Disentangling the Cosmic Web: Characterizing Relationships Between Cosmic Structures

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Gravity and expansion shapes the universe into a vast cosmic web of empty regions (voids), flat sheets (walls), thin threads (filaments), and dense clusters. While filaments and clusters are well studied, walls are harder to detect and therefore less understood. Because walls and filaments form at different stages of gravitational collapse, comparing their density and spatial relationship can improve our understanding of how dark matter organizes large-scale cosmic structures. My project automates the full workflow of extracting, analyzing, and visualizing the cosmic web (clusters, filaments, walls) from cosmological snapshots using the Discrete Persistent Structures Extractor (DisPerSE). The pipeline splits the data into tiled volumes of manageable size, executes the components of DisPerSE (Delaunay Tessellation Field Estimator and Morse–Smale Topology Extractor), produces per-crop statistics, 2D/3D visualizations, and aggregates results across the tiles. Results show that structures have become more pronounced over time in visualization due to gravitational collapse making these structures denser. The share of particles associated with each of these structures has also increased between redshifts z=3 and z=0, while the number of particles not assigned to any of these categories has declined. Additionally, the density distribution in categories other than clusters has widened, mostly by extending towards higher-density values. These findings are the first step in allowing us to understand the material skeleton of the universe and the gravitational backbone shaped by dark matter. Future research should aim to look at the cosmic web using different cosmological models.

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Arizona State University: Arizona State University ISEF Scholarship (valued at up to $32,000 each)