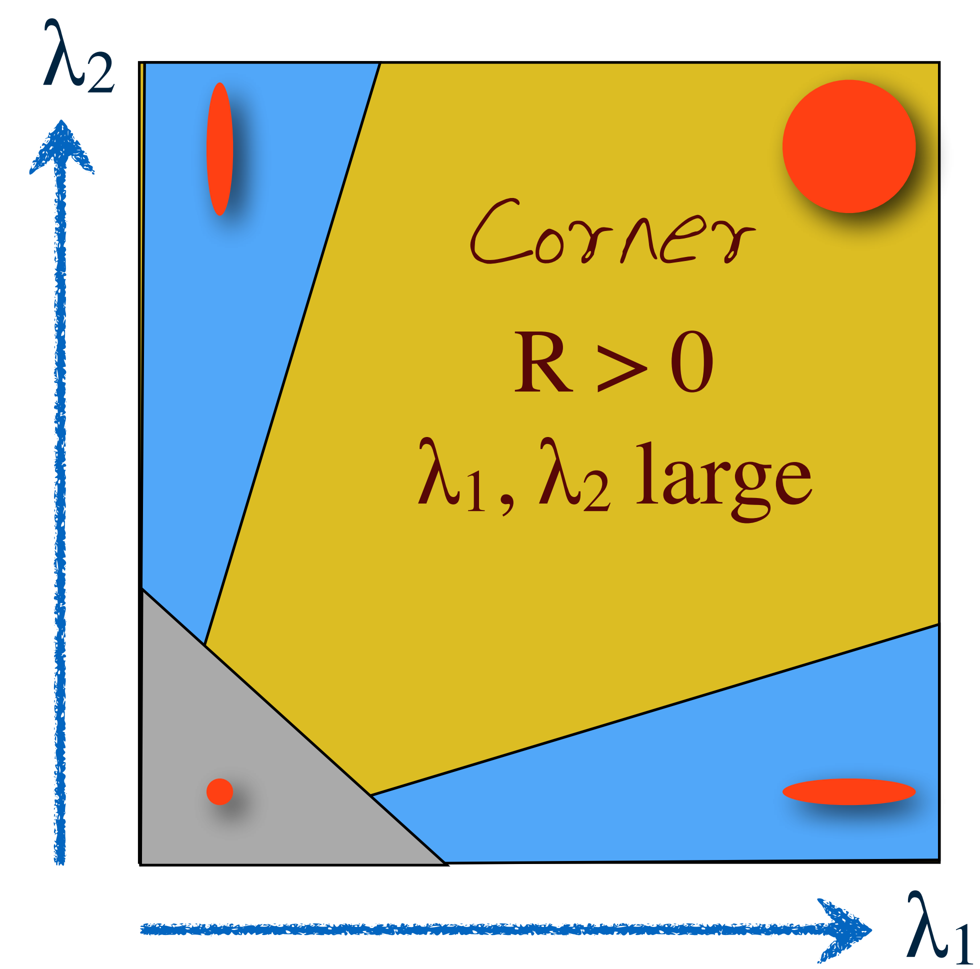
Recall: Harris Corner Response Function

$$R = \det(M) - \alpha\, \text{trace}(M)^2 = \lambda_1\lambda_2 - \alpha(\lambda_1 + \lambda_2)^2$$

α: constant (0.04 to 0.06)

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

* R depends only on eigenvalues of M
* $R \Rightarrow$ large for a corner
* $R \Rightarrow$ negative with large magnitude for an edge
* $|R| \Rightarrow$ small for a flat region
* Note: No explicit computation of eigenvalues required



Harris Detector: Step by Step

1. Compute horizontal and vertical derivatives of the image (convolve with derivative of Gaussians)
2. Computer outer products of gradients $\boldsymbol{M}$
3. Convolve with larger Gaussian
4. Compute scalar interest measure $\boldsymbol{R}$
5. Find local maxima above some threshold, detect features!

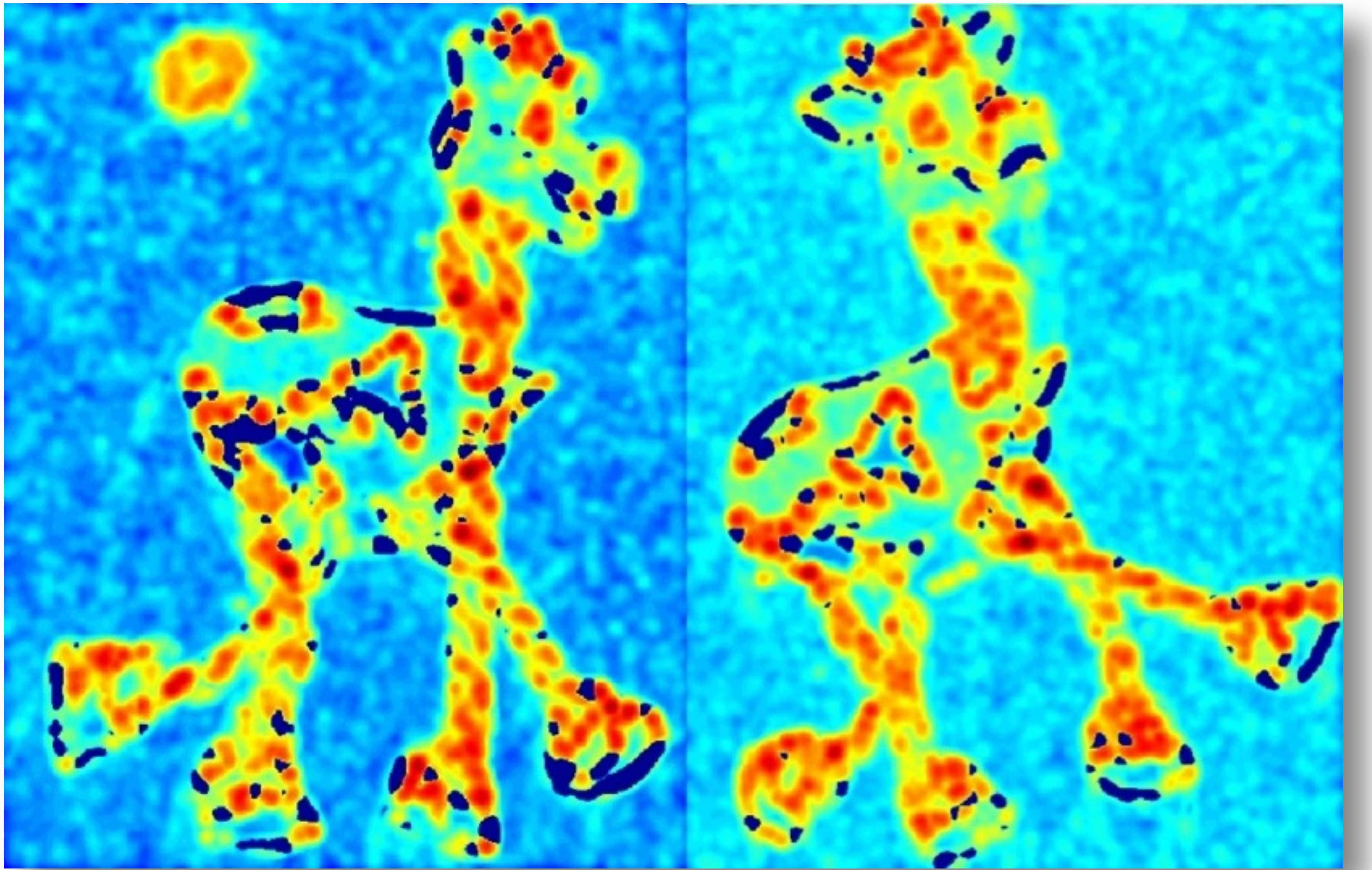
Harris Detector: Workflow

Image Pair

Slides adapted from Aaron Bobick, Alysosha Efros, etc.

Harris Detector: Workflow

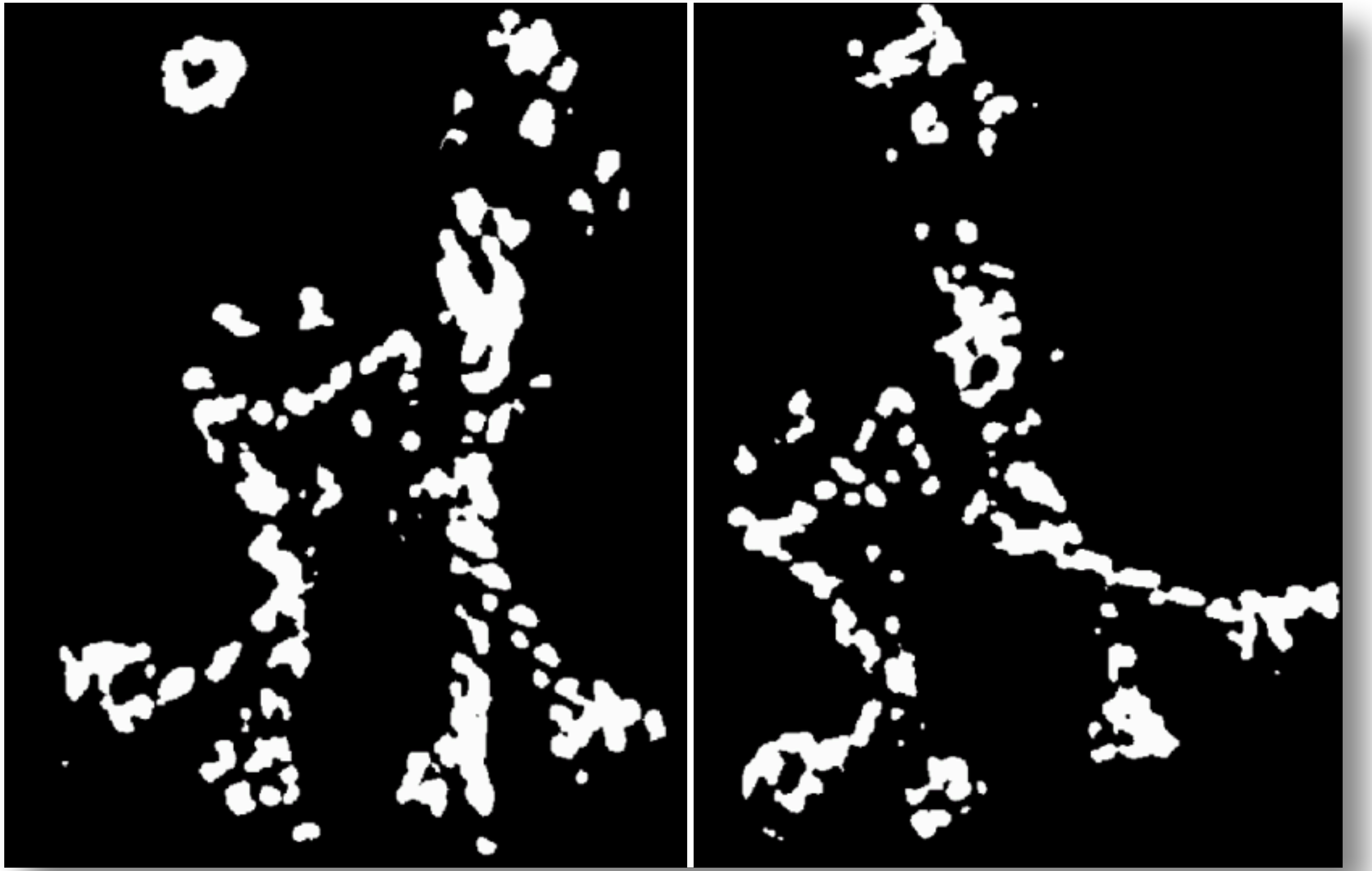
Compute corner response R



Slides adapted from Aaron Bobick, Alysosha Efros, etc.

Harris Detector: Workflow

Find points with large corner response: R>threshold



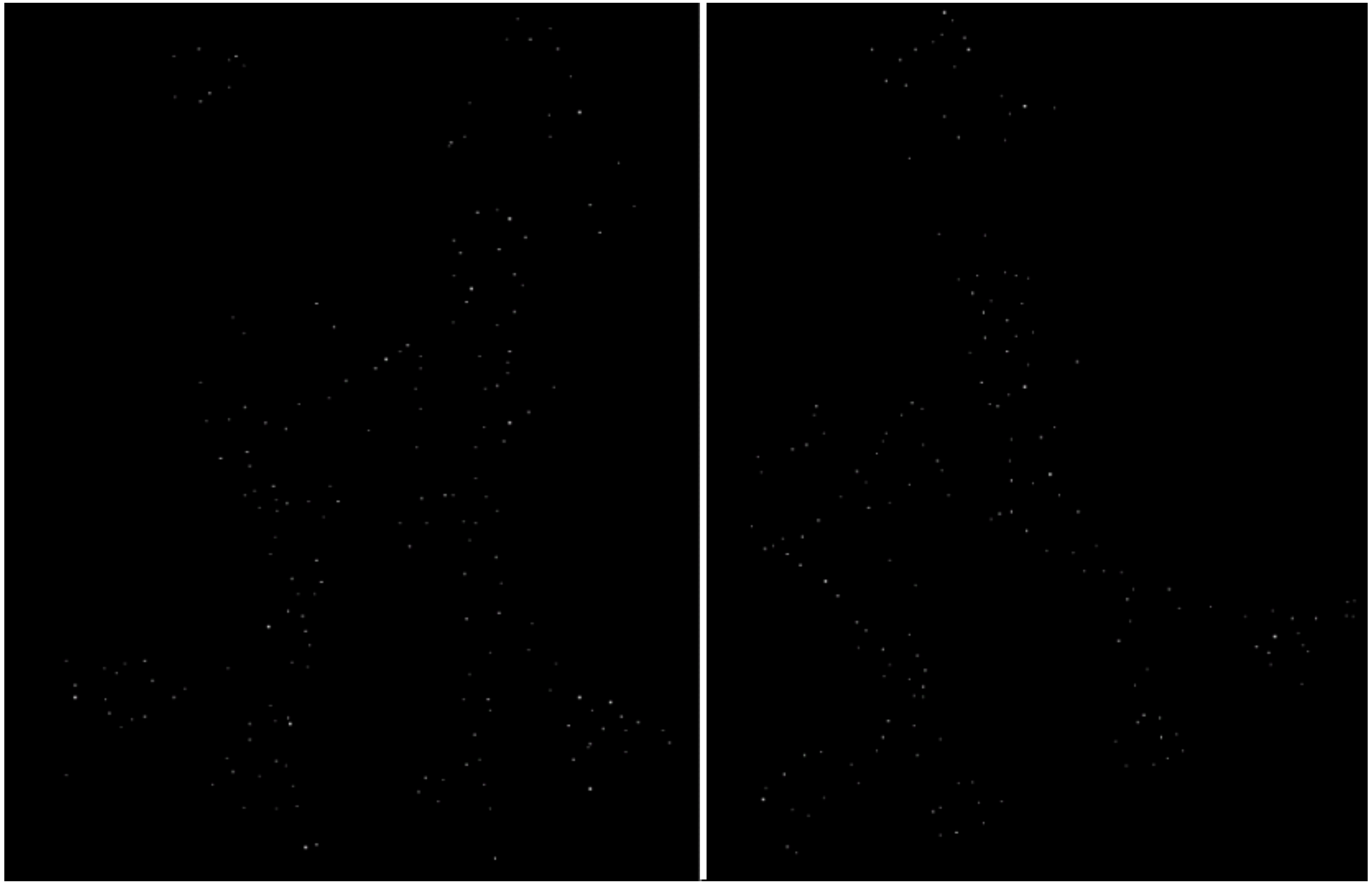
Slides adapted from Aaron Bobick, Alysosha Efros, etc.

Harris Detector: Workflow

Take only the points of local maxima of R

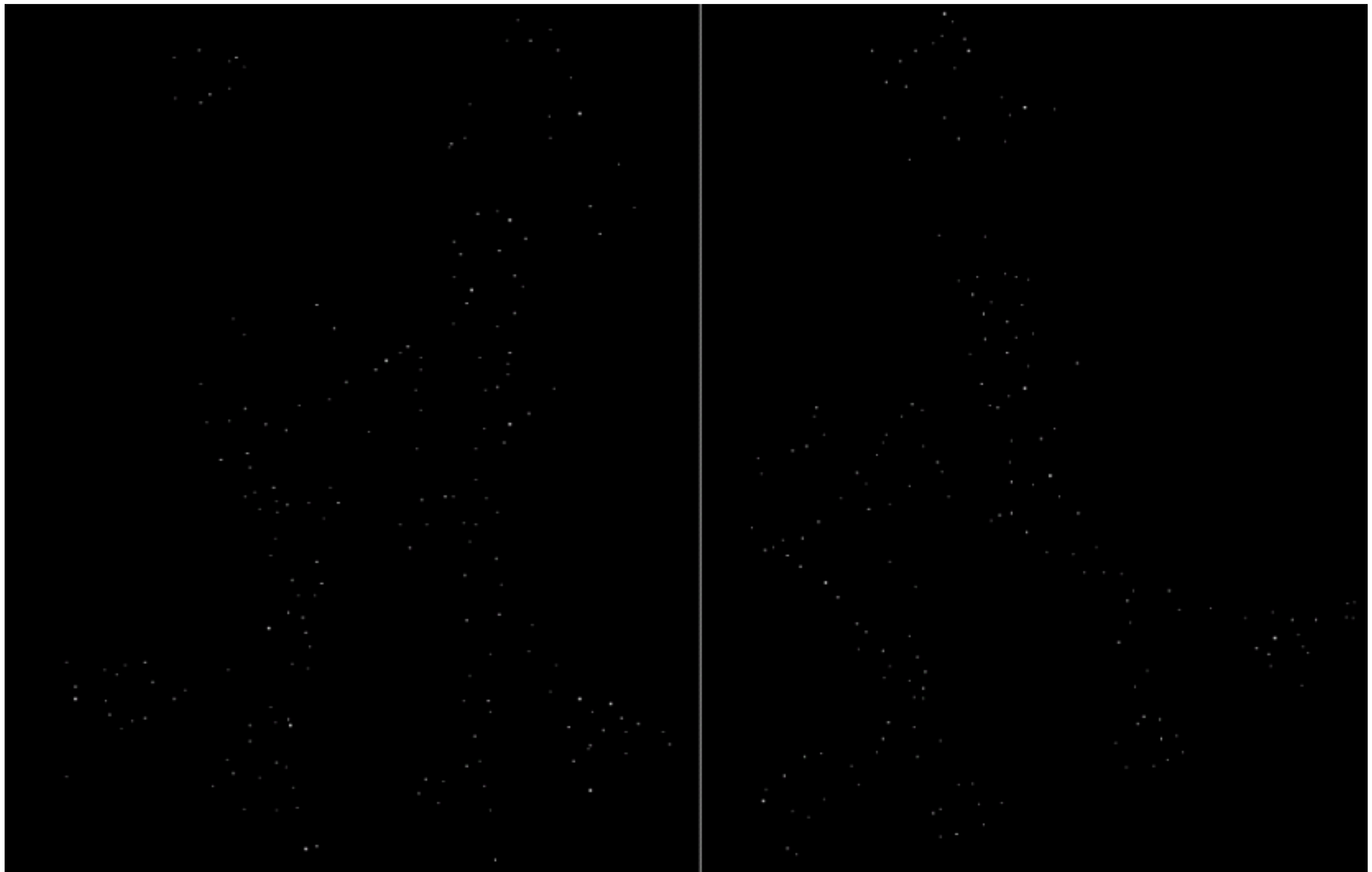
Slides adapted from Aaron Bobick, Alysosha Efros, etc.

Harris Detector: Workflow



Take only the points of local maxima of R

Slides adapted from Aaron Bobick, Alysosha Efros, etc.



Harris Detector: Workflow

Output

Harris Detector Algorithm (Preview)

* Compute Gaussian derivatives at each pixel
* Compute second moment matrix M in a Gaussian window around each pixel
* Compute corner response function R
* Threshold R
* Find local maxima of response function (non-maximum suppression)

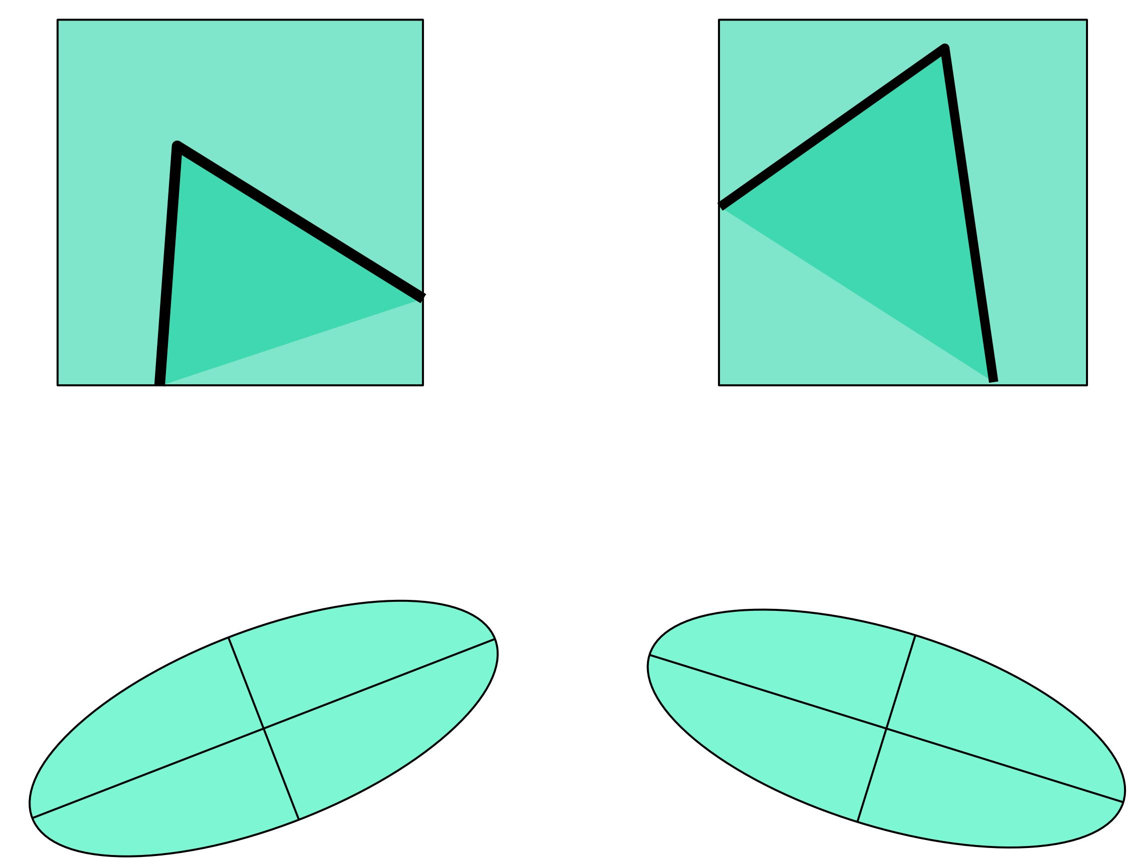
Harris Detector: Some Properties

* Invariant to Rotation?
* Invariance to image intensity?
* Invariant to image scale?

Slides adapted from Aaron Bobick

Harris Detector: Some Properties

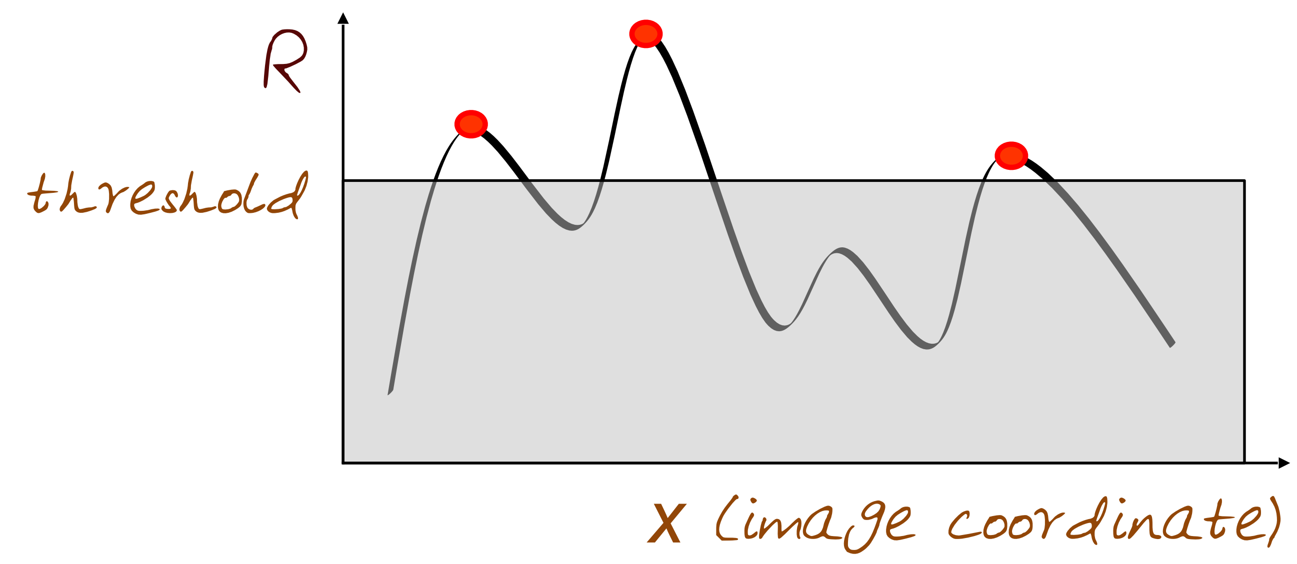
* Invariant to Rotation?
* Ellipse rotates but its shape (i.e. eigenvalues) remains the same
* Corner response R is invariant to image rotation

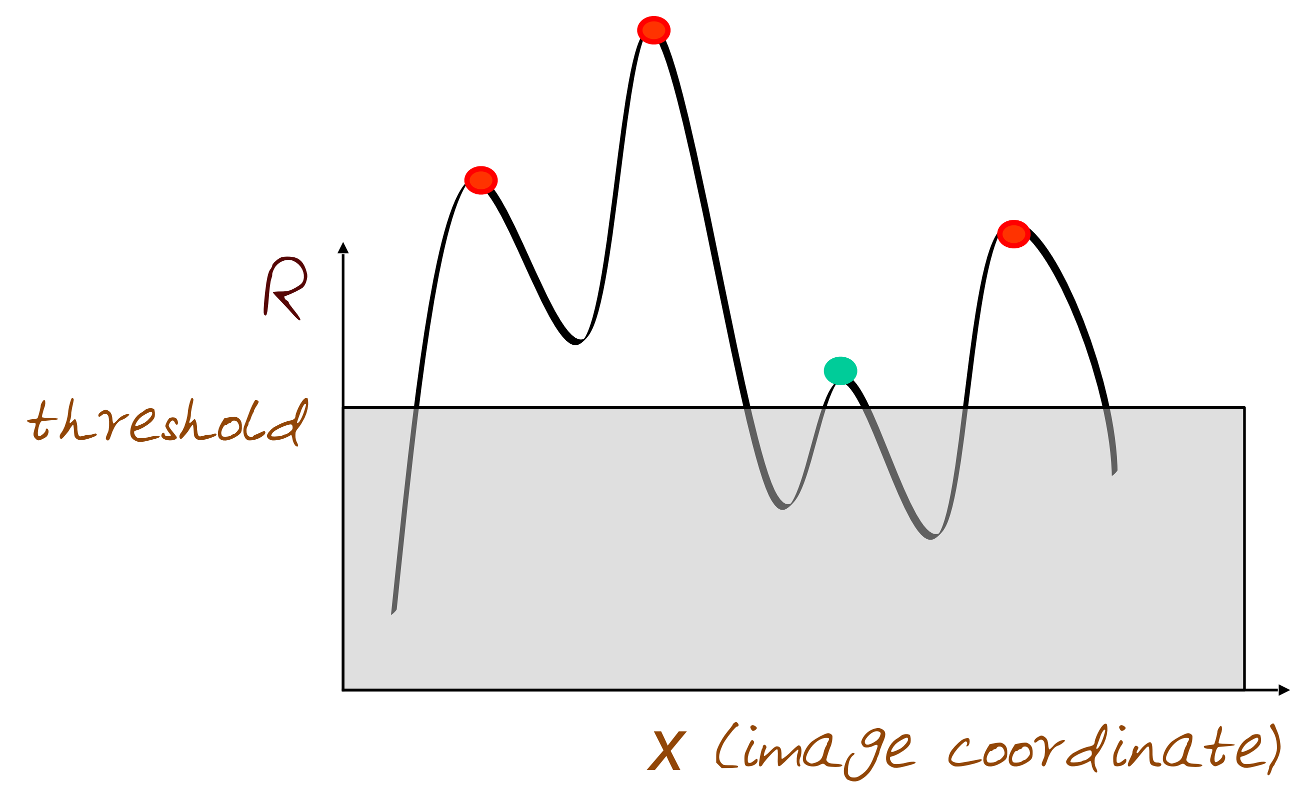


Slides adapted from Aaron Bobick

Harris Detector: Some Properties

- Invariance to image intensity?
- Mostly invariant to additive and multiplicative intensity changes
- Only derivatives are used
  - Invariance to intensity shift:
    - $I \rightarrow I + b$
  - Intensity scale:
    - $I \rightarrow a\, I$

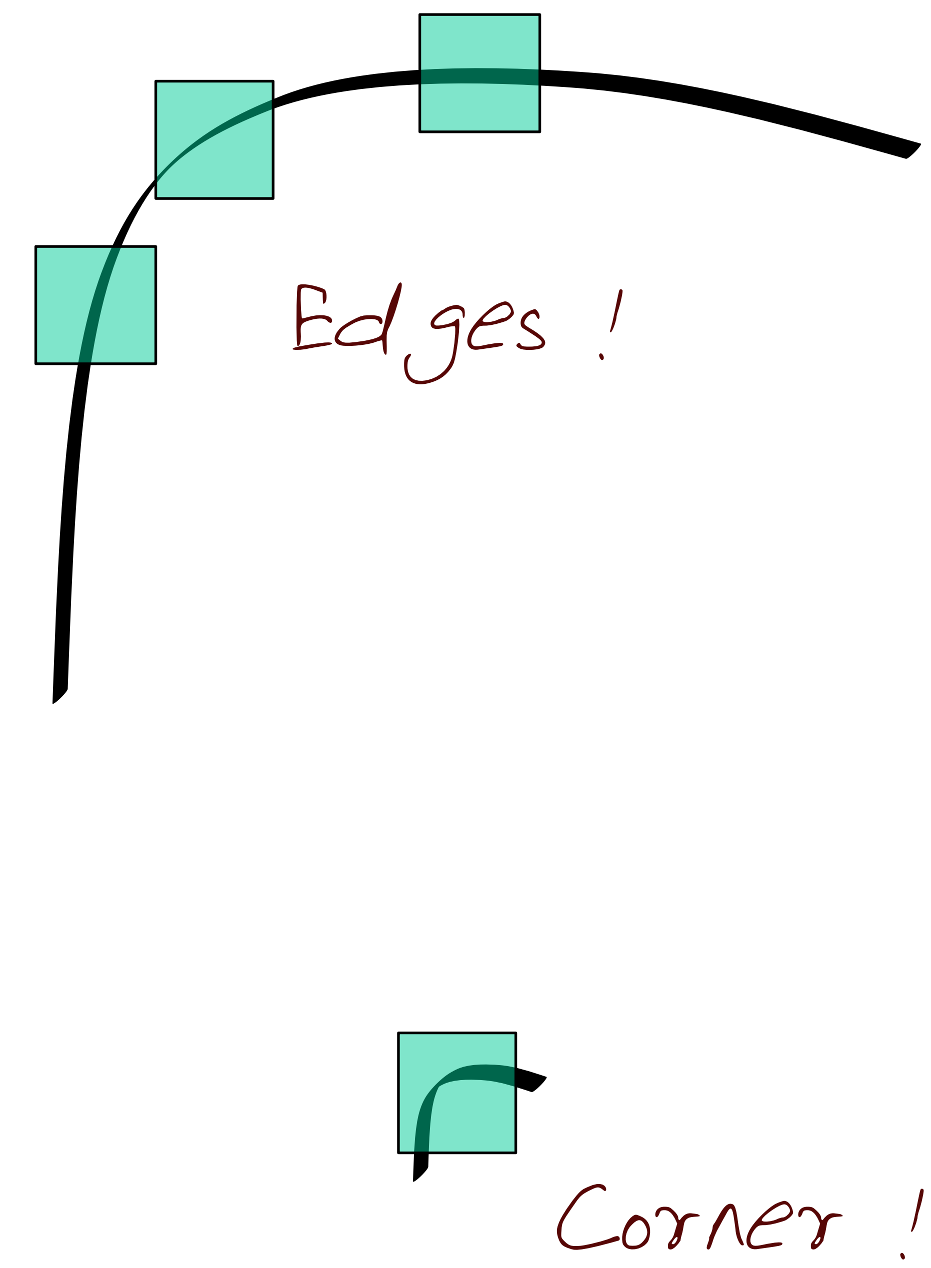




Slides adapted from Aaron Bobick

Harris Detector: Some Properties

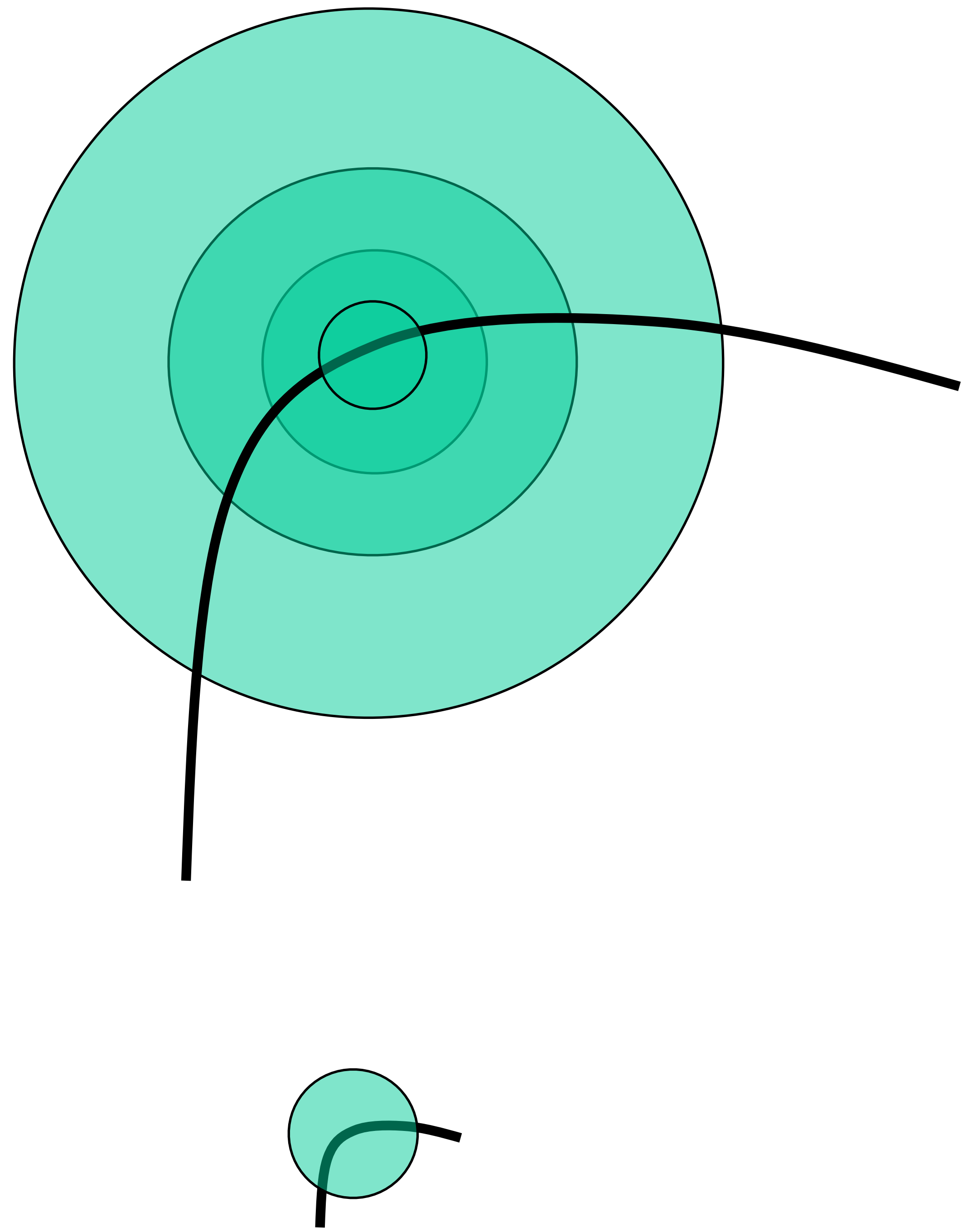
* Invariant to image scale?
* Not Invariant to image scale,
  * But can we do something about this?



Slides adapted from Aaron Bobick

Scale Invariant Detection

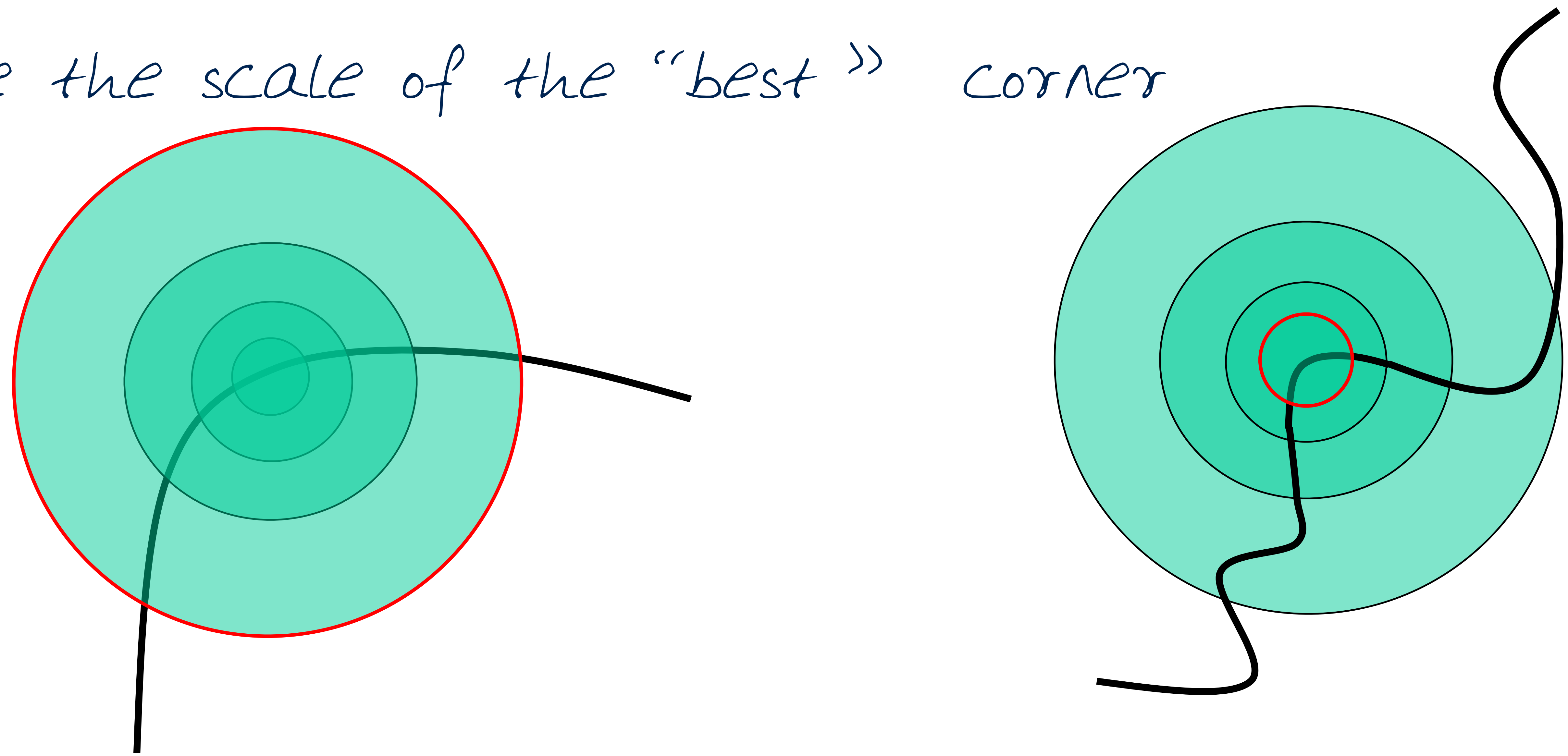
- Consider regions (e.g. circles) of different sizes around a point
- Regions of corresponding sizes will look the same in both images



Slides adapted from Aaron Bobick

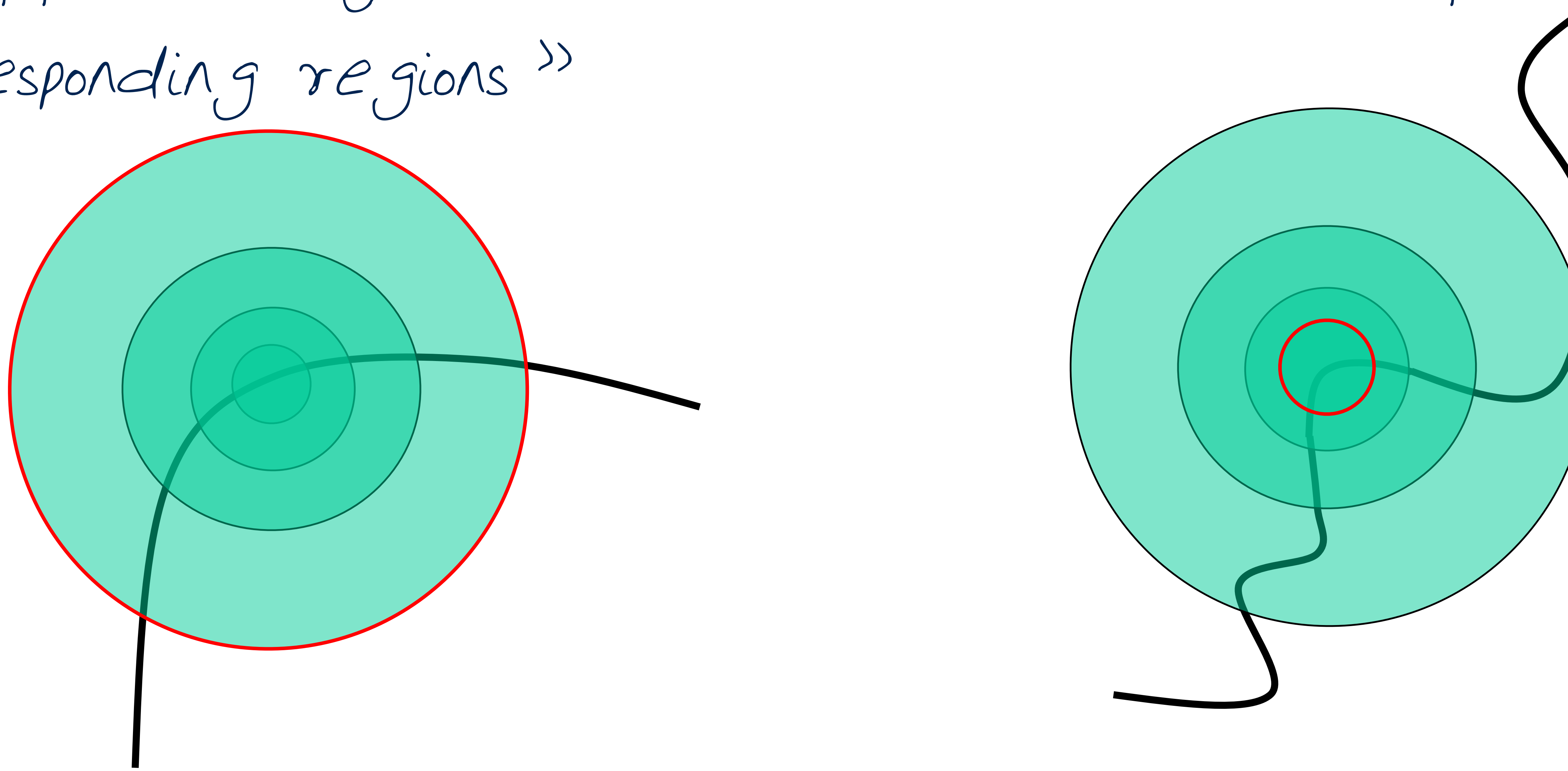
Scale Invariant Detection

* The problem: how do we choose corresponding circles independently in each image?
* Choose the scale of the "best" corner



Scale Invariant Detection

- A region (circle), which is "scale invariant"
- Not affected by the size but will be the same for "corresponding regions"



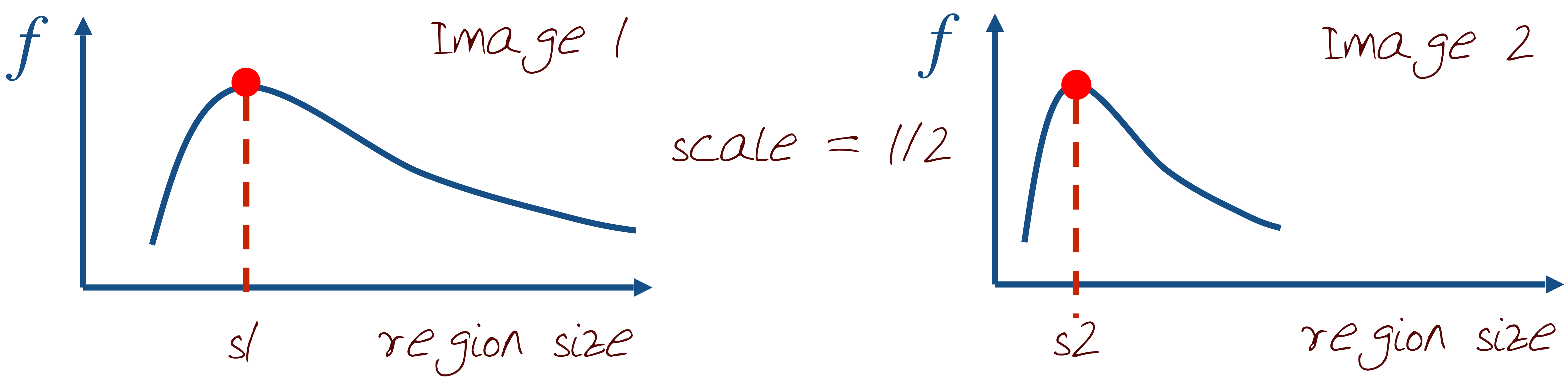
Scale Invariant Detection

* A region (circle), which is "scale invariant"
* Not affected by the size but will be the same for "corresponding regions
* Example: Average intensity. For corresponding regions (even of different sizes) it will be the same

Slides adapted from Aaron Bobick

Scale Invariant Detection

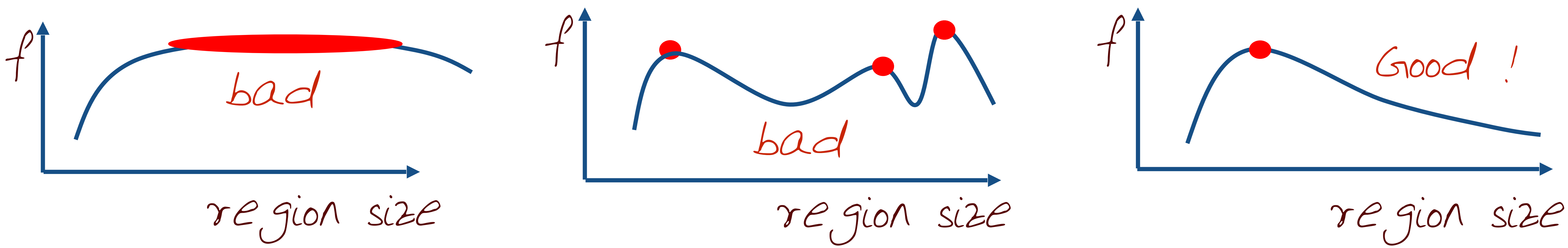
* At a point, compute the scale invariant function over different size neighborhoods (different scales)
* Choose the scale for each image at which the function is a maximum



Slides adapted from Aaron Bobick

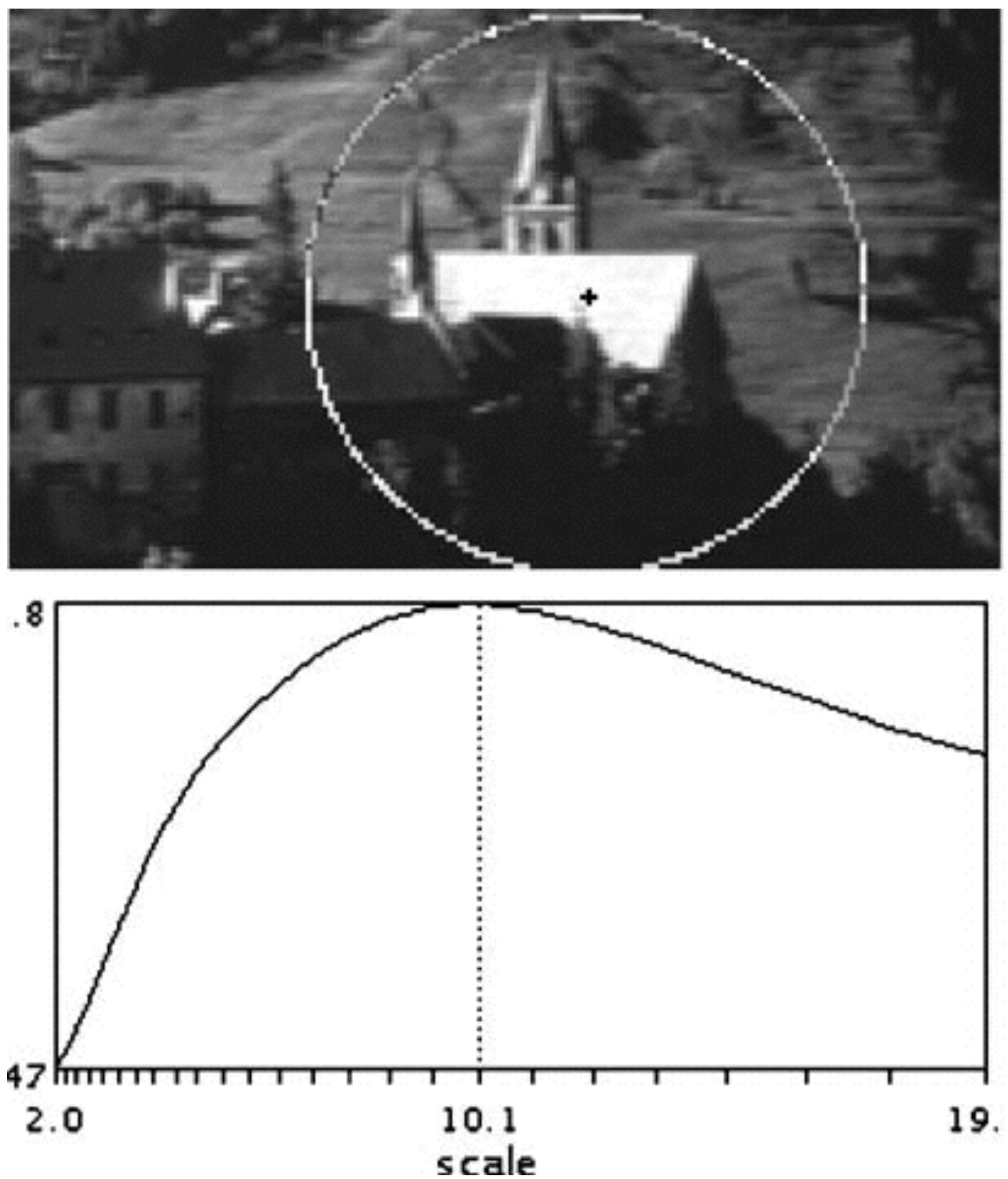
Scale Invariant Detection

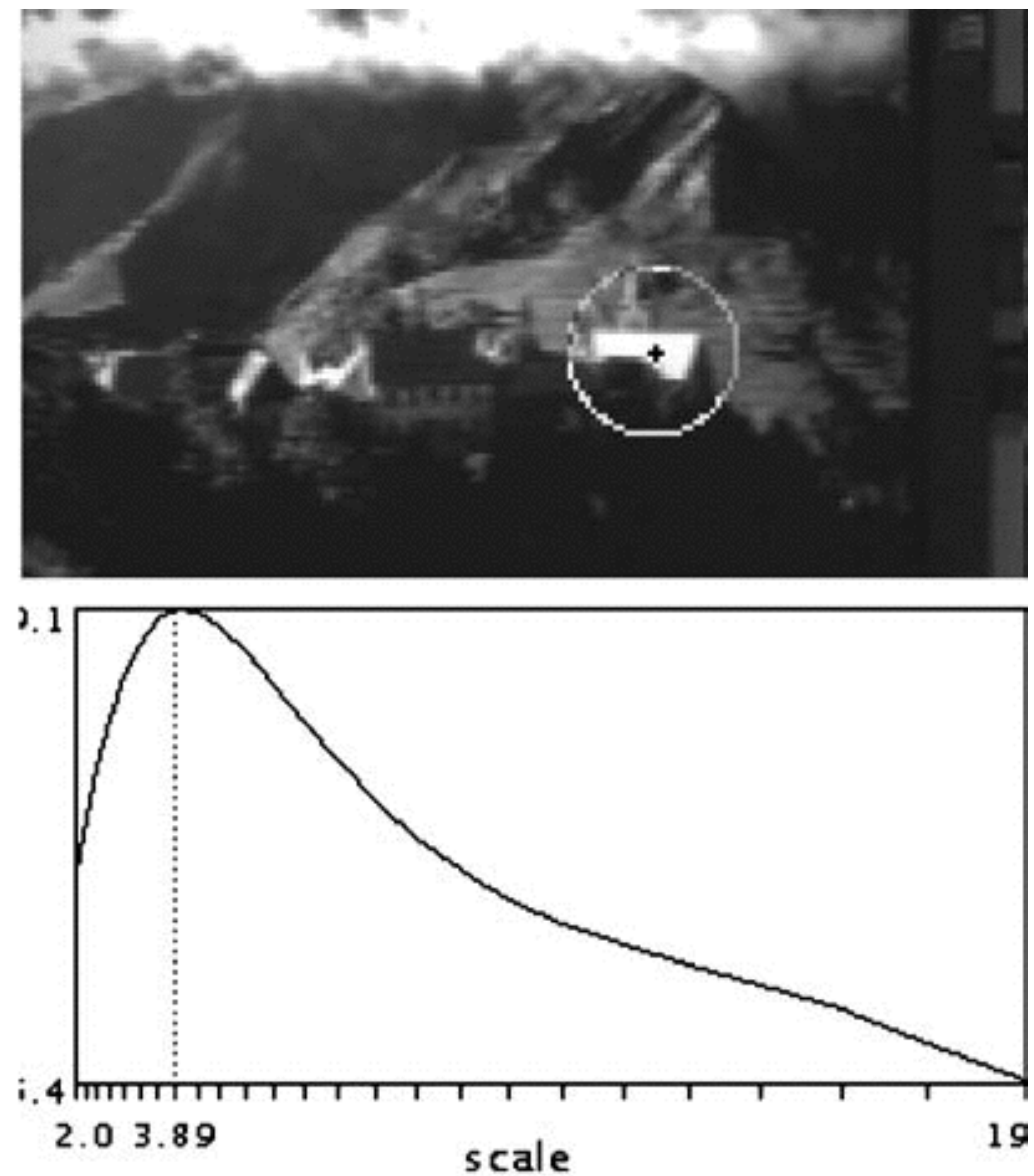
* A "good" function for scale detection has one stable sharp peak



* For usual images: a good function would be a one which responds to contrast (sharp local intensity change)

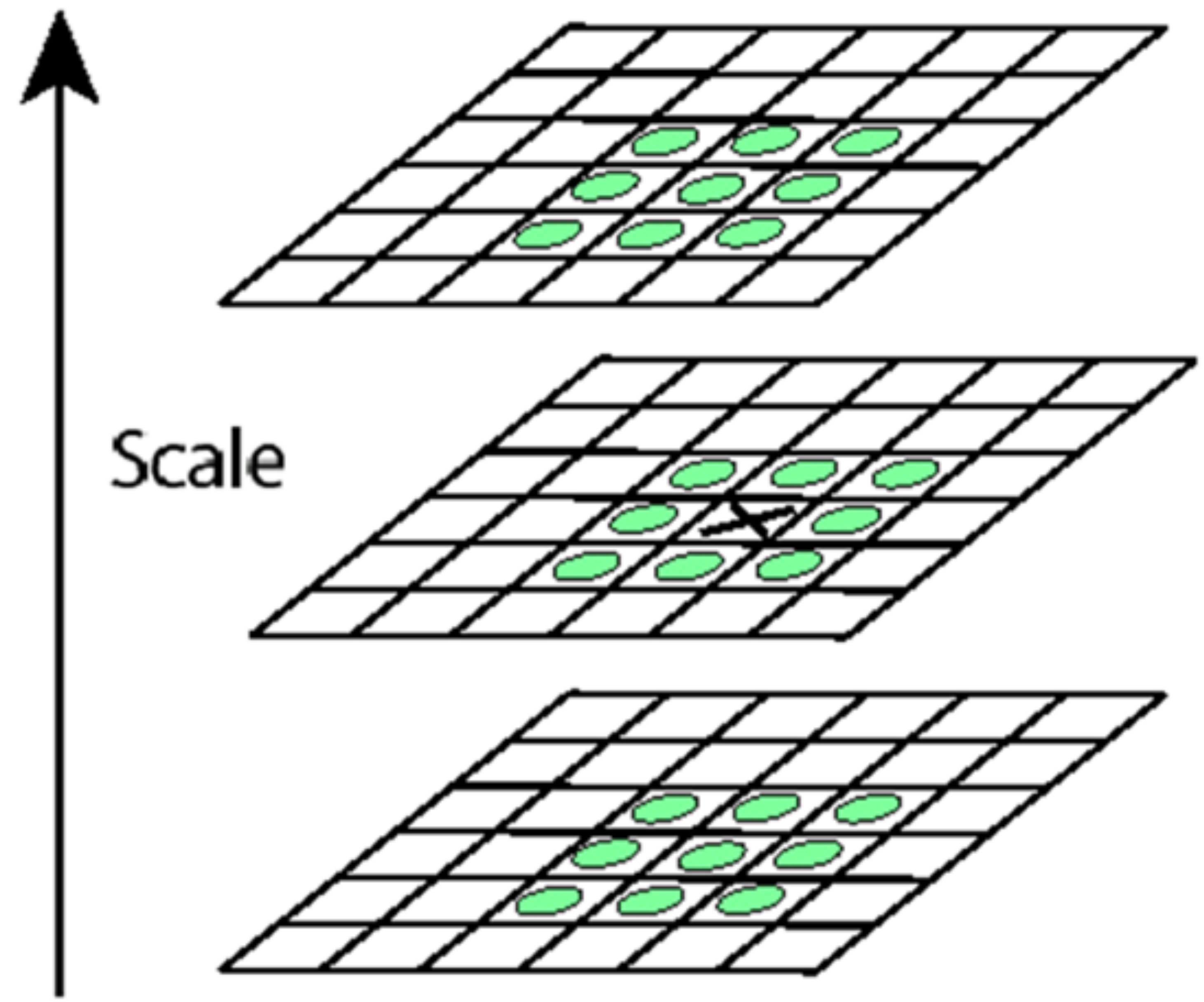
Scale Sensitive Response





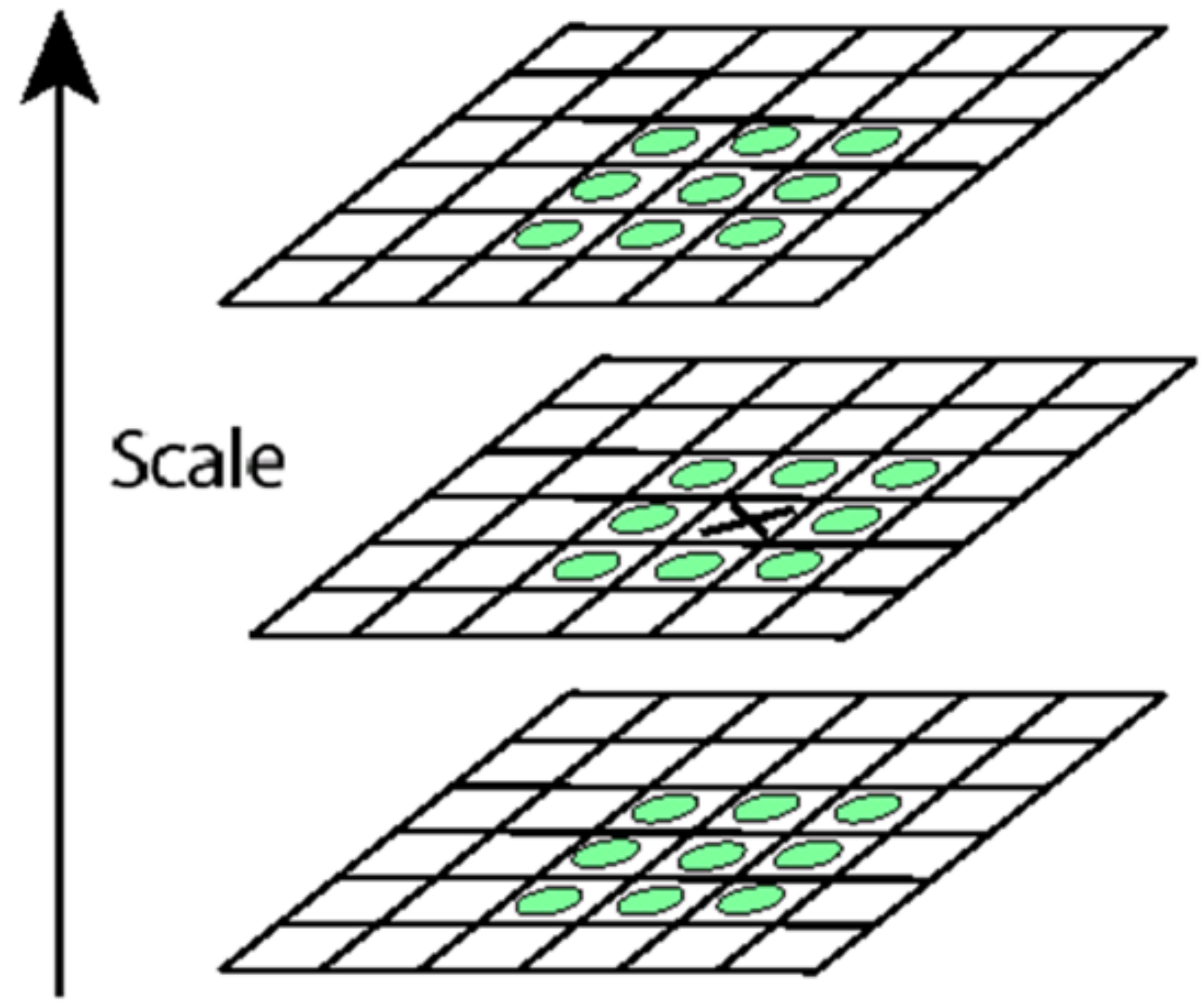
Key Point Localization in Space

* Find robust extremum (maximum or minimum) both in space and in scale



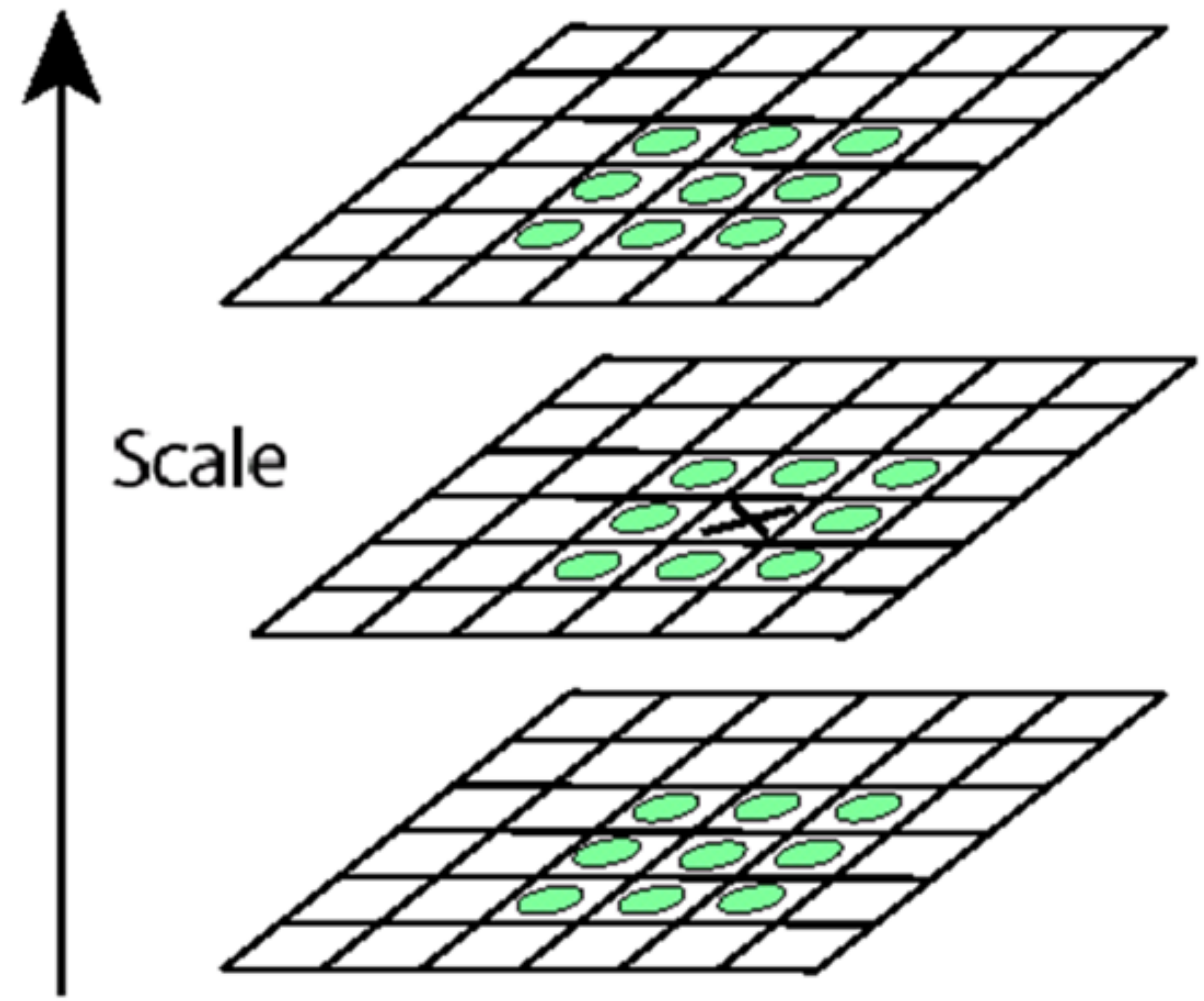
Key Point Localization

* SIFT: Scale Invariant Feature Transform
* Specific suggestion: use pyramid to find maximum values (remember edge detection?) – then eliminate "edges" and pick only corners

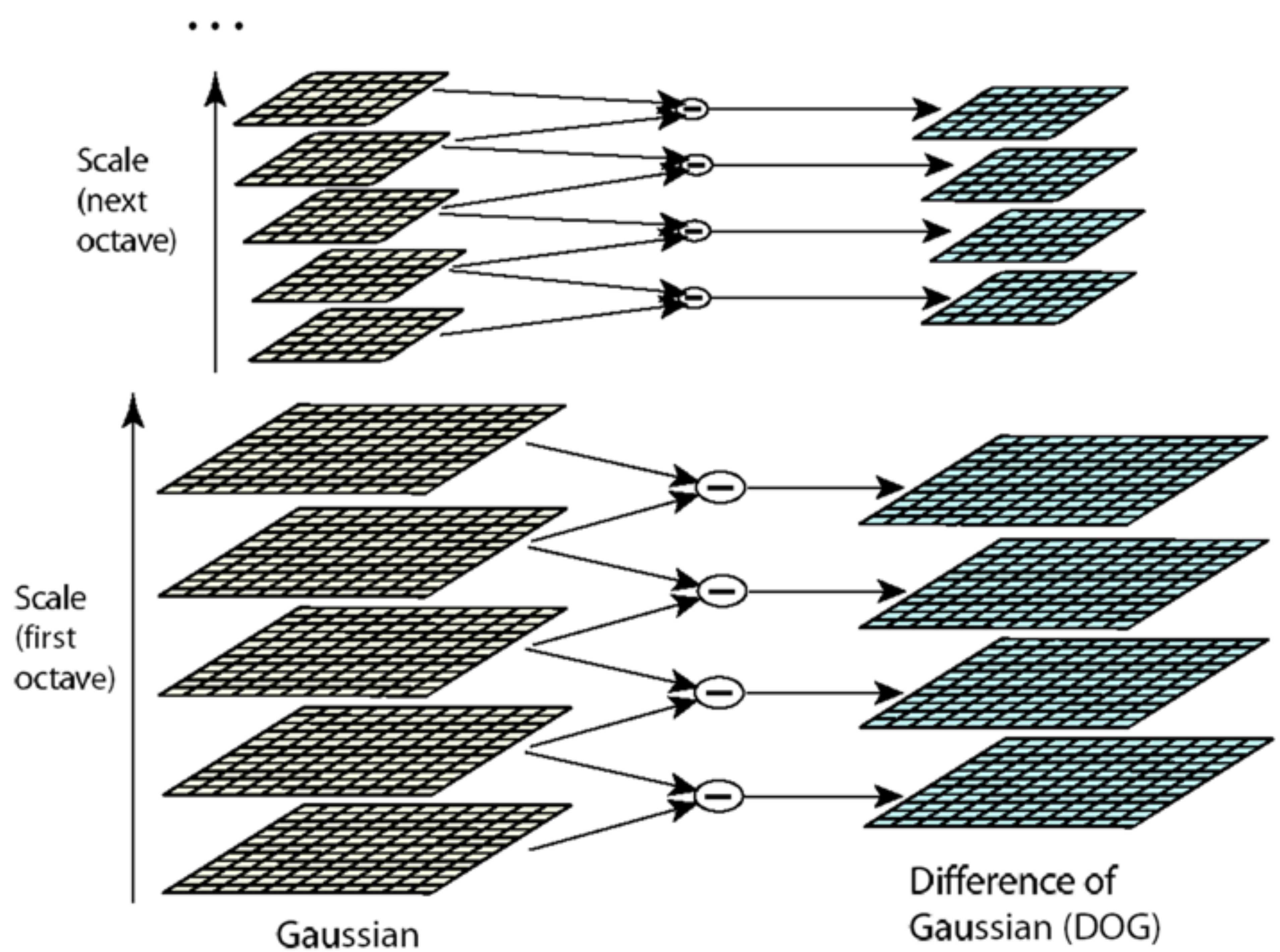


Key Point Localization

* Each point is compared to its 8 neighbors in the current image and 9 neighbors each in the scales above and below)

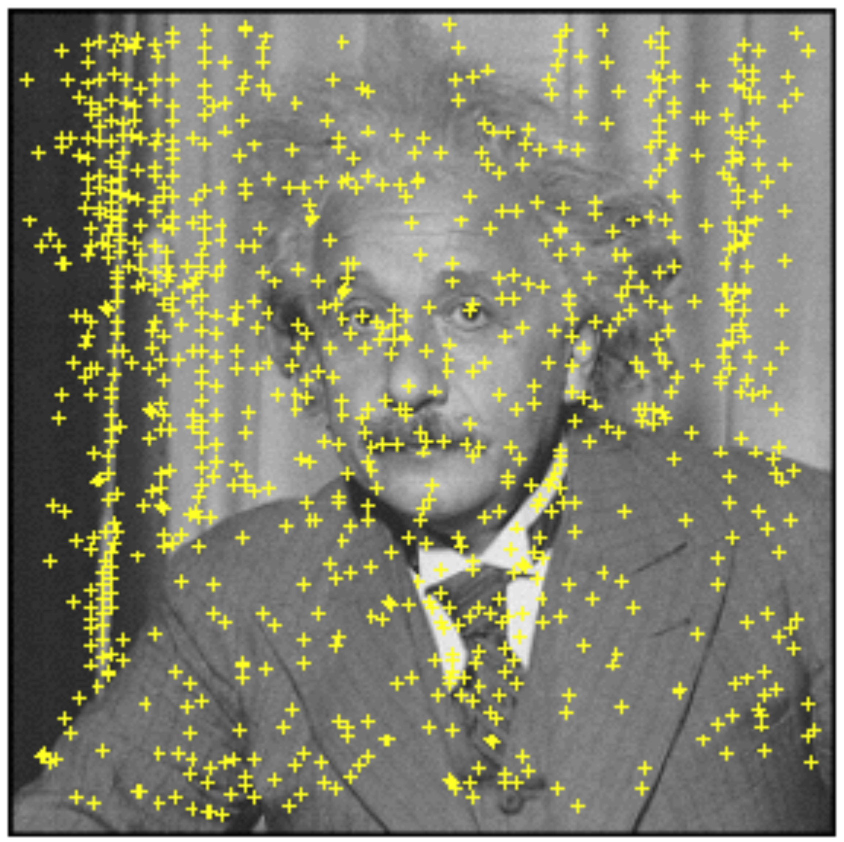


Scale Space Processed One Octave at a Time

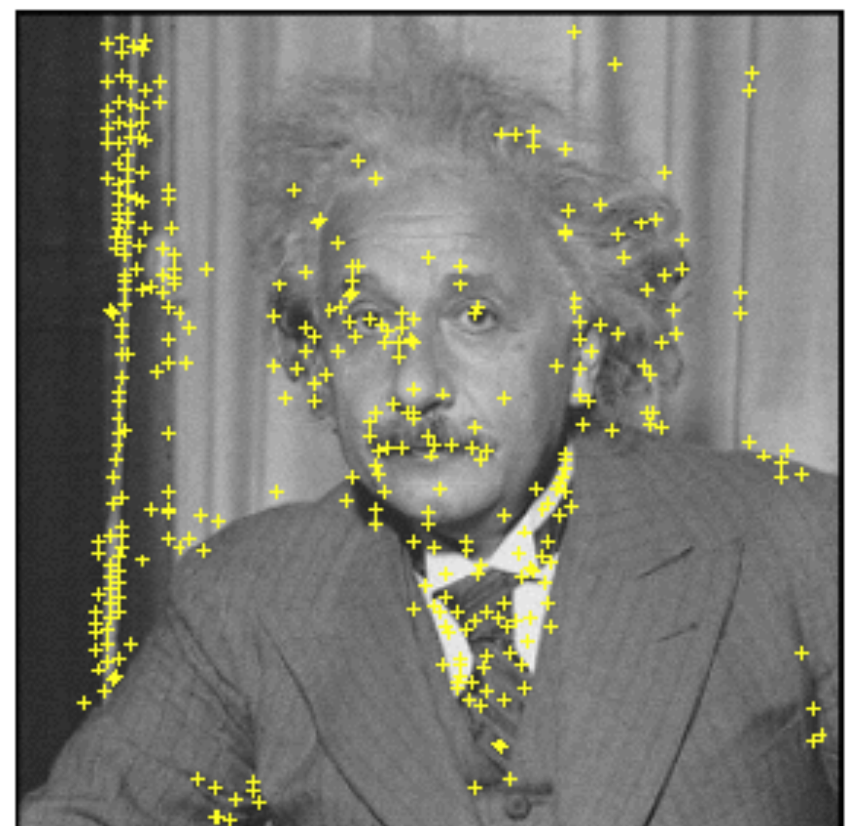


Extrema at Different Scales

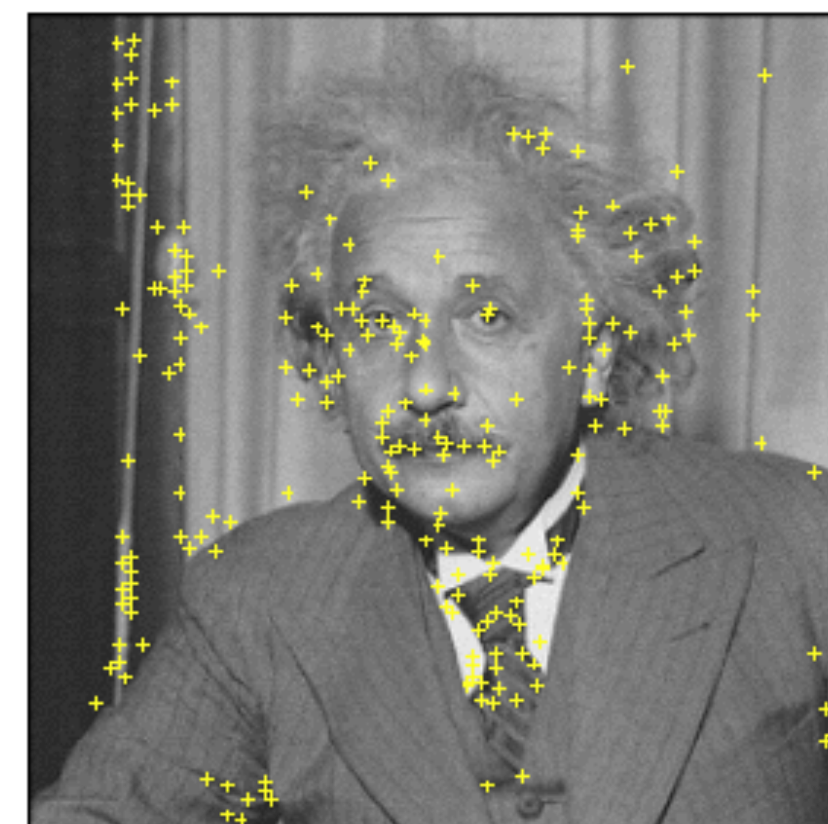
Remove Low Contrast, Edge Bound



Extrema points



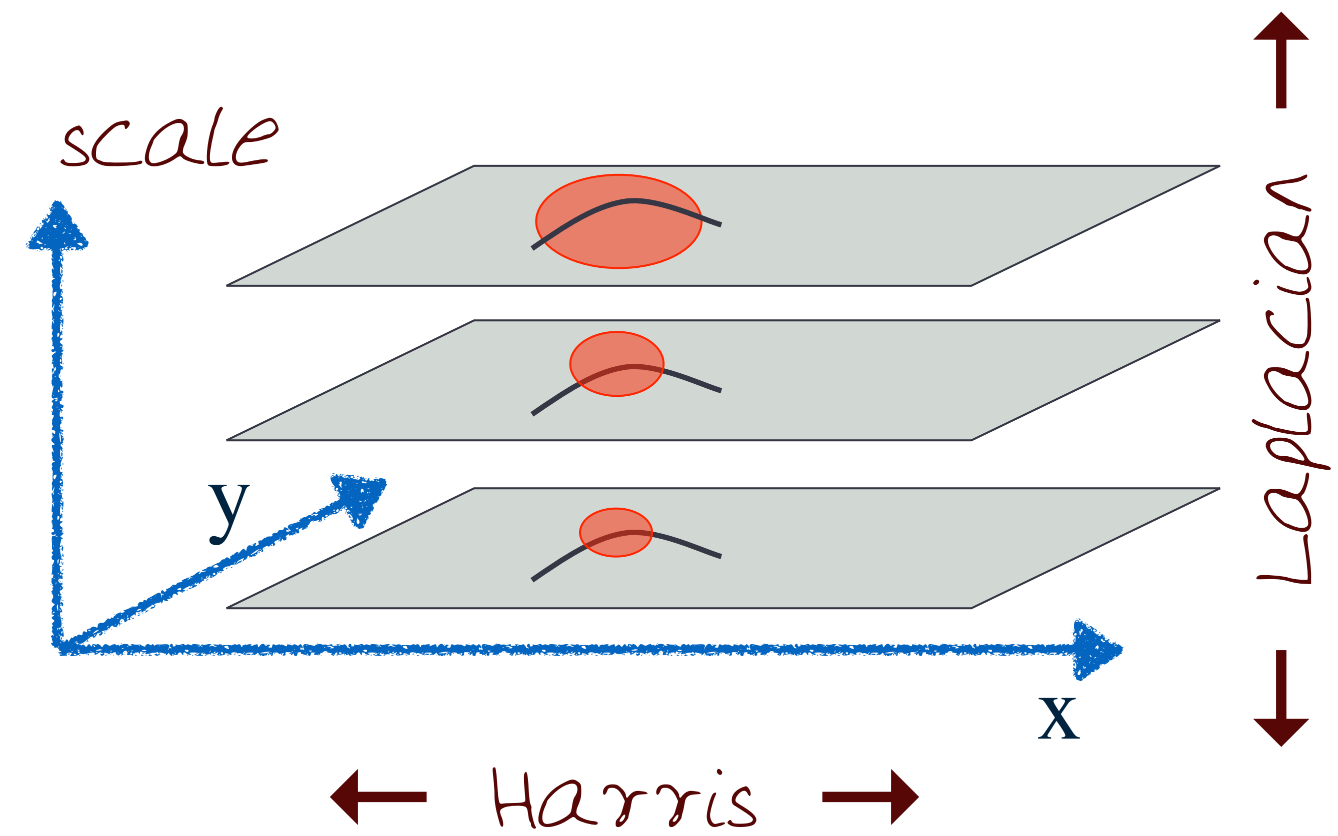
Contrast > C



Not on edge

Scale Invariant Detectors

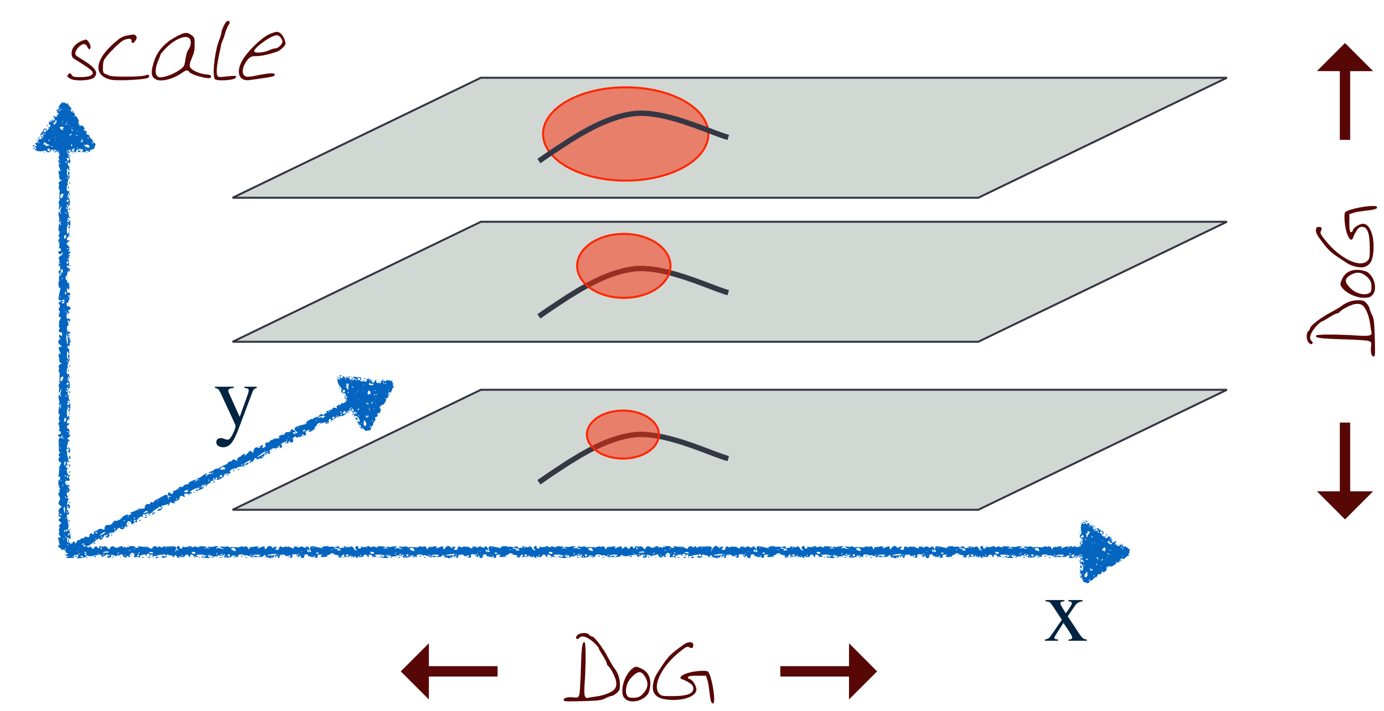
- Harris-Laplacian
- Find local maximum of:
  - Harris corner detector in space (image coordinates)
  - Laplacian in scale



(Mikolajczyk and Schmid, 2001)

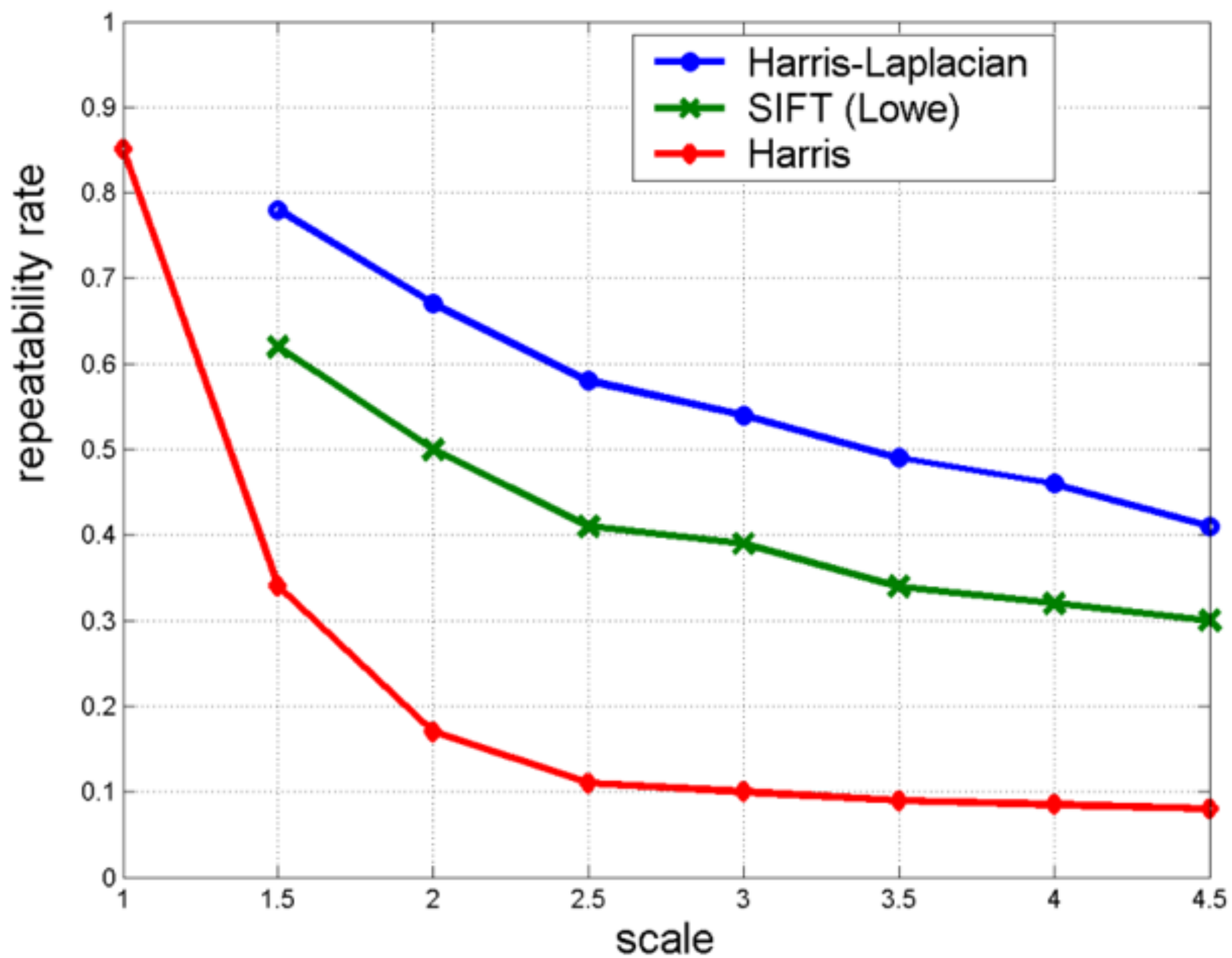
Scale Invariant Detectors

* SIFT (Lowe, 2004)
* Find local maximum of:
  * Difference of Gaussians (DoG) in space and scale
  * DoG is simply a pyramid of the difference of Gaussians within each octave



Lowe 2004

Scale Invariant Detectors



K. Mikolajczyk, C. Schmid (2001) "Indexing Based on Scale Invariant Interest Points". ICCV 2001

SIFT (Scale-Invariant Feature Transform)

* Orientation assignment
  * Compute best orientation(s) for each keypoint region.
* Keypoint description
  * Use local image gradients at selected scale and rotation to describe each keypoint region.

http://en.wikipedia.org/wiki/File:Sift_keypoints_filtering.jpg

Invariant Local Features

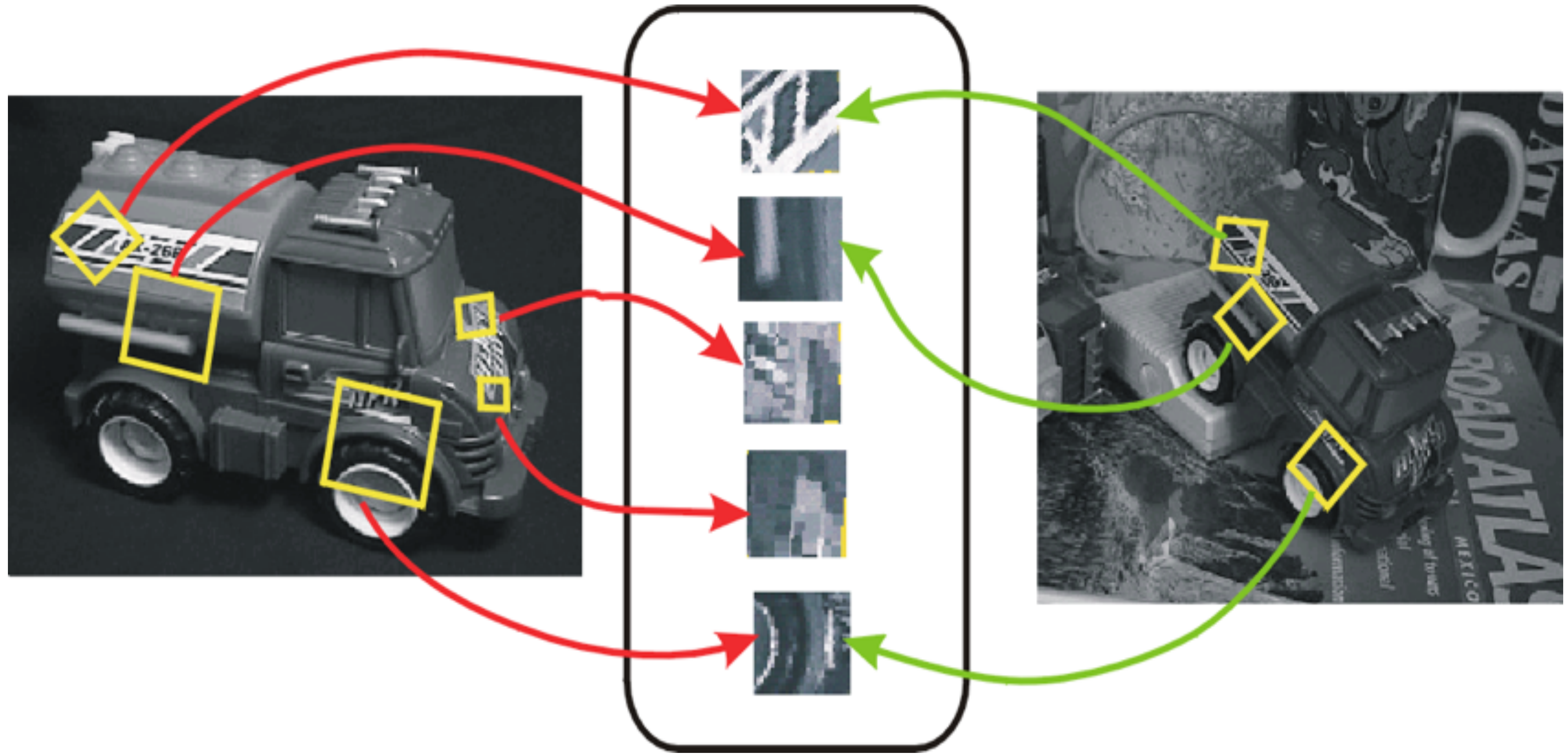


Image content is transformed into local feature coordinates that are invariant to translation, rotation, scale, and other imaging parameters

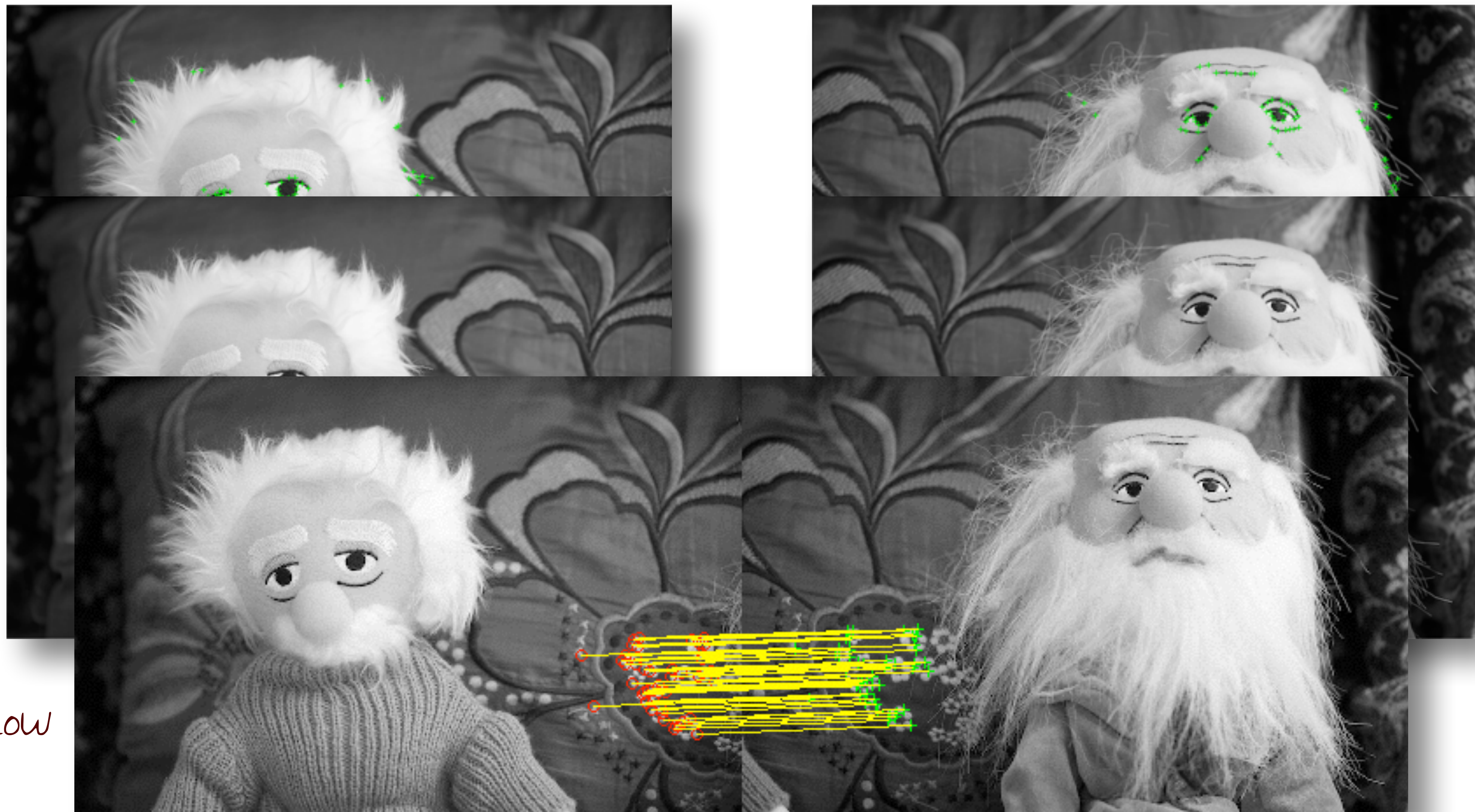
Lowe 2004

Results

Detect

Match

Show



Summary

* Discussed invariants for feature detection
* Harris Corner Detector Framework
* SIFT detector

Further Reading

- Harris and Stephens (1988) "A Combined Corner and Edge Detector." Proceedings of the 4th Alvey Vision Conference, 1988,
- Mikolajczyk and Schmid (2001). "Indexing Based on Scale Invariant Interest Points". ICCV 2001
- Lowe (2004) "Distinctive Image Features from Scale-Invariant Keypoints". IJCV 2004
- Search for "Features" on OpenCV site

Next Class

* Moving on to more advanced topics

Credits

- For more information, see:
  - Richard Szeliski (2010) Computer Vision: Algorithms and Applications, Springer
- Some concepts in slides motivated by similar slides by Aaron Bobick, Alysoha Efros and Greg Turk
- Additional list will be available on website

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