N-Body simulation using the Barnes-Hut method

Given a system of N particles, simulating the forces that influence each particle is computationally expensive, as a direct calculation of all pairwise interactions requires O(N²) operations. This makes large-scale simulations infeasible.

The Barnes-Hut simulation [1] is a method to approximate the gravitational interactions in an N-body problem. Instead of computing every force individually, the Barnes-Hut algorithm organizes particles into a hierarchical quadtree (in 2D) [2] or octree (in 3D) [3], allowing distant groups of particles to be treated as single mass centers. This reduces the computational complexity to $O(N \log N)$ while maintaining reasonable accuracy.

The goal of the project is to implement a 3D Barnes-Hut algorithm using polar coordinates [4]. The target for vectorization needs to include x86 AVX-512 or ARM NEON, with use of the proper intrinsics.

As a baseline, start with a 2D implementation that uses cartesian coordinates. If needed, you can consider this code as reference [5] for the baseline, although many such projects can be found online.

References

[1] http://arborjs.org/docs/barnes-hut
[2] https://en.wikipedia.org/wiki/Quadtree
[3] https://en.wikipedia.org/wiki/Octree
[4] https://en.wikipedia.org/wiki/Spherical_coordinate_system
[5] https://github.com/ntta/barnes-hut-algorithm