

The Future of NBODY @ MODEST-17

by Sverre Aarseth

Discussion Chair: Rainer Spurzem

Wednesday, Sep. 20, 2017, 14:30 – 16:00, Prague, CZ

Suggested: 15 minutes approx. per major topic

External:

N-body interface ARC interface

Internal:

nbint & nbintp; ksint, ksintp

TRIPLE & QUAD

Standard chain; Algorithmic chain

GPU & SSE

Documentation/User Services/Output:

Documentation; Output (Formats, Files)

Debugging; More Technical

Github

NBODY6++

Astrophysics:

Post-Newtonian

Stellar Evolution (single/binary) Tidal Fields?

Others?

Open Discussion:

New problems

Any questions

Discussion on the perspectives of NBODY6/7 with Sverre Aarseth

chair: Rainer Spurzem, notes: Václav Pavlík

September 20, 2017

NBODY6 (Aarseth, 2003) is a direct N -body integrator written in FORTRAN. The newest version of the code has been upgraded to include the SSE¹ and GPU compatibility (Nitadori & Aarseth, 2012).

1 Few-body subsystems

NBODY6 uses the Ahmad & Cohen (1973) integration scheme with a four order Hermite integrator (Makino, 1991). In order to be effective, NBODY6 contains several routines for special purposes, e.g. for the integration of binaries (e.g. Mikkola & Aarseth, 1998). In principle multiple methods may be combined together, because the code is the same before and after these routines. Obviously, the biggest bottleneck of any calculation is the *decision making*, i.e. when do you decide to switch the equations that you integrate (methods to use).

For instance, we mention the chain regularizations (Mikkola & Aarseth, 1993) that are intended for the integration of a binary and a strong perturber. However, after integrating three particles, we might want more, e.g. two colliding binaries. The code will allow us to draw a chain how long we want but it is not practical. Every time we include another body in the chain, we must consider it as a perturber to the other bodies. This is very costly for a large number of bodies. The best is to use this routine for three to four (maximum of five) bodies, i.e. a binary with a perturber, two binaries, or a small hierarchical system.

¹Streaming SIMD (Single Instruction Multiple Data) Extensions

2 Data structure

The code is intended to be as clean as possible in the output, but we must to prepare it. Data are stored in several dedicated binary files. To keep track of the stars in between outputs, each star has its own identifier. The main output contains arrays for mass, coordinates, velocities etc. If we wish to follow the stellar evolution we may print out the stellar type, e.g. add (KSTAR(J), J=1, NTOT) in the WRITE (3) statement in output.f.

The data structure is generalised. For binaries, we store their relative motion and the centre of mass. In the case of stable (hierarchical) multiples, ghost particles with zero mass may appear in the output. Dealing with them is sort of an IQ test but it is a way to keep all the components in one table.

It would be a great challenge to keep all the methods working if we wanted to change them.

If everything is working and you do not get any errors, you do not need to worry.

A custom output can be done but we need to follow the data structure. However, beware that almost all units of the FORTRAN output are already used for something. Before printing other results, we must check empty units, overwrite them or rename the output. The precision of the existing outputs can be changed as well.

Sometimes more decimals in the output is better to catch what is going on (but you cannot please everybody).

3 NBODY6 & NBODY7

The main difference between those two versions of the code is in the post-Newtonian treatment

present in NBODY7. It was included mainly for educational purposes and black holes. We definitely need improvements! NBODY7 has different levels of the post-Newtonian. The cross terms for the third body are not easy to write – we need *a volunteer* to do it. To get the seventh version, we compile with the source code of NBODY6 after changing a few lines in the `Makefile`.

4 Discussion

4.1

If there is a binary BH and a possible third member, Sambaran found that before the BH coalescence, the chain breaks and the third member is lost without any output.

4.2

Maxwell pointed out that NBODY6++GPU has 6 outputs.

4.3

Wang Long recommended to update the `common6.h` and variable names, so that the code is more readable and comprehensive to the user. Also to keep consistent names to recognise global and local variables. **To do that, we need volunteers.**

4.4

How far has the inclusion of NBODY6 to AMUSE gone?

Answer

Interface is working for a version of NBODY6 from 2013. Maxwell has also a plan to include the latest NBODY6 and NBODY6++. Maxwell has also a Python interface to running NBODY6. The current progress is on GitHub.

4.5

Would it be easy to switch the stellar evolution code?

Answer

In principle yes, but there is still work to do. Single stars are “easy”, the binaries are complicated.

4.6

We need a comprehensive **documentation** on platforms and compilers. There is not yet any suite of test problems and examples. In NBODY6++ there are figures as a guide what to switch for a specific kind of problem.

4.7

Interaction between the GPUs and CPUs on the machine is to be done by the user, there is no automated way built in.

4.8

Is NBODY6 and NBODY7 compatible? Can we use dumps from one of them to run in the other one?

Answer

So far, we do not have a definite answer, however, Sverre was unsuccessful to restart dump from NBODY7 from NBODY6. Rainer suggests to make an ASCII output in this case and read it in the other version. We may also try to detect the structure of the binary dump file.

4.9

There is a missing documentation for a couple of the routines. **A complete documentation is needed and would be useful.** Perhaps do it on Wiki or GitHub.

Answer

There is actually a GitHub site for NBODY6 <https://github.com/nbodyx/nbody6/wiki>, however, not maintained from 2016. We address to the **community to help**, e.g. with test runs, FAQ etc. **This should be done.**

4.10

What is the best way to approach a model of a cluster in a galactic field?

Answer

Routines exist in NBODY6 or there is NBODY6tt for cosmological purposes (a separate branch).

4.11

From the user point of view, is it possible to do gas expulsion/tidal field within NBODY6?

Answer

Already possible, can be done with setting a tidal tail potential, there is KZ(14) (e.g. =3 for galactic disk, bulge, halo).

4.12

The stellar evolution should be done better. At least test against newest results.

4.13

Maxwell and Rainer pointed out that there is HDF5 output in NBODY6++ which is better for frequent output, as it only stores those particles that have been integrated in a particular block. Flag KZ(46). It is readable by Python, R etc.

5 NBODY6++

The community may support the project by joining the list of users. Contact Rainer Spurzem.

6 Conclusions

NBODY6 is considered a project. It is not a dead code.

References

Ahmad, A. & Cohen, L. (1973). A numerical integration scheme for the N-body gravitational problem. *Journal of Computational Physics*, 12:389–402.

Makino, J. (1991). A Modified Aarseth Code for GRAPE and Vector Processors. *PASJ*, 43:859–876.

Mikkola, S. & Aarseth, S. J. (1993). An implementation of N-body chain regularization. *Celestial Mechanics and Dynamical Astronomy*, 57:439–459.

Mikkola, S. & Aarseth, S. J. (1998). An efficient integration method for binaries in N-body simulations. *New A*, 3:309–320.

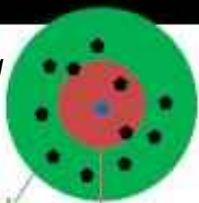
Aarseth, S. J. (2003). *Gravitational N-Body Simulations*. Cambridge University Press, Cambridge, UK.

Nitadori, K. & Aarseth, S. J. (2012). Accelerating NBODY6 with graphics processing units. *MNRAS*, 424:545–552.

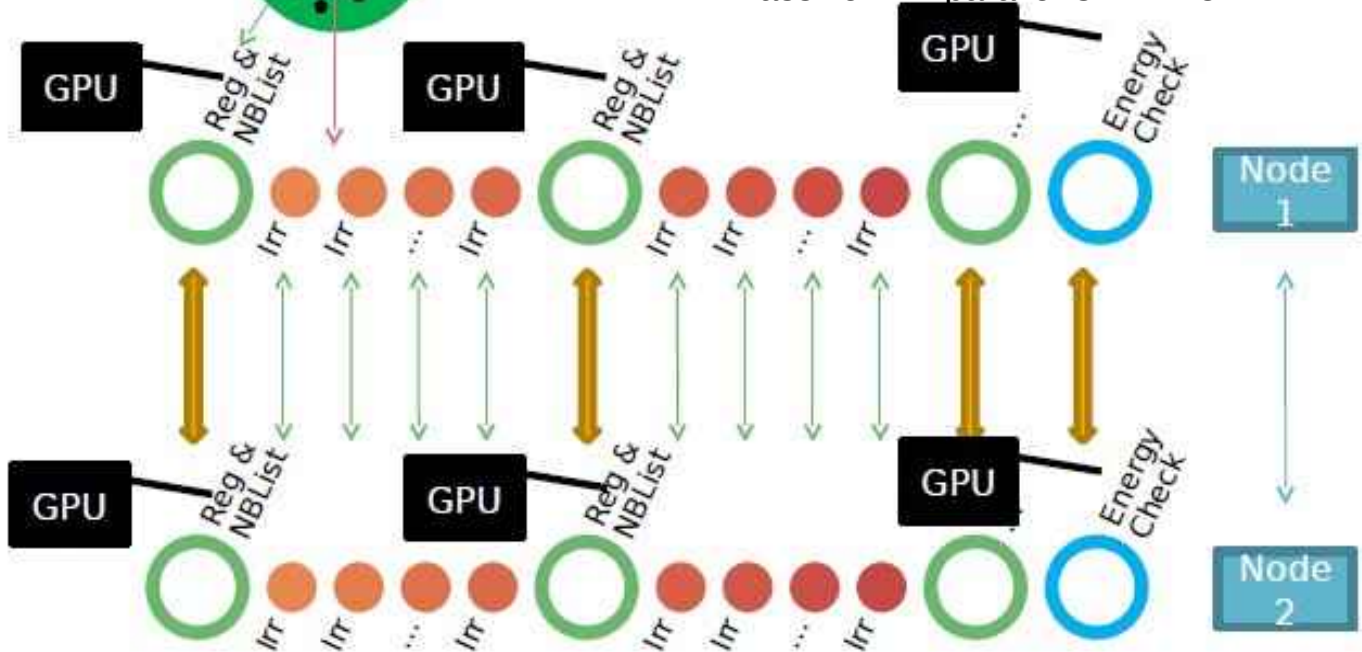
Nbody6++ Structure

Download: github Wang et al. 2015, 2016
 Soon: svn:silkroad.bao.ac.cn

Slide of: Long Wang



Spurzem & Aarseth 96: NBODY5 Vector Computer (CRAY)
 Spurzem (1999): NBODY6++
 massive MPI parallel CRAY T3E



Nitadori & Aarseth (2012): NBODY6GPU: CUDA GPU Force routine
 Berczik & Spurzem (~2013, unpubl.): utilGPU use Nitad. CUDA routines in MPI program
 Wang, Spurzem, Aarseth, Berczik et al. 2015: NBODY6++GPU
 openMP + CUDA + MPI full performance mill. body

DFG Call

Research Software Sustainability

- Morgan MacLeod, NASA Einstein Fellow, Institute for Advanced Study, morganmacleod@gmail.com
- Aaron Geller, Northwestern University CIERA & The Adler Planetarium, a-geller@northwestern.edu
- Sambaran Banerjee, Argelander Inst. For Astronomy, Univ. Bonn, sambaran@astro.uni-bonn.de
- Peter Berczik, Main Astronomical Observatory Acad. Of Sciences, Kiev, berczik@mao.kiev.ua
- Michael Fellhauer, Faculty Member, Univ. Concepcion, mfellhauer@astro-udec.cl
- Michele Trenti, Senior Lecturer and ARC Future Fellow, Univ. of Melbourne, michele.trenti@unimelb.edu.au
- Holger Baumgardt, Faculty Member, Univ. of Queensland, h.baumgardt@uq.edu.au
- Peter H. Johansson, Associate Professor of Astrophysics, Dept of Physics Univ of Helsinki, peter.johansson@helsinki.fi
- Douglas C. Hoggie and Phil Breen, Dept. of Maths. And S d.c.heggie@ed.ac.uk, Phil.Breen@ed.ac.uk

More teams and members welcome! **Late "enrolments" already:**

- **Jarrod Hurley, Melbourne**
- **Christian Boily, Strasbourg**
- **Ladislav Subr, Prague**
- **...**

**NBODY - astrophysics for star clusters,
galactic nuclei, black holes**

**NBODY - Astrophysik für Sternhaufen, Galaxienkerne und
Schwarze Löcher**

Spurzem, Rainer (Astronomisches Rechen-Institut, Zentrum
für Astronomie der Universität Heidelberg)

Naab, Thorsten (Max-Planck Institut für Astronomie, Garching)

April 4, 2017

Collaboration/Coordination with Sverre

Supporting Teams
Registered in Application

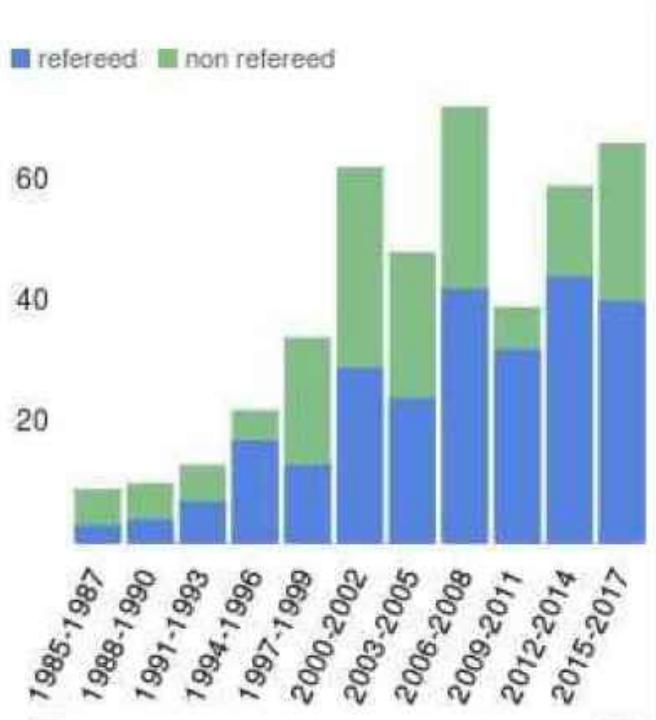
Submitted ~April 2017
Decision ~January 2018

- Marina Ryabova, Denis Ryabov, Southern Federal Univ., Rostov-on-Don, mryabova@sfedu.ru
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- Nadine Neumaier, Max-Planck Institute for Astronomy, neumayer@mpia.de, team members at MPIA Alessandra Mastrobuono-Battisti and Arianna Picotti; and team of Glenn van de Ven with Anna Sippel
- Michela Mapelli, Astronomical Observatory of Padova, michela.mapelli@oapd.inaf.it

To demonstrate how successful the direct NBODY codes are in our field we have collected the following three figures from the ADS Bumblebee (full text search) facility. The search string

full:NBODY5 OR full:NBODY6 OR full:"NBODY6++" OR full:NBODY7 OR full:NBODY4

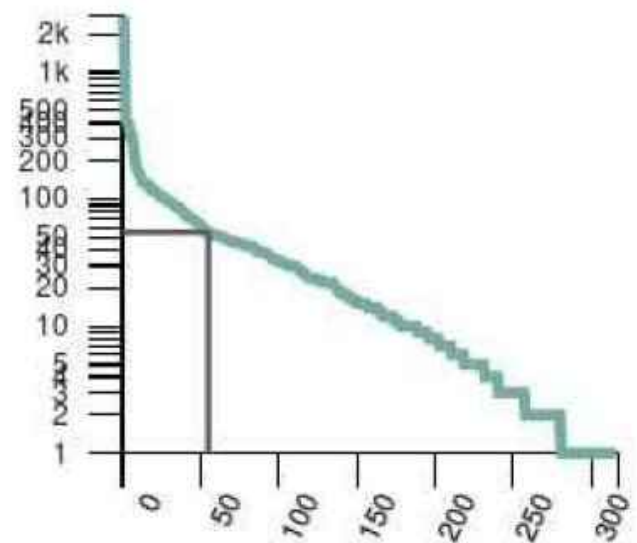
has been used to catch all publications using or citing the different variants of the code.



total number of citations : 13,733

H-Index for results: 55

Y-axis: linear log



Objectives and Funding

Objectives (short):

- Input/Output Management (with Mcluster for input?
e.g. already working: HDF5 output)
- Internal data structure
- Modularity (Stellar Evolution / Multiples / Tidal / ... ?)
- Keep the legacy...

Funding requested:

- 1.5 positions, networking (Workshops/Travel)
- little hardware for testing