Master Internship in Computer Vision and geometry processing

Efficient data structures and algorithms for processing massive point clouds

Context

Analyzing 3D point clouds captured from real-world environments is a core component of Geometry Processing and 3D Computer Vision. Processing tasks include, for instance, the estimation of local geometric properties, semantic segmentation, extraction of geometric primitives or reconstruction into surface meshes. Algorithms that perform these tasks are typically designed to handle up to a few million points efficiently [1,2]. With the technological advances on sensors and storage capacity, new acquisition protocols generate more and more massive point clouds that contain billions of points, as illustrated in Figure 1. The naive solution then consists in decomposing the space into blocks of reasonable number of points before performing parallel computing. This solution is however prone to border effect errors and does not allow the analyze of point clouds at global scales. Moreover, it requires high computing resources and storage capacity.

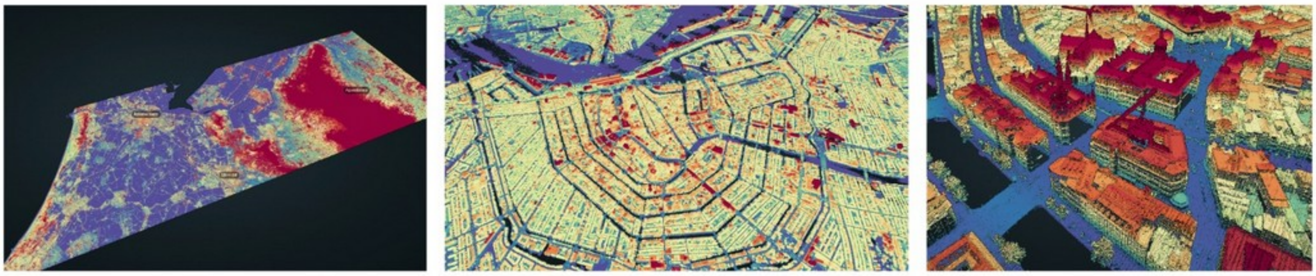

Fig.1 – Illustration of a massive point cloud at three scales with, from left to right, the city of Amsterdam and its surroundings, the downtown and a few building blocks. Image from [6].

Scaling point cloud processing algorithms to billion points and more without naïve block decomposition is a challenging scientific problem. Among existing works, streaming and distributed methods that process data on the fly have been designed towards this goal to enable the processing of datasets that do not fit into memory, or even on the distributed memory of the computing cluster [11,12]. They however are tailored made for specific applications [3,4] and cannot be generalized easily to a generic toolbox. Other methods, e.g. [5], operate block decomposition by focusing on border effect reduction. Besides these strategies, the nature of the data structure that encodes input points is also a central question. For visualization applications for instance, octrees constitute a popular choice as levels of details for rendering points can be easily defined by this hierarchical structure [6,7].

Objectives

The goal is to (i) investigate new data structures to read, compress and store the information contained in massive point clouds efficiently, and (ii) to rethink popular processing tasks so that they can operate at multiple scales directly from such data structures.

The candidate will study the potential of different space partitioning data structures that can be built efficiently in a hierarchical way and from which information can be stored and requested easily, including octrees and Binary Space Partitioning trees [8]. He/she will also propose compression operations to convert clusters of input points into lightweight geometric objects, and clusters of these geometric objects into single one. The choice of geometric objects will have to account for representation genericity, compactness and efficiency to connect and aggregate them. Prior work shows, for example, that planar components (which are frequent in urban environments) can be turned into a hierarchy of floating polygons with a limited loss of information. Alternatively "covariance trees" introduce a hierarchy of Gaussian densities [8]. Similarly, the notion of "superpoints" introduced in [9] could also be a solution for compressing non-planar components.

The candidate will also revisit a traditional point cloud processing task: the planar shape detection problem, and explore the idea that the atomic geometric element is not a 3D point anymore, but geometric object living at a given scale of the data structure. We plan to integrate the outcome of this study in the popular CGAL library.

Keywords

Geometry processing, computer vision, massive point clouds, point set processing, geometric data structures

Candidate profile

The ideal candidate should have good knowledge in 3D geometry and applied mathematics, be able to program in C/C++, be fluent in English, and be creative and rigorous.

Application deadline: asap

Location : Saint-Mandé (Paris) or Sophia Antipolis (Nice)

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References

[1] The CGAL Project. *CGAL User and Reference Manual*. CGAL Editorial Board, 5.5.1 edition, 2022.
[2] CloudCompare, version 2.10.3, 2022.
[3] Pajarola. Stream-Processing Points. IEEE Visualization 2005
[4] Zhou and Neumann. A streaming framework for seamless building reconstruction from large-scale aerial lidar data. CVPR 2009
[5] Mostegel, Prettenthaler, Fraundorfer and Bischof. Scalable Surface Reconstruction from Point Clouds with Extreme Scale and Density Diversity. CVPR 2017
[6] Schütz, Ohrhallinger, Wimmer. Fast Out-of-Core Octree Generation for Massive Point Clouds. Computer Graphics Forum, vol 39(7), 2020
[7] Elseberg, borrmann and Nuchter. One billion points in the cloud – an octree for efficient processing of 3D laser scans. ISPRS Journal of Photogrammetry and Remote Sensing, vol 76, 2013
[8] Guillemot, Almansa and Boubekeur. Covariance Trees for 2D and 3D Processing. CVPR 2014
[9] Landrieu and Simonovsky. Large-scale Point Cloud Semantic Segmentation with Superpoint Graphs. CVPR 2018
[10] Laurent Caraffa, Yanis Marchand, Mathieu Brédif, Bruno Vallet. Efficiently Distributed
[11] Watertight Surface Reconstruction. 2021 International Conference on 3D Vision (3DV), Dec 2021, London, United Kingdom.
[12] Mathieu Brédif, Laurent Caraffa, Murat Yirci and Pooran Memari: Provably Consistent Distributed Delaunay Triangulation, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-2-2020, 195–202, 2020.