# Detecting Interpretable and Accurate Scale-Invariant Keypoints

Wolfgang Förstner, Timo Dickscheid, Falko Schindler

igg

universitätbonn

## Motivation

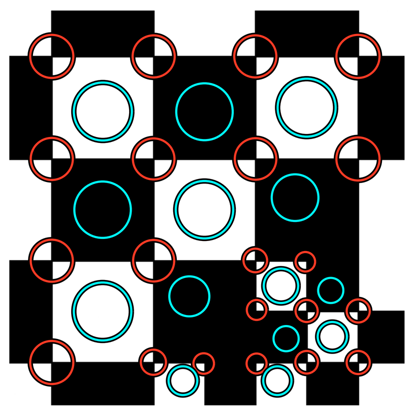
Desired properties of keypoint detectors:

- **Invariance and repeatability** for object recognition
- **Accuracy** to support camera calibration
- **Interpretability**: Especially **corners and circles**, should be part of the detected keypoints (see figure).
- As few **control parameters** as possible with clear semantics
- **Complementarity** to known detectors

We make use of

- **spiral model** [1]
- **feature operator** [2]

to end up with a **scale-invariant corner/circle detector**.



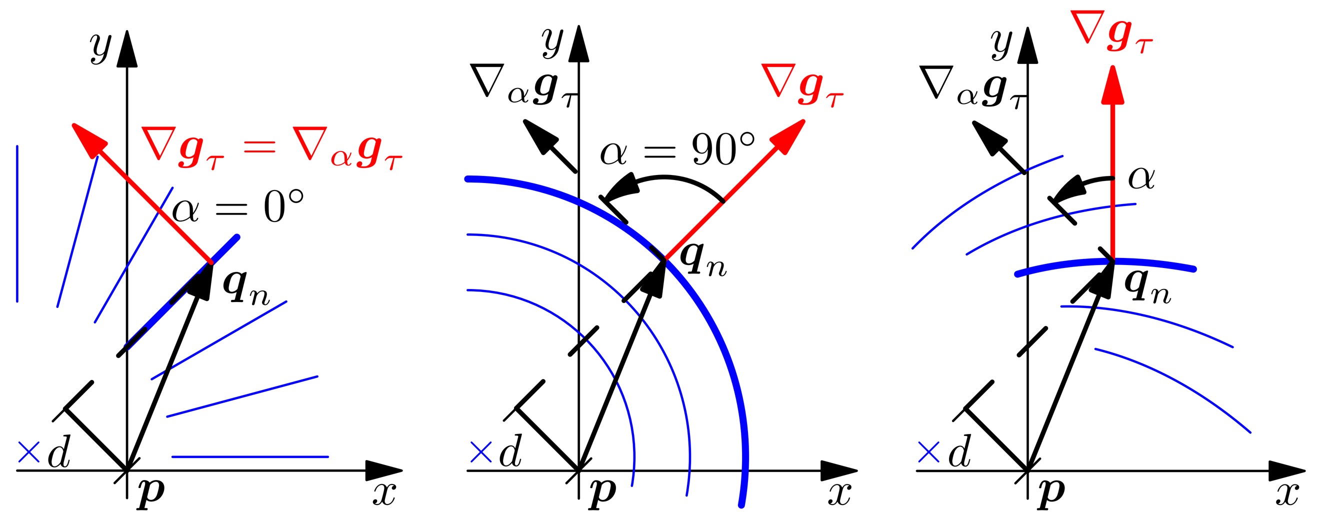
## Theory

### Maximize the weight = 1/variance of a point $p$

$$\boxed{w(\boldsymbol{p},\alpha,\tau,\sigma) = (N(\sigma)-2)\frac{\lambda_{\min}(M(\boldsymbol{p},\alpha,\tau,\sigma))}{\Omega(\boldsymbol{p},\alpha,\tau,\sigma)}}$$

comprising

- the *image model* [1]




$$\Omega(\boldsymbol{p},\alpha,\tau,\sigma) = \sum_{n=1}^{N(\sigma)} \left[(\boldsymbol{q}_n-\boldsymbol{p})^{\mathsf{T}}\boldsymbol{R}_\alpha\nabla_\tau g(\boldsymbol{q}_n)\right]^2 G_\sigma(\boldsymbol{q}_n-\boldsymbol{p})$$
$$= N(\sigma)\,\mathrm{tr}\left\{R_\alpha\nabla_\tau\nabla_\tau^{\mathsf{T}}R_\alpha^{\mathsf{T}} * \boldsymbol{p}\boldsymbol{p}^{\mathsf{T}}G_\sigma(\boldsymbol{p})\right\} \qquad (1)$$

- the smaller eigenvalue of the *structure tensor*

$$\underbrace{M(\boldsymbol{p},\alpha,\tau,\sigma)}_{\text{structure tensor}} = \underbrace{G_\sigma(\boldsymbol{p})}_{\text{weighted summation}} * \underbrace{\left(R_\alpha\nabla_\tau\nabla_\tau^{\mathsf{T}}R_\alpha^{\mathsf{T}}\right)}_{\text{squared rotated gradients}} \qquad (2)$$

### Reduce the 5-dimensional search space by

- *linking the differentiation scale* $\tau$ to the integration scale $\sigma$:

$$\tau = \sigma/3$$

- *solving for the optimal* $\hat{\alpha}$ using the model

$$\Omega(\alpha) = a - b\cos(2\alpha - 2\alpha_0)$$

and determining the parameters from three angles, e. g.

$$\Omega(0°), \Omega(60°), \Omega(120°) \quad\rightarrow\quad a, b, \alpha_0 \quad\rightarrow\quad \hat{\alpha}$$

pre-selection possible:

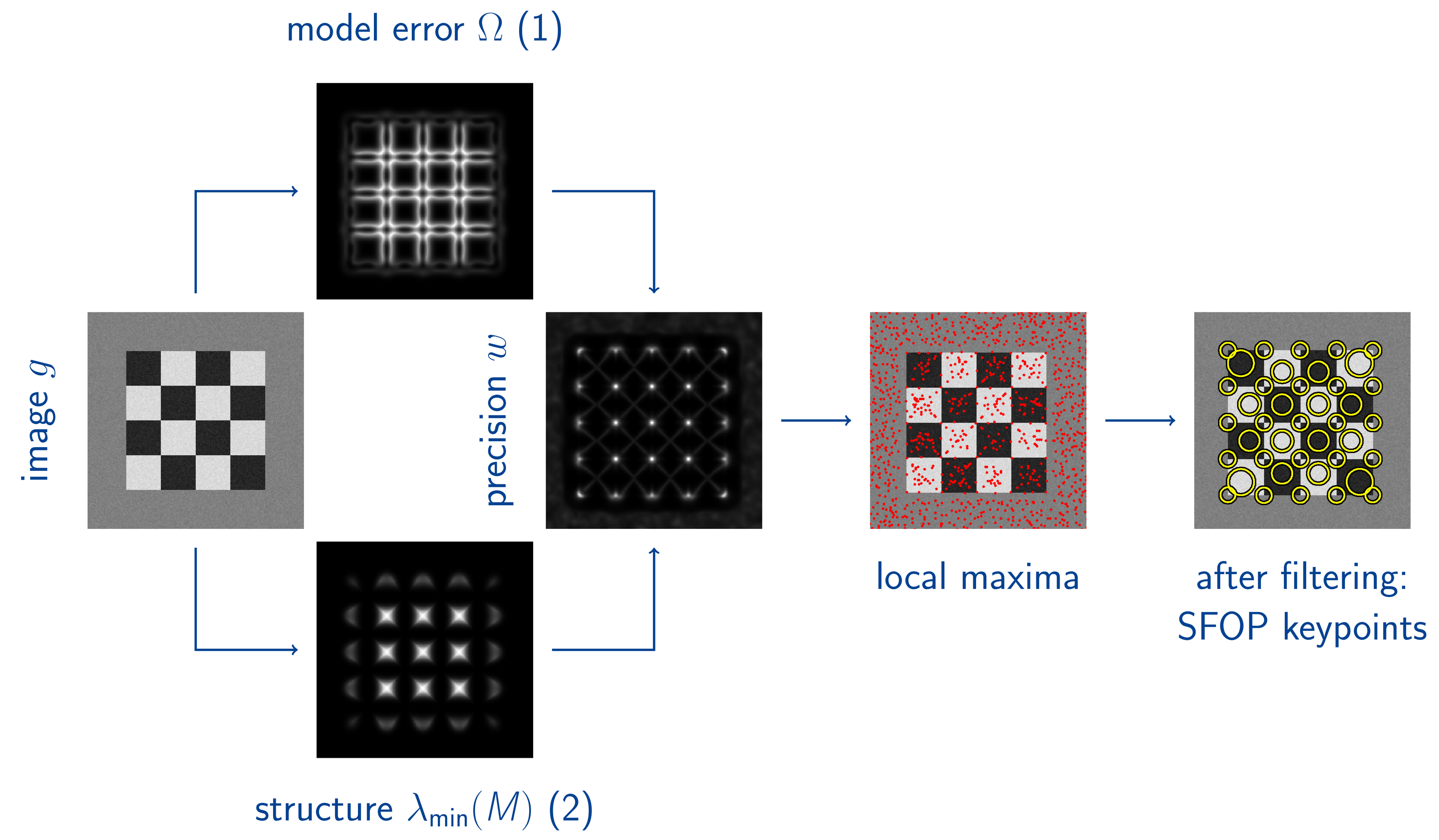
$$\alpha = 0° \rightarrow \text{junctions}, \qquad \alpha = 90° \rightarrow \text{circular features}$$

### Filter potential keypoints

- *non-maxima suppression* over scale, space and angle
- *thresholding the isotropy* $\lambda_2(M)$:
  eigenvalues characterize the shape of the keypoint, smallest eigenvalue has to be larger than threshold $T_\lambda$ derived from noise variance $V(n)$ and significance level $S$:

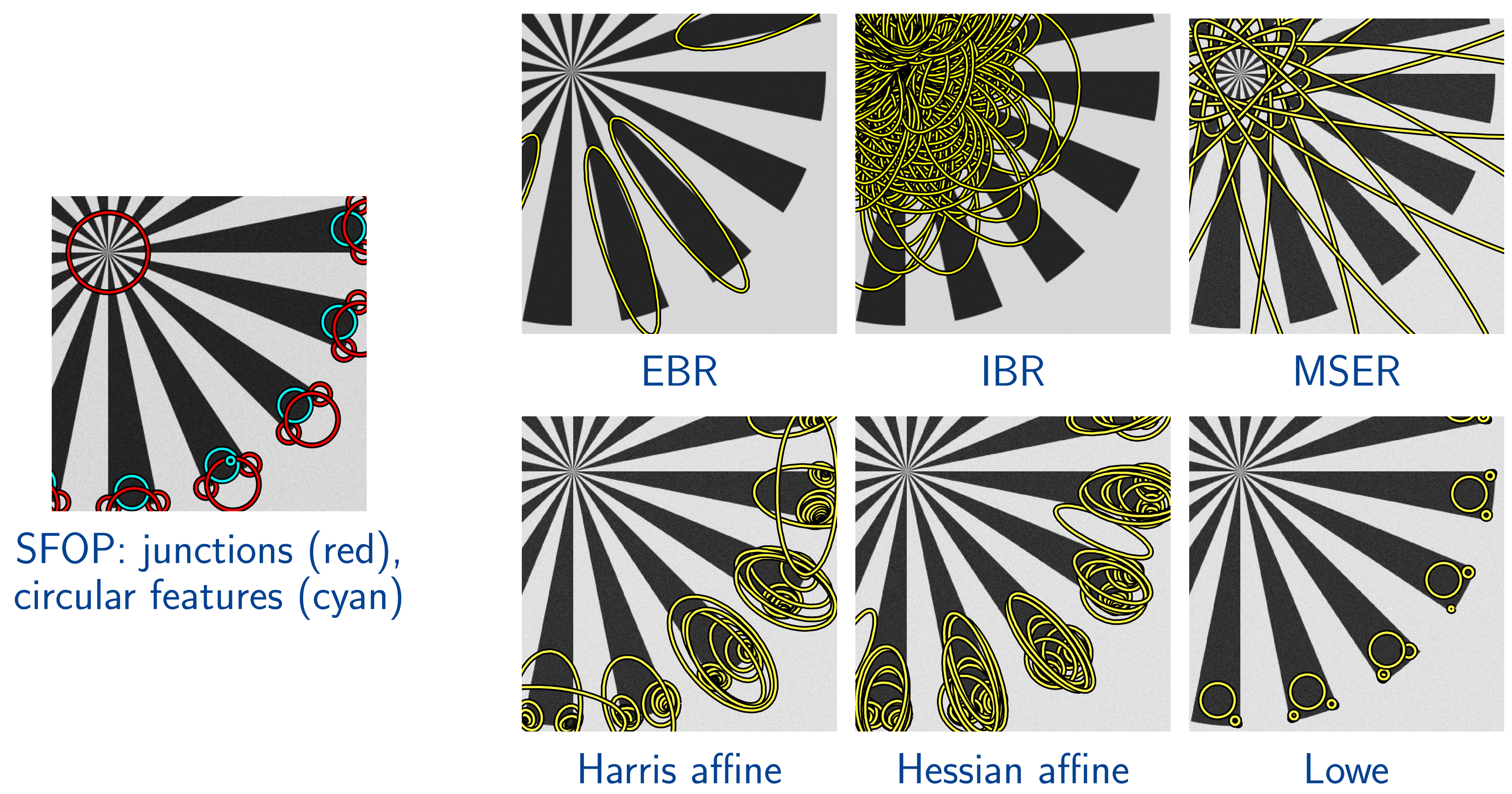
$$T_\lambda(V(n),\tau,\sigma,S) = \frac{N(\sigma)}{16\pi\tau^4}V(n)\chi^2_{2,S}$$

## Algorithm

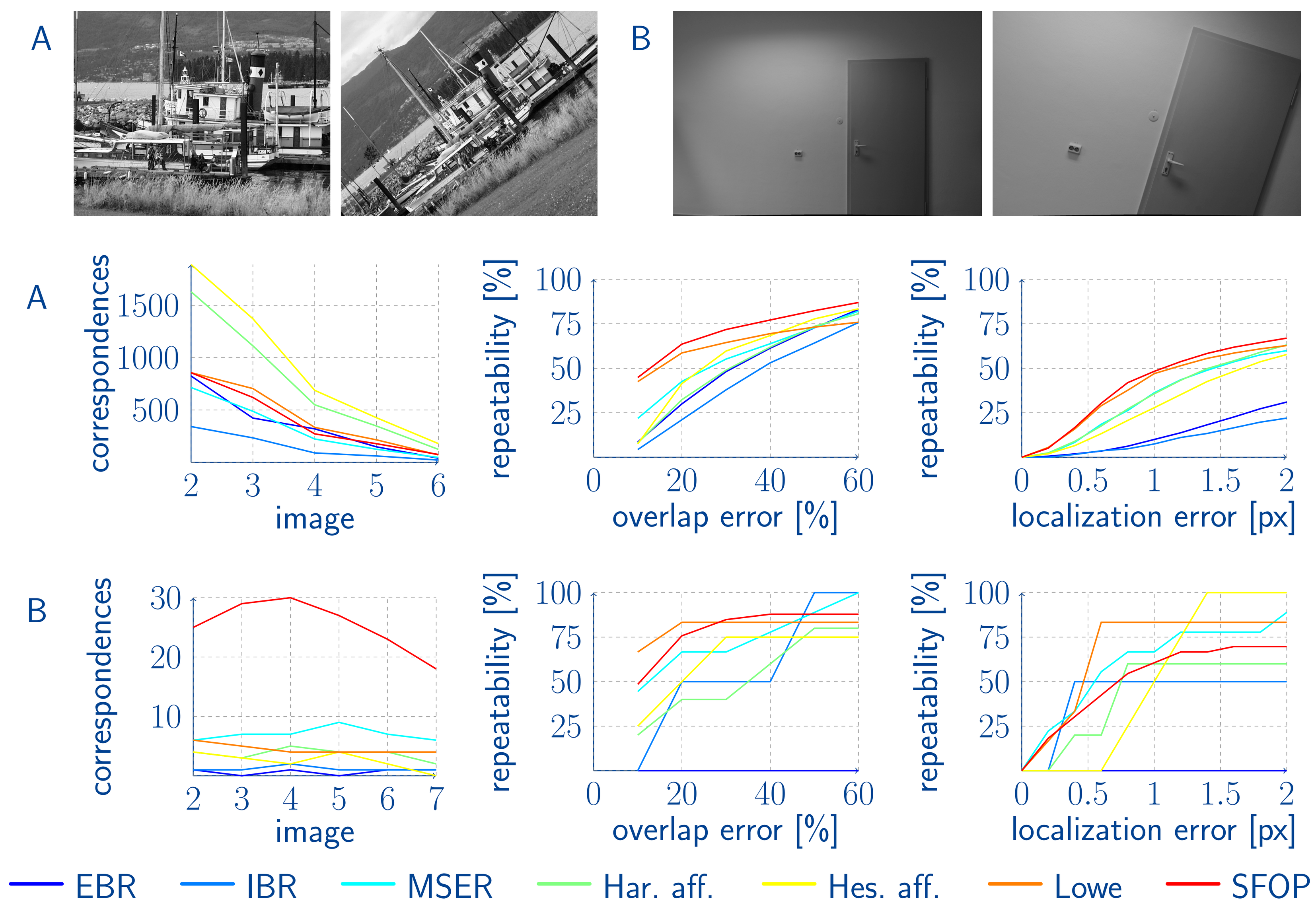



## Results

### Interpretability of SFOP keypoints:




### Repeatability and accuracy evaluation [3]:




### Bundle Adjustment on 3D scenes:

- comparable to other detectors


### References

[1] J. Bigün.
A Structure Feature for Some Image Processing Applications Based on Spiral Functions.
*Computer Vision, Graphics and Image Processing*, 51(2):166–194, 1990.

[2] W. Förstner.
A Framework for Low Level Feature Extraction.
In *Third European Conference on Computer Vision*, volume III, pages 383–394, Stockholm, Sweden, 1994.

[3] K. Mikolajczyk and C. Schmid.
An affine invariant interest point detector.
In *Proc. European Conf. Computer Vision*, pages 128–142, 2002.


igg

University of Bonn
Institute for Geodesy and Geoinformation

Department for Photogrammetry
Nussallee 15, 53115 Bonn, Germany

{wf@ipb.,dickscheid@,falko.schindler@}uni-bonn.de
Project website: http://www.ipb.uni-bonn.de/sfop

universitätbonn