High Performance Computing Systems

- N-Body Simulation

Doug Shook via Roger Chamberlain

N-Body Problem

- How to predict the motion of a group of celestial objects?
- Useful for understanding the motion of visible stars and planets
- First formulation appeared in Newton's Principia

N-Body Problem - Setup

- We have a set of n-bodies in 3D space. For each body we define a set of values

N-Body Problem

- For each object, we need to compute...

N-Body Problem - Example

N-Body Problem

- Number of objects is typically very large
- Computation time?
  - Parallelizable?
- Accuracy?

Accuracy Considerations

- The previous example relied on the Euler Method
  - Assuming h is our time step:

$$X(t + h) = X(t) + h*v(i)$$

- Problems with this?

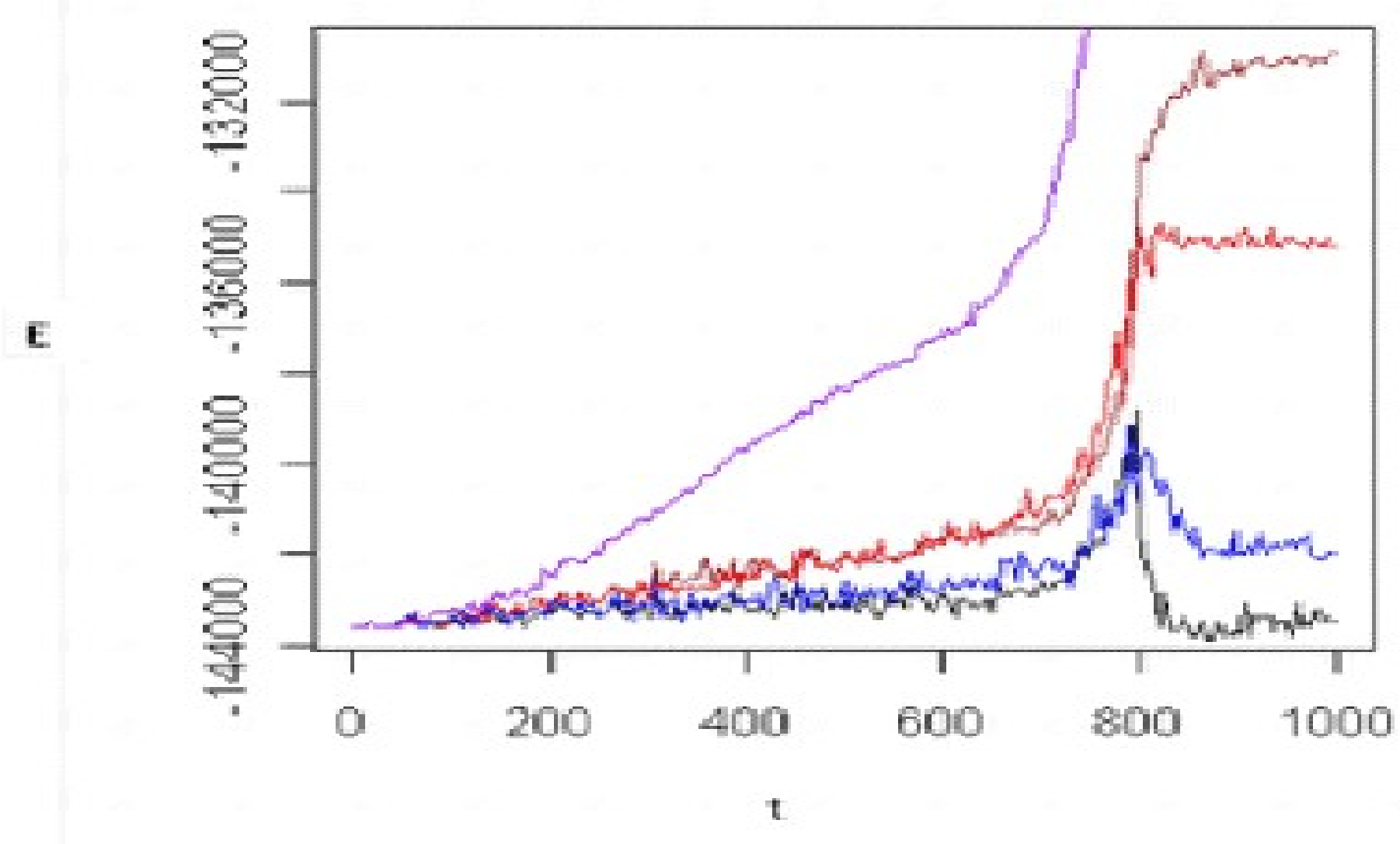
Accuracy Considerations

- The error for a single time step is O(h^2)

- Midpoint method
  - If we can know the velocity at the midpoint of the time step we can achieve more accurate results

- Runge-Kutta

Accuracy Considerations



Black – RK, Red – Midpoint Euler, Purple – Euler
(David Joiner, Kean University)

Other Improvements

- Can we improve the algorithm in other ways?
  - Minimal sacrifice of accuracy?

- Tree Methods
  - Barnes Hut
  - Fast Multipole

- Particle Mesh Methods

Barnes-Hut Simulation

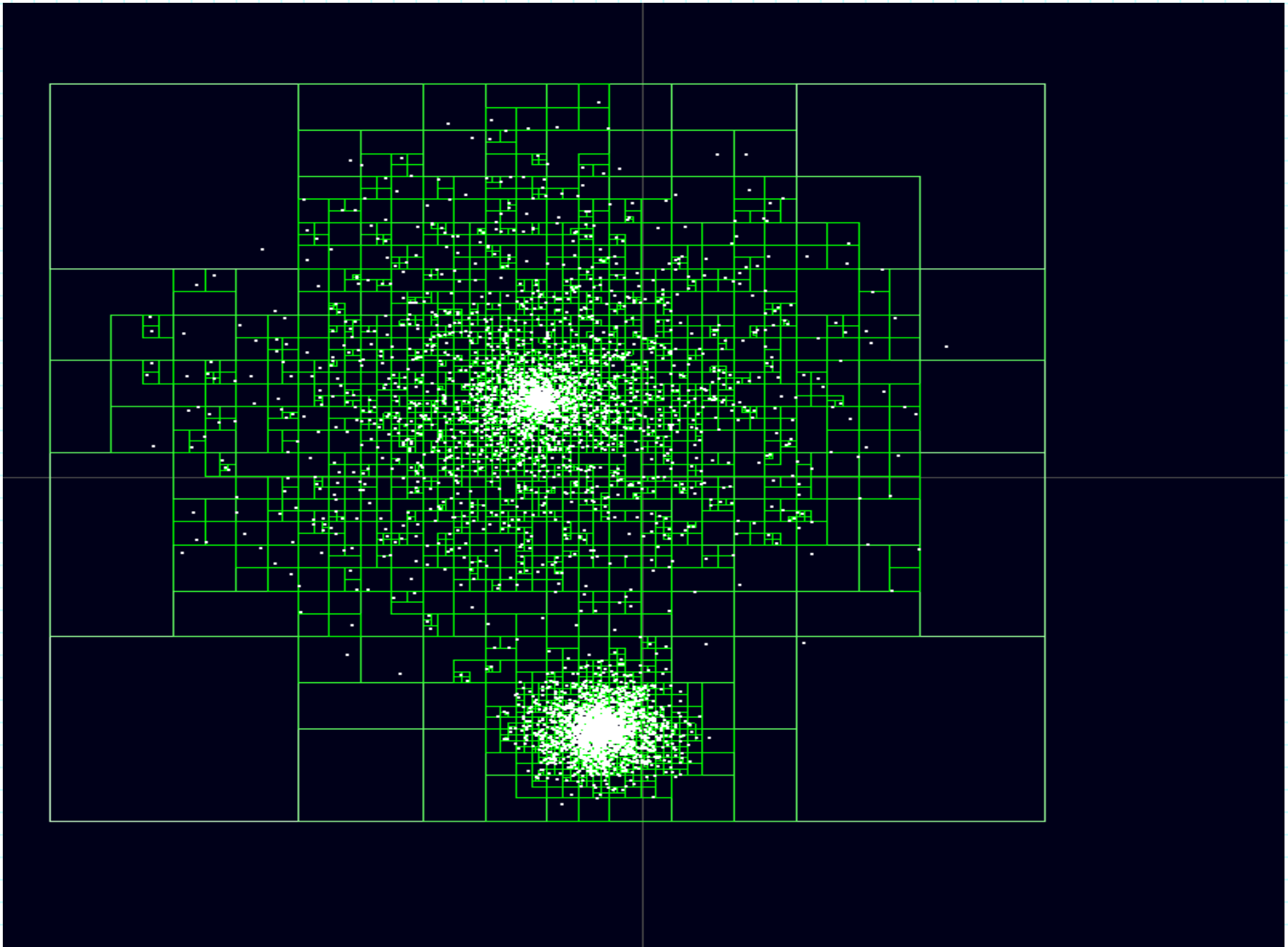
- Idea – Break bodies up into regions

- Bodies are represented as a quad tree (2D) or octree (3D)

Barnes-Hut Simulation

- Compute Center and Diameter
- Construct the tree

Barnes-Hut Simulation



Barnes-Hut Simulation

- Compute centers of mass
- Compute Forces
- Advance particles

Barnes-Hut Parallelization

- Force computations typically dominate running time
- Particle advancement is easily parallelizable as well
- Tree construction is as well, but trickier

Barnes-Hut Parallelization

- What about locality?
  - We need to walk the tree for each computation...

- Tiling the Tree

Barnes-Hut Parallelization

- What about load balancing?
  - Cost zones

- Cost zones

Recap

- The n-body problem requires us to determine the forces acting on all bodies in a system
  - Particle Particle Method
    - O(?)
  - Barnes Hut
    - O(?)

Particle Mesh

- Consider forces involved to be potential fields:
  - Represented by a Poisson Equation

- Main idea: compute potentials over entire space, convert the potentials to forces, move bodies

Particle Mesh - Details

- Compute grid density
- Calculate the potentials
- Find the forces from the potentials
- Integrate the forces for each particle

Particle Mesh - Considerations

- How does this affect our accuracy?
  - What factors determine the accuracy?
- What is the performance of this method?
  - What is the performance bottleneck?
- Can it be parallelized?

Homework 3 Overview