

Feature Detection

Reference: Szeliski, Chapter 4

Today's lecture

- Motivation for feature detection
- Harris corner detector

Motivation

Why do we need feature detection?

A typical application is **panorama building**:



[Brown & Lowe, 2003]

Other example applications are

- object recognition
- 3D reconstruction
- image alignment
- etc.

Motivation

Why do we need feature detection?

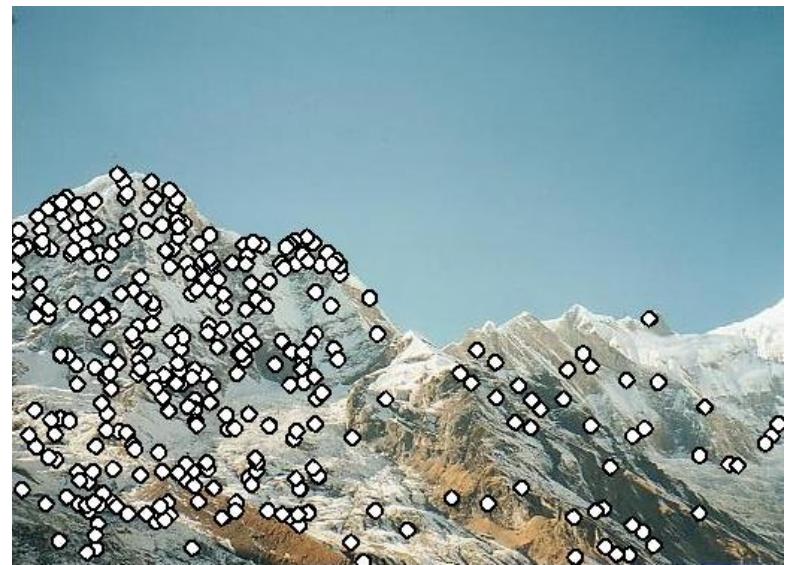
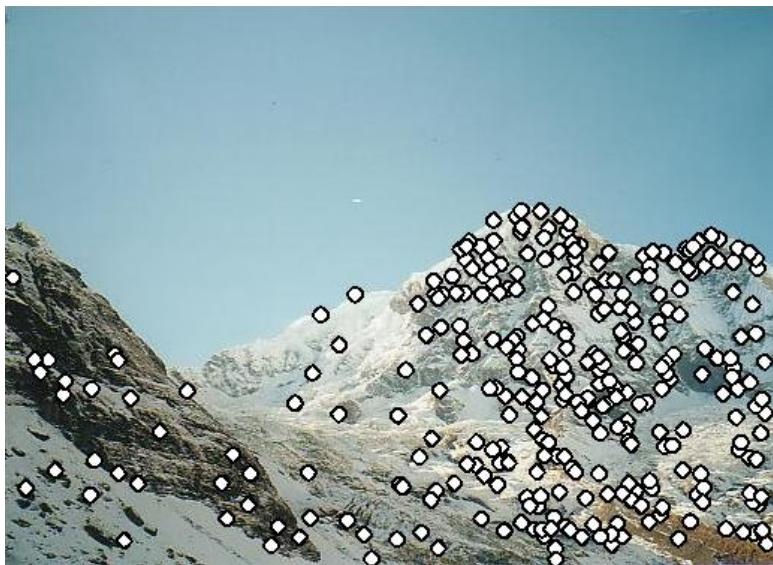
- We need to **match (align)** images first
- Tricky task if done “globally”, due to **occlusion, lighting changes**, etc.
- The idea is to find **local features** in both images **which match well**



Motivation

Why do we need feature detection?

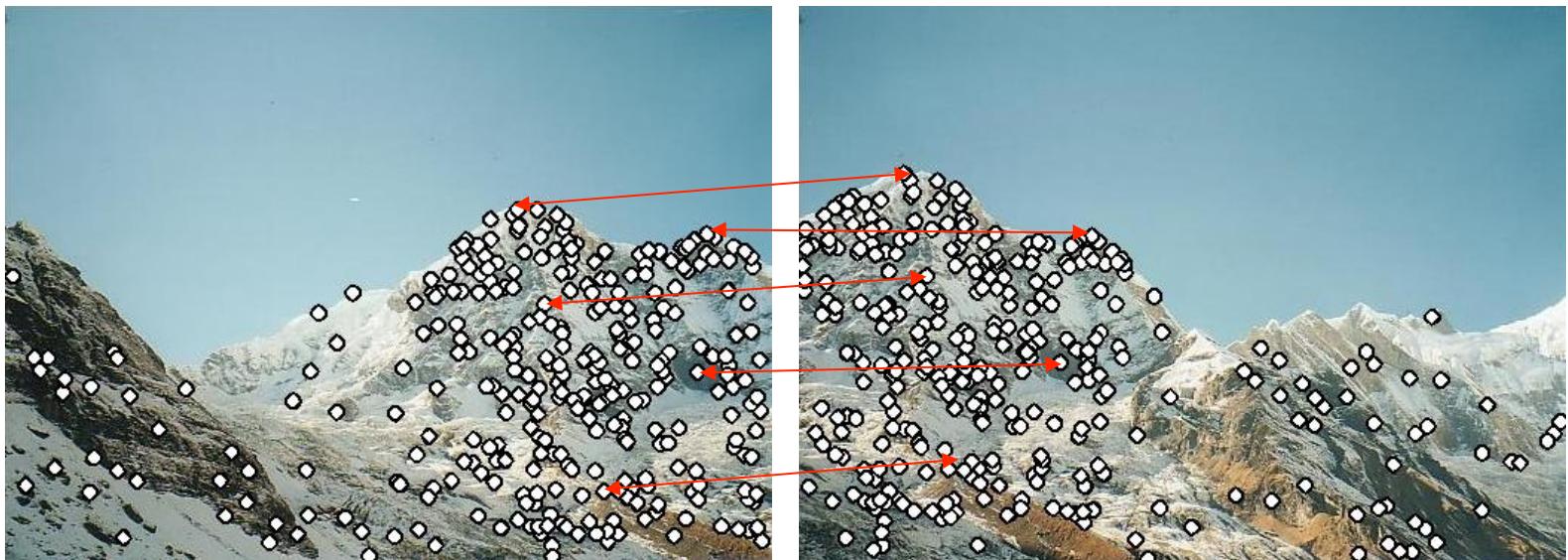
- Find features points in both images



Motivation

Why do we need feature detection?

- Find features points in both images
- **Match corresponding pairs**



Motivation

Why do we need feature detection?

- Find features points in both images
- Match corresponding pairs
- **Use the matched points to merge images together**



Matching with features

Important properties

When matching images using features, two important properties are:

(1) Repeatability

We need to be able to detect the same keypoint in both images independently!

(2) Reliability (or “distinctiveness”)

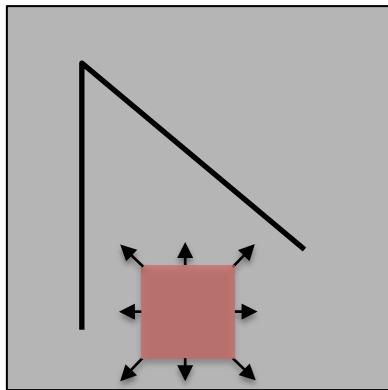
We need a “description” of the image content at each point which reliably identifies the point (in other words, it needs to be distinct).

Note: Property (2) is more a property of the keypoint descriptor and less a property of the keypoint detector!

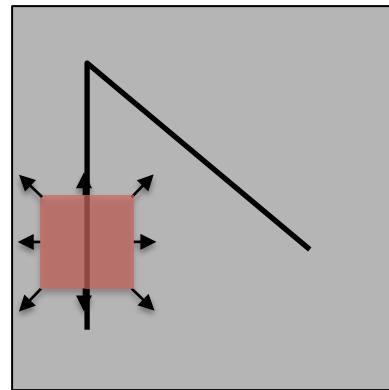
Harris corner detector

[Harris & Stephens, “A Combined Corner and Edge Detector”, 1988]

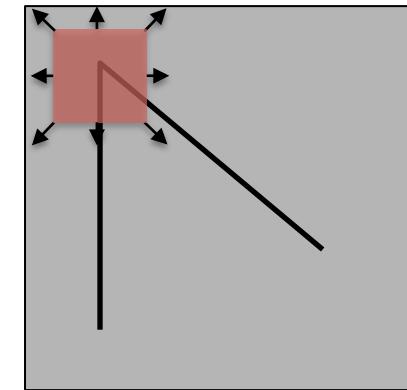
Harris and Stephens observed the following^{*}:



Flat region: no change
as we move freely



Edge: no change as we
move along the edge



Corner: a lot of
change around corner

→ **What is of interest?** Large differences in the shifted image!

$$E(x, y) = \sum_u \sum_v w(u, v) [(I(x + u, y + v) - I(x, y))^2]$$

Window function
(typically Gaussian)

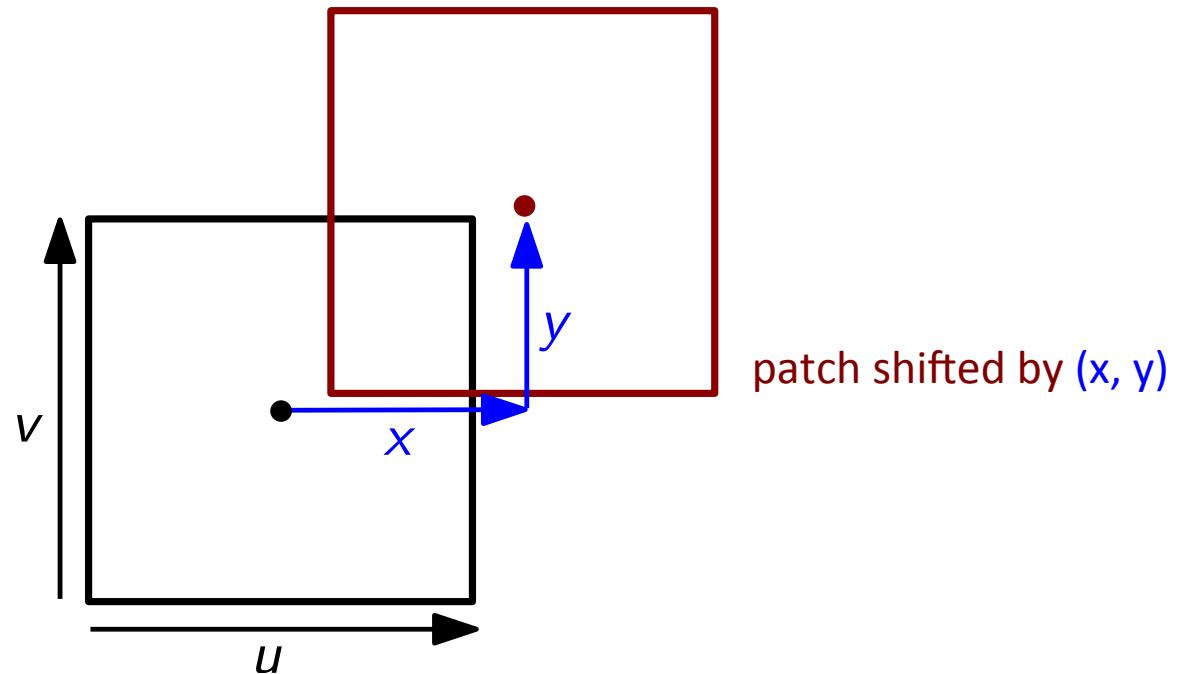
Shifted patch
shifted by (x, y)

*Motivated by work of H. Moravec

Harris corner detector

[Harris & Stephens, "A Combined Corner and Edge Detector", 1988]

Illustration of the **basic principle**:



Harris corner detector

Derivation details

Lets take a look at the **Taylor-series expansion** (1st order) of

$$I(x + u, y + v) = I(u, v) + \frac{\partial I(u, v)}{\partial u}x + \frac{\partial I(u, v)}{\partial v}y$$

If we substitute this into our $E(x, y)$ term we get

$$\begin{aligned} E(x, y) &\approx \sum_{u, v} w(x, y)[I_u^2 x^2 + 2I_u I_v xy + I_v^2 y^2] \\ &= \sum_{u, v} w(x, y) \left[(x \ y)^\top \begin{pmatrix} I_u^2 & I_u I_v \\ I_u I_v & I_v^2 \end{pmatrix} (x \ y) \right] \\ &= (x \ y)^\top \boxed{\left(\sum_{u, v} w(x, y) \begin{pmatrix} I_u^2 & I_u I_v \\ I_u I_v & I_v^2 \end{pmatrix} \right)} (x \ y) \end{aligned}$$

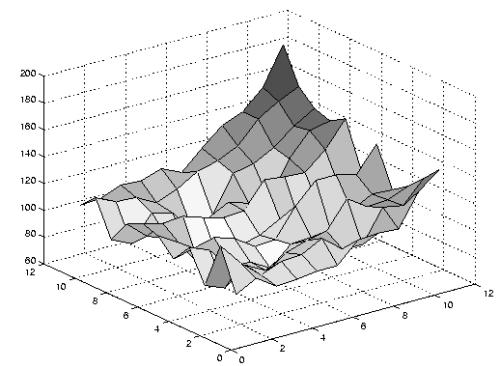
This well be our “quantity” (**M**), of interest!

Harris corner detector

Illustration of the key principle – Eigenvalues of \mathbf{M}



Courtesy of Szeliski



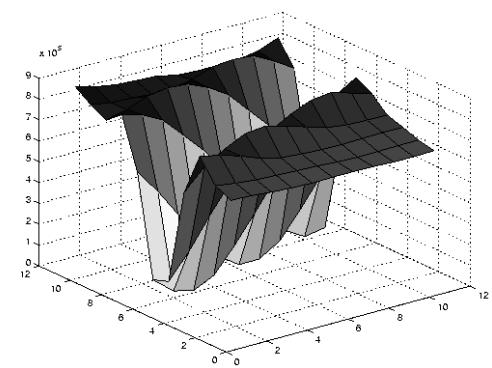
**both eigenvalues
are small**

Harris corner detector

Illustration of the key principle – Eigenvalues of \mathbf{M}



Courtesy of Szeliski



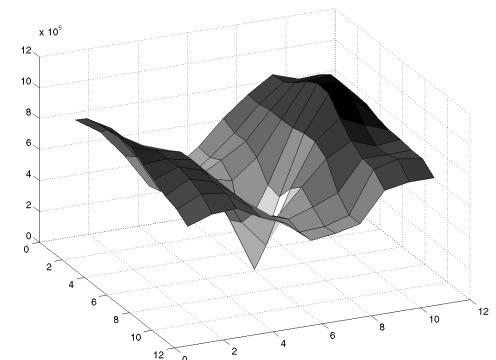
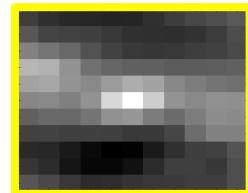
one eigenvalue large,
one eigenvalue small

Harris corner detector

Illustration of the key principle – Eigenvalues of \mathbf{M}



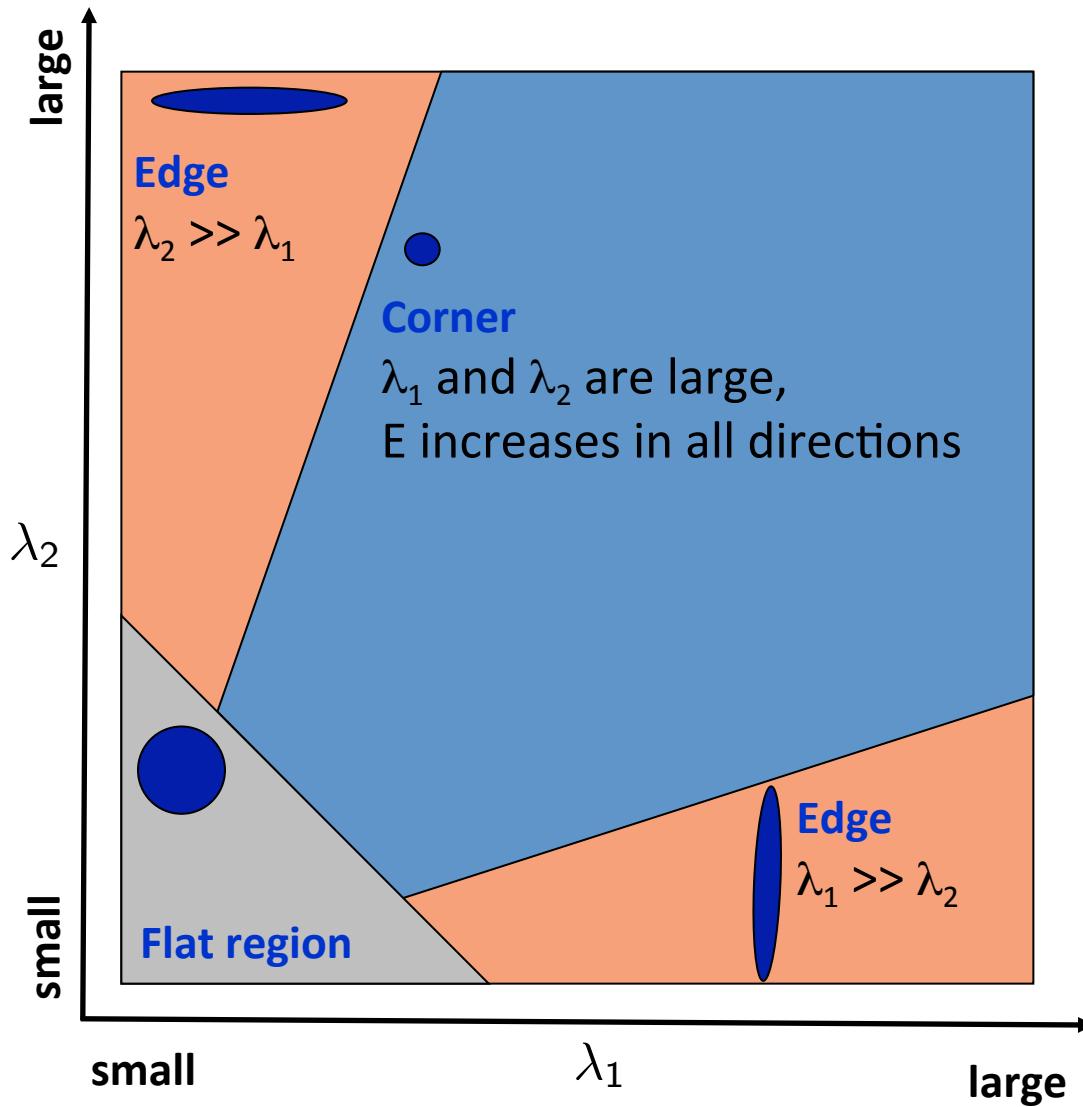
Courtesy of Szeliski



both large

Harris corner detector

Classification of points based on the eigenvalues of \mathbf{M}



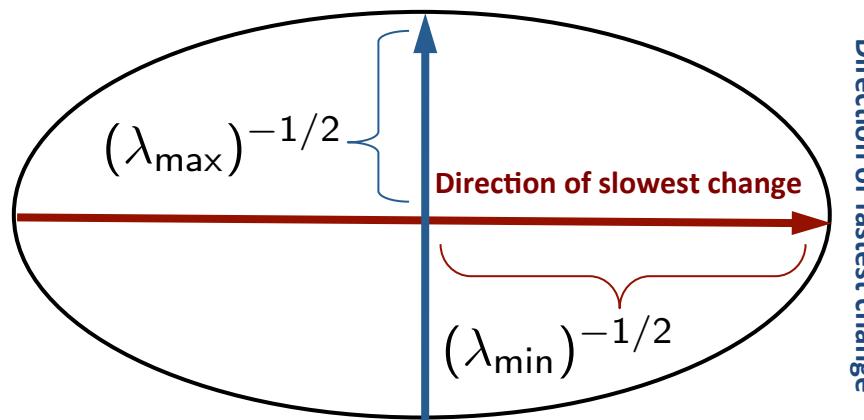
Harris corner detector

Design of a “response” function

We can look at the eigenvalues of \mathbf{M} . If **both are large**, this is indicative of a corner (*i.e.*, large variation in both directions).

Harris & Stephens propose the following **response function**:

$$\begin{aligned} R(\mathbf{M}) &= \lambda_1 \lambda_2 - \gamma (\lambda_1^2 + \lambda_2^2) \\ &= \det(\mathbf{M}) - \gamma \operatorname{trace}(\mathbf{M})^2, \quad \gamma > 0 \end{aligned}$$



Note: Determinant (det) and trace are appealing, since **no** eigenvalues need to be computed!

Harris corner detector

Other response functions

There are many other choices of response functions, *e.g.*,

[Shi & Tomasi, 1994]: take the *minimum* eigenvalue

[Triggs, 2004]: $R(\mathbf{M}) = \lambda_{\min} - \gamma \lambda_{\max}$

(for more examples, see Szeliski's book)

Algorithmically*, we

- 1) determine locations where **response function value > threshold**
- 2) find points of local maxima (*e.g.*, using **non-maximum suppression**)

*to see how this is really implemented, look at the source code of the `vl_harris` function of the `vlfeat` MATLAB toolbox.

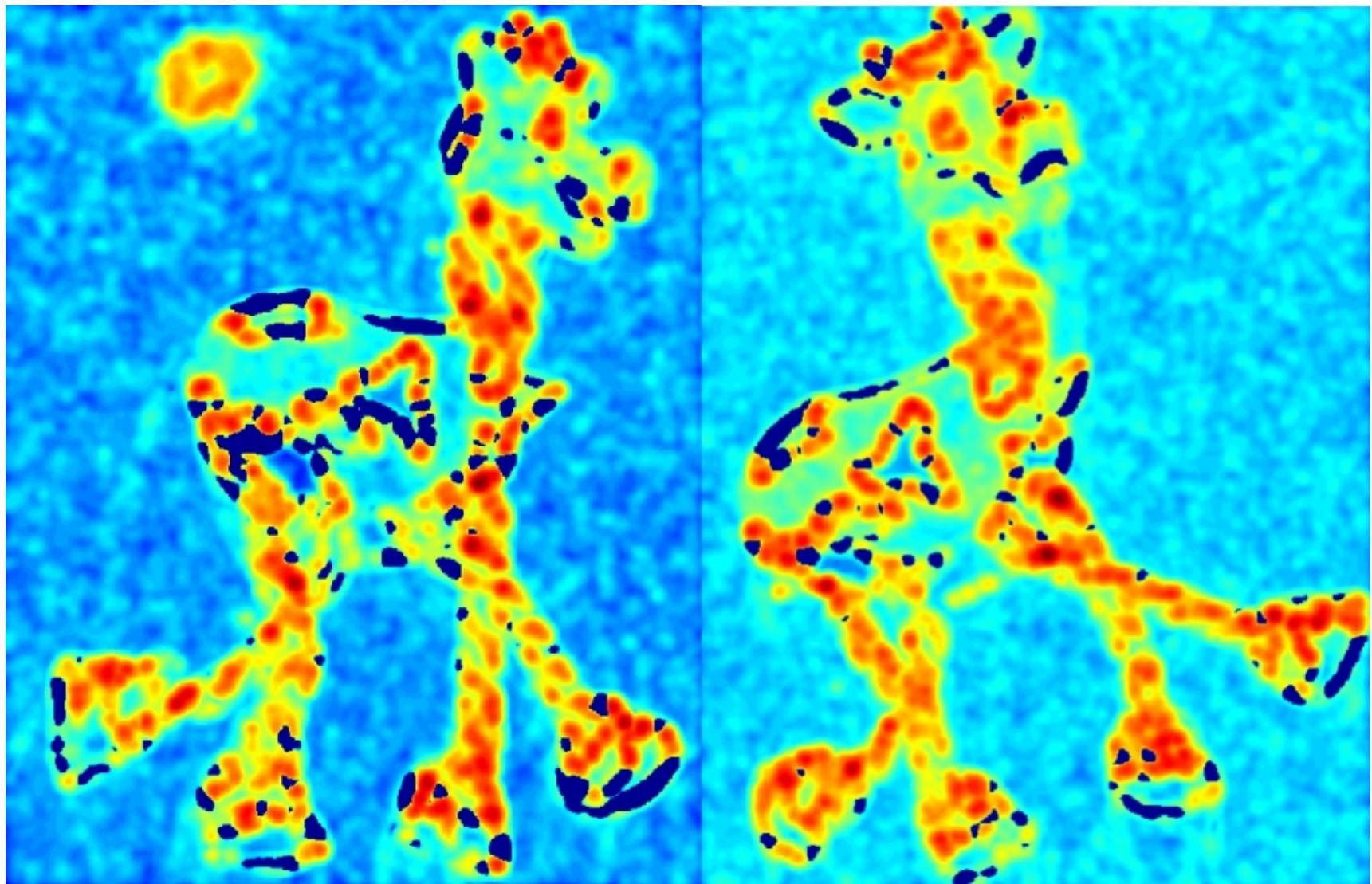
Harris corner detector

Example: Original input image



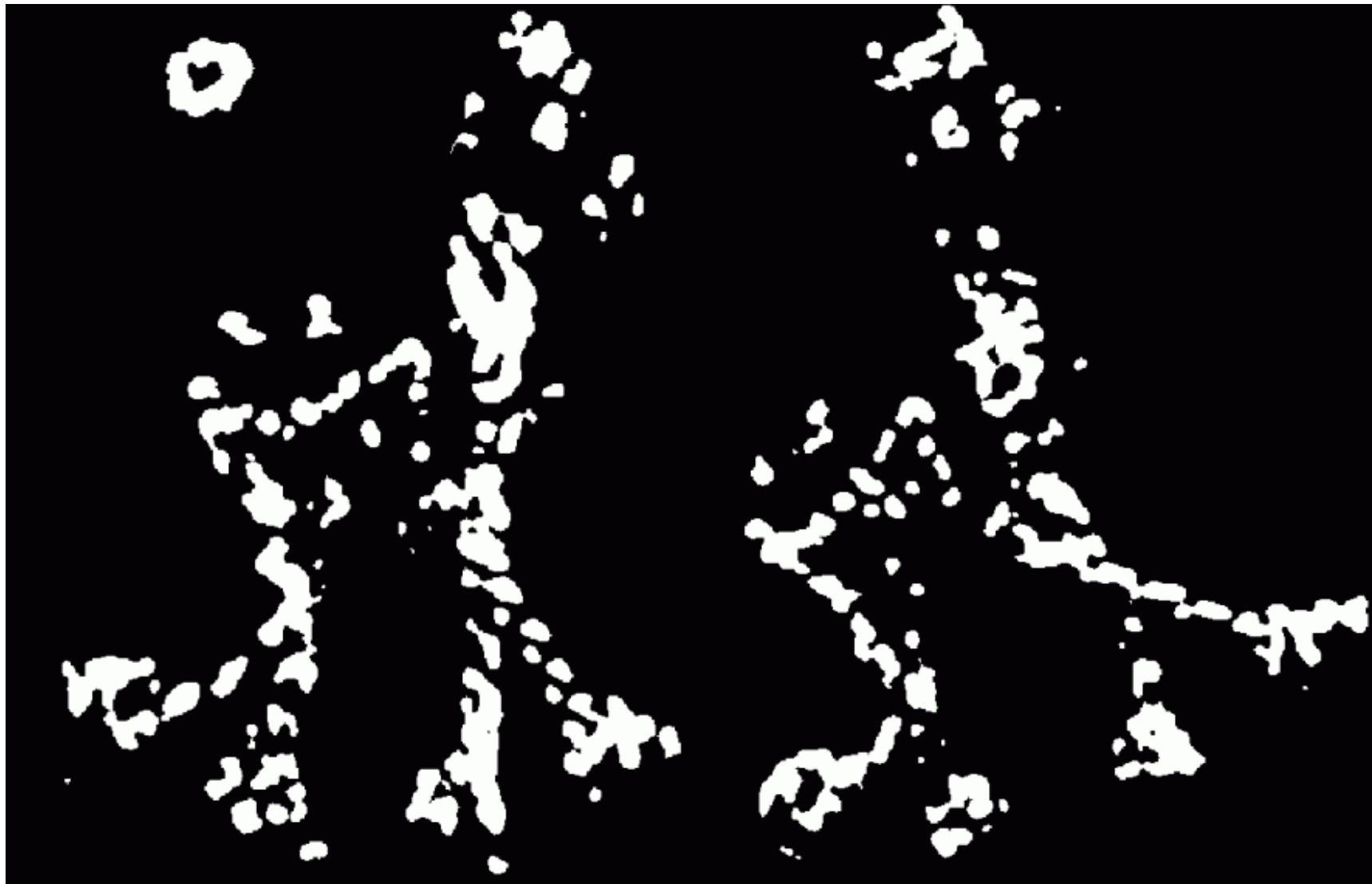
Harris corner detector

Example: Corner response



Harris corner detector

Example: Response values > threshold



Harris corner detector

Example: after non-maxima suppression

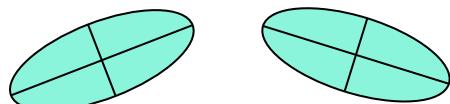
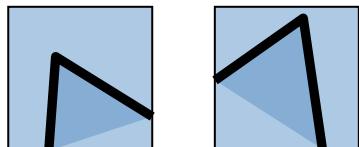


Harris corner detector

Properties

In the **ideal case** (*i.e.*, assuming we would have a “perfect” detector), we would **always** find the same points regardless of lighting, perspective, scale, etc.

Rotation invariance ✓

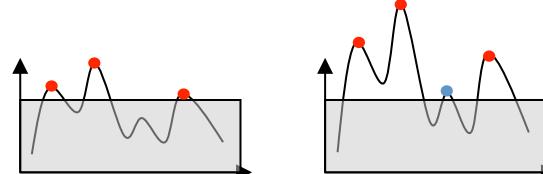


Ellipse rotates, but shape remains

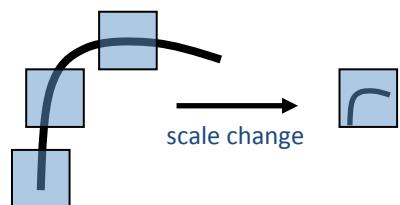
Intensity shift (roughly scale) ✓

Shift: Derivatives are used → no problem

Scale: Intensity threshold fix → no full invariance



Scale X



Edge becomes a corner!

Additional resources

- look at the implementation of the Harris corner detector (function `vl_harris`) in the **vlfeat** toolbox
- read **Chapter 4.1.1** of Szeliski's book
- read the **original paper** on the Harris corner detector:

Harris & Stephens, *A Combined Corner and Edge Detector*, 4th
Alvey Vision Conference, 1988

(online: <http://www.bmva.org/bmvc/1988/avc-88-023.pdf>)