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CS688: Web-Scale Image Search

# Classical Keypoint Localization

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(윤성의)

Course URL:  
<http://sgvr.kaist.ac.kr/~sungeui/IR>

**KAIST**



# Class Objective (Ch. 2 of My Draft)

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- **Get to know related conferences**
- **Understand locally invariant features**
  - **Key point localization**
  - **Harris detector**
- **At Last class:**
  - **Student activities including paper presentations and mid- and final-term project presentations**
  - **Grading policy**

# Homework for Every Class

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- **Preview the lecture slides first; just 5 min**
- **Come up with one question on what we have discussed today**
  - **1 for typical questions (that were answered in the class)**
  - **2 for questions with thoughts or that surprised me**
- **Write questions 3 times before the mid-term**
  - **Multiple questions in one time will be counted as one time**
- **Common questions are addressed at my draft**
  - **Some of questions will be discussed in the class**
- **If you want to know the answer of your question, ask me or TA on person**

# Homework for Every Class

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- **Go over recent papers on image search**
  - **High quality papers: Papers published at the top-tier conf.; e.g., CVPR, ICCV, ECCV, ACM ICMR, NeurIPS, ICML, MM, SIGGRAPH**
  - **Recent publication: papers published since 2017**
  - **Find and browse two papers, and submit two summaries before every beginning of the Tue. Class**
  - **Online submission is possible**
- **Think about possible team members**
  - **You can do the solo project, since we don't have many students in this class of 2021**
  - **Too late if you think them later..**

# Content-Based Image Retrieval (CBIR)

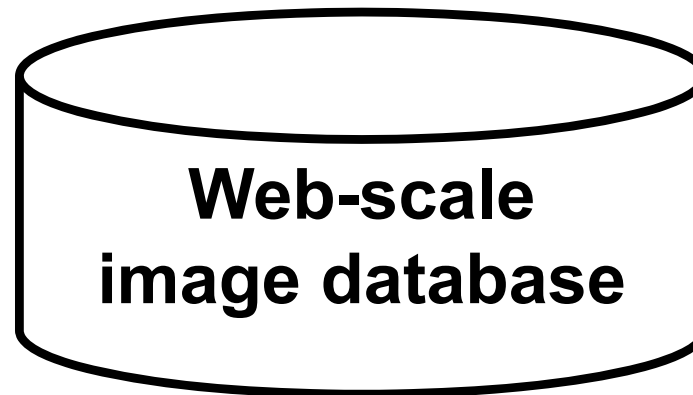
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- **Identify similar images given a user-specified image or other types of inputs**

**Extract image descriptors (e.g., CNN or SIFT)**



**Input**



**Output**

# Key Components of Image Search

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- **Image representations**
- **Indexing algorithms**
- **Matching methods**
- **Classification, Localization, etc.**
  - **Can improve image search or improve these techniques utilizing image search**

# Image Representations

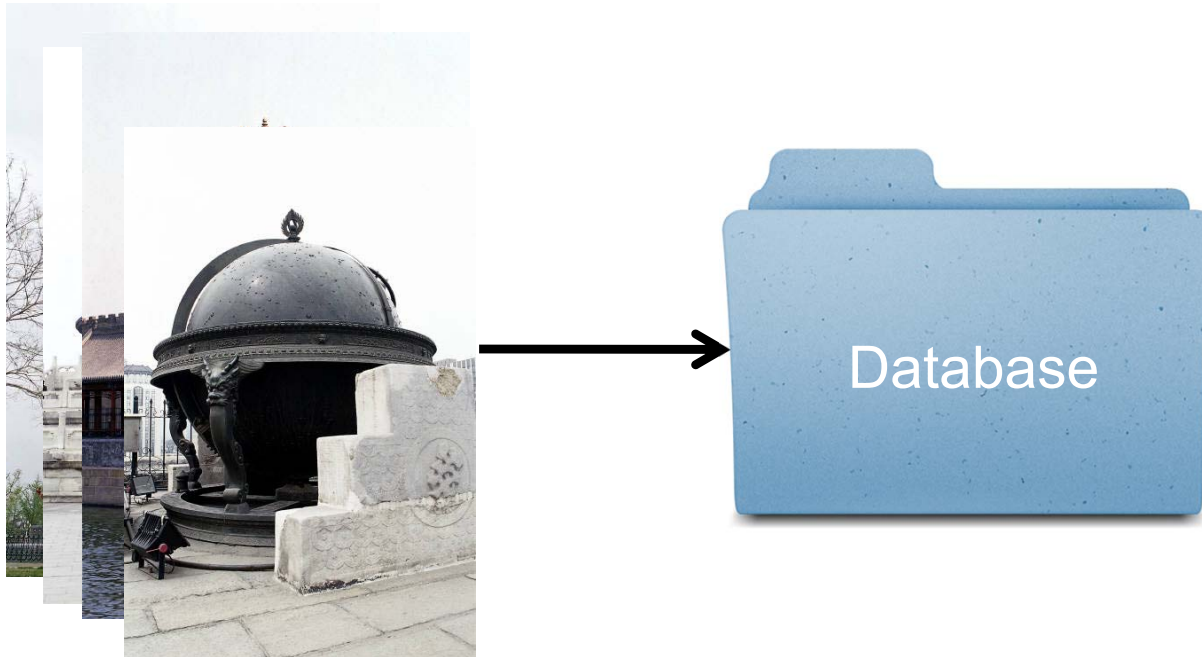
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- **SIFT, GIST, CNN, etc.**
  - **Invariant to different transformations**

# Image Retrieval

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- **At pre-processing, build a database for efficient retrieval at runtime**

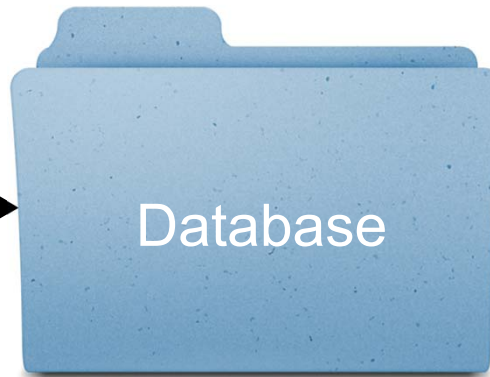
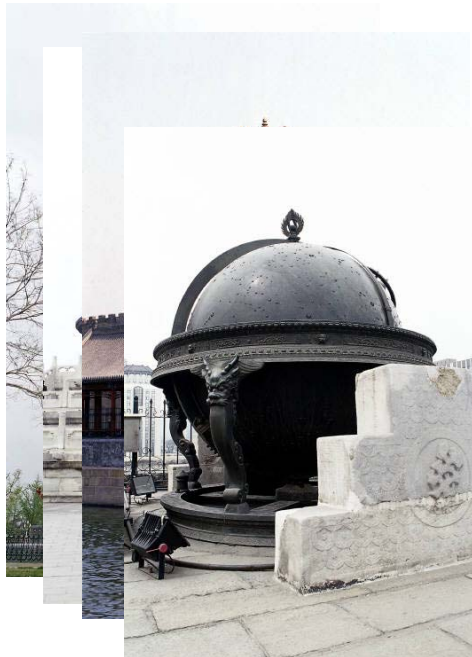




# Image Retrieval

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- **At pre-processing, build a database for efficient retrieval at runtime**

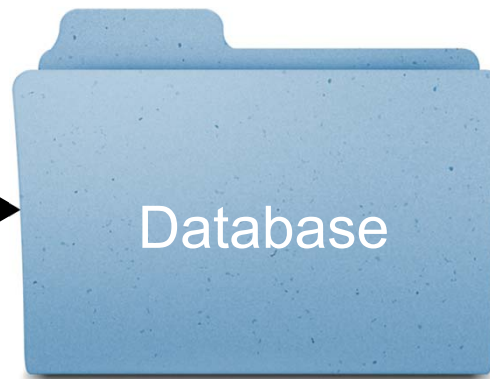


Index schemes:  
vocabulary trees,  
hashing, and  
inverted files

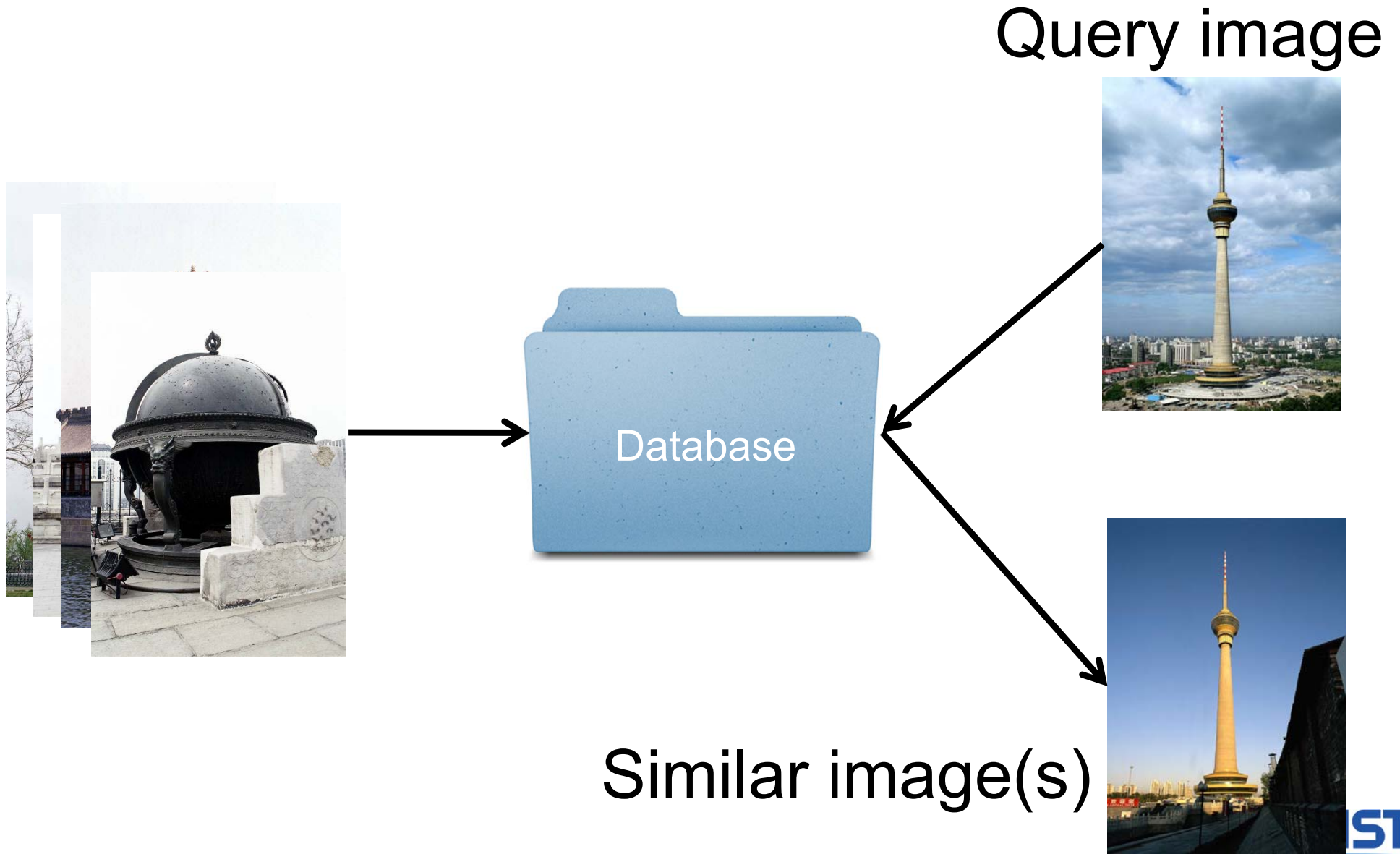
# Image Retrieval: Runtime Procedure

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Query image



# Image Retrieval: Runtime Procedure

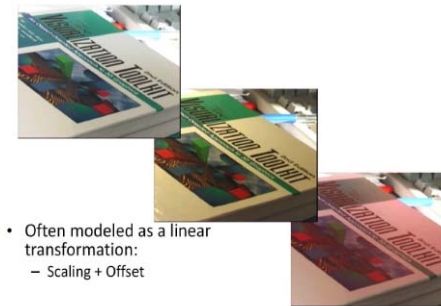


# Post-Processing



# Motivation for Image Descriptors

- **RGB images are not robust for various changes (e.g., geometric and photometric transformations)**



- **Image descriptors are classified into:**
  - **Global feature encoding the overall context**
  - **Local features encoding different parts of objects**
- **Global and local features are useful, but we focus on local features for now**
  - **More robust to various changes**

## Challenges: viewpoint variation



Michelangelo 1475-1564

# Challenges: illumination

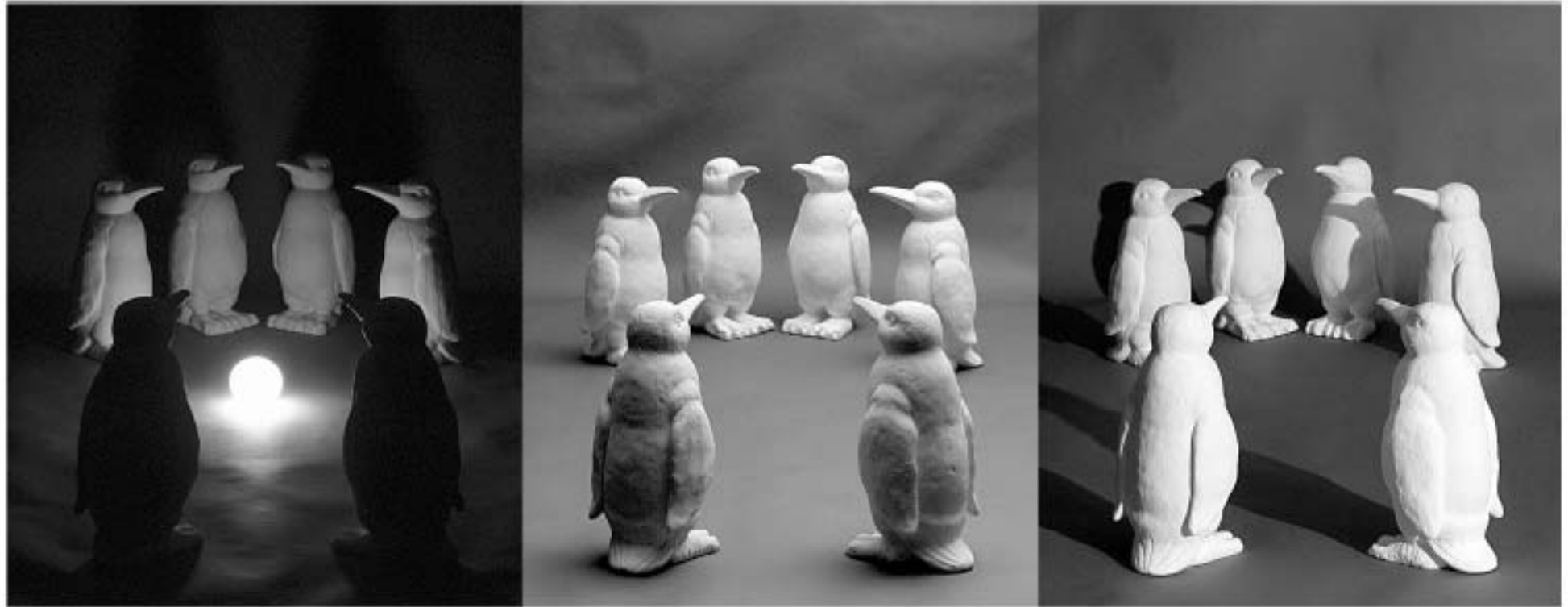


image credit: J. Koenderink

# Challenges: scale



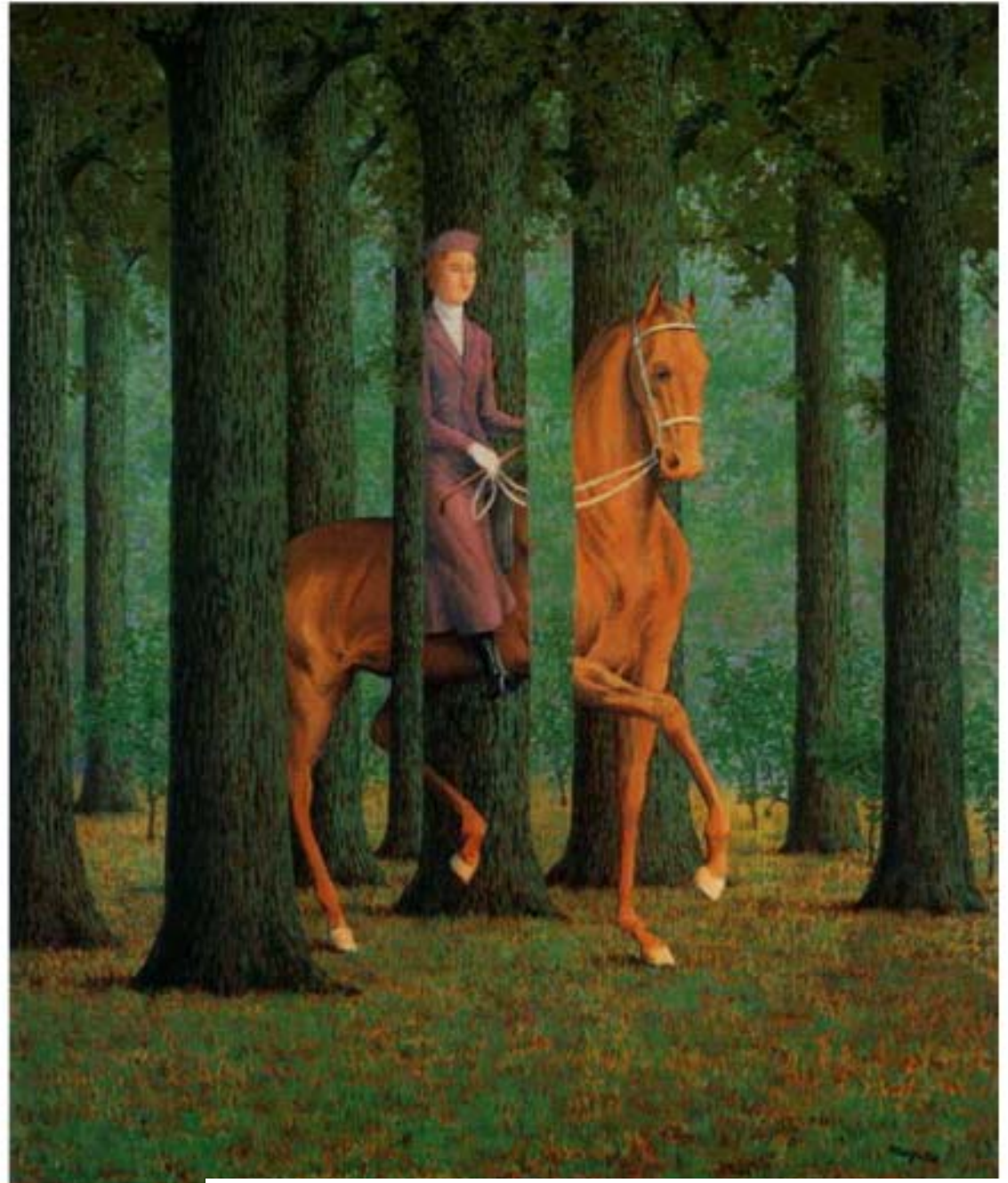
Fei-Fei Li



# Challenges: deformation

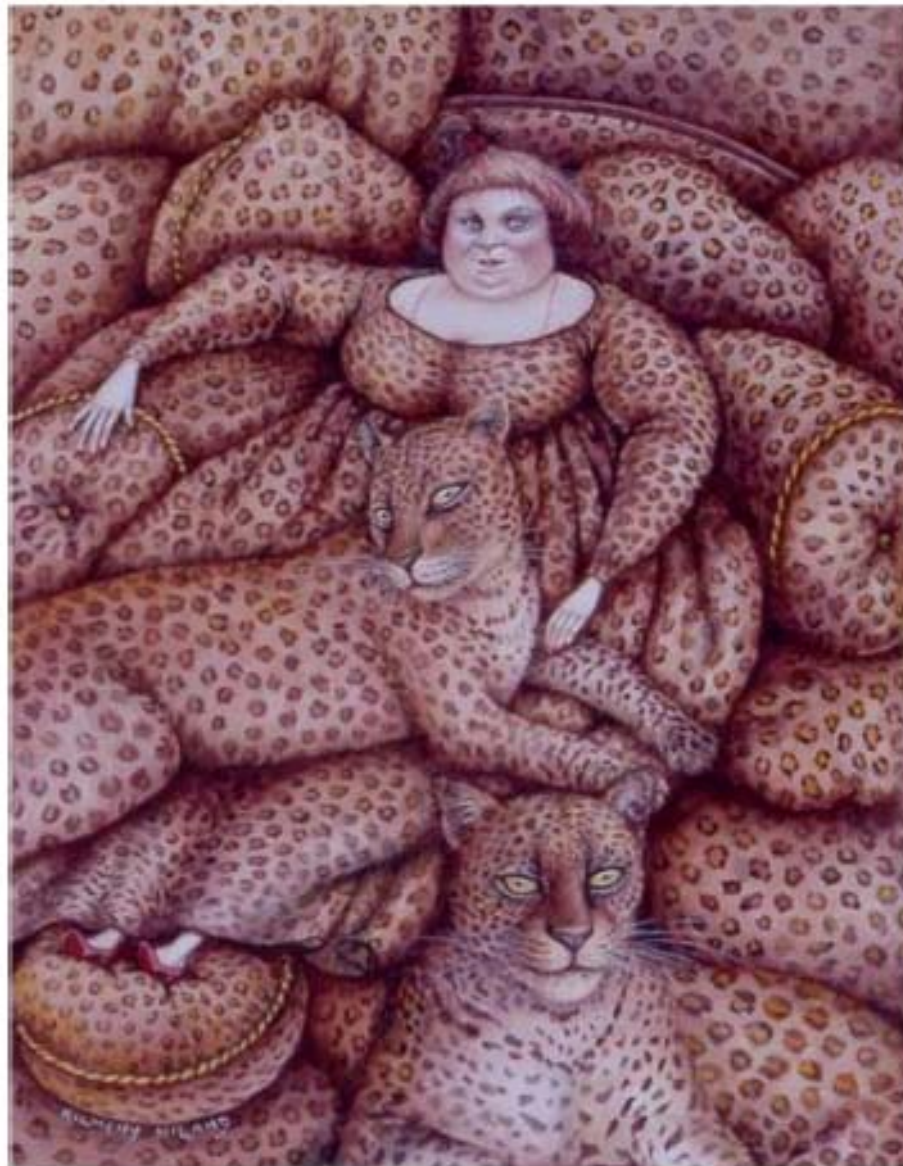


Challenges:  
occlusion



Magritte, 1957

## Challenges: background clutter



Kilmeny Niland. 1995

Fei-Fei Li

# Challenges: intra-class variation



Fei-Fei Li

# Application: Image Matching



by [Diva Sian](#)



by [swashford](#)

Slide credit: Steve Seitz

# Harder Case



by [Diva Sian](#)



by [scgbt](#)

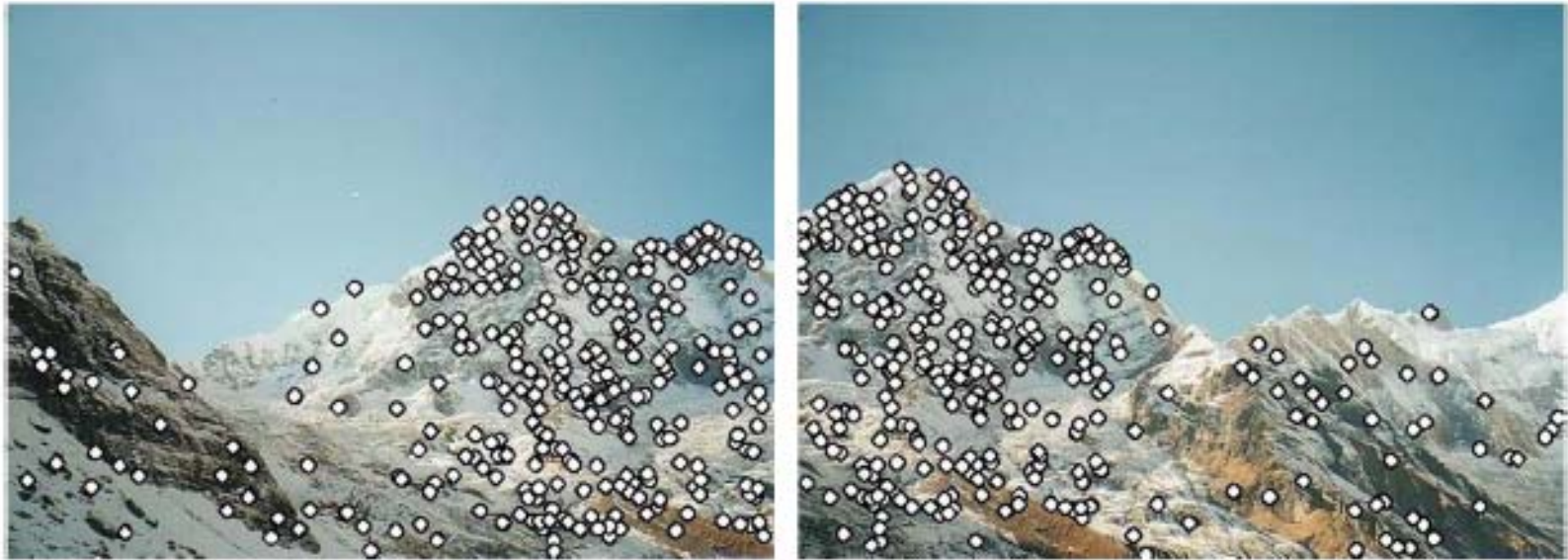
Slide credit: Steve Seitz

# Application: Image Stitching



Slide credit: Darya Frolova, Denis Simakov

# Application: Image Stitching

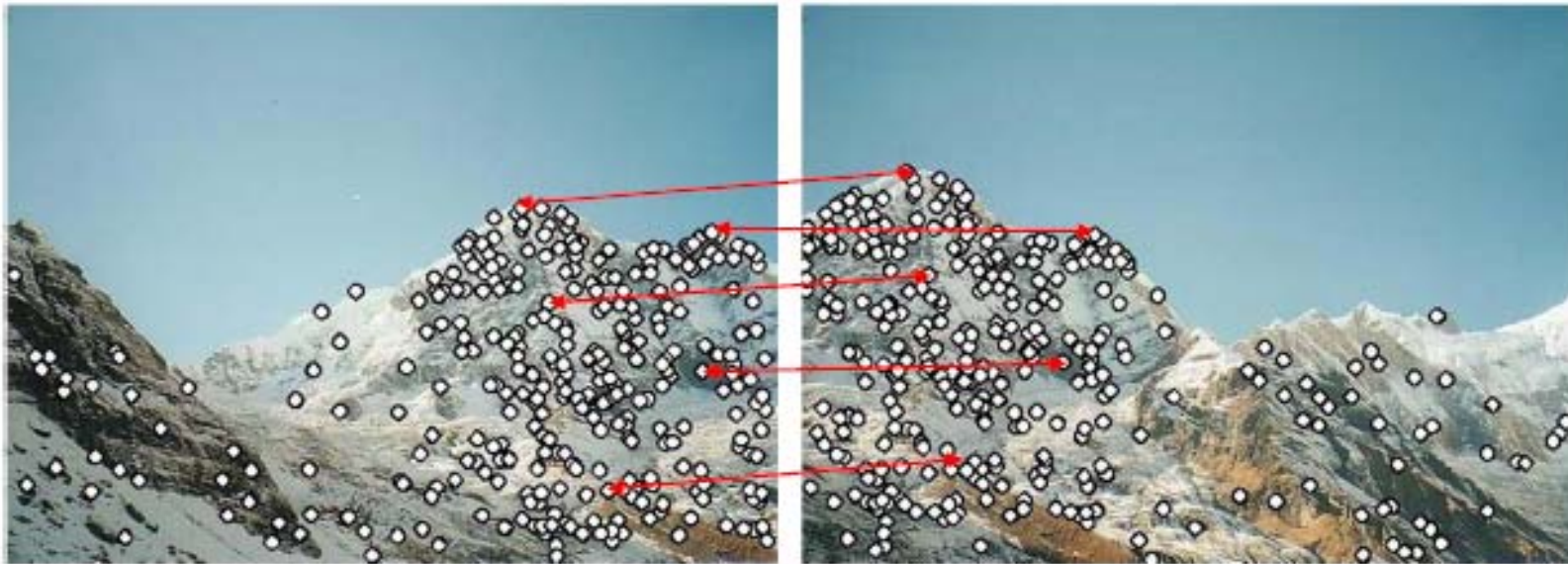


- Procedure:
  - Detect feature points in both images

Slide credit: Darya Frolova, Denis Simakov



# Application: Image Stitching



- Procedure:
  - Detect feature points in both images
  - Find corresponding pairs

Slide credit: Darya Frolova, Denis Simakov

# Application: Image Stitching



- Procedure:
  - Detect feature points in both images
  - Find corresponding pairs
  - Use these pairs to align the images

# Common Requirements

- Problem 1:
  - Detect the same point *independently* in both images



No chance to match!

**This lecture**

**We need a repeatable detector!**

# Common Requirements

- Problem 1:
  - Detect the same point *independently* in both images
- Problem 2:
  - For each point correctly recognize the corresponding one



**Next lecture**

**We need a reliable and distinctive descriptor!**

# Two Different Directions

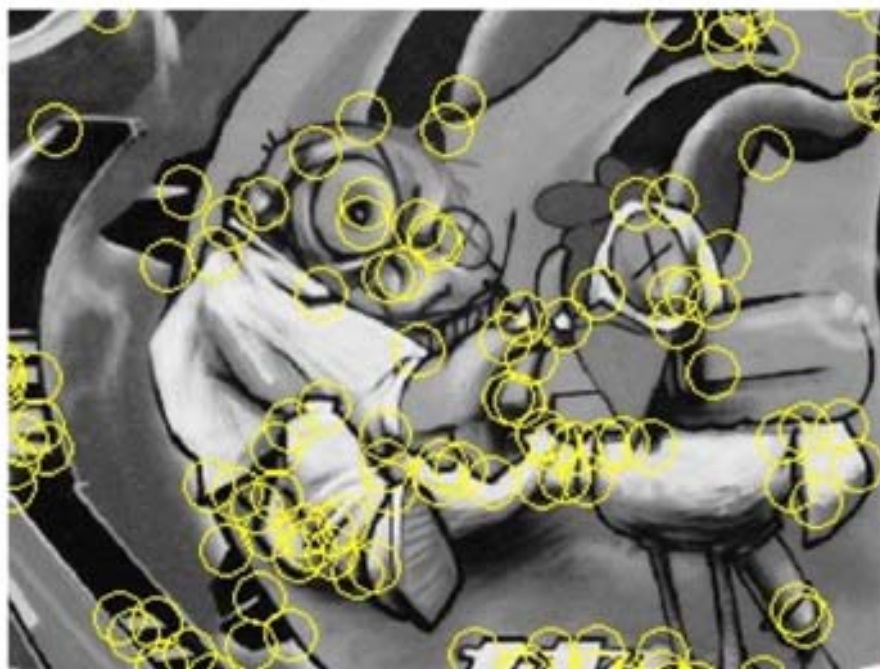
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- **Classical approaches**
  - **Manually designed in image processing and computer vision fields**
- **Deep learning approaches**
  - **Learned approaches, but are inspired by many prior (manually crafted) approaches**
- **In this class**
  - **We first talk about the classical approaches, followed by deep learning approaches**

# Many Existing Detectors Available

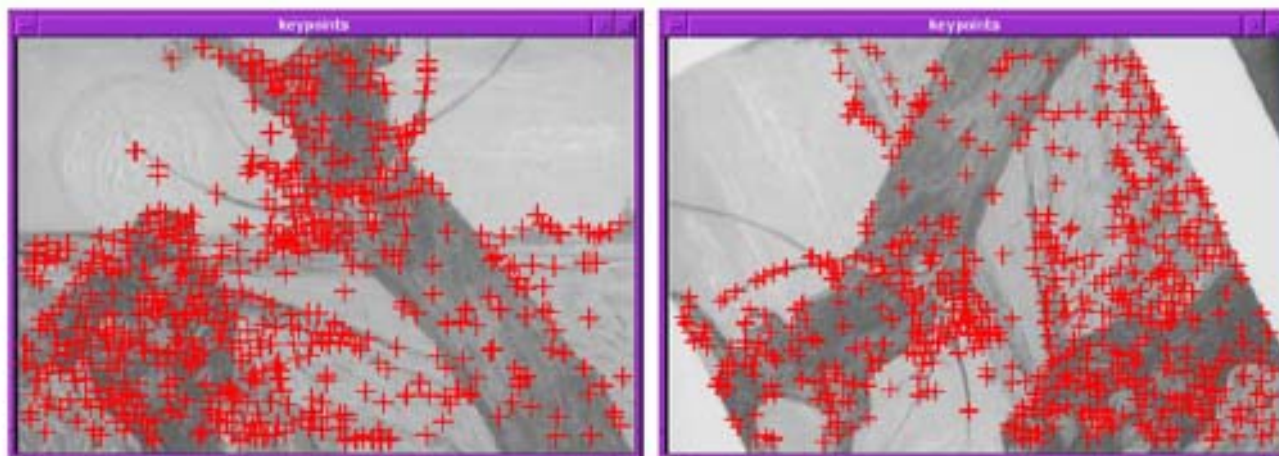
- Hessian & Harris [Beaudet '78], [Harris '88]
  - Laplacian, DoG [Lindeberg '98], [Lowe '99]
  - Harris-/Hessian-Laplace [Mikolajczyk & Schmid '01]
  - Harris-/Hessian-Affine [Mikolajczyk & Schmid '04]
  - EBR and IBR [Tuytelaars & Van Gool '04]
  - MSER [Matas '02]
  - Salient Regions [Kadir & Brady '01]
  - Others...
- *Those detectors have become a basic building block for many recent applications in Computer Vision.*

# Keypoint Localization



- Goals:
    - Repeatable detection
    - Precise localization
    - Interesting content
- ⇒ *Look for two-dimensional signal changes*

# Finding Corners



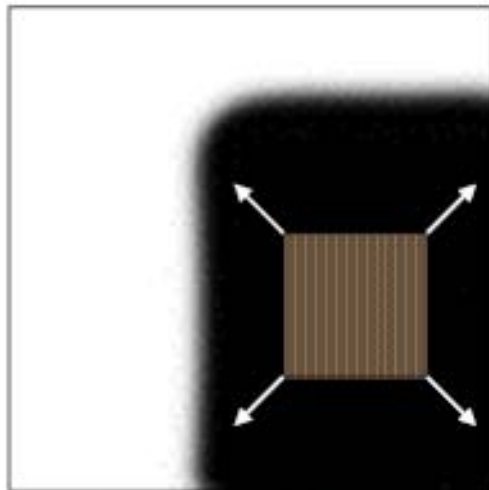
- Key property:
  - In the region around a corner, image gradient has two or more dominant directions
- Corners are *repeatable* and *distinctive*

C.Harris and M.Stephens. ["A Combined Corner and Edge Detector."](#)  
*Proceedings of the 4th Alvey Vision Conference, 1988.*

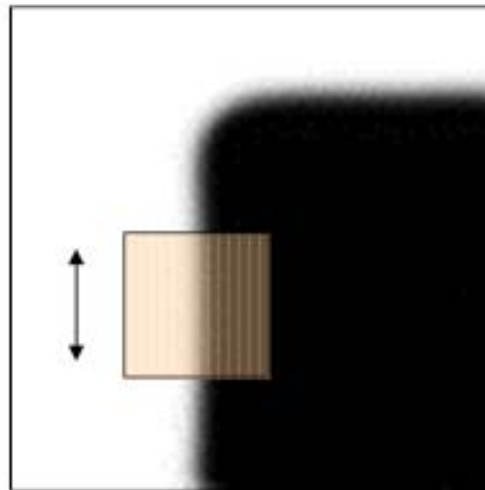


# Corners as Distinctive Interest Points

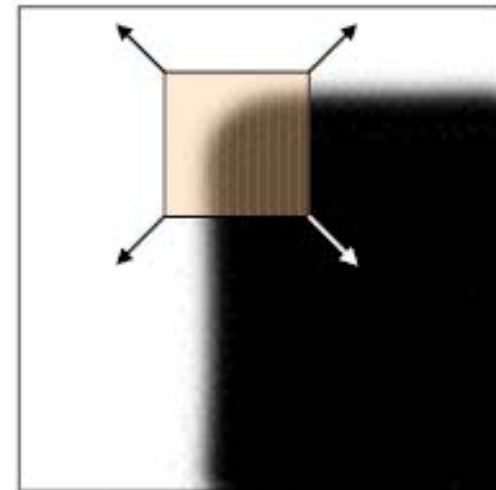
- Design criteria
  - We should easily recognize the point by looking through a small window (*locality*)
  - Shifting the window in *any direction* should give a *large change* in intensity (*good localization*)



**“flat”** region:  
no change in all  
directions



**“edge”**:  
no change along  
the edge direction



**“corner”**:  
significant change  
in all directions

Slide credit: Alyosha Efros

# Harris Detector Formulation

- Change of intensity for the shift  $[u,v]$ :

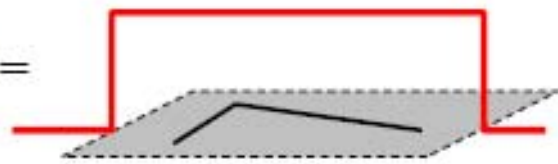
$$E(u, v) = \sum_{x,y} w(x, y) [I(x+u, y+v) - I(x, y)]^2$$

Window function

Shifted intensity

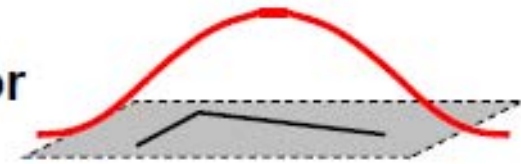
Intensity

Window function  $w(x,y) =$



1 in window, 0 outside

or

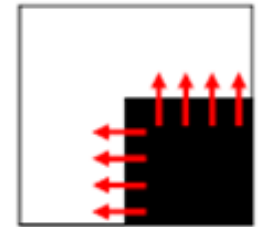


Gaussian

# Main Intuition of Harris Detector

- **Approximated into the following:**

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



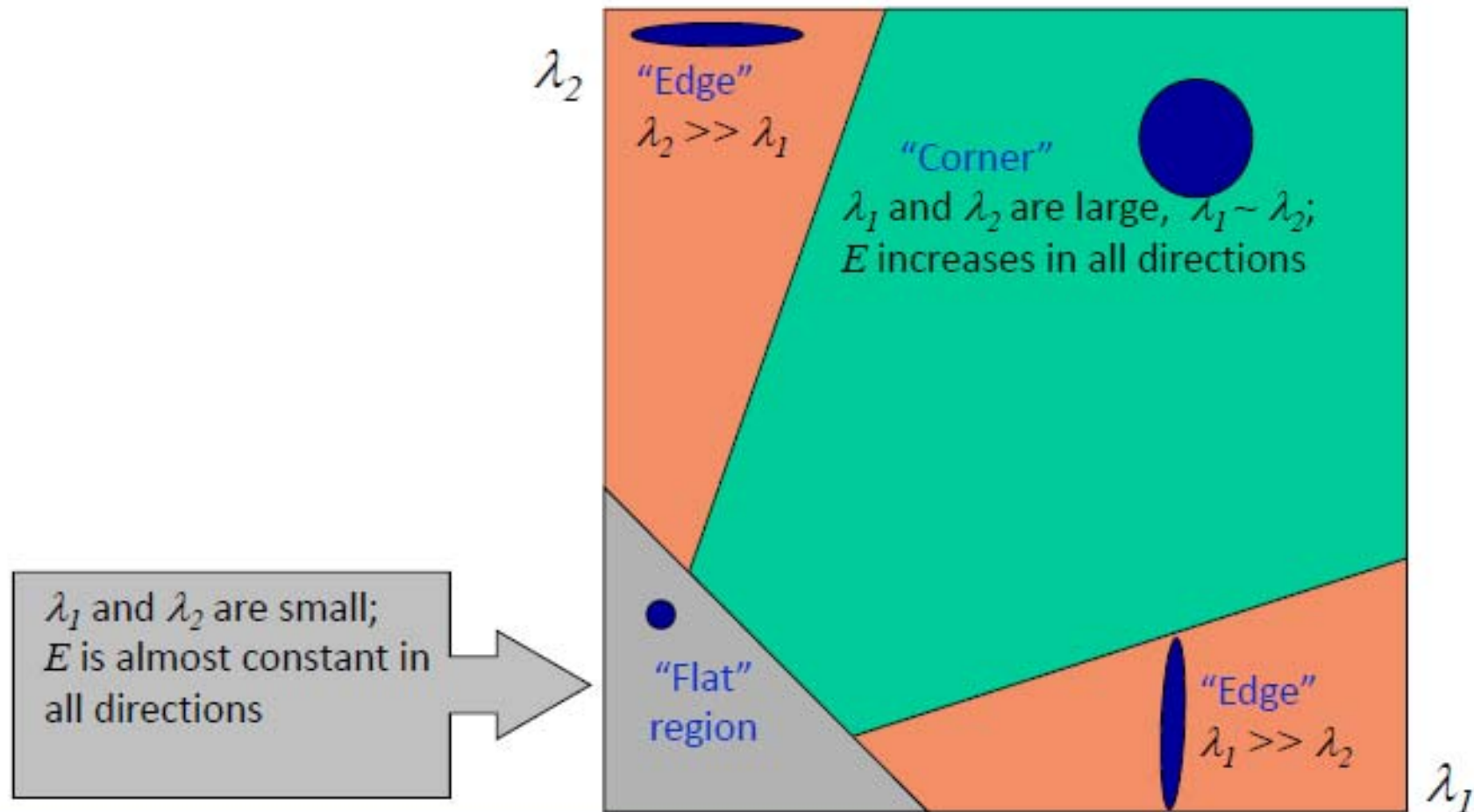
- **In the case of axis-aligned corner:**

$$M = \sum_{(x,y) \in P} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix}$$

- $\lambda$  corresponds gradient directions
- **When both  $\lambda_1$  &  $\lambda_2$  are non-zero, it is corner!**
- **Can be extended to rotated corners**

# Interpreting the Eigenvalues

- Classification of image points using eigenvalues of  $M$ :



Slide credit: Kristen Grauman

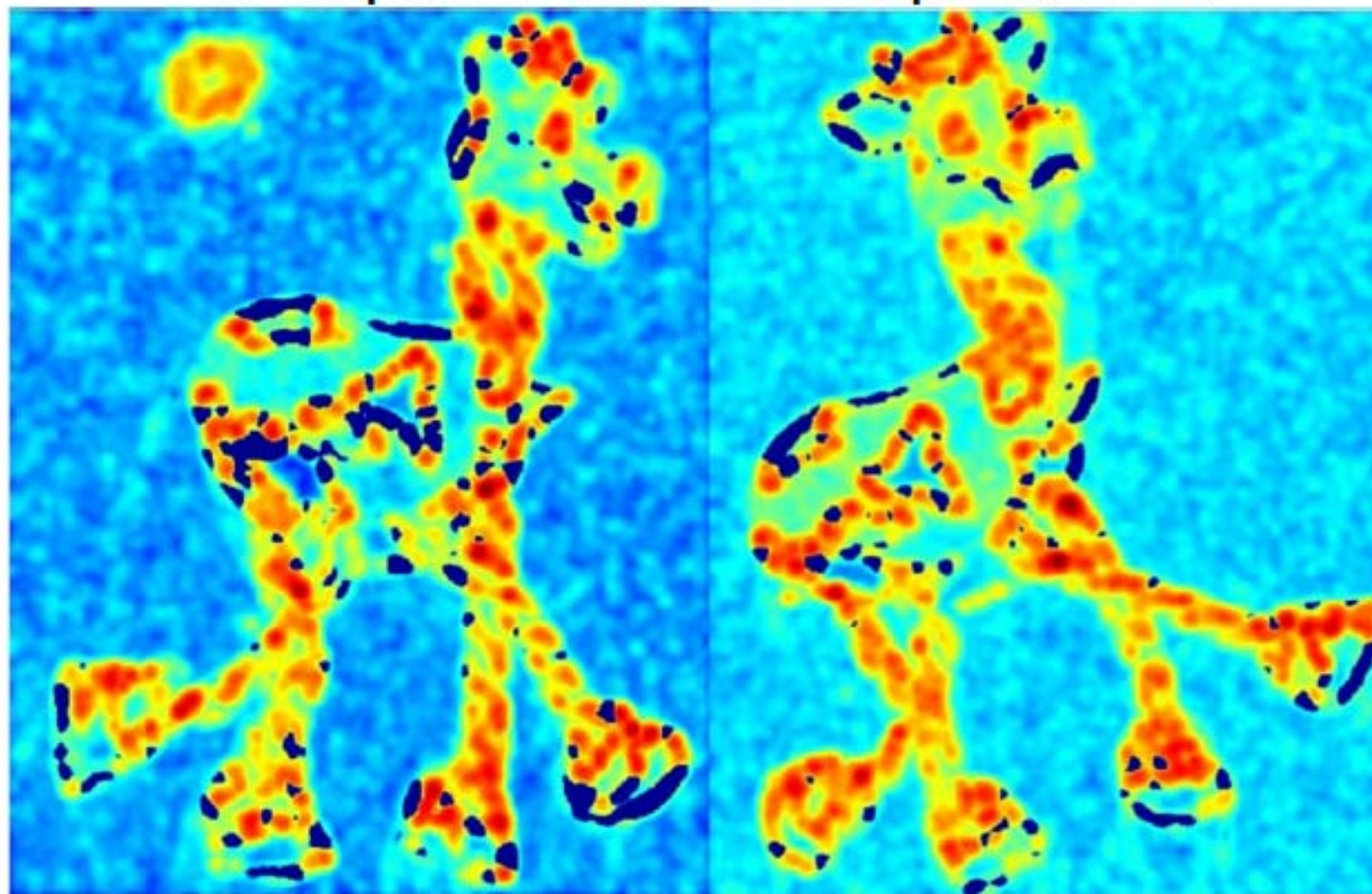
# Harris Detector: Workflow



Slide adapted from Darya Frolova, Denis Simakov

# Harris Detector: Workflow

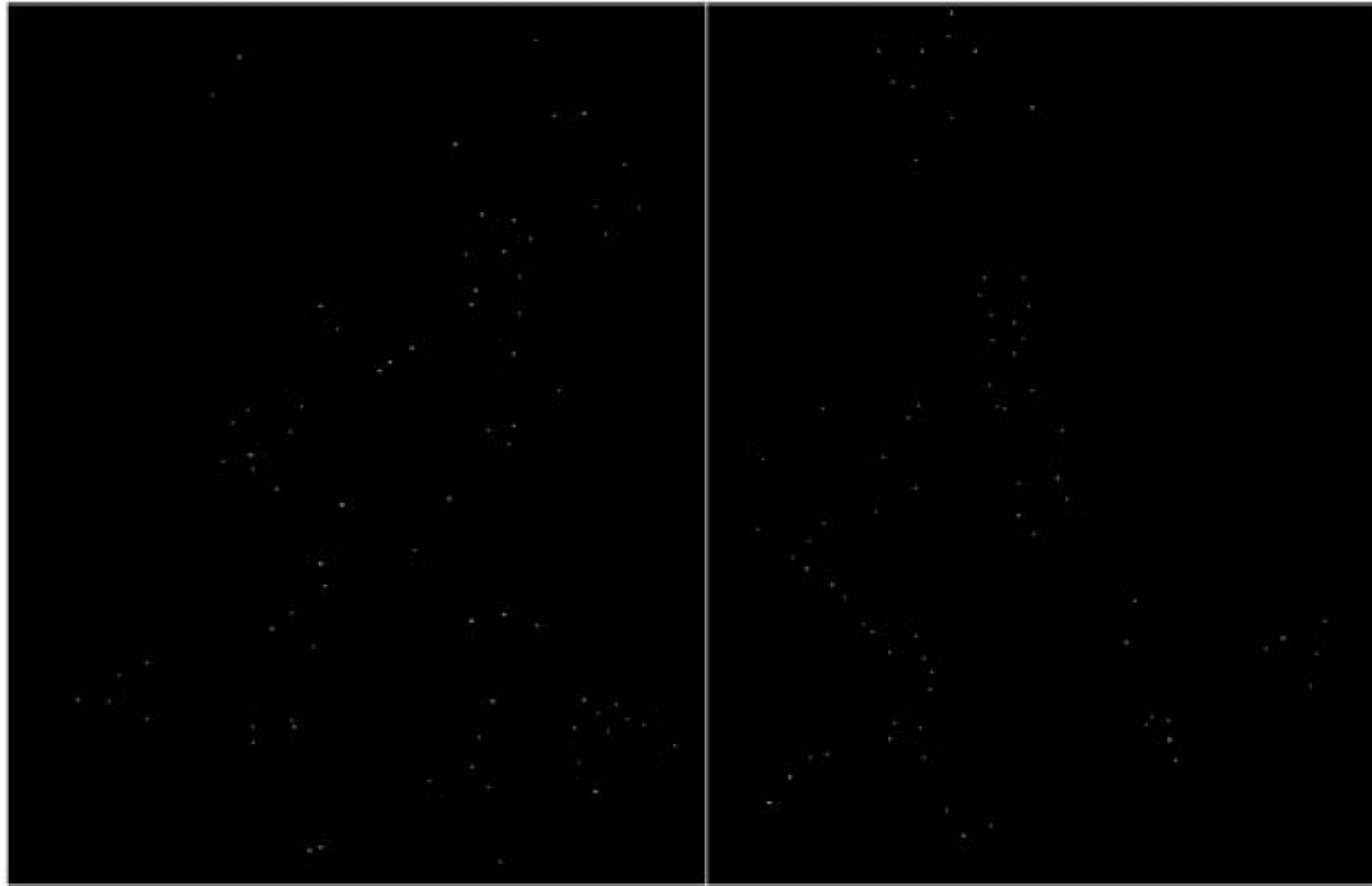
- computer corner responses  $R$



Slide adapted from Darya Frolova, Denis Simakov

# Harris Detector: Workflow

- Take only the local maxima of  $R$ , where  $R > \text{threshold}$



Slide adapted from Darya Frolova, Denis Simakov

# Harris Detector: Workflow

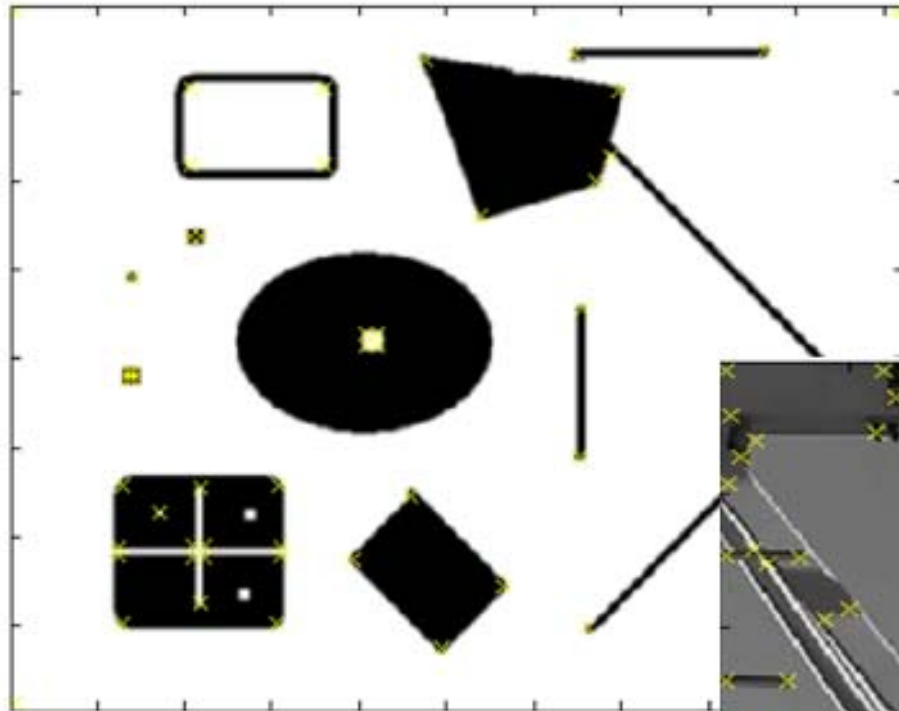
## - Resulting Harris points



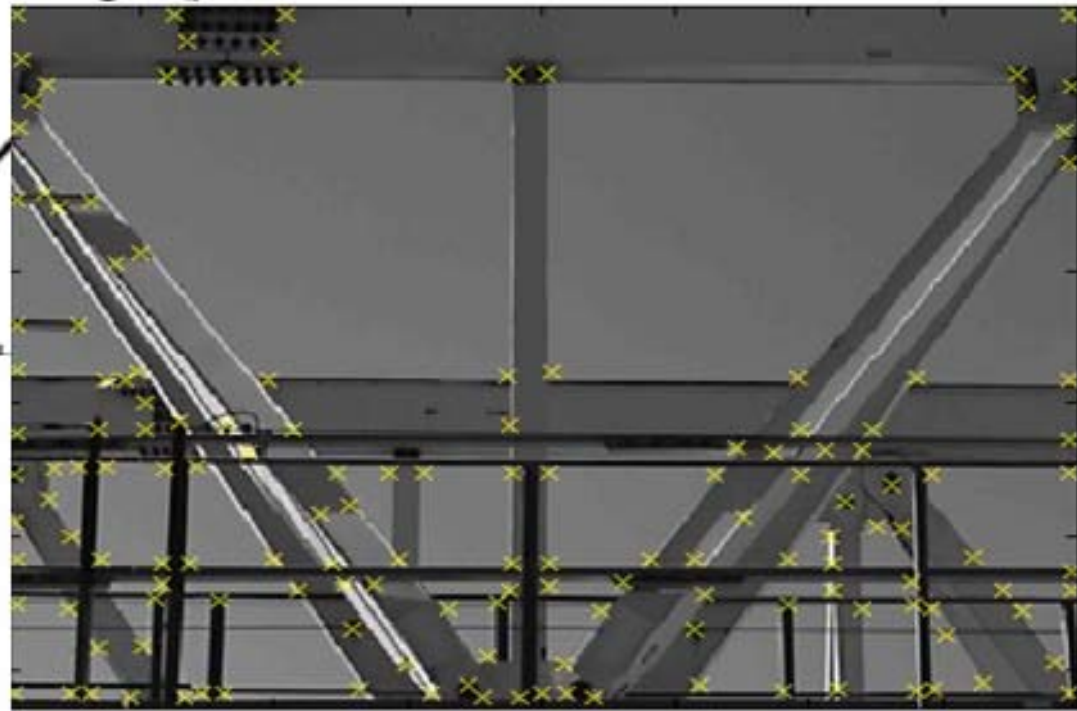
Slide adapted from Darya Frolova, Denis Simakov



# Harris Detector – Responses [Harris88]



*Effect:* A very precise corner detector.



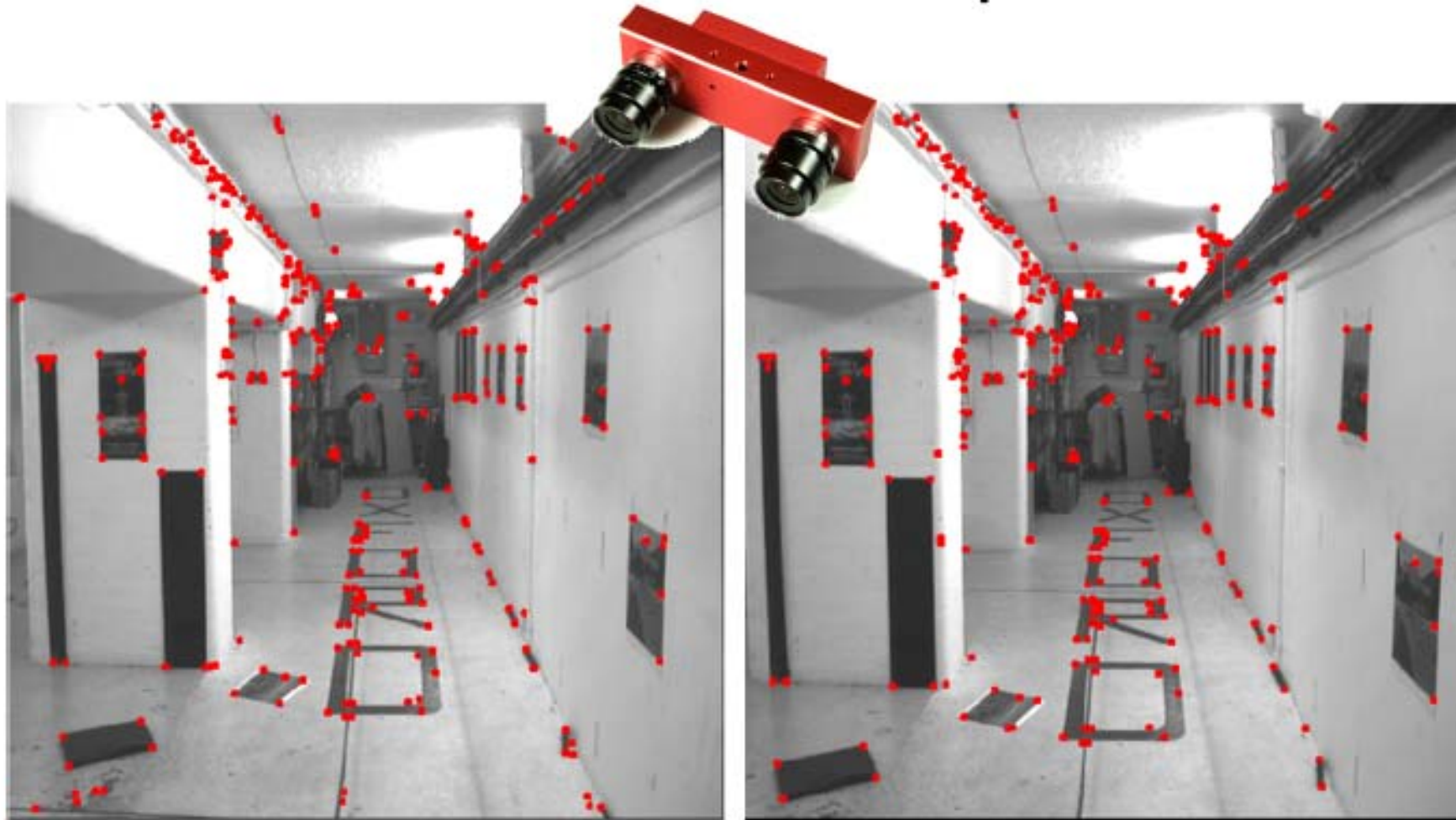
Slide credit: Krystian Mikolajczyk

# Harris Detector – Responses [Harris88]



Slide credit: Krystian Mikolajczyk

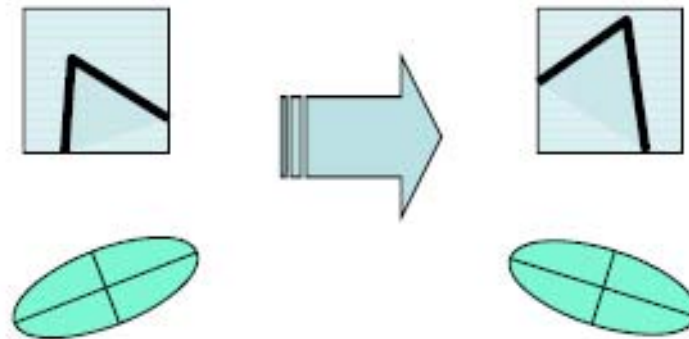
# Harris Detector – Responses [Harris88]



- Results are well suited for finding stereo correspondences

# Harris Detector: Properties

- Rotation invariance?

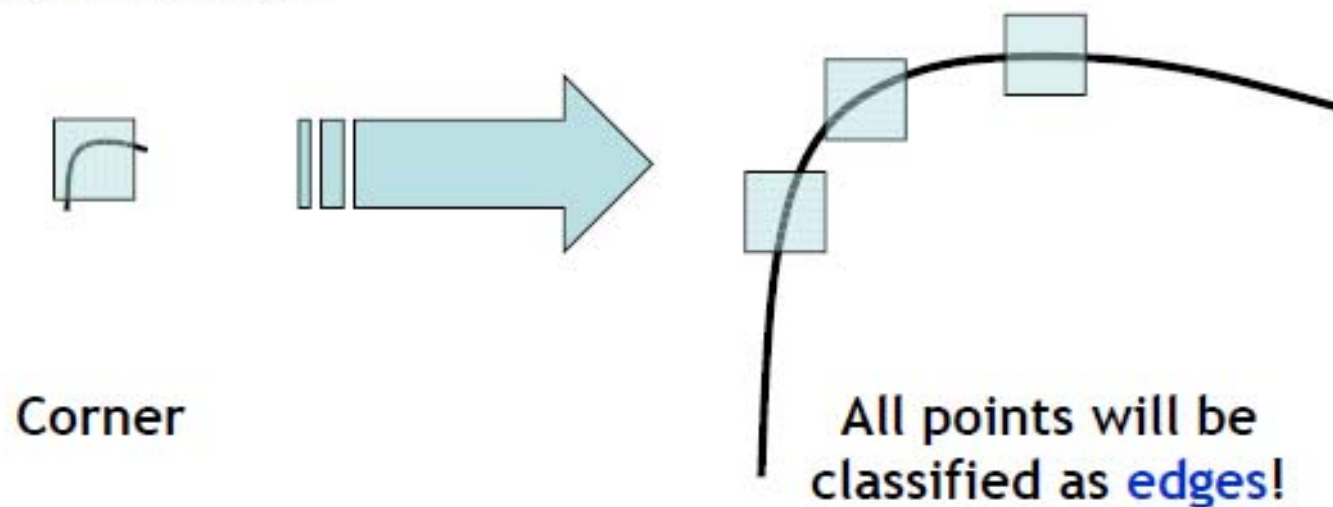


Ellipse rotates but its shape (i.e. eigenvalues) remains the same

***Corner response  $R$  is invariant to image rotation***

# Harris Detector: Properties

- Rotation invariance
- Scale invariance?



**Not invariant to image scale!**

# Class Objective were:

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- **Knew related conferences to our course theme**
- **Understand locally invariant features**
  - **Key point localization**
  - **Harris detector: manually designed detector → automatically learned detector using deep learning**

# Next Time..

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- **Scale invariant region selection**

# Homework for Every Class

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- **Go over the next lecture slides**
- **Come up with one question on what we have discussed today**
  - <https://forms.gle/7vqvJFAcBsebaQs68>
- **Go over recent papers on image search, and submit their summary**
  - **Just one or two (Korean or English) paragraphs are okay**
  - **Do not copy the abstract of the paper**
  - <https://forms.gle/yq19VqqLXwW7TyvZ9>