N-body simulation

- Available codes: http://nbody.sourceforge.net/
- MODEST: http://www.manybody.org/modest/
- Most often used for star cluster: AMUSE and NBODY6/7
- Moving stars around: http://www.artcompsci.org/kali/pub/msa/title.html
- Dark Energy Universe (DEUS) Simulation http://www.deus-consortium.org/
- Complete overview: Sverre J. Aarseth, 2003, *Gravitational N-Body Simulations*, Cambridge University Press

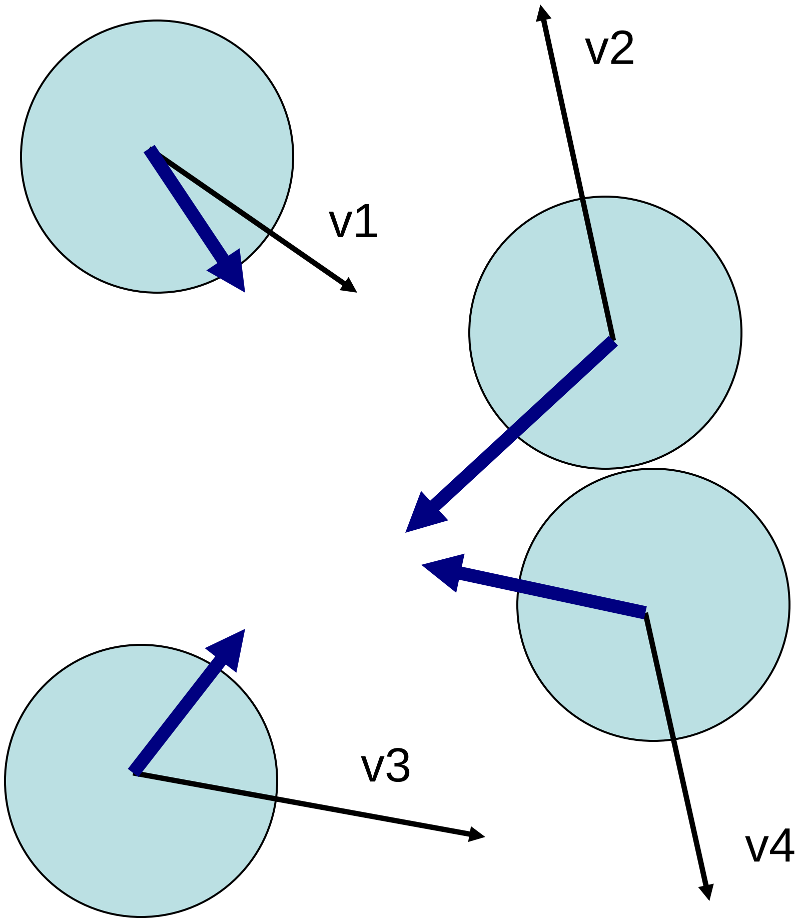
What is a N-body simulation?

- Simulating the interaction of *N* objects in a system
- No limitation of interpretation
- Examples:
  - Movement of stars under the influence of gravity in a galaxy
  - Star cluster formation
  - Clusters of galaxies

Overview

N-body problem

- ➔ Masses
- ➔ Locations
- ➔ Velocities
- ➔ Geometries
- ➔ Other Properties



Basic N-body Simulation

- Start with the *N* bodies
- Initial position and velocity
- For each time step acceleration of each body is calculated, for example based on the influence of gravity
- Velocity is updated based on acceleration
- Position is updated based on velocity

How to update the position and velocity

- The simplest update step is a Forward Euler algorithm:

$$\begin{aligned}\mathbf{r}_{i+1} &= \mathbf{r}_i + \mathbf{v}_i dt \\ \mathbf{v}_{i+1} &= \mathbf{v}_i + \mathbf{a}_i dt\end{aligned}$$

- Not very accurate
- For the time step **dt,** a body is moving in the $\mathbf{v}_\mathbf{i}$ direction
- Only correct at time **i**

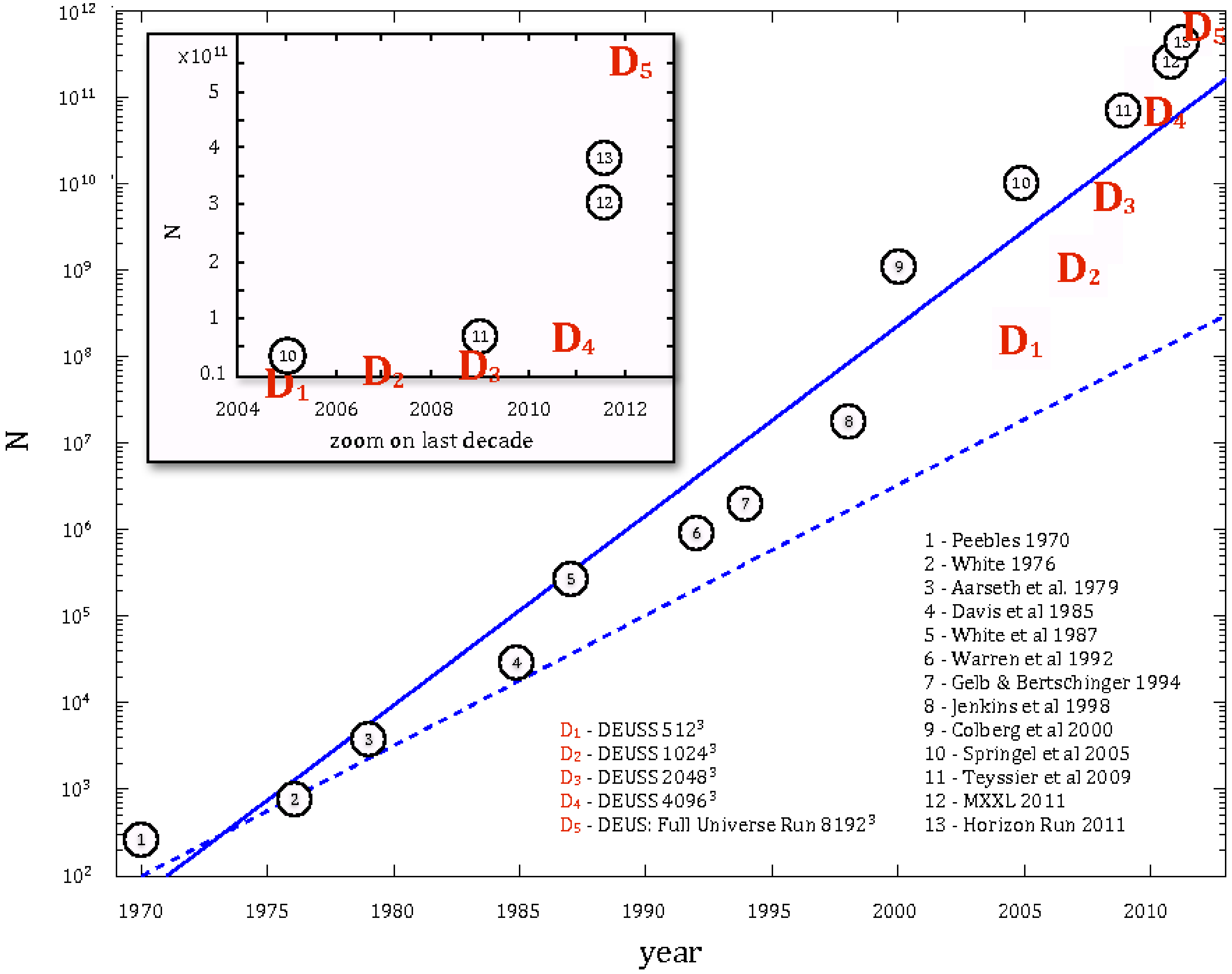
Leap-Frog algorithm

- Position defined on integer time steps
- Velocity defined on integer + ½ time steps
- Velocity updated by **(*a**$_i$ **+ *a**$_{i+1}$**) / 2**
- The approximate value of ***a*** halfway between time steps ***i*** and ***i + 1***.

$$\begin{aligned}\mathbf{r}_{i+1} &= \mathbf{r}_i + \mathbf{v}_i dt + \mathbf{a}_i (dt)^2/2 \\ \mathbf{v}_{i+1} &= \mathbf{v}_i + (\mathbf{a}_i + \mathbf{a}_{i+1}) dt/2\end{aligned}$$

Parallel N-body methods

- **Barnes-Hut algorithm** (Barnes & Hut, 1986, Nature, 324, 446)
- **Fast Multipole Method (http://www.ics.uci.edu/~ihler/papers/ihler_area.pdf)**
- **Parallel Multipole Tree algorithm**



N
year
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
1970
1975
1980
1985
1990
1995
2000
2005
2010
1
2
3
4
5
6
7
8
9
10
11
12
13
D_1
D_2
D_3
D_4
D_5
x10^{11}
N
0.1
1
2
3
4
5
2004
2006
2008
2010
2012
zoom on last decade
D_1 - DEUSS 512^3
D_2 - DEUSS 1024^3
D_3 - DEUSS 2048^3
D_4 - DEUSS 4096^3
D_5 - DEUS: Full Universe Run 8192^3
1 - Peebles 1970
2 - White 1976
3 - Aarseth et al. 1979
4 - Davis et al 1985
5 - White et al 1987
6 - Warren et al 1992
7 - Gelb & Bertschinger 1994
8 - Jenkins et al 1998
9 - Colberg et al 2000
10 - Springel et al 2005
11 - Teyssier et al 2009
12 - MXXL 2011
13 - Horizon Run 2011