Outline

- Introduction
- **Features and Feature Matching**
- Geometry of Image Formation
- Calibration
- Structure from Motion
- Dense Stereo
- Conclusion

Features and Feature Matching

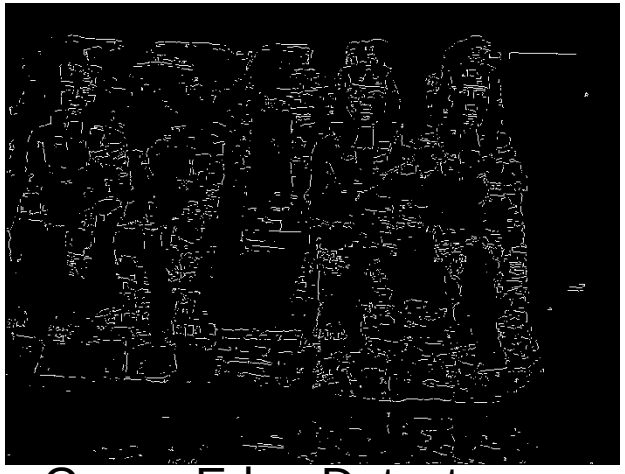
Original Image

Mean Filter

Gauss Filter

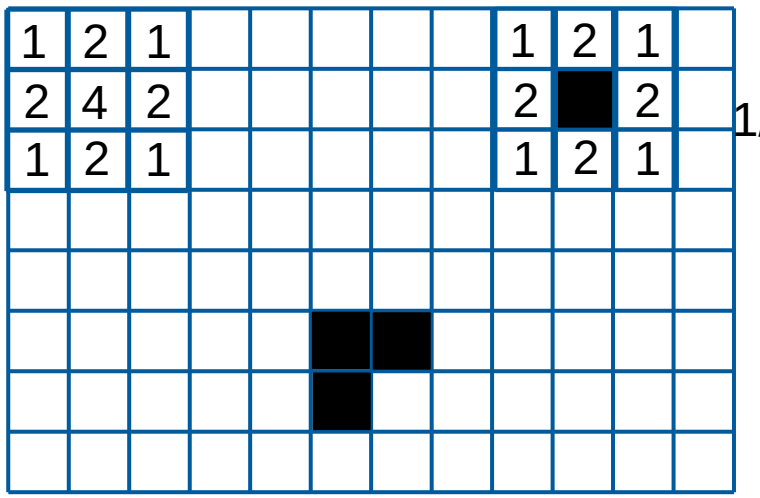
Median Filter

Sharpening



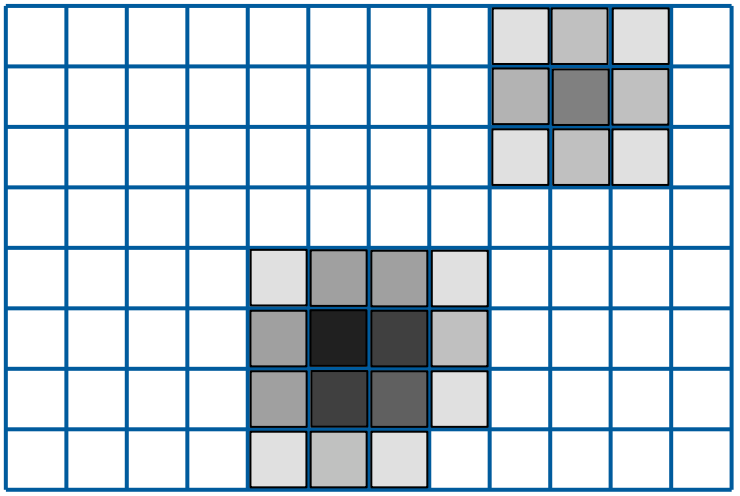
Canny Edge Detector

Gaussian Filter – Smoothing the Image



1/16

1	2	1
2	4	2
1	2	1



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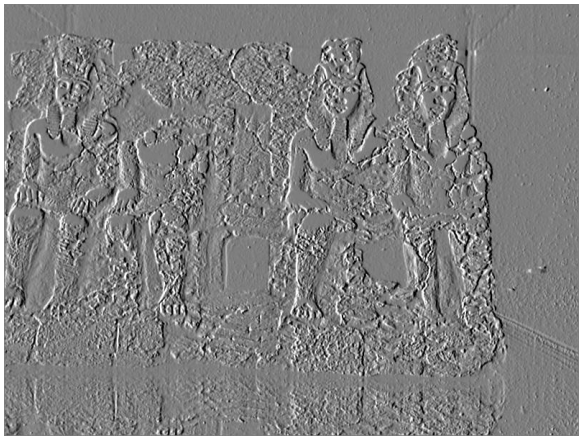
Gradient Filter

-1	0	1
-2	0	2
-1	0	1

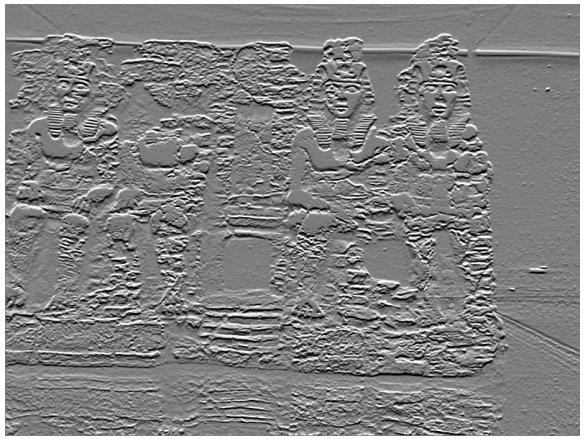
Sobel filter in x-direction



gradient x-direction

-1	-2	-1
0	0	0
1	2	1

Sobel filter in y-direction



gradient y-direction

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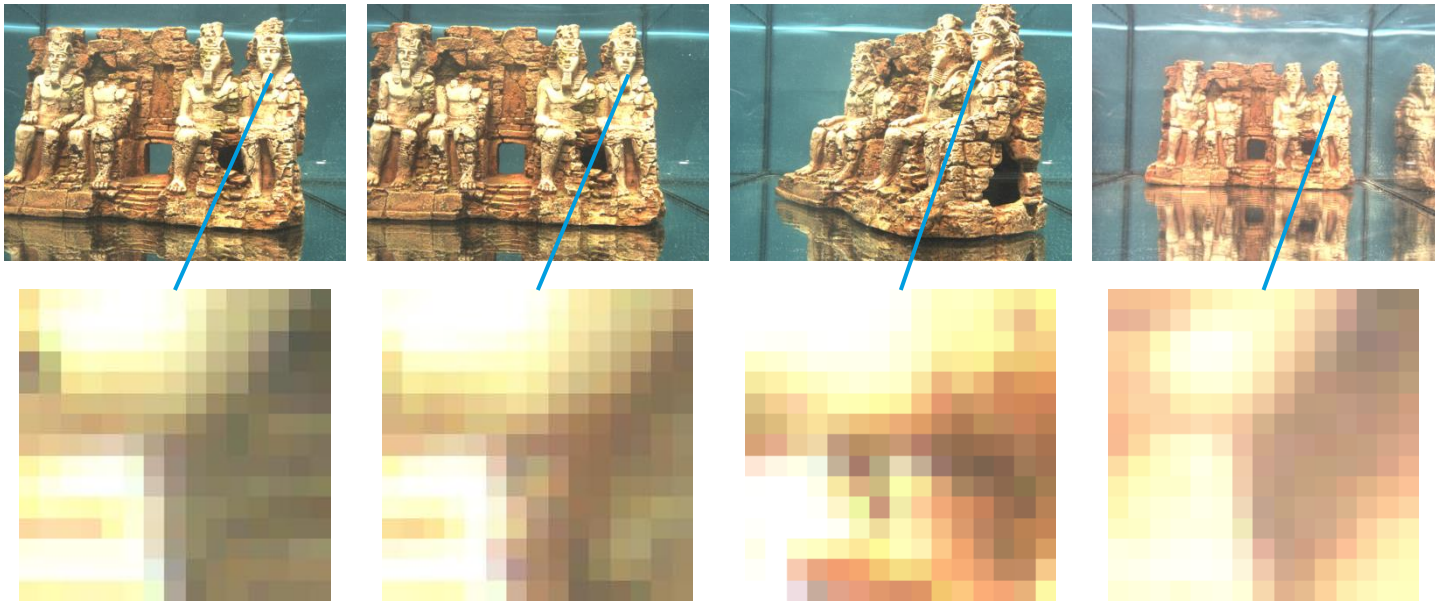
Feature Detection and Matching



Input: dense image sequences (video) or unordered, images (e.g. from the internet)
Question: is there overlap between the images?

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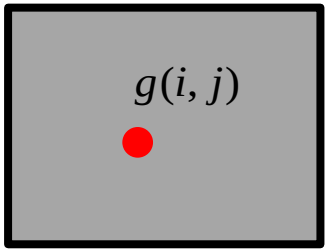
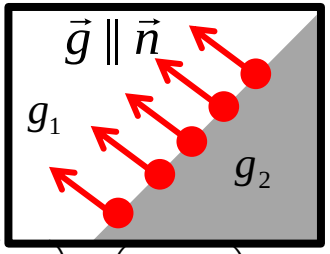
Feature Detection – Harris Corners

Images are composed of 3 basic primitives:

- Planar Patches: regions with constant gray values (zero gradient)
- Edges: regions with constant gradient vector (normal)
- Points (corners): regions with variable gradient

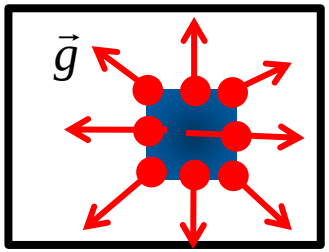


$$g(i,j) = const,$$
$$|\vec{g}| = 0$$



$$\vec{g} = \begin{pmatrix} g_x \\ g_y \end{pmatrix} = \begin{pmatrix} const \\ const \end{pmatrix}, \quad |\vec{g}| > 0$$

$$\vec{n} = \begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix}$$



$$\vec{g} = \begin{pmatrix} g_x \\ g_y \end{pmatrix} = \begin{pmatrix} var \\ var \end{pmatrix}$$
$$|\vec{g}| > 0$$

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Feature Detection – Harris Corners

Corners, edges, and planes can locally be distinguished by computing the structure tensor J. J(i, j) computes information on the local structure at position (i, j) for a local image region S from the gradients:

1. Compute gradient images: $I_x(i,j) = H_{gx} * I(i,j), \quad I_y(i,j) = H_{gy} * I(i,j)$

2. Point-wise products for the components of the structure tensor

$$I_{xx}(i,j) = I_x(i,j) \cdot I_x(i,j), \quad I_{yy}(i,j) = I_y(i,j) \cdot I_y(i,j), \quad I_{xy}(i,j) = I_x(i,j) \cdot I_y(i,j)$$

3. Local smoothing of the gradients

$$J_{xx} = G_{LP} * I_{xx}(i,j), \quad J_{yy} = G_{LP} * I_{yy}(i,j), \quad J_{xy} = G_{LP} * I_{xy}(i,j)$$

4. Computation of trace and determinant

$$J(i,j) = \begin{bmatrix} J_{xx} & J_{xy} \\ J_{xy} & J_{yy} \end{bmatrix}, \quad \text{trace}(J) = (J_{xx} + J_{yy}), \quad \det(J) = J_{xx} \cdot J_{yy} - J_{xy}^2$$

Harris and Stephens, 1988

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Feature Detection – Harris Corners

- Harris Corner Detector evaluates J:

$$\lambda_0, \lambda_1 \text{Eigenwerte} \quad J \Rightarrow \det(J) = \lambda_0 \lambda_1, \quad \text{trace}(J) = \lambda_0 + \lambda_1$$

$$C_H = \det(J) - k \cdot \left(\text{trace}(J)\right)^2, \quad 0 \le k \le = 0.25, \; k = 0.04$$

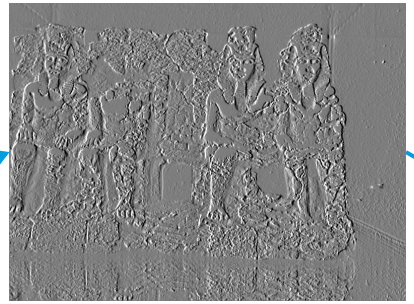
$$C_H \begin{cases} > t \text{ for edges} \\ < t \text{ for corners and planes} \end{cases}$$

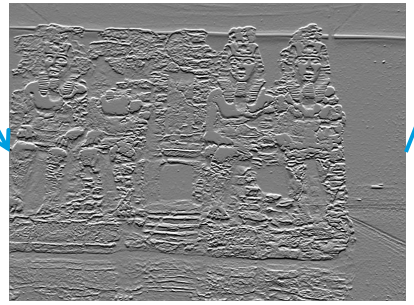
- C_H measures the 'cornerness'
- $C_H > t$, $t > 0$ potential corners
- select local maxima in a neighborhood (Non-Maxima-Suppression).

Harris and Stephens, 1988

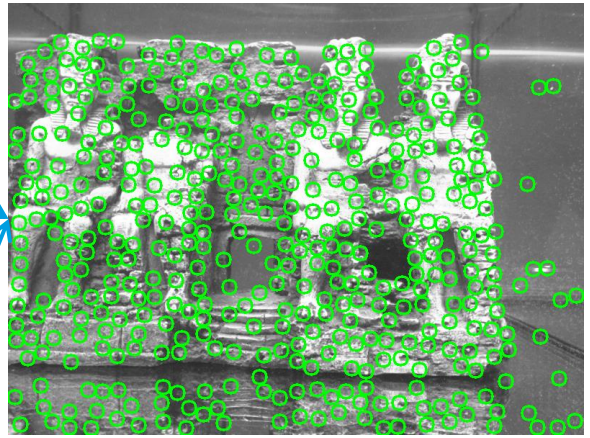
Gradients – Harris Corner Detector

input image





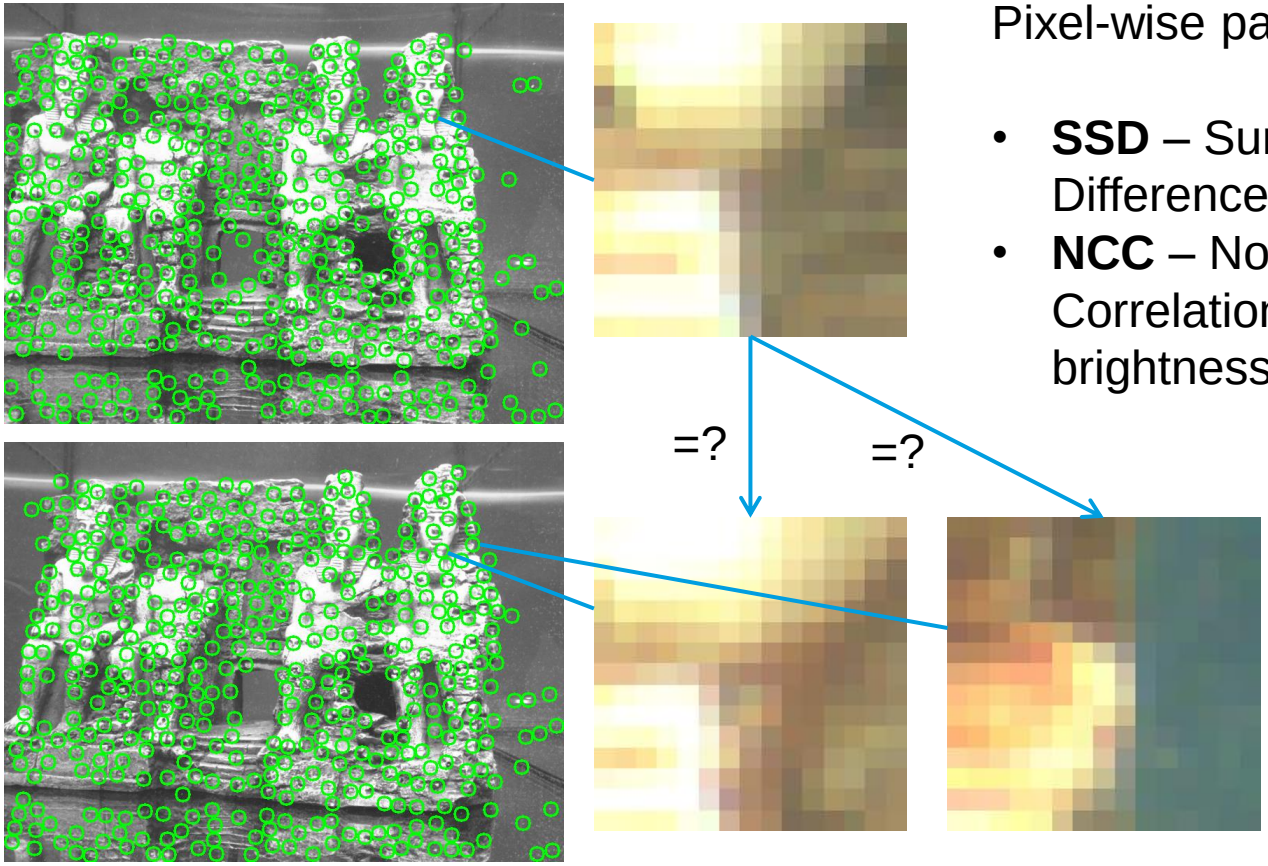
gradient images



Harris corners

Harris and Stephens, 1988

Feature Point Matching



Pixel-wise patch comparison:

- **SSD** – Sum of Squared Differences
- **NCC** – Normalized Cross Correlation (invariant against brightness changes)

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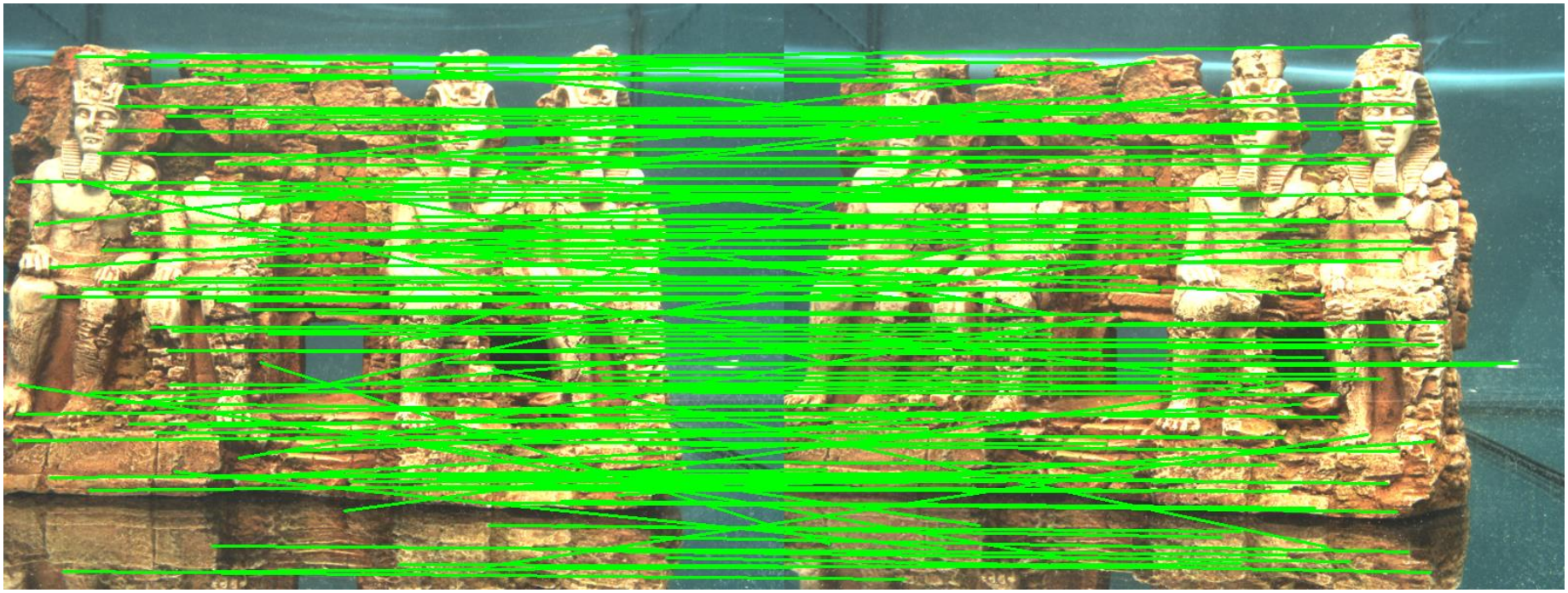
Feature Point Matching



Automatically detect hundreds or thousands of correspondences
Problem: outliers

Features and Feature Matching

Feature Detection and Matching

Projective

Translation

Transformations

Illumination changes:
- brightness
- exposure
- moving light sources/shadows

original feature

Euclidean

Affinity

Similarity

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Feature Detectors & Descriptors

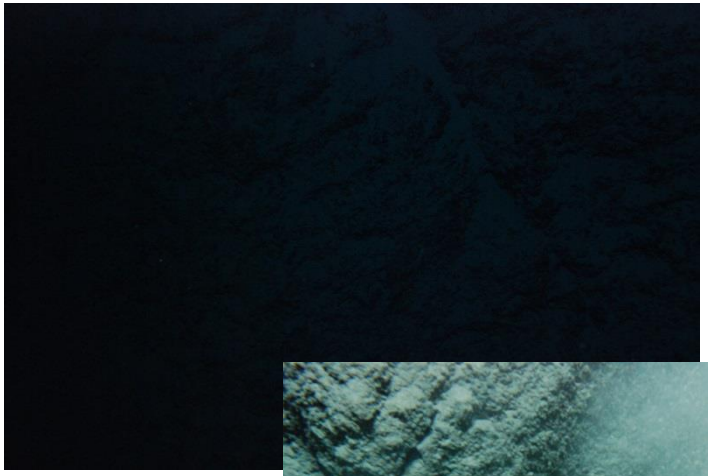
Detector Class	Descriptor	Comparison
Harris Corners	Image patch	SSD, NCC
Difference of Gaussian (DoG)	SIFT	Vector Distance
Maximally stable extremal regions (MSER)	e.g. SIFT	Vector Distance
… many, many more		

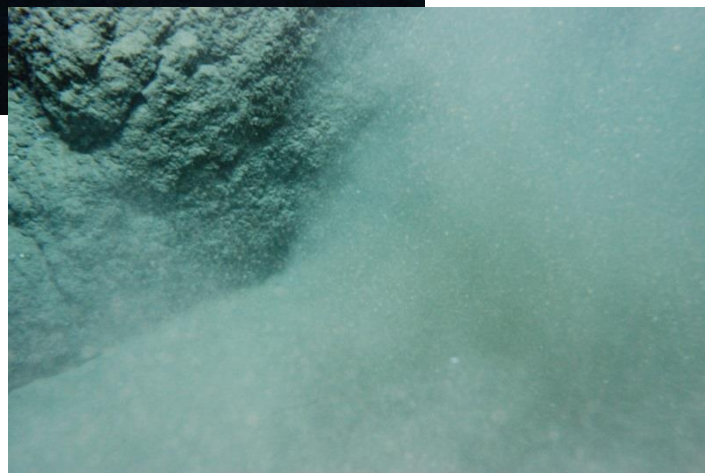
From now on: SIFT-features (out of scope in this tutorial)

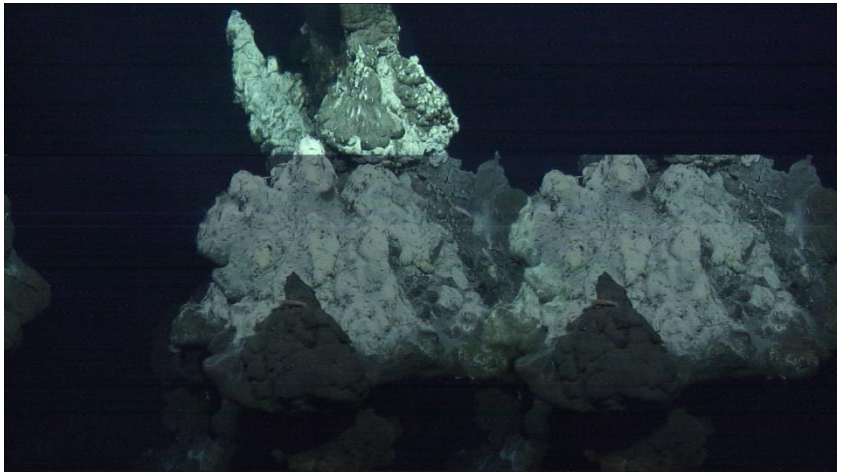
Harris and Stephens, 1988, Lowe 2004, Szeliski 2011

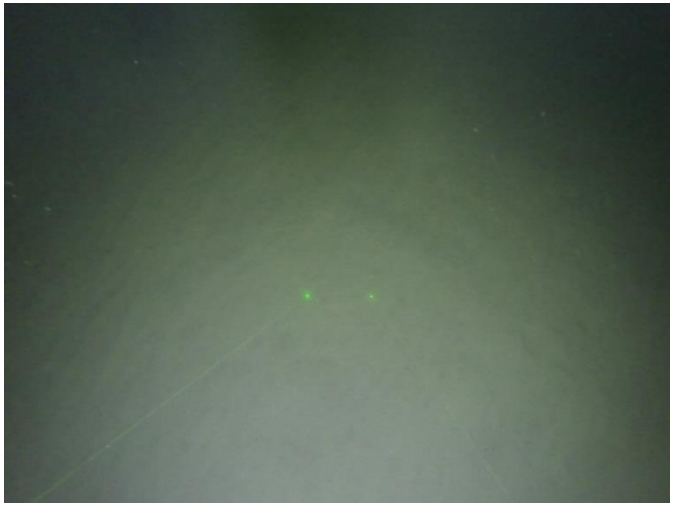
Features and Feature Matching

Problematic Cases









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References

R. Szeliski, Computer Vision Algorithms and Applications, Springer 2011.

C. Harris, M. Stephens. A combined corner and edge detector, Proceedings of the 4th Alvey Vision Conference, pages 147-151, 1988

D. G. Lowe. Distinctive Image Features from Scale-Invariant Keypoints, International Journal of Computer Vision, 2004

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Wrap up

- automated detection of feature points in all images
- match feature points between images
- different methods depending on baseline between images, expected rotation, translation, and scale
- illumination brightness, exposure