RIOD SIMULATION RESULTS COMPUTE ENGINE TEST RESULTS:

Two-Body, High-Eccentricity Orbital Tests

Testing Began November 7, 2019

Riod Website: https://riodsim.weebly.com/

RIOD: COMPUTE ENGINE TEST RUNS

- These tests were designed to demonstrate the Riod compute engine's accuracy and precision. They were originally run as supporting evidence for the gravitational matter wave analysis video and paper I wrote. Here the particle has mass of $5x10^7$ solar masses.
- Two simulation runs were conducted to put the simulation into stressful situation with known outcomes.
- The first test scenario involves a two-body problem, with known solutions thanks to Kepler and Newton.
  - The particles are put at an apoapsis distance of 100 kpc to begin the simulation.
  - They are given an initial velocity perpendicular to their radius vector and speed to give the orbital eccentricity of 0.98.
  - The particle pairs will fall together to a periapsis of 1.01 kpc (Actually, more precisely 1.0101010101…). Note that the force softening length for this type of simulation would normally be about 1 kpc. However for this test, force softening is turned off.
- The second test is designed to test the multithreaded components of the compute engine.
  - Now there are 100 pairs configured exactly like the above test.
  - All pairs are placed on the surface of an imaginary sphere of radius 50 Mpc and constrained to be no less than 14 Mpc apart.
  - To further stress this scenario, the test was run limited to 3 threads. An odd number removes any threading symmetries that might arise from the even number of particles.

TEST EXPECTATIONS

- For each pair, we know the expected orbital period.
- I use the value of the gravitational constant is 6.67408×10^{-11} $N \cdot m^2 \cdot kg^{-2}$
- Using the Kepler third law the orbital period for this test will be 106 GY or 10151899 simulation iterations.
- The first test was run for 11 orbital periapsis passages or more than 107 million iterations. The second test was also run for 11 orbital periapsis passages and for the same number of iterations.

SINGLE PAIR TEST RESULTS

Iterations at Periapsis	Pair Indices	Separation Distance at Periapsis	Iterations between Periapsis	Expected Period Delta	Net Accumulated Period Delta	Separation of pair at Periapsis Delta($x10^6$)
5075947	001, 002	1.010101	5075947	3		
15227844	001, 002	1.010101	10151897	2	3	0
25379741	001, 002	1.010101	10151897	2	0	0
35531638	001, 002	1.010101	10151897	2	0	0
45683536	001, 002	1.010101	10151898	1	1	0
55835433	001, 002	1.010101	10151897	2	-1	0
65987330	001, 002	1.010101	10151897	2	0	0
76139227	001, 002	1.010101	10151897	2	0	0
86291124	001, 002	1.010101	10151897	2	0	0
96443021	001, 002	1.010101	10151897	2	0	0
106594918	001, 002	1.010101	10151897	2	0	0

- Orbital period matches the expected period to within 2 ppm
- Periapsis distance is exactly as expected and is unchanging during the test
- Orbital period virtually unchanged over these thirteen orbital passes.

200 PAIR TEST RESULTS: LARGEST APOAPSIS CHANGE

Iterations at Periapsis	Pair Indices	Separation Distance at Periapsis	Iterations between Periapsis	Expected Period Delta	Net Accumulated Period Delta	Separation of pair at Periapsis Delta($x10^6$)
5075948	001, 002	1.0101	5075947	3		
15227848	001, 002	1.0101	10151896	3	2	10
25379749	001, 002	1.0101	10151896	3	0	11
35531649	001, 002	1.0101	10151896	3	0	10
45683549	001, 002	1.0101	10151897	2	1	10
55835449	001, 002	1.0102	10151896	3	-1	10
65987349	001, 002	1.0102	10151896	3	0	10
76139249	001, 002	1.0102	10151896	3	0	10
86291148	001, 002	1.0102	10151895	4	-1	10
96443048	001, 002	1.0102	10151896	3	1	10
106594948	001, 002	1.0102	10151896	3	0	10

200 PAIR TEST RESULTS: SMALLEST APOAPSIS CHANGE

Iterations at Periapsis	Pair Indices	Separation Distance at Periapsis	Iterations between Periapsis	Expected Period Delta	Net Accumulated Period Delta	Separation of pair at Periapsis Delta($x10^6$)
5075945	165, 166	1.0101	5075945	5		
15227840	165, 166	1.0101	10151895	4	5	-20
25379736	165, 166	1.0101	10151896	3	1	-20
35531632	165, 166	1.0100	10151896	3	0	-19
45683527	165, 166	1.0100	10151895	4	-1	-20
55835422	165, 166	1.0100	10151895	4	0	-19
65987318	165, 166	1.0100	10151896	3	1	-20
76139213	165, 166	1.0100	10151895	4	-1	-19
86291108	165, 166	1.0099	10151895	4	0	-19
96443004	165, 166	1.0099	10151896	3	1	-19
106594899	165, 166	1.0099	10151895	4	-1	-19

200 PAIR TEST RESULTS: DISCUSSION

- The worst case tested resulted in a -20 ppm change in the expected apoapsis separation.
- No measured period was greater than 5 ppm from the expected period.
- Since the simulation particle size is 0.5 kpc, based on the relative speeds at periapsis, the simulation takes about 3200 iterations to traverse on particle diameter.
- There may be some orbital precession but if it is there it is imperceptible.
- Single pair results are measurably better and the differences in the two tests are attributed to influences of neighboring pairs.

TEST RESULTS AND COMPUTATIONAL EQUIVALENCE.

- These test may seem at first glance specific to only one set of test conditions.
- However, the Riod simulation recasts all physical units, like MKS or GGS systems into unique Riod simulation units (RSU) for computational purposes.
- Just as the choice of coordinate systems is a matter of convenience, so too, one unit system is a good as any other unit system.
- The operator can set up the element units so that distances, velocities, masses are all numerically not far from unity.
- For example, if the user picks a length unit as 1 kpc, all the vector distances can be set up to be a few hundred, to a few thousand RSU distance units. Or if the mass unit is solar masses, the elemental mass unit is 1 RSU.

TEST RESULTS AND COMPUTATIONAL EQUIVALENCE (CONT.)

- The interesting thing about pick simulation units is, once they are picked, a gravitational constant is recalculated for those units. All velocities and distances calculated within the code are relative to those units and G for those units.
- Suppose one could create a different scenario with completely different RSU elemental units, (I call them the "Big Three": time, length and mass) but still have the same numerical value of G? Place objects the same RSU distance out with the same RSU mass and same softening length, wouldn't the computation of the evolution of such a system be the same result after the same number of iterations?

YES!

With caveats.

TEST RESULTS AND COMPUTATIONAL EQUIVALENCE (CONT.)

- Let's examine two scenarios. First the one we just reported the test results on, as noted in Galaxy scale column and then look at the Human Scale column:

Simulation Unit	Scale: Galaxy	Scale: Human
Length	3.086×10^{19} m	1m
Mass	5.0×10^{38} kg	1 kg
Time	3.3×10^{11} sec.	1.9×10^{1} sec.
Softening length (RSU)	1.0	1.0
G (RSU)	2.47×10^{-8} sec.	2.47×10^{-8} sec.

- Since G is identical for both systems, pick particle positions the same in RSU distance, then velocities will have the same numerical values in each of these two seemingly disparate simulations and this be computationally identical!

TEST RESULTS AND COMPUTATIONAL EQUIVALENCE (CONT.)

- Thus, it is not necessary to rerun these tests for other scenarios. If it works for one, there are a host of other computationally equivalent simulations that will have exactly the same outcome.
- The caveats to this are: clearly in the two cases presented above, the initial densities are very different (some twenty orders of magnitude). The collapse times will be identical in RSU iterations but converted to say MKS units, significantly different. Keeping things in mind, the equivalence of calculations can be a powerful ally.
- Other significant changes, such number of objects and softening lengths will introduce variations that cannot be accounted for in an equivalent way.