Master Internship in Computer Vision and geometry processing

Reconstruction of the Cosmic Web skeleton

Context

The large-scale structure of the universe, also called cosmic web, is represented and analyzed through the distribution of galaxies and dark matter. The cosmic web is a dynamic structure that evolves under the effect of gravity and the expansion of the universe. This structure is not random but organized as a network of filaments connecting dense regions of galaxies, as illustrated in Fig. 1. Identifying these features and reconstructing the cosmic web with vectorized representations is a key scientific challenge to better understand the structure of the universe. Numerous algorithms have been proposed in the literature for performing these tasks, as underlined in the survey of Libeskind et al [1]. Popular approaches rely upon mathematical tools such as graph theory [2], stochastic geometry [3], or Morse theory [4] to cite just a few of them. Only a few methods have addressed this problem from computational geometry tools that construct space-partitioning data structures to decompose the 3D space into volumes, surfaces and lines. Yet such data structures seem particularly well suited for reconstructed the underlying structure of the universe.

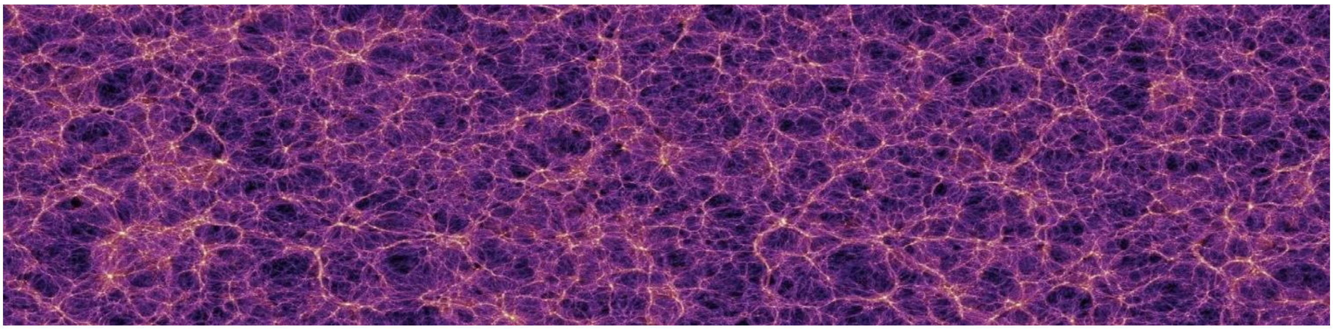

Fig.1 – Representation of the cosmic web with clusters of galaxies, filaments and voids.

Objectives

The goal of this internship is to investigate new methods for reconstructing the skeleton of the cosmic web that exploit efficient space-partitioning data structures from computational geometry field. This topic is particularly timely.

The candidate will study the potential of Delaunay triangulation, Voronoi diagrams and power diagrams for capturing and connecting filaments of galaxies and clusters of galaxies. His/her algorithms will be tested on simulated data with Ground Truth, typically the Millenium simulations, that provide the positioning of the galaxies and halos. Considering as input data, a set of 3D points representing the galaxies, a first objective will be to construct a space-partitioning data structure where edges align with chains of points. One possible solution could be to first group points into either large cluster (ie halos connecting the extremities of filaments) or secondary clusters (contained in the filaments), before connecting them using a Delaunay triangulation. If time remains, one could also imagine adapting a Delaunay triangulation dynamically to the distribution of dark matter with a Delaunay point process [5].

This is a fast-growing topic with the imminent start of major new generation galaxy surveys performed with the recently launched ESA Euclid mission and the Large Synoptic Survey Telescope at Rubin Observatory. which will enable unequaled tri-dimensional mapping of the galaxy and dark matter distribution.

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

Candidate profile: The ideal candidate should be student in M2 or M1 in Computer Science or Mathematics, 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: 15th of November 2024

Contact: Florent Lafarge (Inria , florent.lafarge@inria.fr)

Duration: 6 months

Location: Inria (2004 route des Lucioles, 06902 Sophia Antipolis) with visits at the Observatoire de la Côte d'Azur

References

[1] Libeskind et al. Tracing the Cosmic web. *Monthly Notices of the Royal Astronomical Society*, Volume 473, 2018
[2] Bonnaire et al. T-ReX: a graph-based filament detection method. Astronomy and Astrophysics, volume 637, 2020
[3] Tempel et al. Bisous model - Detecting filamentary patterns in point processes. Astron.Comput. volume 16, 2016
[4] Sousbie. DisPerSE: robust structure identication in 2D and 3D. ArXiv 1302.6221, 2013
[5] Favreau et al. Extracting Geometric Structures in Images with Delaunay Point Processes, **I**EEE Trans. on Pattern Analysis and Machine Intelligence (PAMI), Vol. 42(4), 2020