Preamble

We, the people of the N–body community, in order to form more perfect N–body simulations, establish justice, insure domestic tranquility, provide for the common defense, promote the general welfare, and secure the blessings of scientific accuracy to ourselves and our posterity do ordain and establish this Constitution for the conduct of numerical N–body simulations.

Article I.

On the Gravitational Softening Length

Section I—The gravitational Softening length should be chosen large enough to minimize the effects of two body relaxation.

The softening length should be chosen such that there is at least 8 particles in each softening volume in objects of interest.

Article II.

On the Size of Time steps

Section I—Time steps should be chosen to be small enough to eliminate the effects of two body scattering introduced through integration errors.

The time step must satisfy

$$\Delta \mathrm{t} < \frac{1}{10}\left(\frac{1}{G\rho}\right)^{1/2}.$$

For an isothermal sphere this is equivalent to

$$\Delta \mathrm{t} < .38\frac{\epsilon_{grav}}{v_{max}}$$

for a standard Plummer softening. For a typical cosmological simulation

$$N_{steps} = \frac{\mathrm{T}_{\mathrm{HUBBLE}}}{\Delta \mathrm{t}} \sim 4500\frac{10\mathrm{kpc}}{\epsilon_{grav}}.$$

Spline kernel softening requires 33% more time steps.

Article III.

On the Number of Particles

Section I—The number of particles should be large enough that random potential fluctations do not dominate the dynamics that one is trying to study.

To correctly model the internal dynamics of a galaxy halo requires at least one million particles.

Article IV.

On the Accuracy of Forces

Section 1—Forces ſhould be calculated with a maximum abſolute and relative error.

The maximum relative error, $\frac{\Delta a}{a_i}$, and the maximum abſolute error, $\frac{\Delta a}{a_{rms}}$, in the calculated acceleration ſhould always be leß than 0.5% and be leſſ than the errors introduced by diſcreteneß effects.

Article V.

On the Accuracy of the Integrator

Section 1—The integrator muſt retain at leaſt ſecond order accuracy at all times, be time ſymmetric, and avoid any correlated higher order error terms.

Retaining ſecond order accuracy is particularly important when the length of the time ſtep in changed during the calculation. However, one muſt be careful not to introduce correlated third order errors when correcting to ſecond order accuracy. If the integrator if not time ſymmetric then energy need not be conſerved.

Article VI.

On the Size of the Simulation Volume

Section 1—The ſimulation volume muſt be large enough to correctly model all important non–linear effects.

There are mode couplings between large and ſmall ſcales that increaſe power on ſmall ſcales. Theſe couplings manifeſt themſelves aſ filaments and greatly effect the gravitational evolution at ſmall ſcales. The diameter of the ſimulation for a CDM ſpectrum with $\sigma_8 = 0.7$ muſt be at leaſt $40h^{-1}$ Mpc. Models with more large ſcale power will require larger volumes. This may be related to the ſcale where the ſlope of the power ſpectrum becomes leß ſteep than n^{-1}.

Section 2—No one object ſhould dominate the evolution of the ſimulated volume.

To prevent objects from tidally influencing themſelves and to prevent objects from artificially lowering the mean background denſity, the ſimulation volume muſt be large enough to enſure that no virialized object contains more than 1/10 the total ſimulated maß.

Section 3—The fundamental mode ſhould remain well within the linear regime.

The ſimulated volume ſhould be choſen to be large enough to enſure that the amplitude in the fundamental mode $\delta_1 < 0.01$ when the ſimulation is concluded.

Article VII.

On the Starting Redſhift of the Simulation

Section 1—The ſimulation muſt ſtart at a redſhift high enough to enſure that all repreſented maß ſcales are ſtill in the linear regime.

In particular, if the initial conditions are generated uſing the Zel'dovich approximation, the ſtarting redſhift muſt be ſufficiently high to enſure that the abſolute maximum $|\delta| = 1$. For example, a CDM ſimulation with $\sigma_8 = 0.7$ in a cubic volume $40h^{-1}$ Mpc on a ſide ſimulated with 128^3 particles would require a ſtarting redſhift of at leaſt $z = 50$.

Article VIII.

What Ratification Shall Establish Constitution

Section I—This constitution must be ratified by the representatives of at least two different research groups.

The effects of violating the above articles are not known. Some violations will introduce unphysical dissipative effects, others will introduce errors that act like an artificial heat source, while the effects of other violations are not clear but equally unphysical. Hence, we the undersigned insist that to ensure scientific accuracy all N–body simulations should meet the above guidelines.

Done in convention by the unanimous consent of the summer school members present the Third day of July in the year of our Lord one thousand nine hundred and ninety eight. In witness whereof we have hereunto subscribed our names.