Tracking and Visualizing the Evolution of the Universe: In Situ Parallel Dark Matter Halo Merger Trees

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1. What are Dark Matter Halos?

- Dark matter constitutes nearly 83\% of the matter in the universe, much of it is in the form of localized clumps called halos.
- Atomic matter falls into the clumps where stars and galaxies form. Mergers of halos lead to formations of galaxy groups and clusters.
- Dark matter neither emits nor absorbs electromagnetic radiation and thus cannot be directly seen by telescopes.
- Can be detected by observing its gravitational effects on stars and galaxies and gravitational lensing of background galaxies.
- Essential to study dark matter evolution by observing the sky and then building theories to understand the underlying physics.

2. Contribution

- Track halos and satellite halos at each time step, in parallel and in situ with a cosmological N-body simulation.
- Detect and classify events such as birth, death, merger, split and continuation for satellite halos and host halos to understand their behavior.
- Store the tracking results, event detection and changes in halo properties in halo merger trees.
- Visualize the merger trees in an open-source visualization application, ParaView.

3. Framework

In Situ Setup

- Hardware/Hybrid Accelerated Cosmology Code (HACC)
- Data partitioning, Data exchange, Parallel I/O
- Halo Tracking
- Merger Trees
- Paraview (Visualization)

Halo Tracking and Merger Tree Process

- Satellite Halo Tracking
- Satellite Halo Merger Tree
- Satellite Halo Extraction Module
- Host Halo Tracking
- Host Halo Merger Tree
- Host Halo Extraction Module

4. Possible Halo Interactions

- Dark matter halo substructure dominated by satellite halos. Gravitational forces exerted by halos and satellite halos can give rise to the following interactions:
  - Two or more halos can merge into a bigger halo.
  - Two or more satellite halos within a host halo can merge into a single satellite halo.
  - A satellite halo can change host halos.

5. MergerTree Visualization

Redshift axis represents the evolution period of halos. Lower redshift corresponds to younger halos. The size of each sphere represents the halo mass at that redshift.

- Merger Tree for Halo 59
  - A merger with halo 100 at redshift 2.1 increases the velocity and mass of halo 59.
  - Successive merger with a slower halo 114 does not significantly change the velocity of halo 59.
  - At lower redshifts, halo 59 gains mass by accretion as it gradually evolves without any interactions.

- Merger Tree for Halo 73
  - Halo 74 born at the same redshift as Halo 73, gains more velocity and subsequently merges with Halo 73 at redshift 1.93.
  - Halo 527 is born as a result of a split in Halo 73 at redshift 1.77, accompanied by gain in velocity.
  - The fragment halo 527 later merges with its progenitor halo 73 at redshift 1.64.