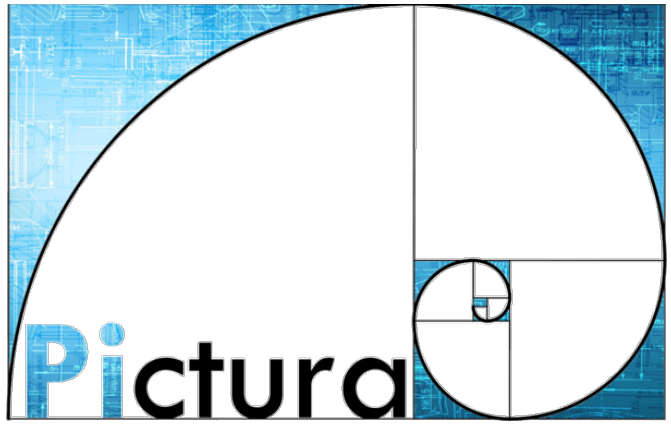
SCALP: Superpixels with Contour Adherence using Linear Path

Rémi Giraud[1,2]

remi.giraud@labri.fr

with Vinh-Thong Ta[1] and Nicolas Papadakis[2]



[1]LaBRI CNRS UMR 5800 - University of Bordeaux, FRANCE
PICTURA Research Group
[2]IMB CNRS UMR 5251 - University of Bordeaux, FRANCE

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Superpixel Context

Low-level representation of an image into homogeneous areas.
Respect of image geometry (contrary to multi-resolution approach).

Properties:

- Adherence to the image contours
- Homogeneity of the color clustering
- Regularity/compactness of the decomposition

1500 superpixels

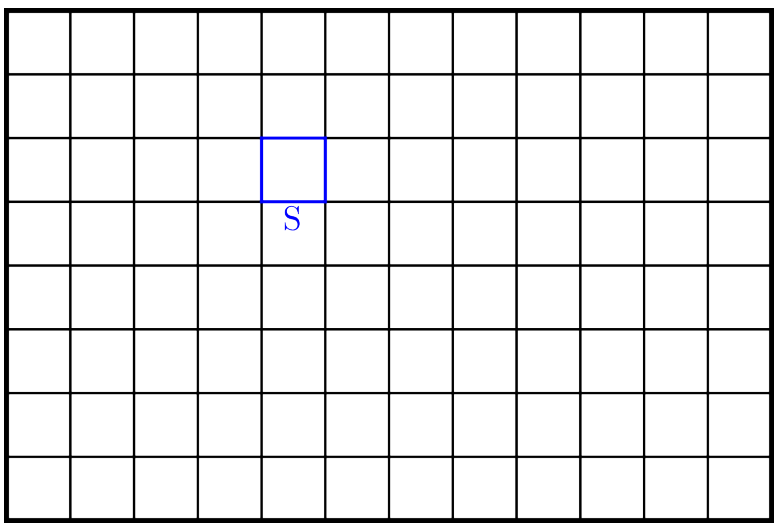
400 superpixels

400 superpixels

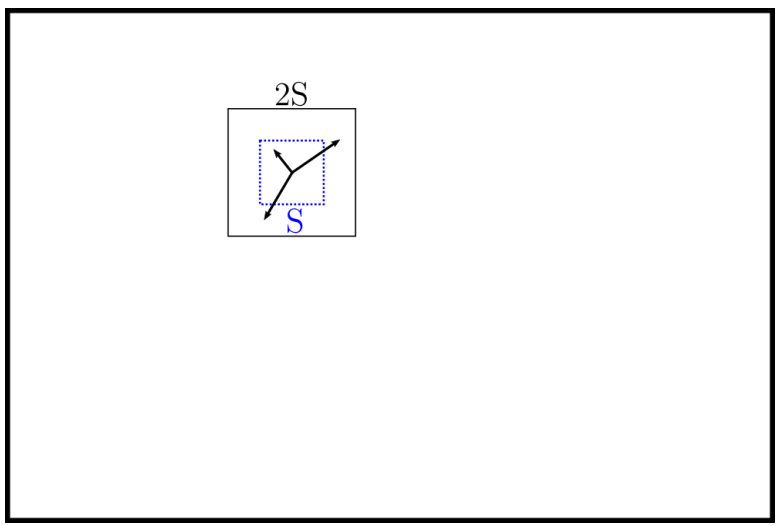
Simple Linear Iterative Clustering (SLIC) - (Achanta, et al. 2012)

- State-of-the-art results on standard superpixel metrics
- Produces regular superpixels in limited computational time

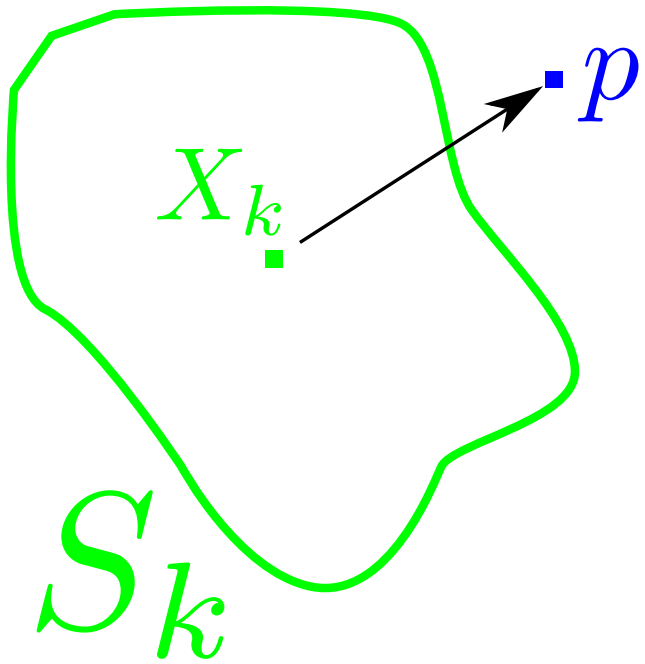
Regular grid initialization



Constrained K-means clustering



SLIC - Distance



Distance between pixel p, and average cluster C_k of S_k:

$$D(p, C_k) = d_c(p, C_k)^2 + d_s(p, C_k)^2 m$$

Pixel $p = [(l_p, a_p, b_p), X_p]$

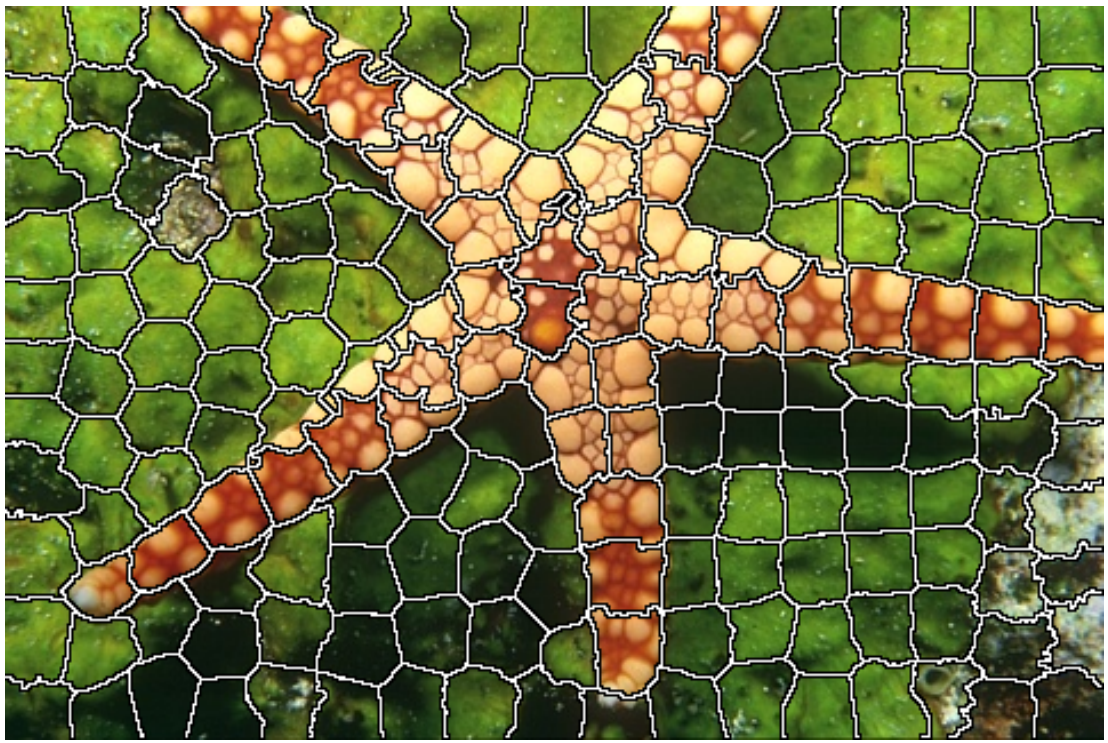
Average feature cluster $C_k = [(l_k, a_k, b_k), X_k]$

d_c color distance

d_s spatial distance

SLIC - Limitations

Parameter m globally set for the whole image



SLIC result

Difficulty to maximize all aspects:
Adherence to contours $\neq$ Color homogeneity $\neq$ Decompositon regularity

Superpixels with Contour Adherence using Linear Path (SCALP)

$\rightarrow$ Enforces respect of image contours, color homogeneity and compactness at the same time

- Definition of the linear path to superpixel barycenter
- Additional features within the clustering distance

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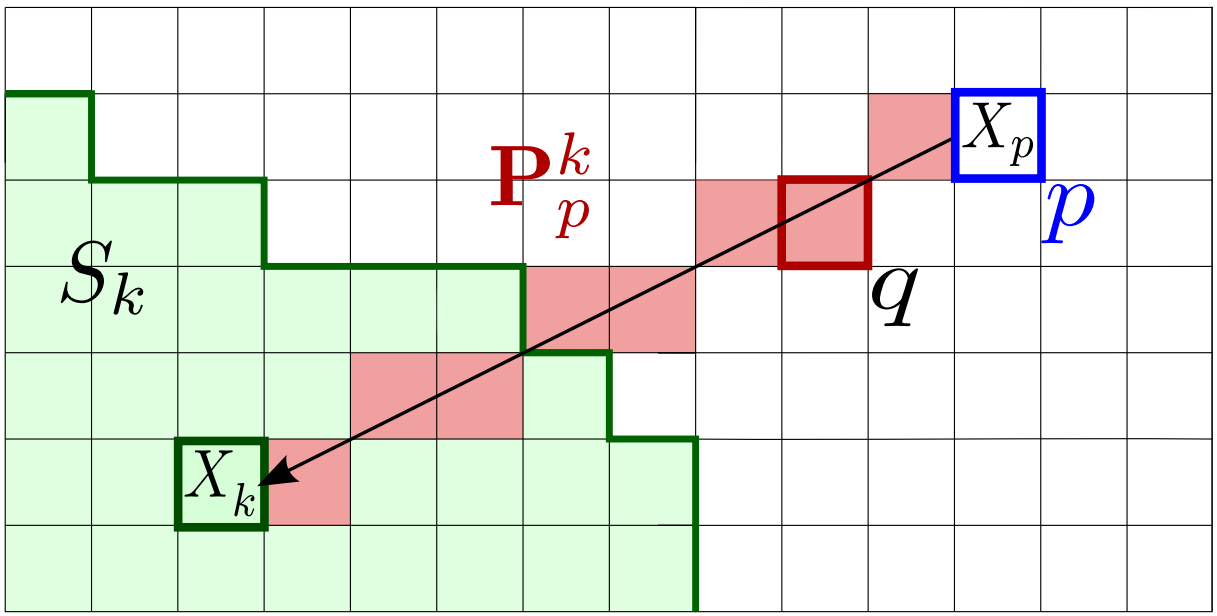
SCALP result

SCALP - Linear Path Definition

Path between pixel p at position X_p and superpixel S_k of barycenter X_k

Near real-time computation (Bresenham, et al. 1965)



SCALP - Features on Linear Path $\mathbf{P}_p^k$

Improvement of color distance:

$$d_c(p, C_k) = (l_p - l_{C_k})^2 + (a_p - a_{C_k})^2 + (b_p - b_{C_k})^2$$

$$\rightarrow d_c(p, C_k, \mathbf{P}_p^k) = \lambda d_c(p, C_k) + (1 - \lambda) \frac{1}{|\mathbf{P}_p^k|} \sum_{q \in \mathbf{P}_p^k} d_c(q, C_k)$$

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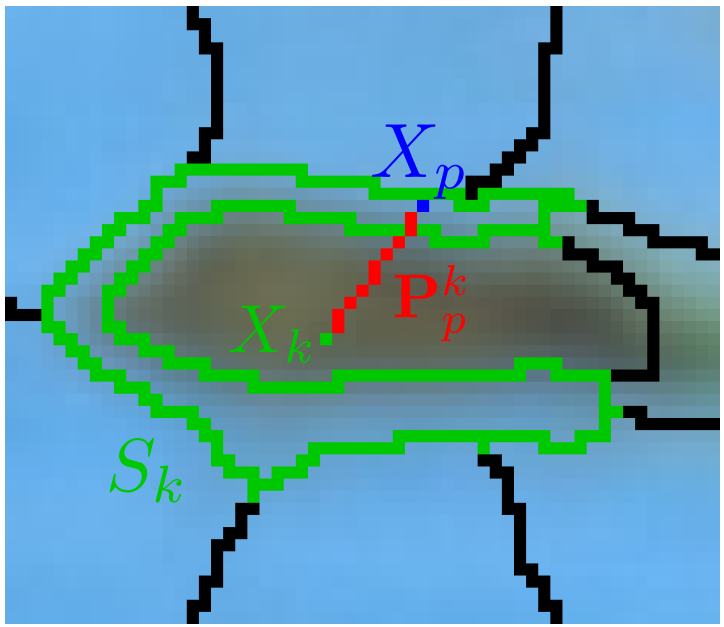

SCALP Framework

Properties:

- Regularity/compactness of the decomposition ✓
- Homogeneity of the color clustering ✓
- Adherence to the image contours

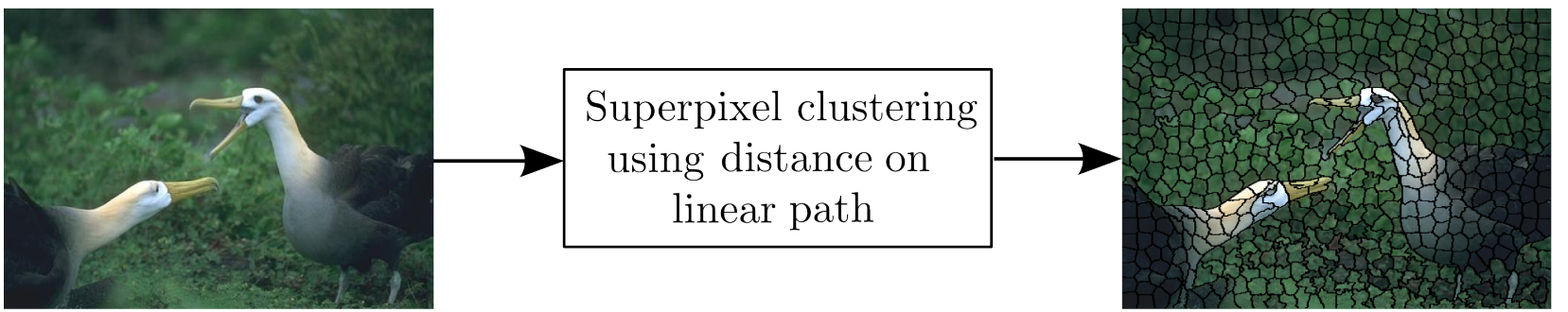

image *superpixel decomposition*

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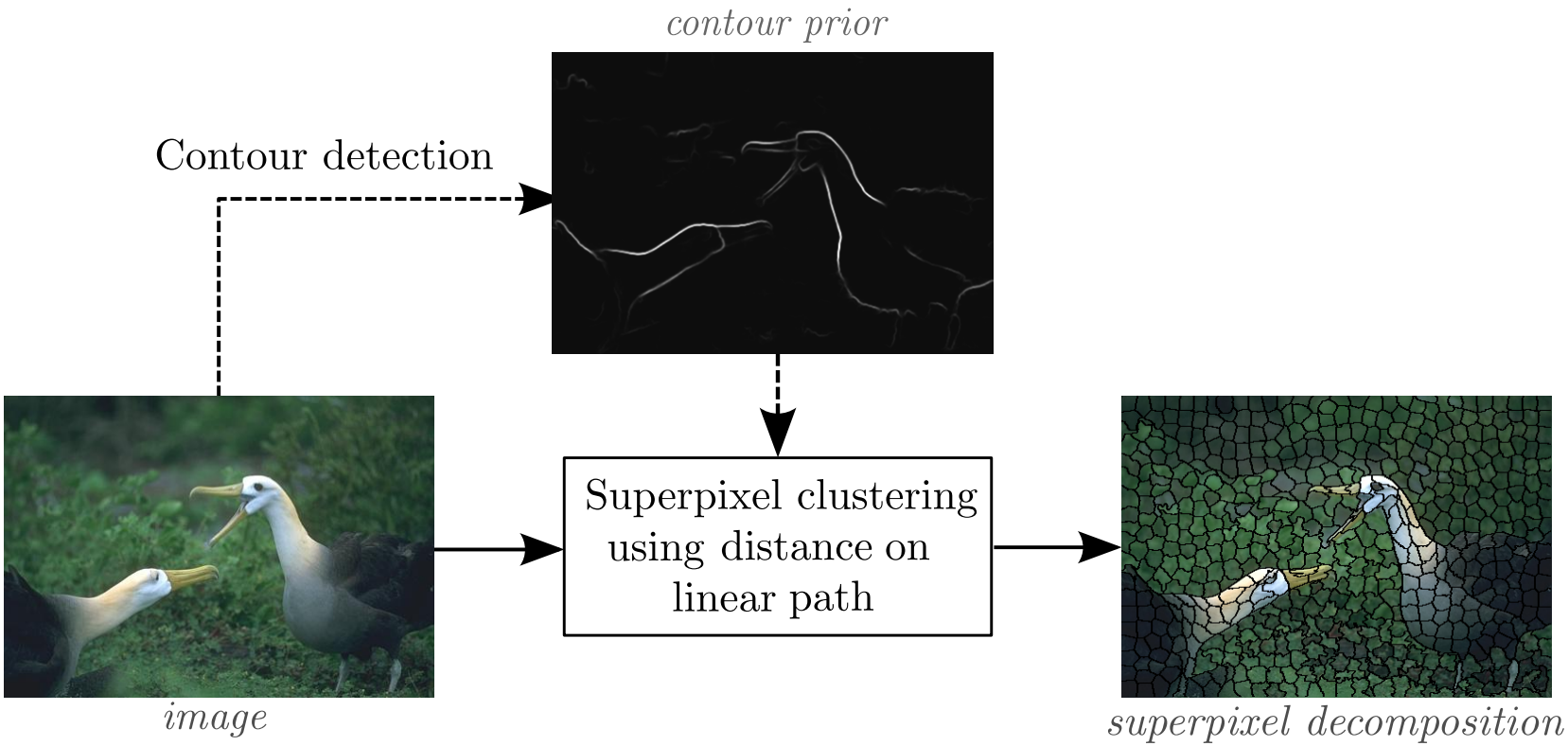
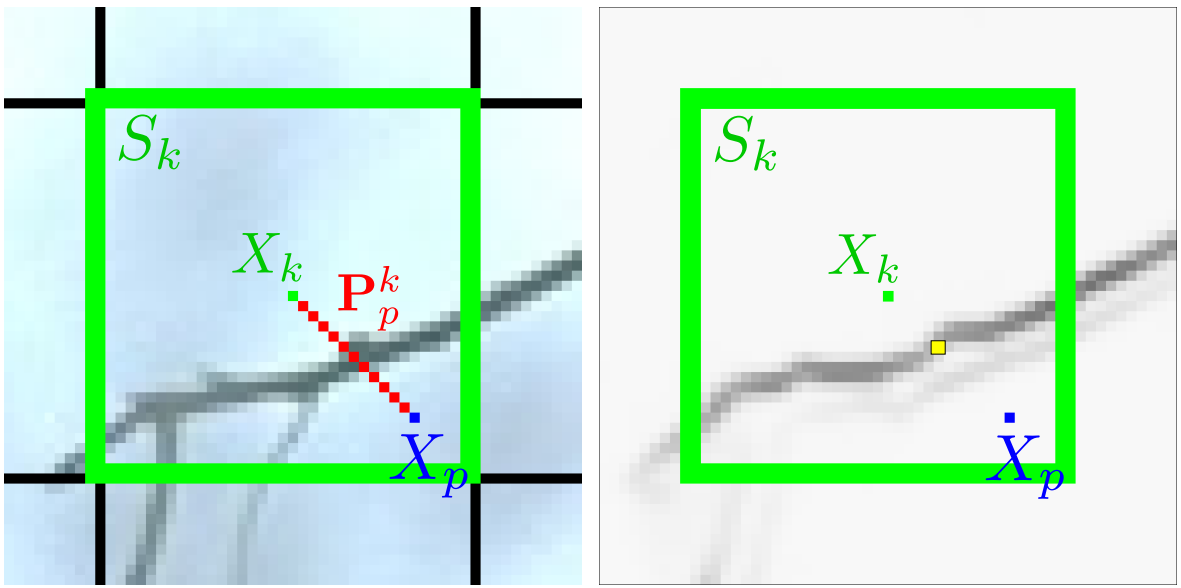


SCALP - Features on Linear Path $\mathbf{P}_p^k$

Use of Contour prior:

$$d_{\mathcal{C}}(p, C_k, \mathbf{P}_p^k) = 1 + \gamma \max_{q \in \mathbf{P}_p^k} \mathcal{C}(q)$$



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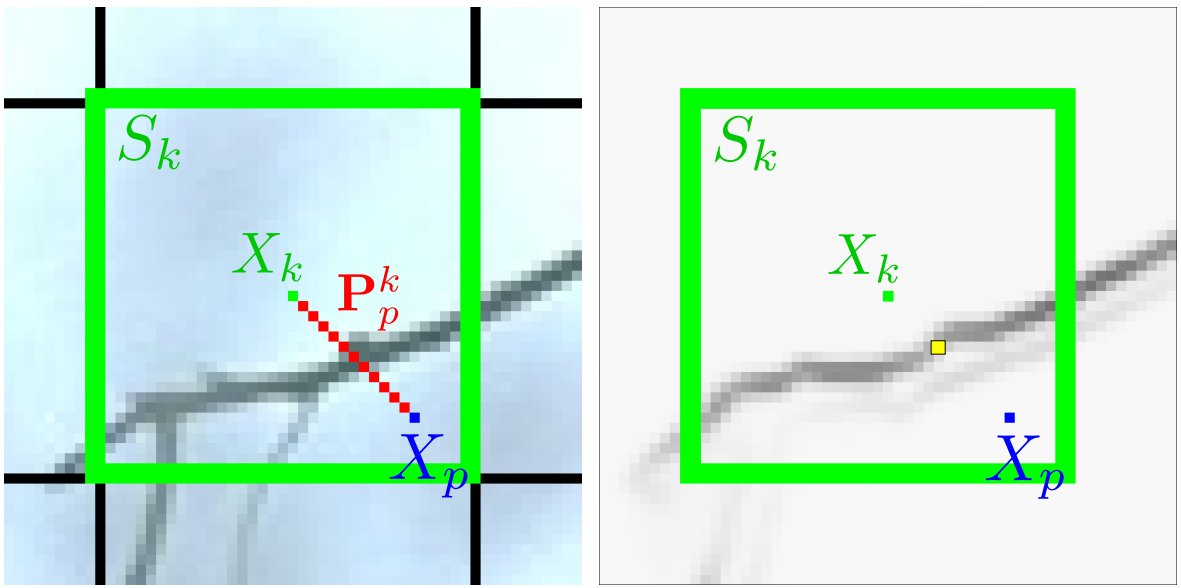
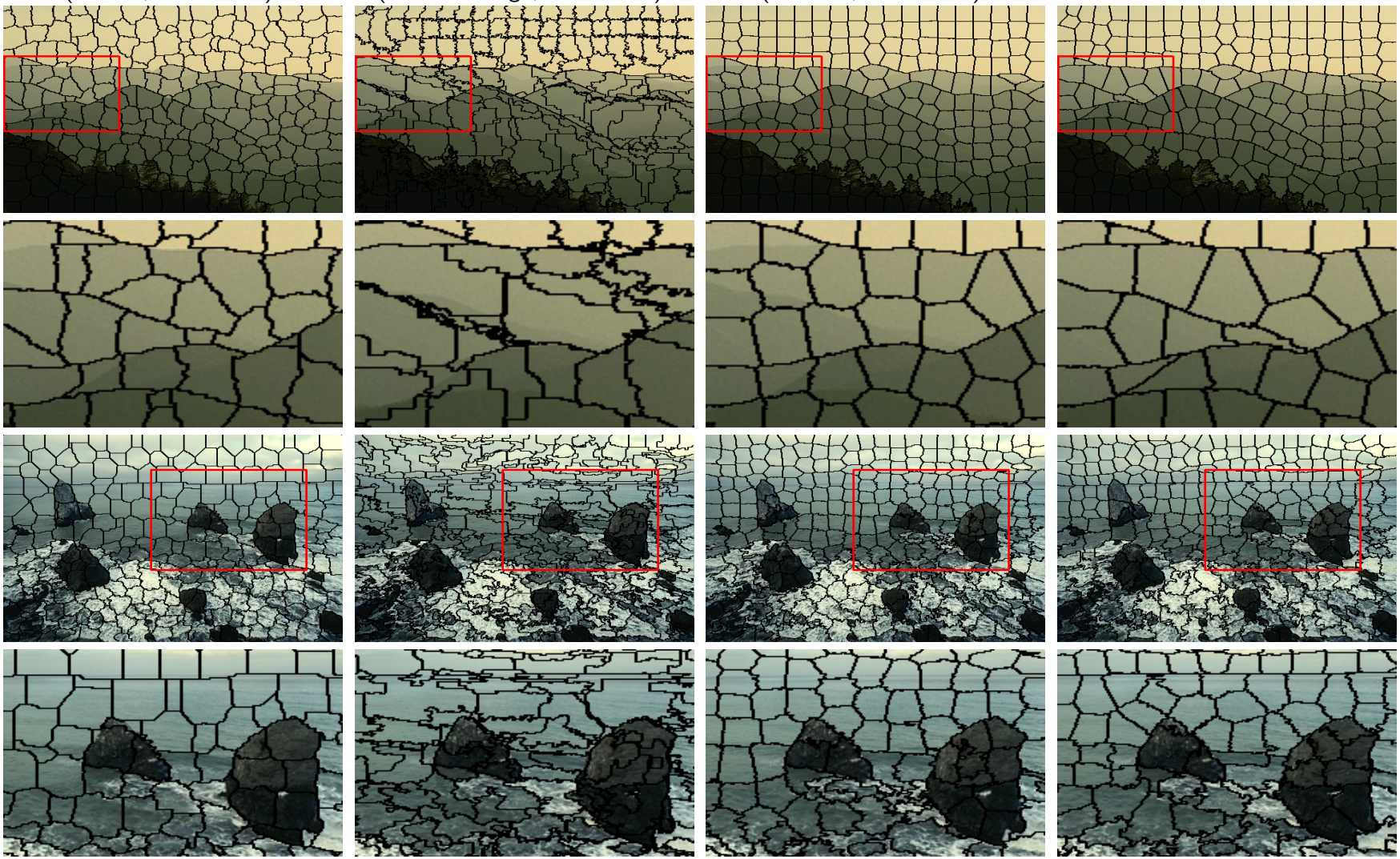


Improved clustering distance:

$$D(p, C_k) = \left(d_c(p, C_k, \mathbf{P}_p^k) + d_s(p, C_k) m \right) d_{\mathcal{C}}(p, C_k, \mathbf{P}_p^k)$$

Example Results



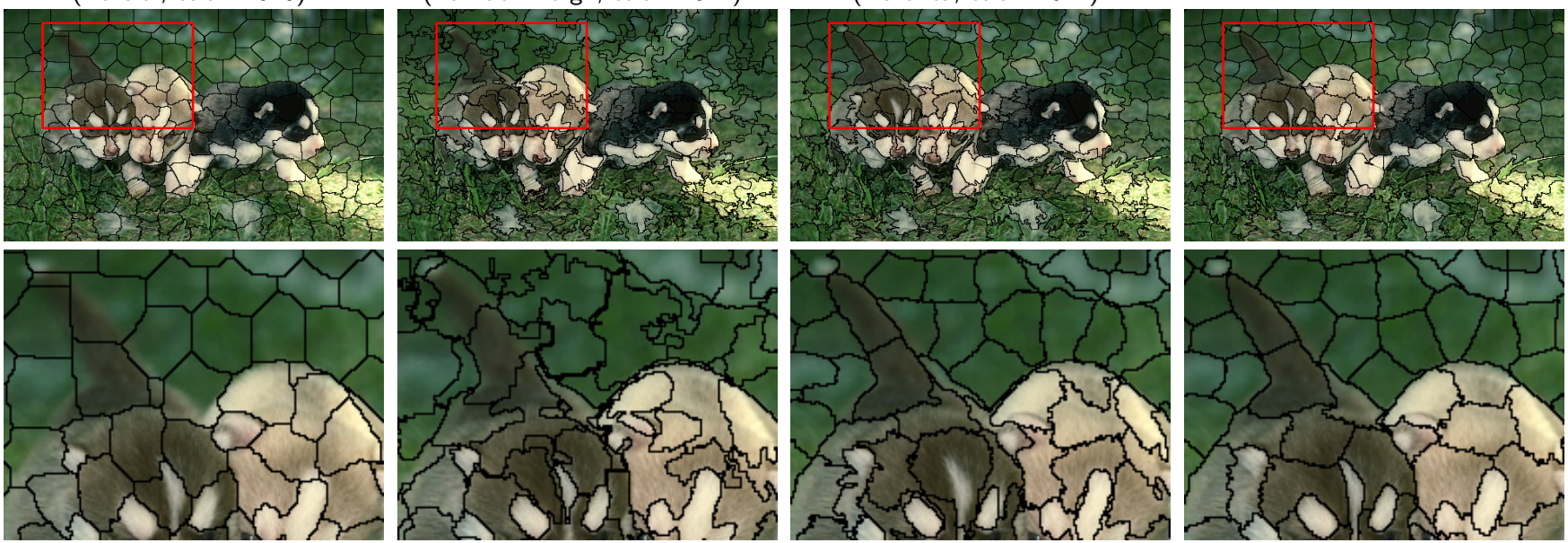
Example Results

GC
(Veksler, et al. 2010)

SEEDS
(Van den Bergh, et al. 2012)

SLIC
(Achanta, et al. 2012)

SCALP



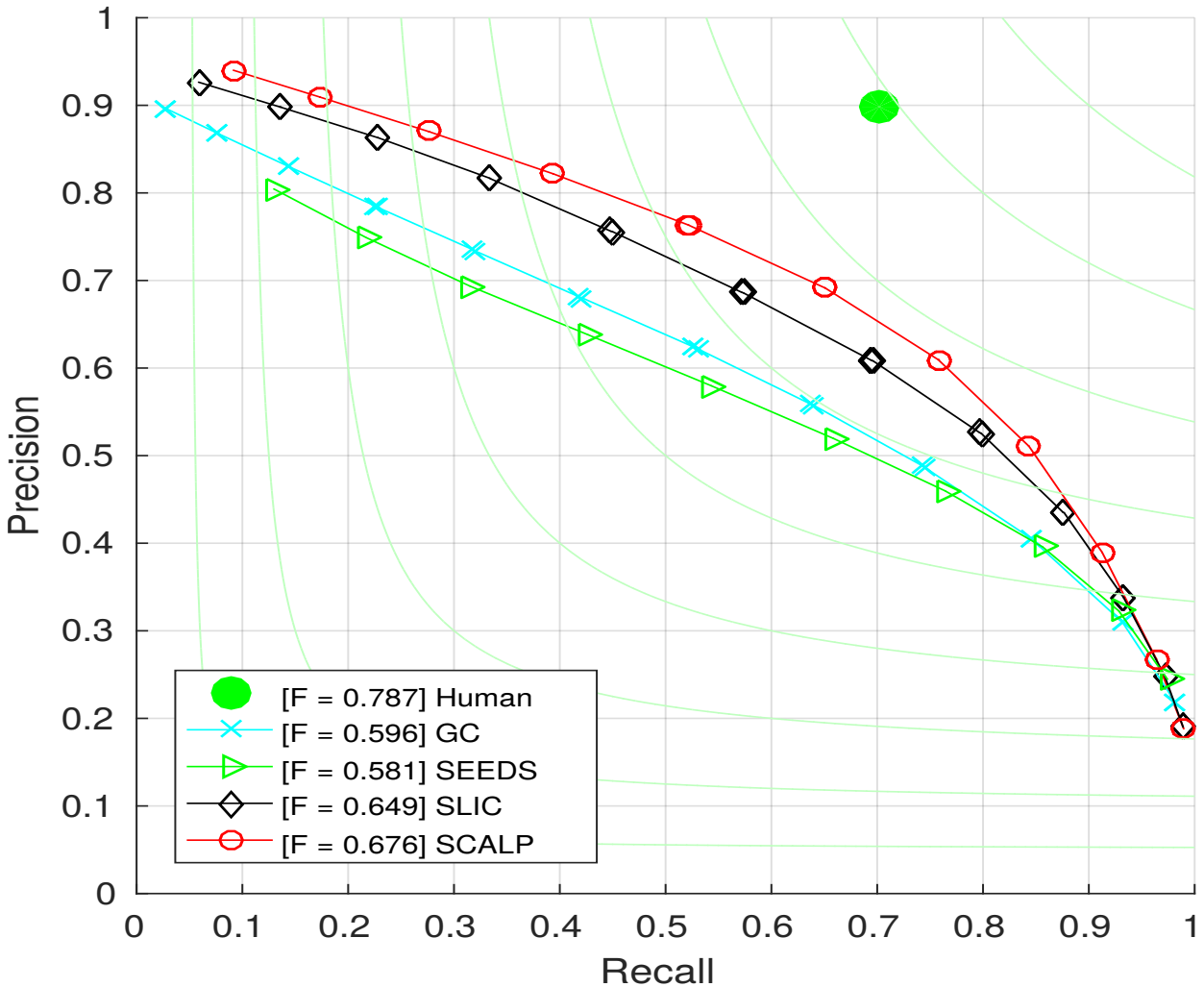
Quantitative Results

Validation on Berkeley segmentation dataset (BSD) (Martin, et al. 2001)
200 test images with human ground truth segmentations

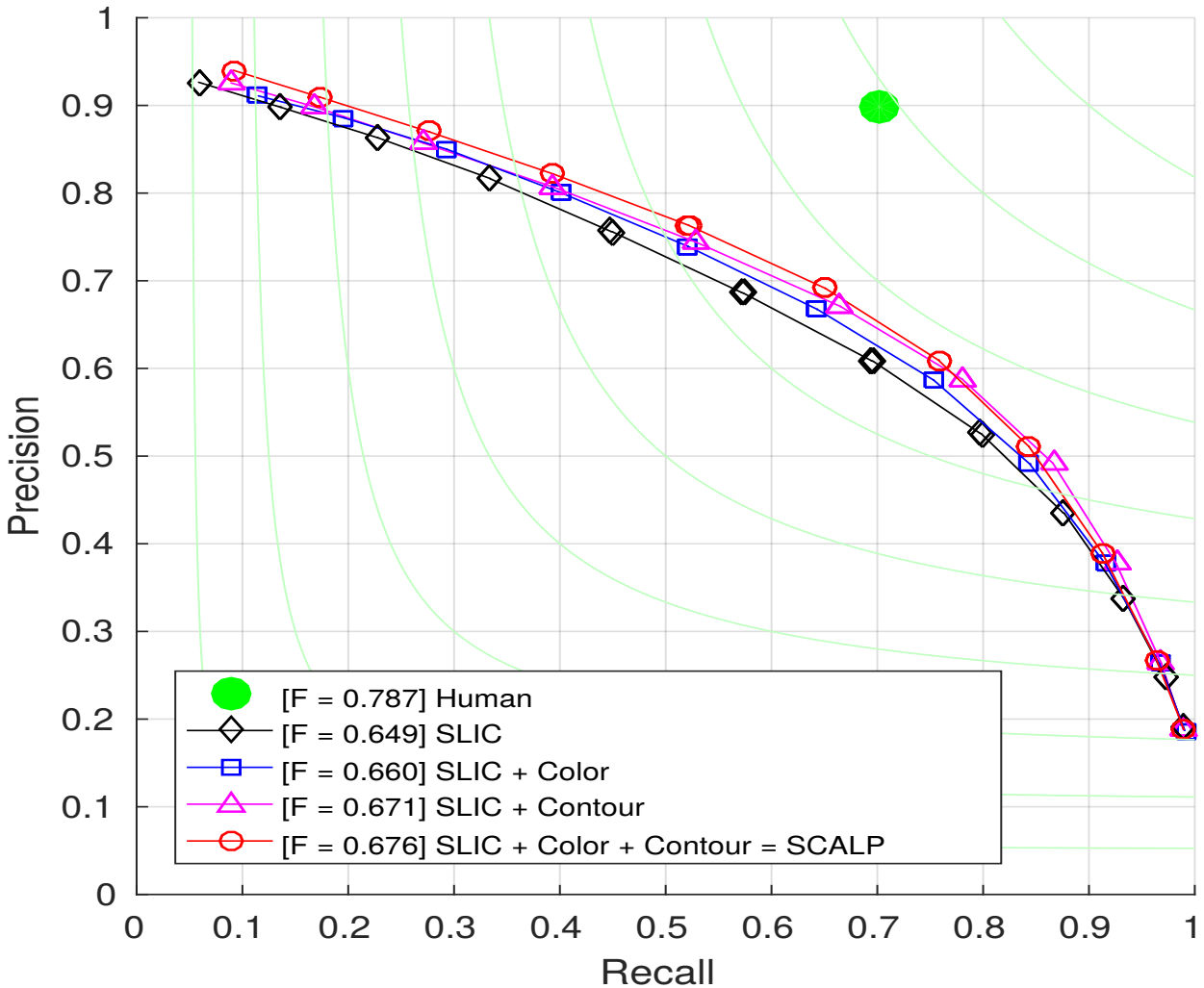
- Undersegmentation Error (UE): Overlap with multiple objects
- Compactness: Regularity of the produced superpixels
- F-measure: Contour detection performances (PR) (Martin, et al. 2004)

Method	UE ↓	Compactness ↑	F-measure ↑
GC (Veksler, et al. 2010)	0.161	**0.520**	0.596
SEEDS (Van den Bergh, et al. 2012)	0.134	0.201	0.581
SLIC (Achanta, et al. 2012)	0.135	0.269	0.649
SCALP	**0.130**	0.278	**0.673**

Quantitative Results (PR)



Quantitative Results (PR) - Influence of parameters



Conclusion

SCALP method summary

- New general method to use color and contour features along linear path
- Increase of contour adherence, compactness and respect of image objects
- Limited computational time (< 0.4s)

Work in progress

- Use of advanced color features (Li et al., 2015) $\rightarrow$ State-of-the-art results

Perspectives

- Adaptation to supervoxels (3D and video)

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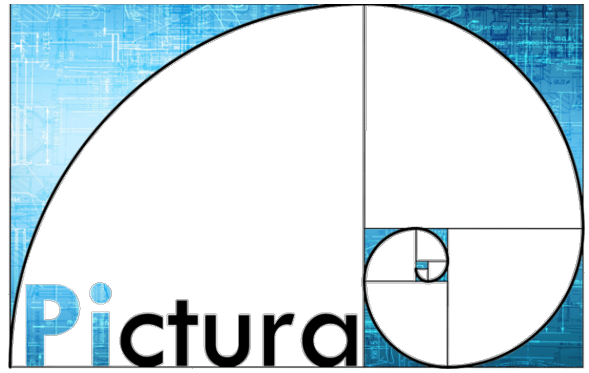

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Superpixel Metrics

Superpixel segmentation $\mathcal{S}$, Ground-truth segmentation $\mathcal{G}$

Precision-Recall Framework: (Average of superpixel boundaries on several scales)

$$R = |\mathcal{B}(\mathcal{S}) \cap \mathcal{B}(\mathcal{G})|/|\mathcal{B}(\mathcal{G})|$$
$$P = |\mathcal{B}(\mathcal{S}) \cap \mathcal{B}(\mathcal{G})|/|\mathcal{B}(\mathcal{S})|$$
$$F = (2.P.R)/(P+R)$$

Undersegmentation Error: (Overlap with multiple objects)

$$\mathrm{UE}(\mathcal{S},\mathcal{G}) = \frac{1}{|I|}\sum_i \sum_{k:S_k \cap G_i \neq \emptyset} |S_k \backslash G_i|$$

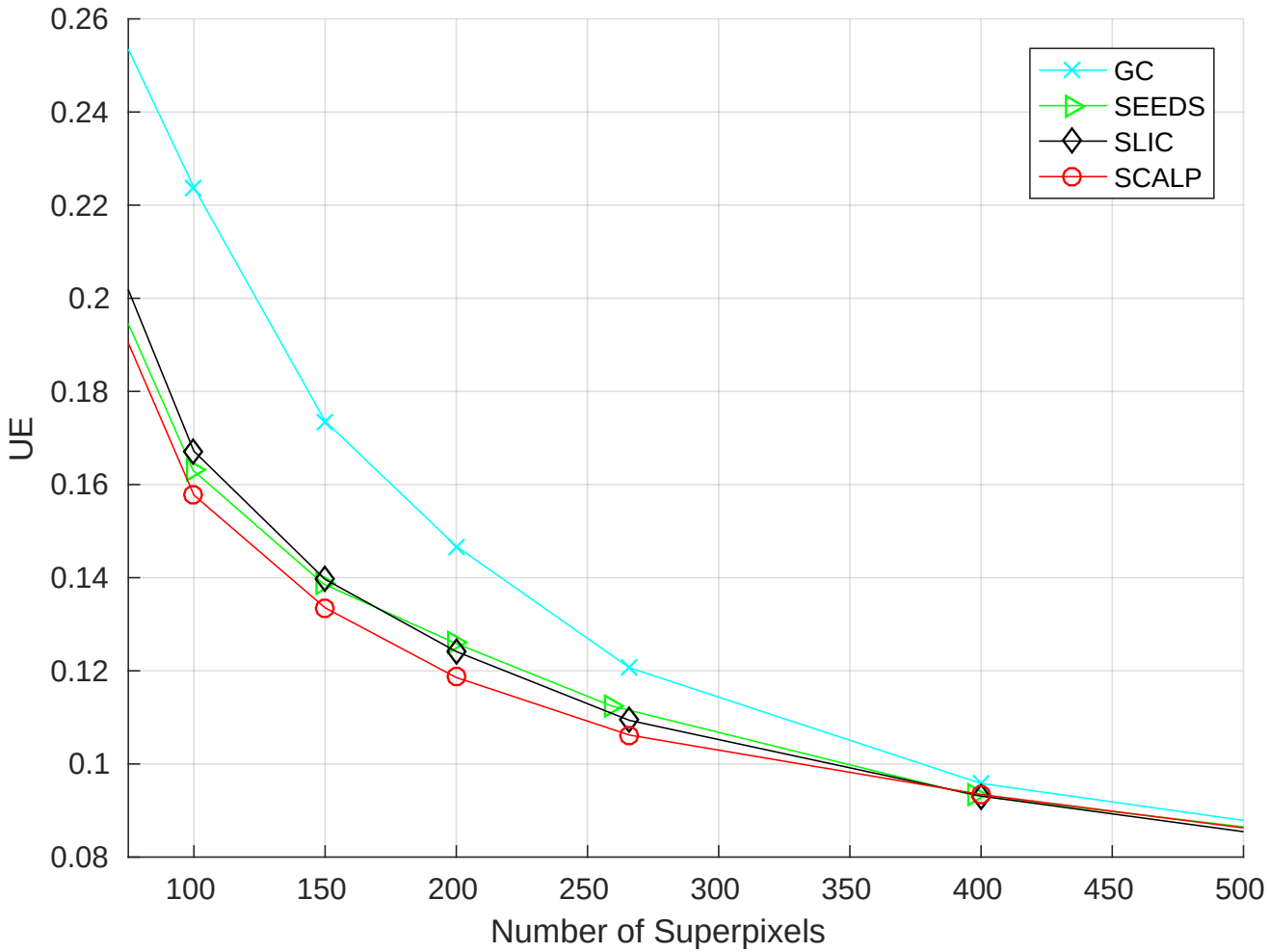
Achievable Segmentation Accuracy: (Respect of image objects)

$$\mathrm{ASA}(\mathcal{S},\mathcal{G}) = \frac{1}{|I|}\sum_k \max_i |S_k \cap G_i|$$

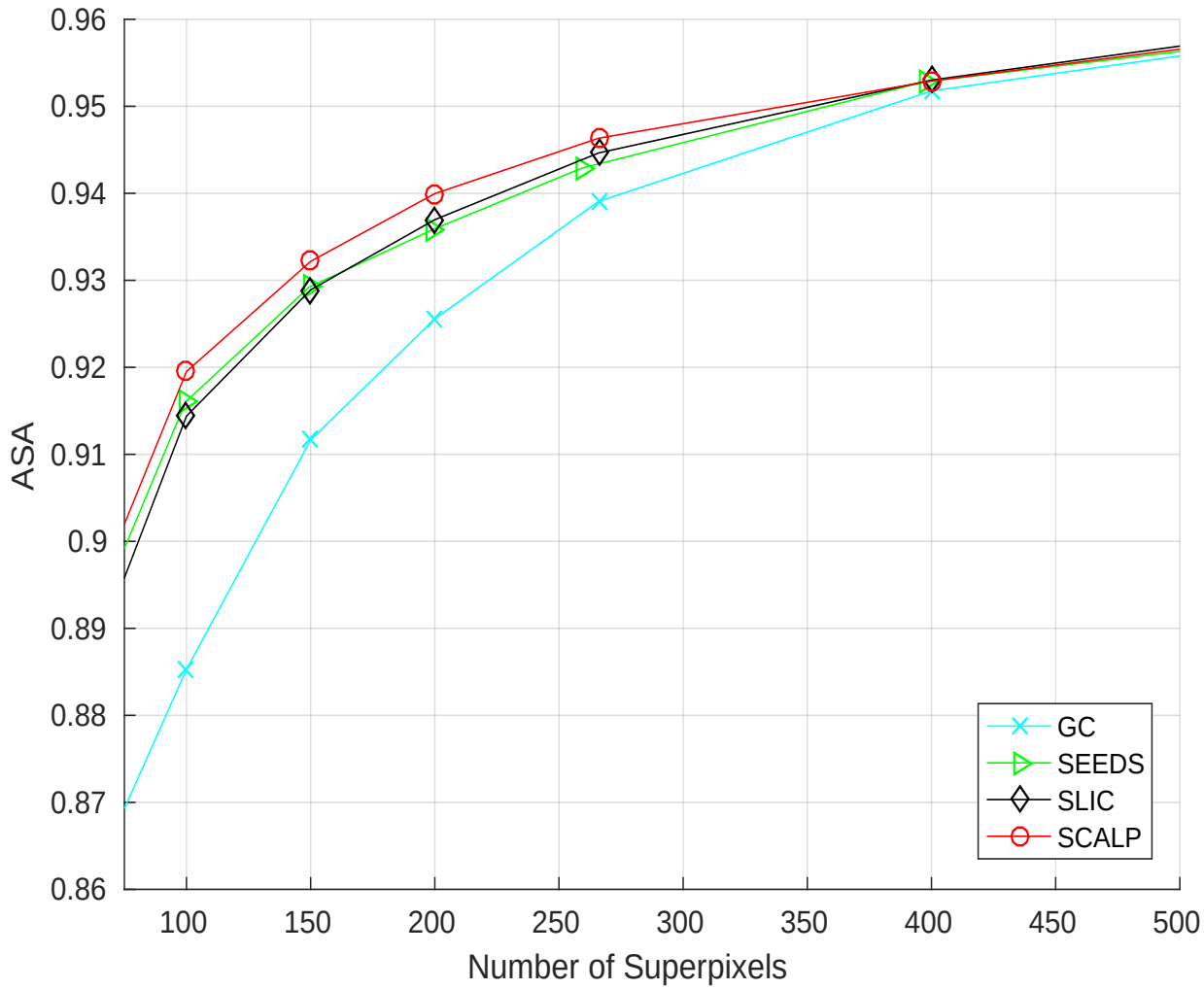
Compactness: (Regularity, circularity of the superpixels)

$$\mathrm{CO}(\mathcal{S}) = \frac{1}{|I|}\sum_k \frac{4\pi|S_k|^2}{|\mathcal{B}(S_k)|^2}$$

Quantitative Results (UE)

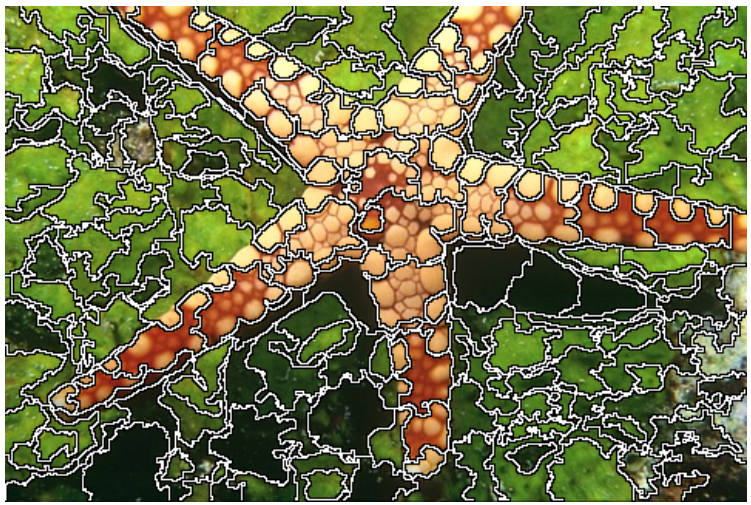


Quantitative Results on BSD (ASA)

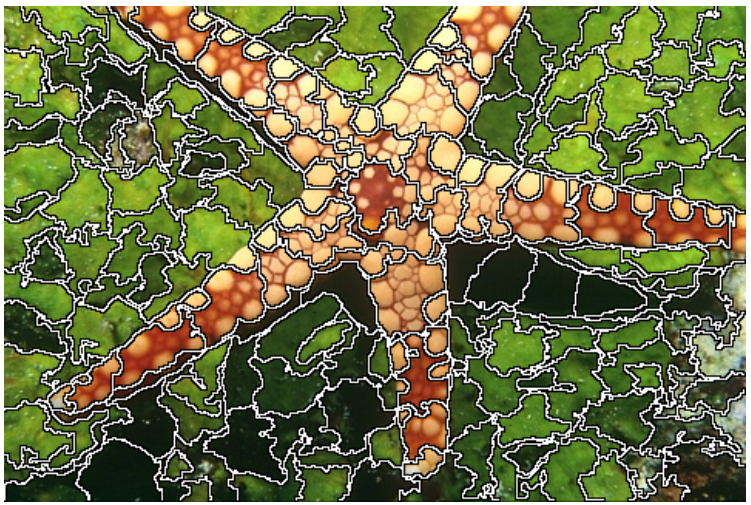


SLIC - Limitations

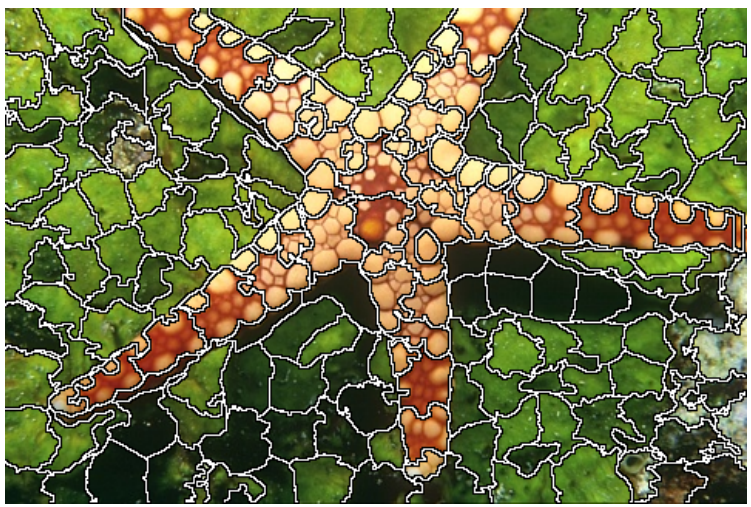
$m = 5$



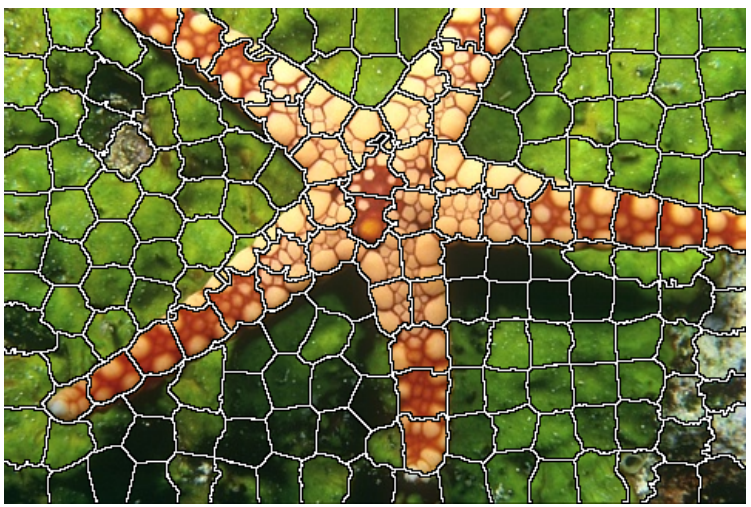
$m = 10$



$m = 20$



$m = 50$



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