Documentation Physical Background

Summary

To simulate galaxies and their collisions, an N-body simulation is essential. It calculates the motion of bodies over time, considering forces like gravity in 3D space based on masses and positions. Due to variable acceleration, numerical integration is necessary. We tested various numerical methods, evaluating them by energy loss in the system (Section 5.4). We also implemented the Barnes-Hut algorithm for computational efficiency, especially with many bodies. It divides space into cubes, simplifying distant masses. Simulating a spiral galaxy with about 100 billion stars and numerous gas clouds is impractical, so we use density regions represented as single bodies in our simulation. To prevent unrealistic clustering in direct gravitational force calculations, we assume these regions behave like ideal gases. We use the Smoothed Particle Hydrodynamics technique, adding pressure and friction forces to gravity. Dark Matter and a simple Dark Energy simulation using the Hubble Constant are included to account for the universe's expansion. Our simulation can replicate both elliptical and spiral galaxies, initializing spiral arms according to the Density-Wave Theory. It allows the simulation of any galaxy collision or merger, and with enough computing power or time, entire galaxy clusters. The simulation data can be graphically displayed using a custom engine designed for visualizing galaxies.

Simulation Fundamentals

Our simulation process is divided into two main phases: Calculation and Display. In the calculation phase, algorithms compute the motion of each body over time, considering gravitational forces based on Newton's law and other forces for realistic movement. The display phase presents these data in a 3D environment, allowing users to navigate through the simulated galaxy, view movements from different angles, and fast-forward or rewind time for detailed insights into galaxy interactions.

Gravitational Force Calculation

Calculating gravitational forces between numerous independent bodies involves assessing the force between each pair of objects, known as an N-Body Simulation. The N-Body Problem in astrophysics, currently unsolvable mathematically, requires numerical methods for approximation. We use Newton's law of gravitation, modified with Plummer Softening to prevent division by zero or extreme forces at small distances.

SPH Forces

Numerical Methods

Semi-implicit Euler Method (2. Order):

Runge-Kutta Method (4. Order):

Leapfrog Methods (2. Order):

Drift Kick Drift (DKD):

Kick Drift Kick (KDK):