Getting Started

1. Download code `nbody6.tar.gz`
2. Unzip `gunzip nbody6.tar.gz`
3. Extract files `tar xvf nbody6.tar`
4. Check `params.h` `NMAX, LMAX, KMAX, MMAX`
5. Compile the code `make nbody6`
6. Create run directory `mkdir Run`
7. Run test input `time nbody6 <input >output &`
8. Profiling Makefile with -O3 -pg
9. Performance data `gprof nbody6 gmon.out -p >OUT`

NBODY6 Input File

1 20.0

1000 1 5 50000 95 1

0.02 0.03 0.3 2.0 10.0 100.0 2.0D-05 1.0 0.5

0 0 0 0 1 0 1 0 0 0

0 0 0 1 1 1 0 1 0 0

1 0 2 0 0 2 0 0 0 2

0 0 0 0 0 0 0 0 0 1

1.0D-05 1.0D-04 0.2 1.0 1.0D-06 0.001

2.3 10.0 0.2 0 0.02 0

0.5 0 0 0

KSTART TCOMP

N NFIX NCRIT NRAND NNBMAX NRUN

ETAI ETAR RS0 DTADJ DELTAT TCRIT QE RBAR ZMBAR

OPTIONS (40)

DTMIN RMIN ETAU ECLOSE GMIN GMAX

ALPHA BODY1 BODYN NBIN0 ZMET EPOCH0

Q 0 0 0

Essential Input Parameters

Particle numbers	$N,\ n_{\rm max},\ N_{\rm crit}$
Integration variables	$\eta_{\rm I},\ \eta_{\rm R},\ S_0,\ \Delta T,\ T_{\rm crit},\ Q_{\rm E},\ R_{\rm pc},\ \bar{m}$
Optional procedures	consult list of 40 choices
KS parameters	$\Delta t_{\rm cl},\ R_{\rm cl},\ \eta_{\rm U},\ \gamma_{\rm min}$
IMF	$\alpha,\ m_1,\ m_N,\ N_{\rm b},\ \#20$
Virial theorem	$Q_{\rm V}\ =\ 0.5$ for equilibrium
Primordial binaries	$a_{\rm max},\ e_0,\ m_1/m_2,\ a_{\rm min},\ \#20$

Numerical examples	$N = 1000,\ n_{\rm max} = 70,\ \eta_{\rm I} = 0.02,\ \eta_{\rm R} = 0.03,$
	$S_0 = 0.3,\ \Delta T = 2,\ T_{\rm crit} = 100,$
	$Q_{\rm E} = 1 \times 10^{-5},\ R_{\rm pc} = 2,\ \bar{m}\ =\ 0.5$
	$\#\ \ 1,\ 2,\ 5,\ 7,\ 14,\ 16,\ 20,\ 23$
	$\Delta t_{\rm cl} = 10^{-4},\ R_{\rm cl} = 0.001,\ \eta_{\rm U} = 0.2,\ \gamma_{\rm min} = 10^{-6}$
	$\alpha = 2.3,\ m_1 = 10.0,\ m_N = 0.2,\ \#20 = 1$

Integration Parameters

$\eta_{\rm I}$	Time-step parameter for irregular force	0.02
$\eta_{\rm R}$	Time-step parameter for regular force	0.03
S_0	Initial radius of the neighbour sphere	0.30
$n_{\rm max}$	Maximum neighbour number	70
$\Delta t_{\rm adj}$	Time interval for energy check	2.0
$\Delta t_{\rm out}$	Time interval for main output	10.0
$Q_{\rm E}$	Tolerance for energy check	1×10^{-5}
$R_{\rm V}$	Virial cluster radius (length unit) in pc	2.0
$M_{\rm S}$	Mean stellar mass in solar units	0.5
$Q_{\rm vir}$	Virial theorem ratio $(T/\|U+2W\|)$	0.5
$\Delta t_{\rm cl}$	Time-step criterion for close encounters	1×10^{-4}
$R_{\rm cl}$	Distance criterion for KS regularization	1×10^{-3}
$\eta_{\rm U}$	Regularized time-step parameter	0.2
$h_{\rm hard}$	Energy per unit mass for hard binary	1.0
$\gamma_{\rm min}$	Limit for unperturbed KS motion	1×10^{-6}
$\gamma_{\rm max}$	Termination criterion for soft binaries	0.001

Basic Variables

$\mathbf{x}_0$	`X0`	Primary coordinates
$\mathbf{v}_0$	`X0DOT`	Primary velocity
$\mathbf{x}$	`X`	Prediction coordinates
$\mathbf{v}$	`XDOT`	Prediction velocity
$\mathbf{F}$	`F`	One half the total force (per unit mass)
$\mathbf{F}^{(1)}$	`FDOT`	One sixth the total force derivative
m	`BODY`	Particle mass (also initial mass m_0)
Δt	`STEP`	Irregular time-step
t_0	`T0`	Time of last irregular force
$\mathbf{F}_\mathrm{I}$	`FI`	Irregular force
$\mathbf{D}_\mathrm{I}^1$	`FIDOT`	First irregular force derivative
$\mathbf{D}_\mathrm{I}^2$	`D2`	Second irregular force derivative
$\mathbf{D}_\mathrm{I}^3$	`D3`	Third irregular force derivative
ΔT	`STEPR`	Regular time-step
T_0	`T0R`	Time of last regular forcex
$\mathbf{F}_\mathrm{R}$	`FR`	Regular force
$\mathbf{D}_\mathrm{R}^1$	`FRDOT`	First regular force derivative
$\mathbf{D}_\mathrm{R}^2$	`D2R`	Second regular force derivative
$\mathbf{D}_\mathrm{R}^3$	`D3R`	Third regular force derivative
R_s	`RS`	Neighbour sphere radius
L	`LIST`	Neighbour and perturber list

KS Variables

$\mathbf{U_0}$	`U0`	Primary regularized coordinates
$\mathbf{U}$	`U`	Regularized prediction coordinates
$\mathbf{U}'$	`UDOT`	Regularized velocity
$\mathbf{F}_{\mathrm{U}}$	`FU`	One half the regularized force
$\mathbf{F}'_{\mathrm{U}}$	`FUDOT`	One sixth the regularized force derivative
$\mathbf{F}^{(2)}_{\mathrm{U}}$	`FUDOT2`	Second regularized force derivative
$\mathbf{F}^{(3)}_{\mathrm{U}}$	`FUDOT3`	Third regularized force derivative
h	`H`	Binding energy per unit reduced mass
h'	`HDOT`	First derivative of specific binding energy
$h^{(2)}$	`HDOT2`	Second derivative of binding energy
$h^{(3)}$	`HDOT3`	Third derivative of binding energy
$h^{(4)}$	`HDOT4`	Fourth derivative of binding energy
$\Delta\tau$	`DTAU`	Regularized time-step
$t^{(2)}$	`TDOT2`	Second regularized derivative of time
$t^{(3)}$	`TDOT3`	Third regularized derivative of time
R	`R`	Two-body separation
R_0	`R0`	Initial value of the two-body separation
γ	`GAMMA`	Relative perturbation

Optional Procedures

1	Manual common save on unit 1 at any time
2	Common save on unit 2 at output time or restart
3	Data bank on unit 3 with specified frequency
5	Different types of initial conditions
7	Output of Lagrangian radii
8	Primordial binaries (extra input required)
10	Two-body regularization diagnostics
14	External tidal force; open or globular clusters
15	Multiple regularization or hierarchical systems
16	Updating of regularization parameters $R_{\rm cl}$, $\Delta t_{\rm cl}$
17	Modification of $\eta_{\rm I}$ and $\eta_{\rm R}$ by tolerance $Q_{\rm E}$
19	Synthetic stellar evolution with mass loss
20	Different types of initial mass functions
23	Removal of distant escapers (isolated or tidal)
26	Slow-down of KS and/or chain regularization
27	Tidal circularization (sequential or continuous)
28	Magnetic braking and gravitational radiation
30	Chain regularization (with special diagnostics)

N-Body Scheduling

1.	(Re-)Initialize times	$\Delta t_{\rm min}$ & $t_{\rm min}, \quad i = 1, \ldots, N$
2.	Determine smallest level	$L_{\rm Q}$ from $\Delta t_{\rm quant}(L) = \Delta t_{\rm min}$
3.	Enforce block-step search	$t_{\rm L} = t$
4.	Count lowest levels	$N(L), \quad [L_{\rm Q} - 4, L_{\rm Q}], \quad i = 1, N$
5.	Sum levels backwards	$\Sigma\, N(L) = N^{1/2}, \quad L = L^*$
6.	Increase list interval	$t_{\rm L} + \Delta t(L^*) \Rightarrow t_{\rm L}$
7	Form due soon list	$t_i + \Delta t_i \leq t_{\rm L}, \quad i = 1, \ldots, N$
8.	Record next time	$t_{\rm min} = \min\,(t_i + \Delta t_i)$
9.	Extract block members	$t_i + \Delta t_i = t_{\rm min}, \quad i = 1, \ldots, N_{\rm Q}$
10.	Set block time	$t_{\rm block} = t_k + \Delta t_k$
11.	Check list renewal	$t_{\rm block} > t_{\rm L} \quad \Rightarrow \#\,4$
12.	Update next step	$t_{\rm min} = \min\,(t_i + \Delta t_i), \quad i = 1, N_{\rm block}$
13.	Change of data structure	$\Rightarrow \#\,1$
14.	Continue cycle	$\Rightarrow \#\,9$ or $\#\,6$ (after new case)

Modification of COMMON

(a) Constant size

Existing dummies	..., $XDUM(10)$, $NDUM(10)$
New variables	$XNEW(2)$, NEW
	..., $XNEW(2)$, $XDUM(8)$, NEW, $NDUM(9)$

(b) Enlargement

Increase COMMON	$COMMON/EXTRA/\ \ A(5)$, B, $NEW(6)$
Add to MYDUMP	$REAL*4\ \ XNEW$
New COMMON	$COMMON/EXTRA/\ \ XNEW(18)$
Add READ/WRITE	..., $XNEW$

NBODY6 Output

Control line	$T\ \ Q_{\rm V}\ \ DE/E\ \ E_{\rm tot}\ \ R_{\rm cl}\ \ \Delta t_{\rm min}$
Main output	$T\ \ N\ \ NB\ \ KS\ \ NM\ \ MM\ \ NS\ \ NSTEPS\ \ DE/E$

Optional Procedures:

Cluster core	N^2 algorithm for core radius and density centre
Lagrangian radii	Percentile mass radii and half-mass radius
Error control	Automatic error check and restart from last time
Escape	Removal of distant members and table updates
Time offset	Rescaling of all global times
Events	Stellar types and energy partition
Binary analysis	Regularized binary histograms and energy budget
Binary data bank	Characteristic parameters for regularized binaries
HR diagram	Evolutionary state of single stars and binaries
General data bank	Detailed snapshots for data analysis

Energy Budget

Definition of total energy

$$E_{\rm tot} = T + U + E_{\rm tide} + E_{\rm bin} + E_{\rm merge} + E_{\rm coll} + E_{\rm mdot} + E_{\rm cdot} + E_{\rm ch} + E_{\rm sub}$$

T Kinetic energy of single bodies and c.m. particles

U Potential energy of single and c.m. bodies

$E_{\rm tide}$ Tidal energy due to external perturbations

$E_{\rm bin}$ Binding energy in regularized pairs

$E_{\rm merge}$ Total internal energy of hierarchical systems

$E_{\rm coll}$ Sum of binding energies released in collisions

$E_{\rm mdot}$ Energy change from mass loss and Roche mass transfer

$E_{\rm cdot}$ Neutron star kicks and common envelope evolution

$E_{\rm ch}$ Total energy of any existing chain subsystem

$E_{\rm sub}$ Energy of unperturbed triple and quadruple subsystems

ΔE Energy change due to removal of escapers