Meshing the Universe: Integrating Analysis in Cosmological Simulations

**Motivation**

Mesh tessellations are indispensable tools for analyzing point data because they transform sparse discrete samples into dense continuous functions. Meshing the output of petascale simulations, however, can be as data-intensive as the simulations themselves and often must be executed in parallel on the same supercomputers in order to fit in memory. To date, however, no general-purpose large-scale parallel tools exist.

We present a method for computing a Voronoi tessellation in situ during the simulation of cosmology. In principle, similar methods can be applied to other computational geometry problems such as Delaunay tetrahedralization and convex hull in other science domains. We demonstrate the utility of our approach as part of an in situ cosmology tools framework that runs various analysis tools at selected timesteps, saves results to parallel storage, and includes visualization and further analysis in ParaView. For example, connected components of Voronoi cells are interrogated to detect and characterize cosmological voids.

**Objective**

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**Voronoi Tessellation**

Each Voronoi cell is associated with one input particle; the site of the cell. A cell consists of the volume of all points closer to the site of that cell than to any other site. We can now determine the optimal ghost size of particles in one block.

**Parallelism Infrastructure**

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**Postprocessing**

ParaView cosmology tools plugin and toolkit includes parallel reader for Voronoi tessellations and Minkowski functions on connected components of Voronoi cells.

**Minkowski Functionals**

- **Basic**
  - Volume
  - Surface area
  - Extrinsic curvature
  - Genus
- **Derived**
  - Thickness
  - Breadth
  - Length
  - Convex components of Voronoi cells that have been filtered

Left: Overview of ParaView framework for in situ analysis of large-scale simulations. Right: Algorithm for computing Voronoi tessellation in situ. Above: Neighborhood communication with vertex and edge exchange and information sharing. Right: Connected components of output Voronoi tessellation are visualized in ParaView.

**Software**

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**Results**

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