Postdoctoral Research Topic

March 4, 2024

- Title of the proposed topic: Error quadrics for learning-based reconstruction of large-scale 3D environments for the smart territories
- Research axis of the 3IA: Axe 4 - AI for Smart and Secure Territories
- Supervisor: Pierre Alliez - pierre.alliez@inria.fr
- Research group: TITANE project-team, Inria center at Université Côte d'Azur

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Apply by sending an email directly to the supervisor.
The application will include:

- Letter of recommendation of the supervisor indicated above
- Curriculum vitæ including the list of the scientific publications
- Motivation letter
- Letter of recommendation of the thesis supervisor

All the requested documents must be gathered and concatenated in a single PDF file named in the following format: LAST NAME of the candidate_Last Name of the supervisor_2024.pdf

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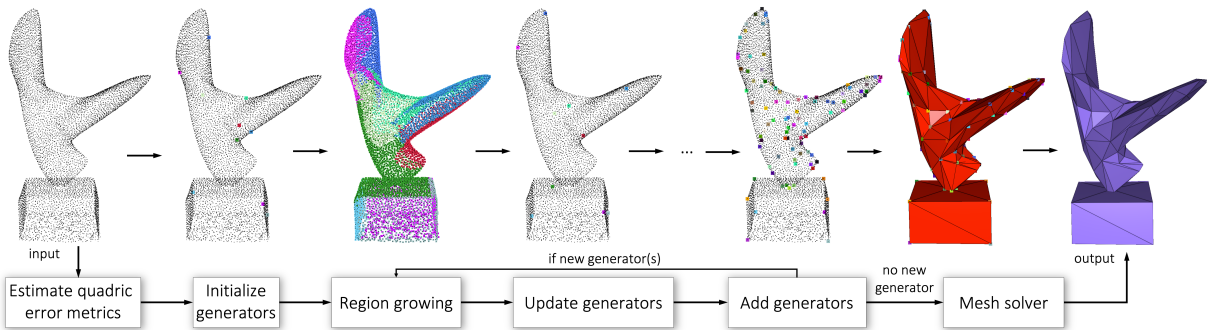

Figure 1: Example of QEM-based variational shape reconstruction as presented by Zhao et al. [2023].

1 Description of the topic

Shape reconstruction is a classic problem in geometry processing—in which one seeks to recover the underlying structure of a digitized scene. Advancements have enabled the practical use of reconstruction for a breadth of real-world tasks, including: urban modelling [Buyukdemircioglu et al., 2022], computer-aided medicine and computational engineering. For such real-world tasks, the input measurements encountered are largely imperfect and noisy; causing the problem to be ill-posed. The ill-posed nature of the problem means that priors must be exploited to solve this challenge. However, the diverse variety of applications for reconstruction mean that no single algorithm has emerged supreme. In the context of AI, the adoption of contemporary data-driven techniques has led to a wealth of problem-specific algorithms that dominate the current state of the art.

This project seeks to complement and expand upon the recent innovative breakthroughs from 3IA supported PhD theses supervised by Pierre Alliez [Zhao et al., 2023, Maruani et al., 2024]. The principal scientific objective is to explore the versatility of the *quadric error metric* (QEM) and the role of AI for reconstructing urban scenes. Given a set of plane equations (or equivalently points with normals), QEM measures the sum of squared distances between the planes and a given query point. For scene reconstruction, QEM possesses two notable properties:

- it exhibits robustness to missing data, being able to rectify structures at corners and edges despite a lack of data;
- and it is capable of uniformly describing and combining multi-modal inputs (*e.g.,* images, volumes, implicit functions and meshes), requiring only positional and tangential information, which can often be approximated.

Despite the seminal work exploiting this observation for the task of mesh simplification two decades ago [Garland and Heckbert, 1997]; remarkably, it has only recently emerged to be a practical tool for reconstruction [Zhao et al., 2023]. This work has inspired us to use the metric to learn to regress quadrics from a signed distance field, and then reconstruct the underlying shape from the optimal points of said quadrics [Maruani et al., 2024]. This is an exciting and promising step towards the development of machinery capable of quality scene reconstruction using quadrics.

These novel techniques have yet to be applied in the context of urban scene reconstruction, and—while these preliminary results are encouraging—they leave several problems open that require further attention. As illustrated in Figure 1, Zhao et al. [2023] encounter a chicken-or-the-egg problem comprising of two inter-dependent tasks. These can be thought of as progressively seeking to find clusters that respect the scene's geometry and topology, while also seeking to determine the scene's geometric and topological properties based on clustering. Off-the-shelf clustering algorithms therefore provide sub-optimal results, and the current heuristic initialization should be replaced by a supervised learning approach for regressing quadric error metrics, including quadrics deriving from multiple planes for sharp creases or corners. It is anticipated that this can be addressed by harnessing data-driven techniques. Note that such clustering differs from works on primitive detection where (often) point clouds are decomposed into large sections that can be represented by a single primitive shape. In the context of reconstructing urban scenes, the scale and complexity of structures varies greatly, and primitive-based methods do not offer the flexibility and scalability desired [Berger et al., 2014, Kaiser et al., 2019].

As a short-term objective, we aim to enhance the rule-based QEM reconstruction framework Zhao et al. [2023] by incorporating learning-based priors for point clustering. Since the resulting output is

highly dependent on the recursive clustering step, overhauling it with a data-driven approach will enable greater control; with the use of task-specific criteria (*e.g.,* no. of vertices/facets, global/local error bounds such as one-sided Hausdorff distance, quality of mesh simplices, geometric/topological constraints, etc.).

As a mid-term objective, we wish to replace the current batch-refinement approach (heuristic and leading to over-refinement) by a supervised learning approach that learns to predicts the impact of a local refinement over the local and global approximation errors.

In the final stage, for Zhao et al. [2023], a combinatorial problem must be solved in order to determine a valid triangulation—free from self intersections and non-manifoldness. Maruani et al. [2024] combine classical techniques to avoid this; however, the result is over-refined. Despite this, the consolidation of these two approaches with penalties to avoid over-refinement are a natural progression for this emerging avenue of research.

References

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