Generalized Shortest Path-based Superpixels for Accurate Segmentation of Spherical Images

Rémi Giraud, Rodrigo Borba Pinheiro, Yannick Berthoumieu

Bordeaux INP, Univ. Bordeaux, CNRS, IMS, UMR 5218, F-33400 Talence, France

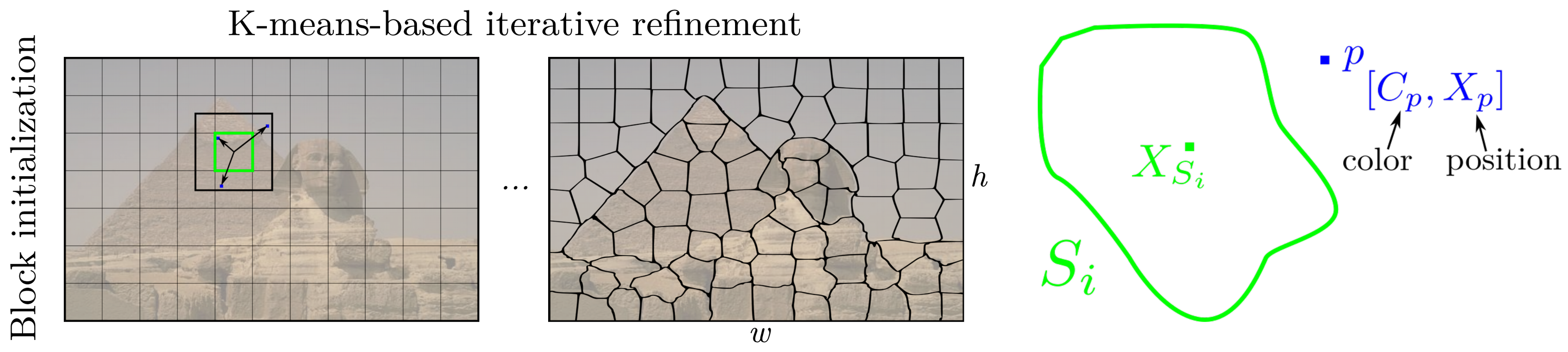
remi.giraud@ims-bordeaux.fr   https://github.com/rgiraud/sphsps

Abstract

Most of existing superpixel methods are designed to segment standard planar images as pre-processing for computer vision pipelines. Nevertheless, the increasing number of applications based on wide angle capture devices, mainly generating 360° spherical images, have enforced the need for dedicated superpixel approaches. In this paper, we introduce a new superpixel method for spherical images called SphSPS (for Spherical Shortest Path-based Superpixels). Our approach respects the spherical geometry and generalizes the notion of shortest path between a pixel and a superpixel center on the 3D spherical acquisition space. To relevantly evaluate this last aspect in the spherical space, we also generalize a planar global regularity metric. Finally, the proposed SphSPS method obtains significantly better performances than both planar and spherical recent superpixel approaches on the reference 360° spherical panorama segmentation dataset.

Spherical Superpixels based on SLIC [1]

- **SLIC (Simple Linear Iterative Clustering) [2]:**



$$D_{\text{SLIC}}(p, S_i) = d_{\text{color}}(C_p, C_{S_i}) + d_{\text{spatial}}(X_p, X_{S_i})$$

- **Adaptation to spherical geometry SphSLIC [1]:**
  - Search area: Regular in the acquisition (spherical) space

  - Distance $d_{\text{spatial}} = \|X_p^a - X_{S_i}^a\|_2^2$ on spherical coordinates X^a :

$$\text{X}^a = \begin{bmatrix} x^a = \sin(\frac{y\pi}{h})\cos(\frac{2x\pi}{w}) \\ y^a = \sin(\frac{y\pi}{h})\sin(\frac{2x\pi}{w}) \\ z^a = \cos(\frac{y\pi}{h}) \end{bmatrix} \leftrightarrow X = \begin{bmatrix} x = \frac{\text{arctan2}(y^a, x^a)w}{2\pi} \\ y = \frac{\arccos(z^a)h}{\pi} \end{bmatrix}$$

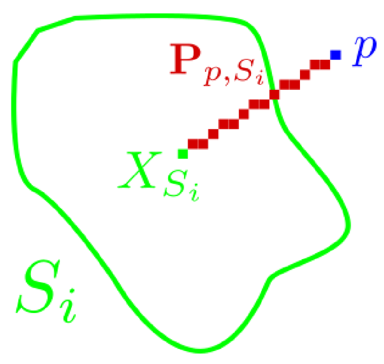
→ Same SLIC limitations: non-robustness to noise, irregular shapes, poor contour adherence, ...

Spherical Shortest Path-based Superpixels (SphSPS)

- **Shortest path-based distance:**

  SCALP (Superpixels with Contour Adherence using Linear Path) [3]

  - Color distance of each pixel in linear path $\mathbf{P}_{p,S_i}$ to the barycenter of the superpixel
    → Robustness to noise + regular shapes
  - Maximum of contour map intensity on $\mathbf{P}_{p,S_i}$
    → Respect of object contours



$$D_{\text{SPS}}(p, S_i) = (d_{\text{color}}(C_p, C_{S_i}, \mathbf{P}_{p,S_i}) + d_{\text{spatial}}(X_p, X_{S_i}))\, d_{\text{contour}}(\mathbf{P}_{p,S_i})$$

- **Generalized shortest path:**

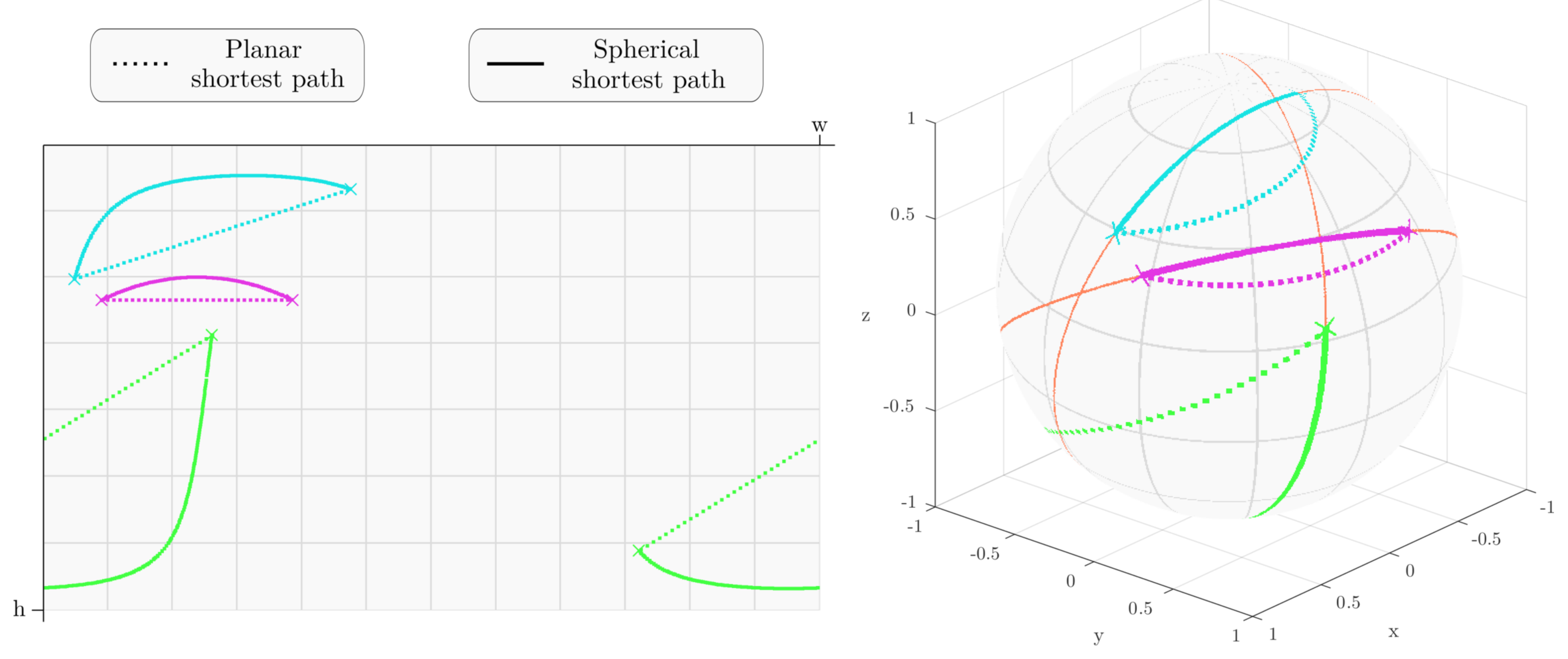
$$\mathbf{P}_{p,S_i} = \mathbf{P}^a_{p,S_i} \overrightarrow{\text{proj}} \{\mathbb{N}^2\}$$

$\mathbf{P}_{p,S_i}$ Path in planar space

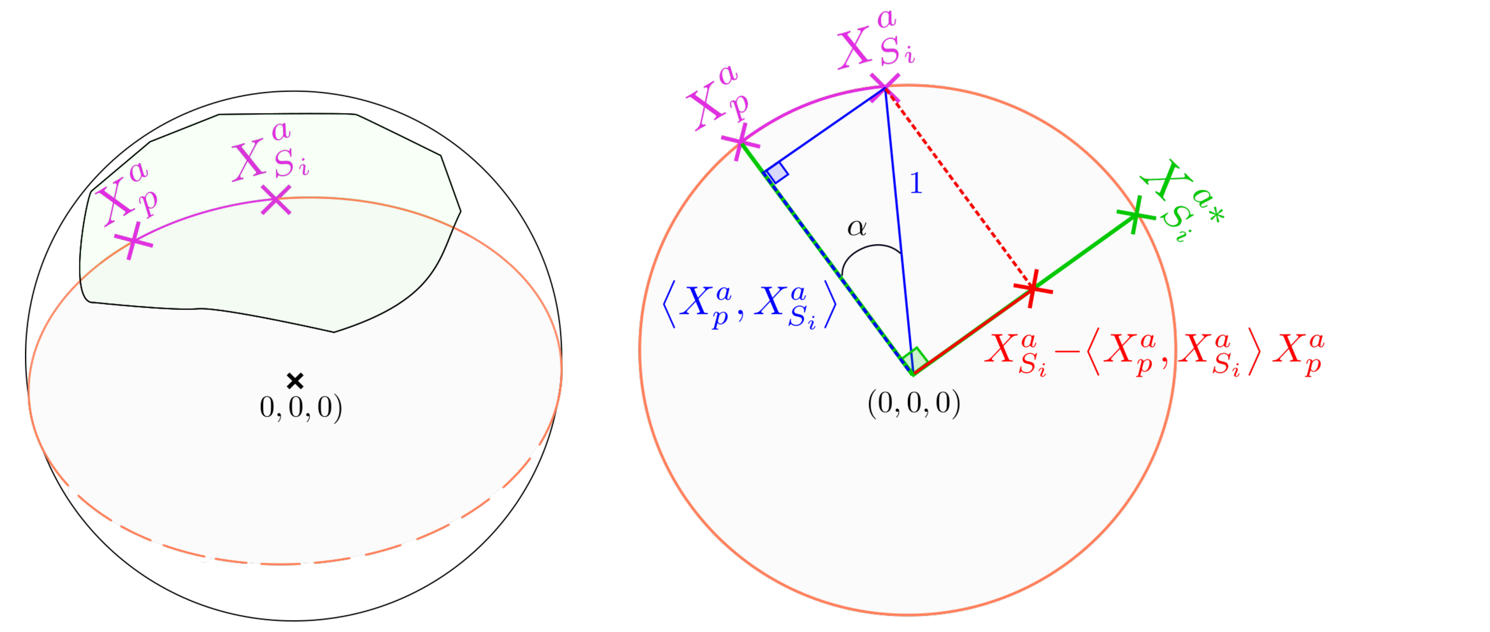
$\mathbf{P}^a_{p,S_i}$ Shortest Path in acquisition space

- **Spherical acquisition space:**

  The shortest path $\mathbf{P}^a_{p,S_i}$ follows the geodesic along the great circle (containing the two points and the sphere center)



- **Fast discrete implementation:** N sampled points on the great circle

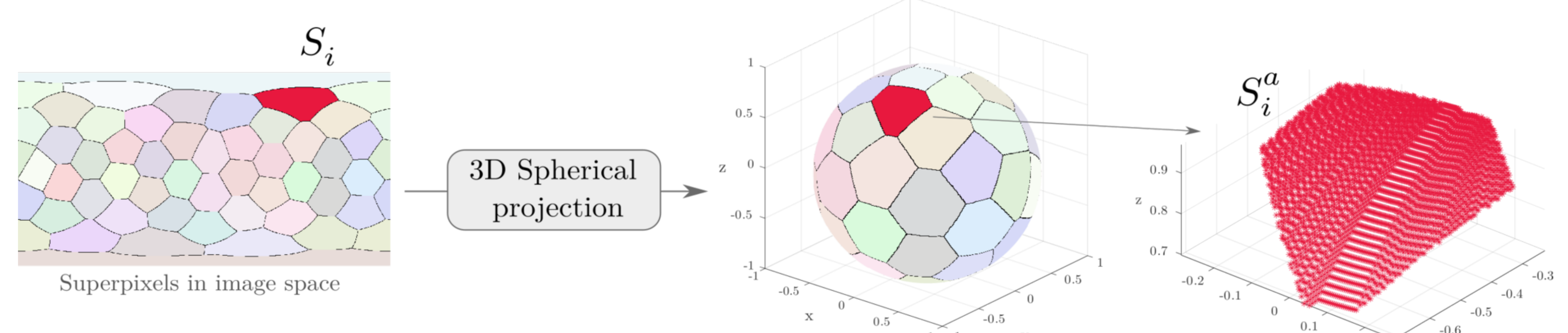


$$\mathbf{P}^a_{p,S_i} = \cos(\alpha_{\mathbf{N}})X_p^a + \sin(\alpha_{\mathbf{N}})X_{S_i}^{a*} \quad \text{with } \alpha_{\mathbf{N}} = \frac{[0, N-1]}{N-1}\alpha \in \mathbb{R}^N$$

- **Recursive optimization using path redundancy:**
  → SphSPS runs in 0.7s for 1024×512 images (SphSLIC [2] ≈ 2.5s)

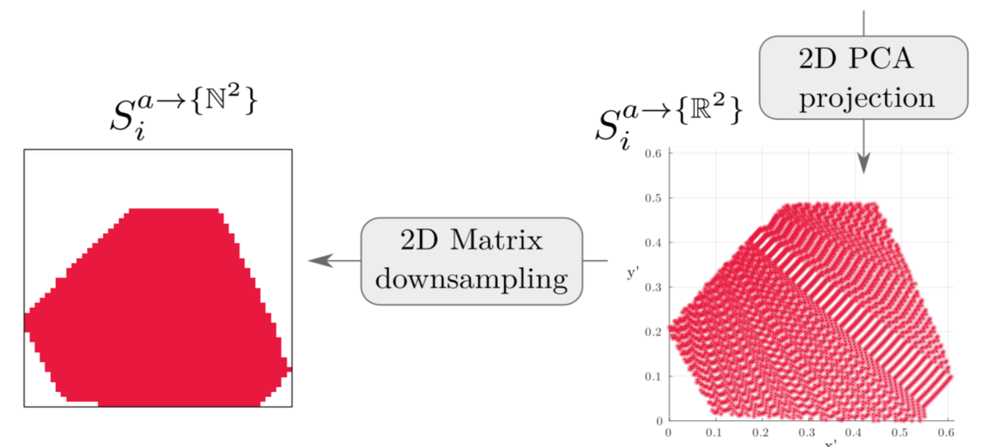
Generalized Global Regularity Metric (G-GR)

- **Extension of robust Global Regularity using 2D convex hull [4]:**



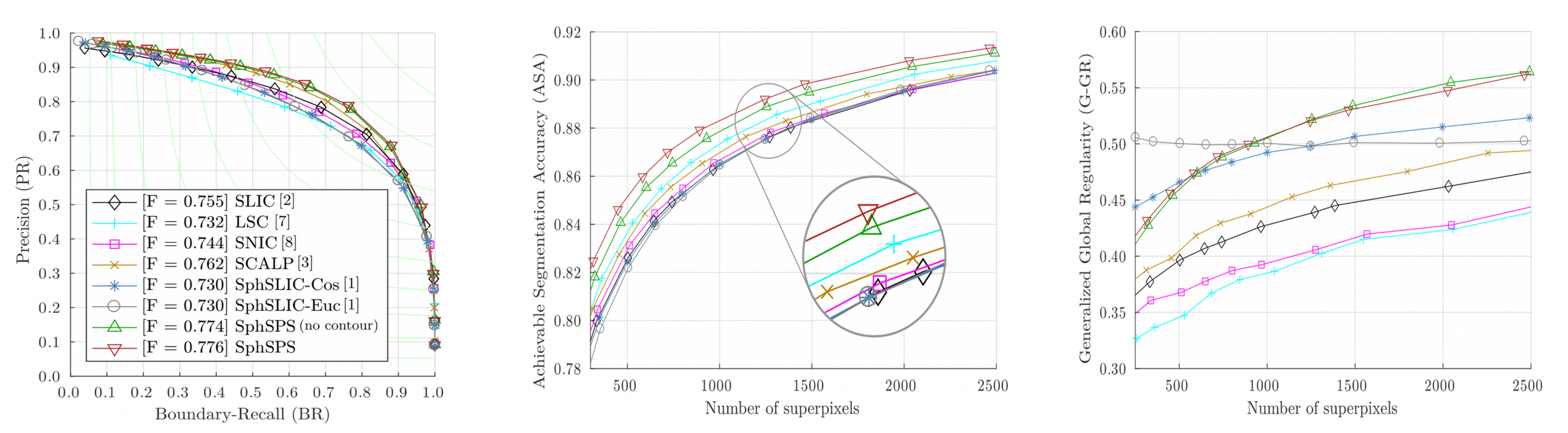
For each superpixel shape S_i :

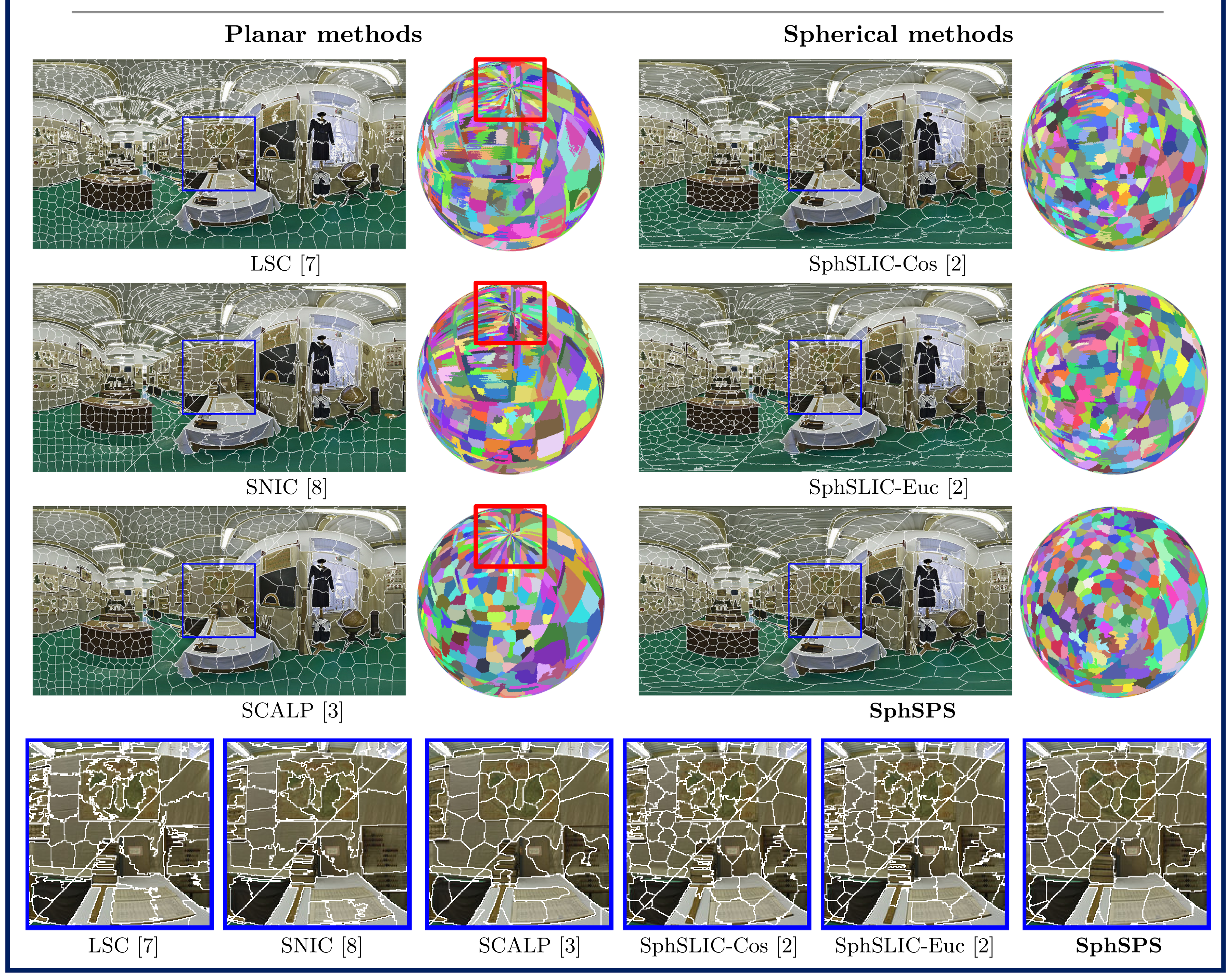
1. Spherical projection on $\mathbb{R}^3$
2. 2D PCA projection on $\mathbb{R}^2$
3. Downsampling for dense discretization on $\mathbb{N}^2$
4. Measure of Global Regularity [4]



Results

- **Validation**
  - Dataset. *Panorama Segmentation* : 75 images (1024x512) + ground truth seg. [5]
  - Metrics. Contour detection (F-measure), object segmentation (ASA [6]) and G-GR
- **Comparison to state-of-the-art methods:**
  → Best accurate and spherically regular results with SphSPS





References :

[1] - Q. Zhao et al., "Spherical superpixel segmentation," Trans. on Multimedia, 2018

[2] - R. Achanta et al., "SLIC superpixels compared to state-of-the-art superpixel methods," PAMI, 2012

[3] - R. Giraud et al., "Robust superpixels using color and contour features along linear path," CVIU, 2018

[4] - R. Giraud et al., "Evaluation framework of superpixel methods with a global regularity measure," JEI, 2017

[5] - L. Wan et al., "Spherical superpixels: benchmark and evaluation," ACCV, 2018

[6] - M.-Y. Liu et al., "Entropy rate superpixel segmentation," CVPR, 2011

[7] - J. Chen et al., "Linear spectral clustering superpixel," TIP, 2017

[8] - R. Achanta et al., "Superpixels and polygons using simple non-iterative clustering," CVPR, 2017