Unit 5: Project Report

Computer Modelling

Due: 16:00 Monday, Week 11, Semester 2

1 Aims

Based on the N-body code you co-wrote, you will run a series of simulations to obtain data. You will contrast your results with the expected outcome and, where possible, compare them with the literature.

Based on these results, you will write and submit a *"computational report"* of up to 2000 words, including figure captions but excluding the equations, abstract, and references[1]. **You will be lose marks if your report is noticeably longer than this limit**.

2 Tasks

The goal of a scientific report is to communicate the results of an experiment or a simulation, a development of a theory, or a hypothesis; with enough detail and information so others can independently judge the merits of your work. It is important to include enough information so your results can be independently reproduced. In computational physics reports, we state the main maths/physics behind the simulation, the main physical and numerical approximations made, as well as the numerical parameters of all relevant simulations presented.

Good quality computational physics requires *convergence*. A simulation has converged if more accurate simulations will not meaningfully change results. In exercise 3 you computed the frequency of a Morse dimer with various dt. In the report you will show that the results of a *representative simulation* have converged.

You should assume the reader is a competent coder, who is familiar with the main algorithms used, and who can represent math and algorithms as code. Therefore, the

[1]Shorter reports will not be penalised, as long as all key points are discussed

main report should *include no code*. Typically, reports over the word limit are too detailed in their code description.

Lastly, good reports will condense the main result in an abstract, set the background of the physics in the introduction in an attractive way, and have a clear conclusion.

3 Report Sections

Your report should usually contain at least the following sections

3.1 Abstract

This should very briefly summarizing the physics of what you have done, and the main result(s), written so it can stand almost alone, separate from the rest of the report.

3.2 Introduction

This should very briefly describe the physics and approximations being used, together with a *physical*, not programmatic, description of your simulation.

The reader cares about physics and algorithms, not code - you could have written the code in a completely different layout, structure, or even language and the report could be identical. So don't explain the names of files and functions you used, or that kind of detail.

3.3 Convergence

This should contains a clear demonstration of how you found the time-step where the results are converged.

If your code allows, it's fastest to do this with a *toy* solar system (the Sun, Mercury, the Earth and the Moon for about 10 years). Test the convergence of the observables (apsides, periods) with respect to the time-step, and the behaviour of the energy.

Discuss which body / measurement is the limiting factor in convergence.

3.4 Results

Your results section should contain:

- Plots demonstrating whether the simulation is working in general.
- Measurements (plots or tables) of the observables of the system.
- A discussion of these basic results, and comparison to literature, where appropriate.
- Results from one **mini-task** from Section 4 and discussion of it.

If any of your results do not make sense then state this clearly and discuss possible causes; don't try to hide or ignore them!

3.5 Conclusions

(Re-)State the main conclusions you have arrived at, and whether (and how you know) your simulation was satisfactory and why.

Finally, briefly reflect on project: are there changes you would make to the algorithms or methods to improve the simulation? What else could be improved?

3.6 Appendix (Optional)

Your code may need substantial fixes after the last source code submission. If that is the case, document any important changes in an Appendix (you can include code here if useful).

4 Mini-Tasks

Your mini-task result should be included in your results section and discussed in your conclusions. Choose **one** of the tasks below.

4.1 Non-functional codes

Codes that don't accurately simulate the solar system can still get reasonable report grades. If your code partially works, for example if it produces reasonable looking trajectories but the period measurements, say, make no sense, then you should probably pick one of the other mini-tasks below.

If your code does not work, discuss, from a a physics point of view, what identifiable problems there are, how you can diagnose these, what the expected behaviour should be, and discuss possible causes of the problem based on what is working.

4.2 Kepler's Third Law

Verify Kepler's third law, that $T^2 \propto a^3$, where T is the orbital period and a the semi-major axis (not aphelion!), for the planets using *your* results.

If you replace Jupiter by a *"super-Jupiter"* 20 times heavier, is Kepler's law still a good fit? Quantify this.

Hint: Power laws are often well-suited to log-log graphs. All fits should be shown with an estimate of their quality.

4.3 Halley's Comet

A 300–year simulation will show a Halley's comet following an open trajectory (i.e. one that does not exactly return to its starting position).

Note how close Halley comes to Venus in 2061 - is Halley's open orbit an artefact of your simulation or is it caused by Venus or other planets? Which planets cause the largest perturbation of the orbit?

You should experiment with removing planets from your simulation to reach a conclusion.

4.4 'Oumuamua

Oumuamua was the first interstellar body to be detected passing through our solar system.

The solar system data files that you used in this project were computed for the 23rd of May 2023. On that date, Oumuamua had these properties:

$$
\begin{aligned}
x &= 32.34886232938575 \\
y &= 5.313375789257013 \\
z &= 13.44876841466759 \\
v_x &= 0.01432769964704524 \\
v_y &= 0.002144206017240314 \\
v_z &= 0.006265218242343174
\end{aligned}
$$

We can assume its mass is 5×10^7 kg.

Add 'Oumuamua to your simulation with these properties. Since it has already left the solar system, run the simulation backwards in time (there are several ways to do this). Make a plot of its trajectory among the other planets, and determine, comparing to literature values where possible:

- the date and distance of its perihelion.
- its velocity at perihelion, comparing this to escape velocity.
- the date when it first arrived in the solar system within the orbit of Neptune.

Depending on its nature, 'Oumuamua may have lost mass during its passage through the solar system. Discuss briefly whether and how this might affect its motion.

4.5 Space 1999

The 1975 TV show *Space 1999* begins with an explosion on the Moon knocking it out of orbit and out to interstellar space.

Use your code to simulate this event happening, and make a diagram of a path the moon could take.

Simulate scenarios where the energy is enough to (i) detach the Moon from the Earth's orbit (ii) detach the Moon from the Sun's orbit, and compare the required energy values to what is expected theoretically. Explain your assumptions and process. Comment on the energy required and whether Space 1999 is realistic.

5 Submission

Submit your report through the Turnitin Link on the course LEARN page.

6 Common Mistakes

- Don't waste space describing your codes classes, files, functions, etc. While this work is the majority of the time that you spend on the project, it's not relevant to the physics or computation.
- Do talk about algorithms that you use - e.g. how you calculate observables, in the mathematical sense not the code sense.
- Your abstract should stand alone and summarize the report and its key findings to someone who knows nothing about the project.
- Don't use screenshots of text in tables. Make a proper table.
- For things like convergence, graphs are usually more informative than tables.
- Render mathematics correctly, e.g. $\surd$ not "sqrt".
- Round off values to sensible numbers of decimal places in the text and in tables.
- Use exponential notation correctly, e.g. 3.56×10^{10} not 3.56E10.
- Your language should be succinct, precise, scrupulously accurate, and formal.
- Make sure your figures have text large enough to read.
- Excel can make good graphs, but the defaults are often awful so you will have to tweak them.

7 Marking Scheme

This assignment counts for 35% of your total course mark. It is made up of the following components, marked according to the rubric visible on the TurnItIn assignment:

1. Abstract & Introduction [10]
2. Convergence tests [10]
3. Main results [15]
4. Mini-Task [10]
5. Conclusions [10]

6. Report layout, language, and graphics [15]

Total: 70 points.