Detecting Salient Sharp Features for 3D Alpha Wrapping

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Discrete geometric representations such as meshes are a crucial part of engineering simulation pipelines. The success and fidelity of numerical methods heavily depend on the accurate representation of the domain, while the pre-processing step of geometry manipulation and mesh generation is one of the most important efficiency bottlenecks in such methods. The challenge is more prominent in modern, real-world applications, where we have to deal with detailed and large-scale datasets, often coming from a variety of sources ranging from traditional CAD modelling to 3D scanning.

The aim of this research position is to revisit discretization methodologies in view of modern requirements and computational capabilities. The candidate will focus on developing mesh generation algorithms meeting the following criteria:

- automatic: requiring minimal user intervention
- generic: being agnostic to the nature of the input
- unconditionally robust: resilient to defects and ill-posed data
- efficient: being able to scale for millions of elements

Traditional methods based on Delaunay triangulation (3D mesh generation, 3D alpha wrapping) typically strive to achieve high geometric accuracy and high-quality elements. While this approach is proven effective for precise mesh generation, it lacks the ability to represent high-level insights about the domain. We want to address this limitation by developing tools that identify and process salient features and/or regions, in order to obtain a more abstract understanding of the geometric domain.

We define saliency of sharp features as a multi-scale property (*persistent* across scales) that can progressively represent the most prominent features of the domain. At a coarse level, salient features capture a large-scale approximation of the domain, while at finer levels they adapt to local details. Our goal is to provide a progressive level-of-detail mesh generation algorithm based on salient features.

Our initial approach will define saliency as a function of domain visibility. Since direct computation of visibility for the whole domain is intractable due to its high computational complexity, we will explore leveraging machine learning techniques such as reinforcement learning for the efficient exploration of the domain, as well as persistence theory.
Additionally, we aim to extend the concept of saliency maps [1][2], used in 2D image analysis, to the 3D context. We will investigate the use of classification techniques with Graph Neural Networks (GNNs) to generate 3D saliency maps that capture geometric features.

[1] Deep Inside Convolutional Networks: Visualising Image Classification Models and Saliency Maps https://doi.org/10.48550/arXiv.1312.6034

[2] PointCloud Saliency Maps https://doi.org/10.48550/arXiv.1812.01687