SIFT and SURF for Biomedical Image Analysis

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Why?

- **Local features**:
  - points/regions in an image that are distinctive and repeatable under changes of **scale**, **rotation**, **viewpoint**, **illumination**, and **noise**.
- **Early methods**:
  - **Moravec (1977)**: corner interest measure via intensity change in 4 directions.
  - **Harris & Stephens (1988)**: improved corner detector using second-moment matrix; **rotation-invariant** but not scale-invariant.
  - **Laplacian-of-Gaussian (LoG) / Difference-of-Gaussians (DoG)**: blob detection across scales.
- **Modern (and/or faster) alternatives**:
  - **FAST** (detector), **BRIEF** (descriptor), **ORB** (FAST + rotated BRIEF; fast, binary). These are often used when speed and licensing are priorities.

SIFT - Scale-Invariant Feature Transform

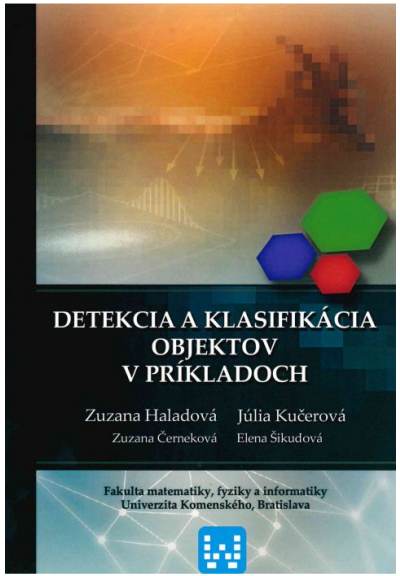
- **Idea**: find keypoints that are stable across **scale** and **rotation**; describe them with a robust, gradient-based descriptor.

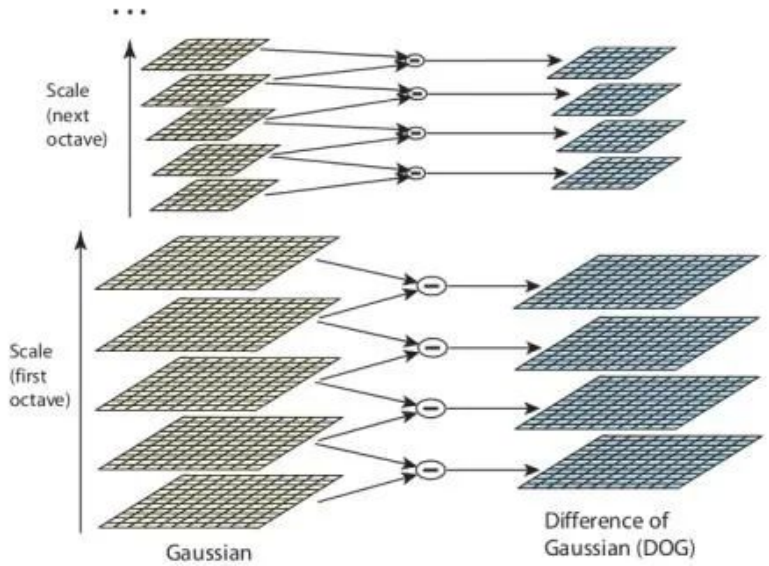
- **Properties**
  - Invariant to uniform scaling, rotation
  - Reasonably robust to illumination/affine changes
  - Typically slower and higher-dimensional than binary descriptors but more accurate/repeatable.

SIFT

1) Scale-space & candidate keypoints

Build Gaussian pyramid and compute **Difference-of-Gaussians (DoG)**:





Gaussian pyramid

DoG through different scales

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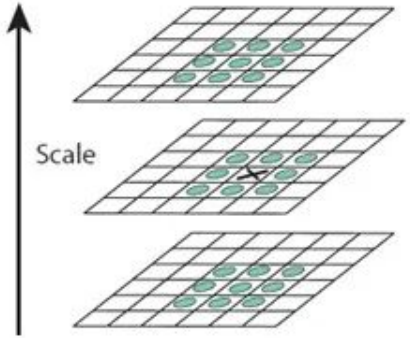
SIFT



2) Keypoint localization

Refine each candidate via Taylor expansion.

Filter out **low contrast** and **edge-like** responses.

3) Orientation assignment

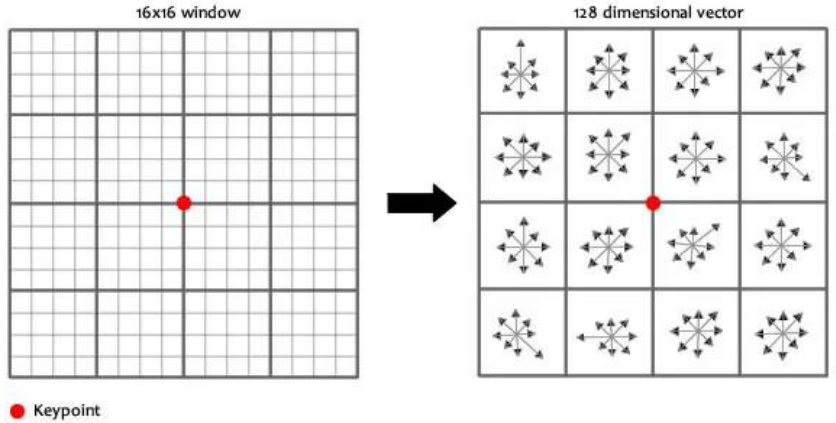
Dominant orientation from local gradient histogram → **rotation invariance**.

SIFT

4) Descriptor (128-D)

4×4 grid of cells; each stores an 8-bin gradient orientation histogram → **128-D** vector (4×4×8).

Normalize to reduce illumination effects; clamp to reduce influence of large gradients.



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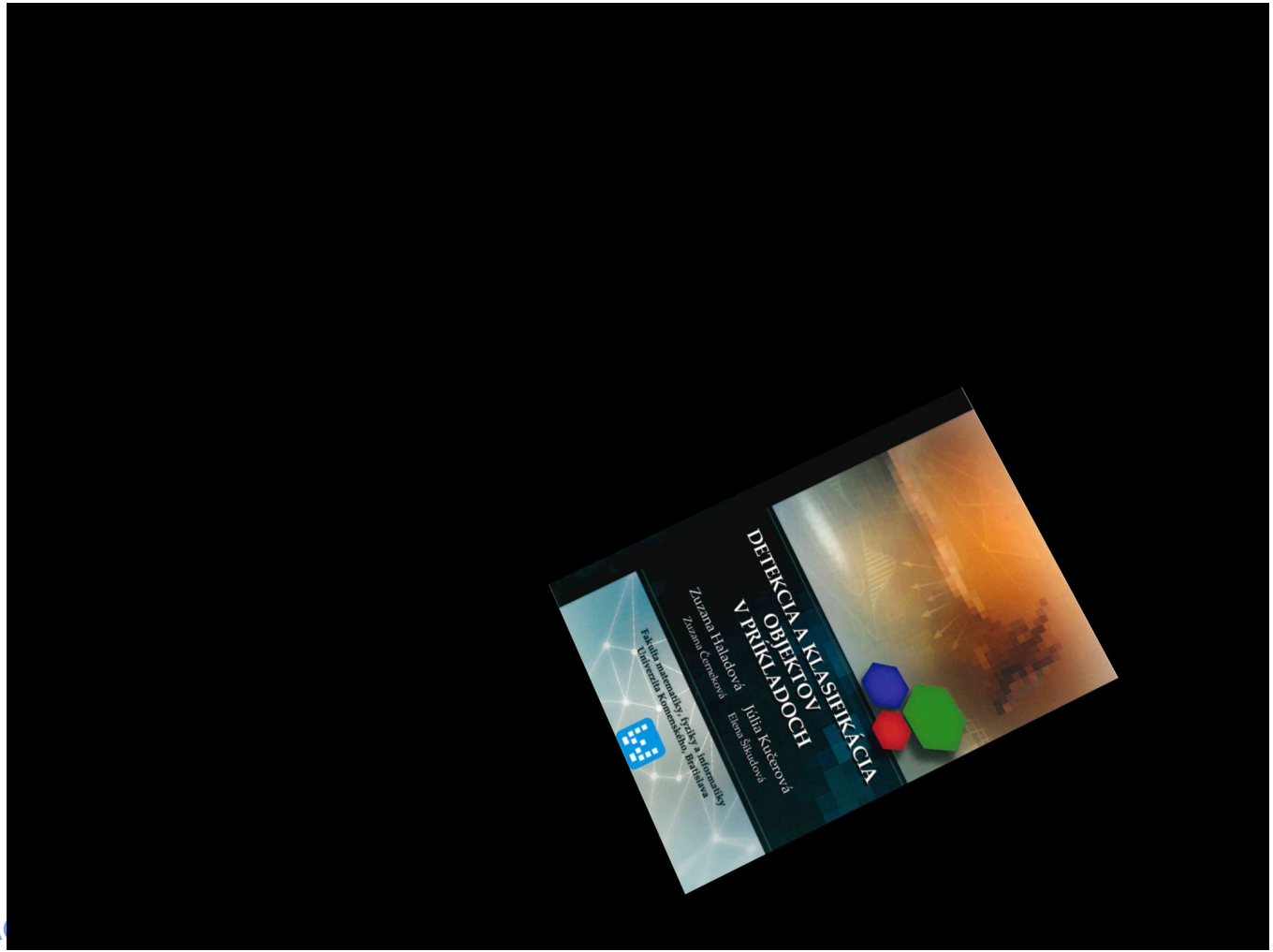
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SURF - Speeded-Up Robust Features

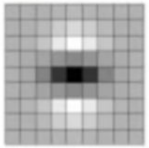
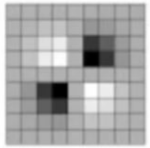
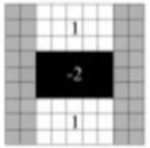
Idea: similar to SIFT but faster - using integral images. SURF builds a scale-space, but replaces Gaussian kernels with box filters that approximate the Laplacian of Gaussian.

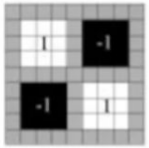
1) **Key points detection** by finding maxima of the determinant of the Hessian matrix (Hessian box filter) across scales and space
2) **Keypoint Localization**: Candidate keypoints are localized at the scale giving the maximal Hessian response.
3) **Orientation Assignment**: SURF computes Haar-wavelet responses (simple Sobel-like filters) in the horizontal and vertical directions over a circular neighborhood (size ≈4×scale) . It sums the wavelet responses in sliding 60° sectors to find the dominant orientation .
4) **Descriptor Generation**: Based on sums of **Haar-wavelet** responses in oriented neighborhood. - **Upright SURF (U-SURF)** skips orientation to gain speed when rotation variance is small.

SURF

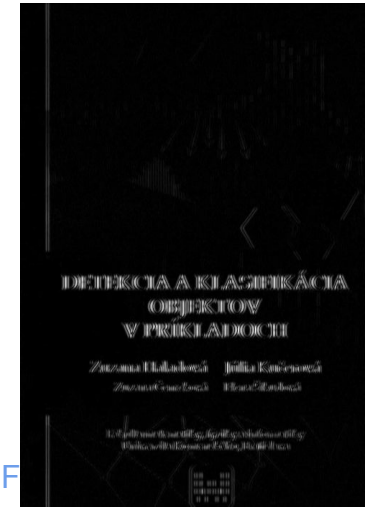
$$\mathcal{H}(\mathbf{x}, \sigma) = \begin{bmatrix} L_{xx}(\mathbf{x}, \sigma) & L_{xy}(\mathbf{x}, \sigma) \\ L_{xy}(\mathbf{x}, \sigma) & L_{yy}(\mathbf{x}, \sigma) \end{bmatrix}$$

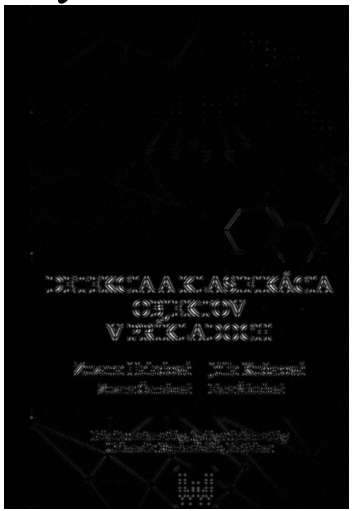
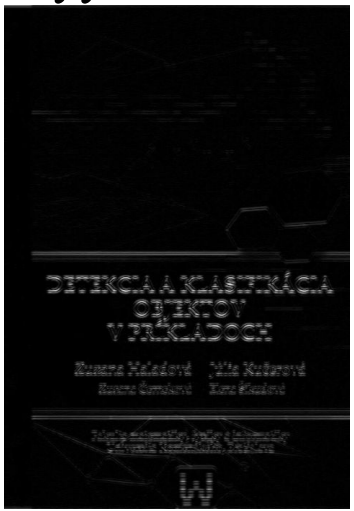
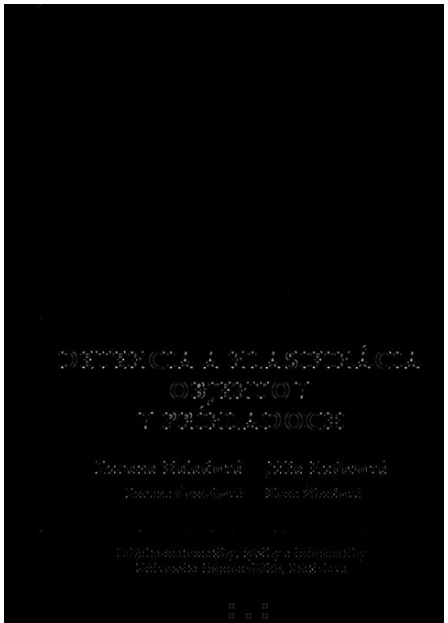
Hessian second-derivative magnitude views

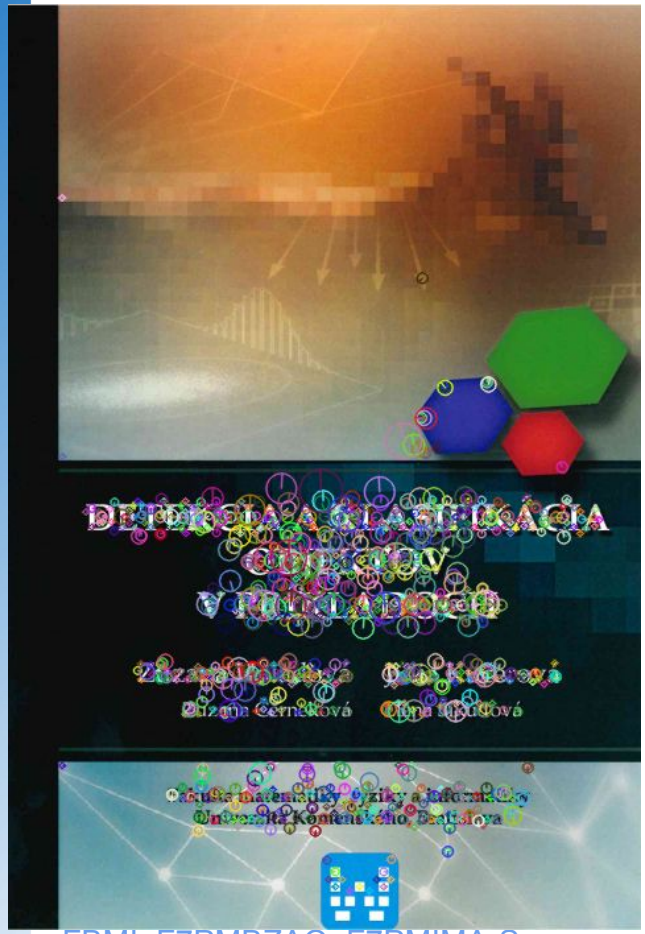






xx xy yy

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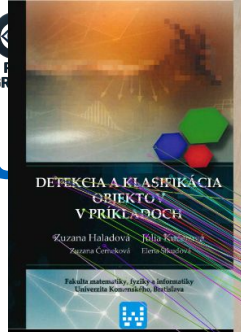
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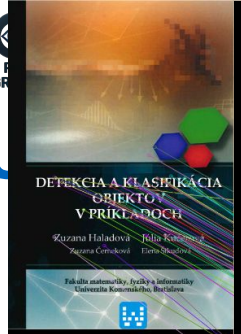
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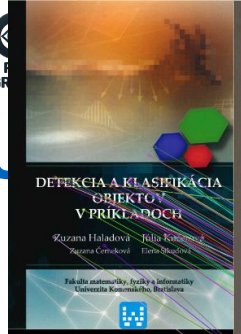
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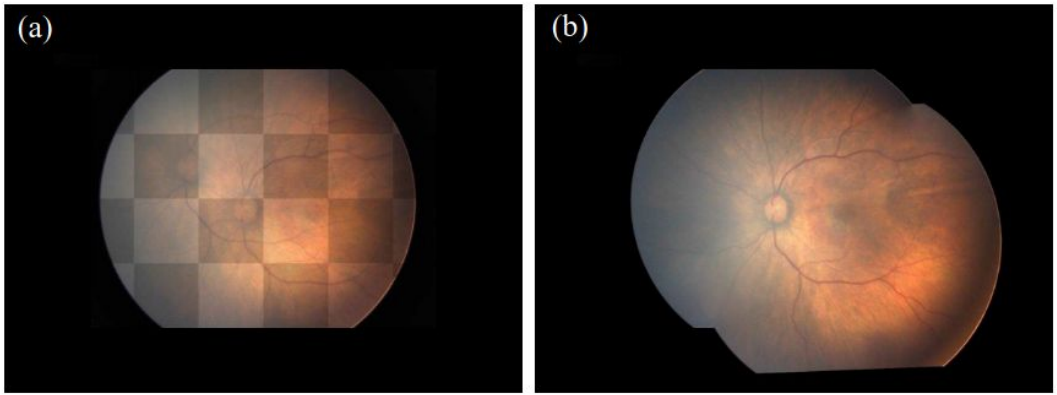
Choosing Between SIFT / SURF / ORB

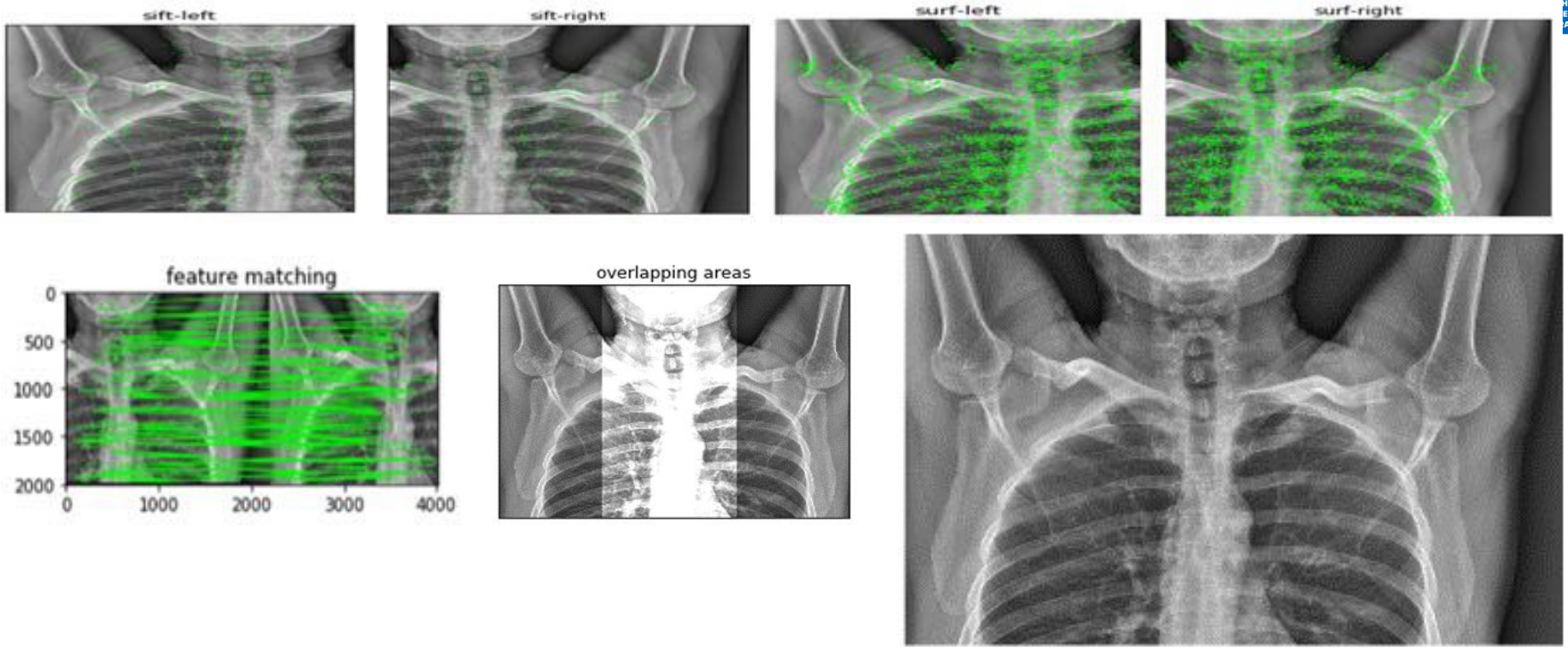
- **SIFT**
  - strong accuracy, robust matching; ok speed today; widely available.
- **SURF**
  - Faster than SURF; may require extra installation; often similar accuracy.
- **ORB**
  - very fast, low memory (binary 256-bit descriptor), good for real-time, but may be less robust on challenging medical textures.

Medical Imaging: Image registration

- **Image registration is often used to align multi-modal or multi-parametric images of the same organ**
  - register MRI to CT of the same anatomy
  - register data from same source over time - tumor tracking
  - register retinal images and CT scans. In *Jiang et al.*, a SURF-based method achieved >90% registration success in neonatal eye images

Jiang H, Gao M, Yang K, Zhang D, Ma H, Qian W. Neonatal Fundus Image Registration and Mosaic Using Improved Speeded Up Robust Features Based on Shannon Entropy. Annu Int Conf IEEE Eng Med Biol Soc. 2021 Nov;2021:3004-3007. doi: 10.1109/EMBC46164.2021.9630593. PMID: 34891876.





Bakar, S., Jiang, X., Gui, X., Li, G., & Li, Z. (2020). Image Stitching for Chest Digital Radiography Using the SIFT and SURF Feature Extraction by RANSAC Algorithm. *Journal of Physics: Conference Series, 1624(4), 042023.*

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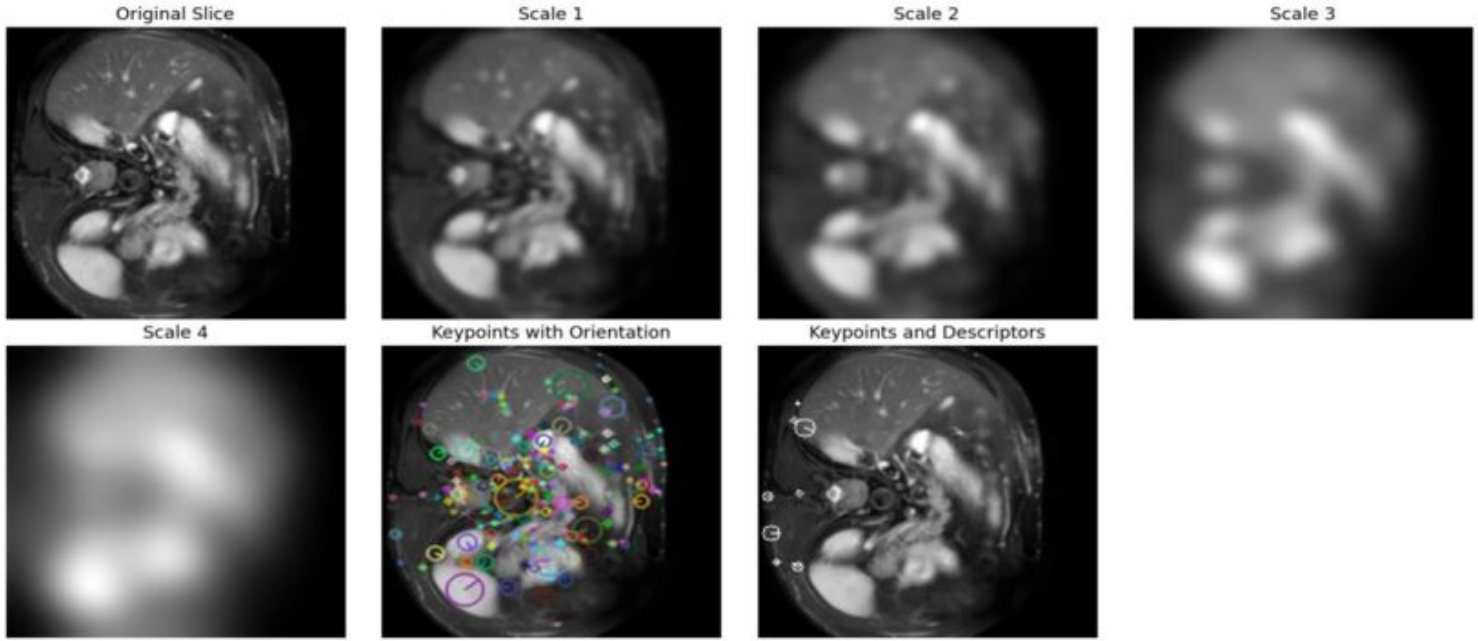
Medical Imaging

Scale - Space Representation and Keypoint Detection on Abdominal MRI Slice (CHAOS Dataset) using SIFT



Medical Imaging: Tumor Detection & Tracking

- detection and quantification of tumor boundaries on X-rays or histology – extracting distinctive local texture features using SIFT .
- tracking tumor landmarks across follow-up scans: e.g. matching keypoints on MRI volumes to monitor growth over time .
  - tuberculosis nodule detection using SURF in chest X-rays (faster matching and comparable accuracy)
- Feature extraction by SIFT methods for prostate cancer early detection

  Shadan Mohammed Jihad, Ali Aalsaud, Firas H. Almukhtar, Shahab Kareem, Raghad Zuhair Yousif, Investigating feature extraction by SIFT methods for prostate cancer early detection, Egyptian Informatics Journal, Volume 29, 2025, 100607, ISSN 1110-8665, https://doi.org/10.1016/j.eij.2024.100607.

Medical Imaging: 3D reconstruction

- **Building 3D models from 2D images.**
  - Stacking serial histology sections or reconstructing vascular networks from slices. Keypoint features (SIFT/SURF) can match points across slices/views to reconstruct volume . SIFT's scale invariance allows matching of features even if slice thickness or zoom varies. (Suggested visualization: multi-planar MRI views or histology slices with matched feature overlays.)