Exercise 2: Cosmology and initial conditions
(see Lecture 03-05: Cosmology, N-body simulations)

date: 06.11.2007 date for handing in: 22.11.2007

Problem 3: Cosmology
A homogeneous, isotropic and flat SCDM-Universe is given where the curvature κ, the pressure p and the cosmological constant Λ are zero. There is no radiation as well. Derive from the first Friedmann equation (cf. lecture) an expression for the time dependence of the scale factor $a(t)$ in this Universe. How does the Hubble parameter $H(t)$ depend on time?

(4 points)

Problem 4: Initial conditions
The goal is to generate the initial conditions for a cosmological simulation using different cosmological models with the program package IC[1]. A short introduction and description of this program is given below.

a) Examine the power spectra $P(k)$ for different cosmological models. Use e.g. gnuplot to draw the curves (for logarithmic scale set: `set logscale`) and plot the power spectra of an OCDM, SCDM, CDM and WDM Universe in one graph for a range of P(k) $[10^{-6} : 10^{8}]$

(2 points)

b) Generate initial conditions for an OCDM, SCDM, CDM and WDM Universe for 4 different box sizes 10, 20, 50, 100 Mpc/h and for 2 different particle numbers: 16^3 and 32^3. Save the binary and ASCII-files for the 32-models (create one file per model) and bring them to the next exercise!

Make a graphic presentation of the results with gnuplot: the command splot `'file' w p` creates projected 3D-graphs that could be rotated with the mouse!

(4 points)

c) Check if the sum of all velocities in the created files is zero (within the rounding error). Why should this be the case? To actually check this write a short C program or use awk. (4 points) (It is worth to get familiar

[1] the package can be downloaded from
`http://www.aip.de/People/aknebe/page3/computational_exercises.html`

with awk - then this task could be solved in one (long) command line. Some information about awk can be found e.g. at:
`http://www.gnu.org/software/gawk/manual/html_node` , or typing `man awk` under Linux).

Problem 5: 3-body problem
Expand the program from the first exercise sheet (Problem 2):

a)Set the particle number N to 3, set up initial values for the three bodies and study the result.

What happens when you increase (decrease) the time step by two orders of magnitude? Do the trajectories of particles remain the same? Create two figures that present the trajectories of the three particles - one with a small and one with a larger timestep!

(3 points)

b) Use in your program the Euler scheme instead of the leapfrog integrator. Repeat the simulation with the smaller timestep (than in a)) and compare the trajectories. Create a plot showing the trajectories of the three particles!

(3 points)

Short instruction to the IC package
This program was written by Anatoly Klypin and its slightly modified version could be found here:
`http://www.aip.de/People/aknebe/page3/computational_exercises.html`

After copying the file `IC.tgz`, follow the instructions below:

- Unpack the package (`tar xfz IC.tgz`). A new directory `IC/` is created. It contains the files:

The subdirectory `Pk/` contains files with power spectra for different cosmological models. The filenames contain information about the cosmological parameters, e.g. `Pk_LCDM_Om.30_Ol.70_h.70.DAT` represents the power spectrum for a LCDM Universe with density parameters $\Omega_{\rm matter} = 0.30$, $\Omega_\lambda = 0.70$ and Hubble-Parameter $h = 0.7$. In all those files the first column contains the wave number k and the second column $P(k)$.

- Compile the necessary program (in directory IC):
`make PMmodels`

`PMmodels.f`:	It generates the input file `InStart.dat`, required for use with `PMstartM`.
`PMstartM.f`:	The program itself. It creates two binary files.
`PM2asciiM.f`:	It converts the binary files in one ASCII-file.
`PMparameters.h`:	It contains the required parameters that need to be set prior to compilation of `PMstartM.f`

```
make PMstartM
make PM2asciiM
```

- Generate the Input file `InStart.dat` for `PMstartM` by using `PMmodels`:
`./PMmodels`

Several parameters must be input interactively. Choosing a file with given power spectrum corresponds to a choice of particular cosmological model for which the initial conditions will be calculated (e.g. LCDM with $\Omega_\lambda = 0.7$, $\Omega_{matter} = \Omega_0 = 0.3$ and $h = 0.7$). The boxsize is specified also at that step.

(Example: $\sigma_8 = 0.9$, File: Pk_LCDM_Om.30_Ol.70_h.70.DAT, $\Omega_0 = 0.3$, $h = 0.7$, $\Omega_\lambda = 0.7$, boxsize = 20 Mpc/h, Number of particles `NROW` per dimension = 32 (the same number as in `PMparameters.h`!!!), starting-redshift = 50.0, Yes, Header: Box20,323,LCDM., random number 12345)
Caution: $d\rho/\rho$ should be between 0.1 and 0.2 (otherwise, e.g. Start-redshift should be changed)!

The file `InStart.dat` has now been created and will be used in the next step.

- Generate the initial positions and velocities of the particles with `PMstartM`:
`./PMstartM < InStart.dat`

The new files `PMcrd.DAT` and `PMcrs0.DAT` contain the needed data in binary format.

- Convert the files with `PM2asciiM` in a readable ASCII format:
`./PM2asciiM`

Again, some parameters should be input interactively. The newly created ASCII file contains the positions in Mpc/h (columns 1-3) and the velocities of the particles in km/s (columns 4-5).