# 7. — PHY 494: Homework assignment (20 points total)

Due **Monday, April 4, 2016, 6pm.**

Submission is to your **private GitHub repository**.

Enter the repository and run the script `scripts/update.sh` (replace *YourGitHubUsername* with your GitHub username):

```
cd assignments-2016-YourGitHubUsername
bash ./scripts/update.sh
```

It should create three subdirectories[1] `assignment_07/Submission`, `assignment_07/Grade`, and `assignment_07/Work` and also pull in the PDF of the assignment and an additional file.

To submit your assignment, commit and push a PDF file inside the `assignment_07/Submission` directory and name it `proposal.pdf`.

*Collaboration is not allowed* for this assignment. Each student must produce their own proposal.

## 7.1. Proposal for the Final Project (20 points)

Write a short proposal for the *Final Project*. You can come up with your own idea or base your proposal on the list of suggestions in the Appendix A.[2]

### 7.1.1. Formatting [5 points]

The proposal must adhere to the following formatting restrictions:

- 1 page maximum, 0.75 pages minimum length
- minimum font size 11pt
- minimum margins 1” on all sides
- include
  - **title**
  - **author** (your name)
  - sections with headings **Problem**, **Approach**, and **Objectives** (in this order); see below for what the content should be.

[1] If the script fails, file an issue in the Issue Tracker for PHY494-assignments-skeleton and just create the directories manually.

[2] The Final Project, the proposal, and the suggested projects were discussed in class on 2016-03-31. The slides are available from Blackboard and in the PDF `final_overview.pdf` within the HW7 repository.

#### 7.1.2. Content [15 points]

The proposal should concisely describe what project you want to undertake and suggest a roadmap for how you are going to do it. It should be written in *full English sentences*. Try to write clear and succinctly. If you can read it to someone not in the class and they get a general idea of what you want to do then you are on the right track.

Specifically, you must address the following points in the individual sections:

**Problem** Describe the problem to be solved: What is the background, what is the overarching question. What is the physics governing the problem, what are the important equations—show them, if possible, but at a minimum name them. You can also comment on why this is an interesting or difficult problem.

Clearly define the overall goal of what you want to find out.

*This should be between 30-50% of your text.*

**Approach** Describe *how* you are going to reach your goal, i.e., answer the overarching question. How are you going to solve the equations that you identified in the Problem section, what kind of calculations are needed, which algorithms are you going to use? Do you need input parameters? Where can you get them from (show URLs or sources if possible).

Be as concrete as possible: you want to convince your audience that it is feasible to solve this problem and you have an idea how to tackle it.

*This should be between 30-50% of your text.*

**Objectives** Use a numbered list to state 3–6 measurable non-trivial outcomes that you need to achieve in order to reach the overall goal. These are the milestones that you have to reach; they are possibly dependent on each other. For each objective it must be clear how to decide if you fulfilled it or not. Objectives are often formulated in terms of deliverables such as "Compile a list of material parameters for walls, windows and doors (heat conduction coefficients, typical thicknesses)."

Your grade will partially depend on achieving the objectives that you set here.[3]

*This should take up your remaining space. The Objectives are very important. Make sure to formulate them clearly. They will be your own roadmap when you do the project.*

# A. Suggested projects

The following are suggestions that can be used to develop projects. The estimated difficulty level is only very approximate (1 being easiest and 4 hardest).

[3] The instructor will vet the objectives for any proposal that is being used as the basis for a Final Project.

## A.1. Monte Carlo simulation of liquid argon

The Lennard-Jones fluid at constant temperature, this time simulated using random numbers.

- difficulty: 1
- implement basic MC for liquid Argon in the $NVT$ ensemble (see *Computational Physics* and/or Frenkel and Smit, *Understanding Molecular Simulations*)
- analyze at different $T$ and calculate the equation of state $P(T, \rho)$; look for a phase transition
- visualize
- extra work: implement $NPT$ ensemble (with volume moves)

## A.2. Monte Carlo simulation of the Ising magnet

The classical application for Monte Carlo methods and one of the best known hard but analytically solvable problems in statistical mechanics.

- difficulty: 2 (2D), 3 (with 3D)
- implement MC sampling for the Ising spin system in 1D, 2D, and possibly 3D
- see *Computational Physics*
- compute magnetization $M(T)$ and look for a phase transition
- visualize
- compare to the exact 2D result (see eg Kerson Huang, *Statistical Mechanics*)

## A.3. Classical chaotic scattering

Inspired by pinball flippers: what is needed for chaotic scattering, i.e., small initial differences in an incoming beam lead to large differences in the scattered beam.

- Difficulty: 1
- Problem 9.4 in *Computational Physics*
- particle interacting with “4-peak” potential
- integrate with RK4
- vary parameters and analyze cross section, assess sensitivity to initial conditions
- visualize trajectories

## A.4. Classical billiard simulator

Simulate an ideal billiard and find out if it behaves like an ideal gas or not.

- Difficulty: 2
- 2D (balls are hard disks)
- implement a collision-based simulation algorithm (fully elastic collisions with balls and walls) and remove balls through "pockets" (holes)
- initially without friction
- How long does it take for all balls to disappear?
- What is the smallest number of turns needed to get rid of 1, 2, . . . 15 balls?
- visualize
- extras:
  - program a computer player that minimizes the number of turns it needs to sink all balls
  - include friction

## A.5. Quantum mechanical wave packet propagation

Simulate a realistic representation of particles interacting with various potentials and see first-hand how different quantum mechanical particles behave from classical ones.

- difficulty: 3
- solve the time-dependent Schrödinger equation for a wave packet interacting with various potentials (e.g. using the explicit Visscher algorithm described in *Computational Physics* 22.2.1 or the Maestri/Askar & Cakmak algorithm (*Computational Physics* 22.3))
- 1d
  - step barrier (vary height compared to wave packet energy and observe tunneling)
  - harmonic well
  - square well
- 2d: observe interference *for particles*:
  - single slit
  - double slit

- calculate transmission coefficient, wave velocity, probability density on a screen behind slits
- visualize

### A.6. Fluid dynamics: 2D Navier-Stokes equations

The Navier-Stokes equations govern all of atmospheric and ocean physics, are needed to design airplanes and ships, and are fiendishly non-linear. But you can solve them with a computer:

- difficulty: 2–3
- Use *Computational Physics* Chapter 25 with code as starting point
- Solve the Navier-Stokes equations for 2d flow (using finite difference with successive over-relaxation)
- investigate the velocity (flow) field and vorticity around various submerged objects:
  - beam
  - sphere/cylinder
  - drop shape
- visualize
- vary Reynolds number: effect on vorticity?

### A.7. Energy efficient houses

Always wondered if you should shade your windows in AZ or get new ones? How much energy can you save by changing the temperature of your AC thermostat by 2 K?

- difficulty: 4 (Needs a lot of own research for parameters and development of a model.)
- Solve the heat equation for a "2d house" (Crank-Nicholson algorithm)
- Implement houses with typical sizes, shapes, and materials for walls, doors, windows.
- Investigate how much energy is needed to maintain the house at a constant temperature throughout a typical AZ year by simulating typical temperature changes.
- Investigate the effect of
  - increasing insulation
  - shading windows
  - changing the target temperature
- visualize temperature distribution

### A.8. Dynamics of the solar system

Extend HW6 and simulate the whole solar system... or simulate a hypothetical binary star system and track hypothetical planets there (Could Tatooine, a planet where one can see two suns, actually exist?)

- difficulty: 2
- simulate the solar system (classical gravitational interactions) with velocity Verlet
- include sun and planets and Halley's comet (or the Shoemaker-Levy comet and let it crash into Jupiter)
- find appropriate parameters (masses, positions, periods)[4]
- investigate
  - stability of the solar system
  - changes in orbits due to interactions (probably to weak to easily notice)
  - Do comets crash into planets?
  - extra: course of small space craft (e.g. a gravity assist swing by maneuver)
- extra: Make Jupiter like the sun and see how it changes the solar system.
- extra: build the Tatooine system: binary star (two suns) and an earth-like planet ("Tatooine"). Does the planet have stable orbits? What would the days on the planet look like? Is there an orbit that allows life?
- visualize[5]

### A.9. Wavelet analysis of Stock markets or Oil prices

Econophysics is a major employer of physicists... apply physical ideas to markets. If you can predict where the prices go you can make a lot of money...

See for instance the paper "Wavelet-based prediction of oil prices", S. Yousefi, I. Weinreich, D. Reinarz, *Chaos, Solitons and Fractals* **25** (2005), 265–275, doi: 10.1016/j.chaos.2004.11.015

- Difficulty: 3
- Implement wavelet analysis (Daubechies) for stock prices and commodity prices time series. (see *Computational Physics*)

[4] See NASA HORIZONS to get data: http://ssd.jpl.nasa.gov/horizons.cgi

[5] For a great example see the animated orrery http://mgvez.github.io/jsorrery/

- Test how well you can forecast known data: correlate forecast vs actual data (which was not used for the wavelet analysis). How does the correlation coefficient of the forecast with the real timeseries vary as a function of the forecasting time interval?

Disclaimer: If you make money from this project, it's all yours.

### A.10. Predicting winning sports teams

Who is going to win March Madness (or the World Cup)? Use simple stochastic simulations to get a quantitative estimate who you should be betting on...

- Difficulty: 2
- Derive simple quantifiers of performance/strength (find data, eg official rankings!) and use them to estimate the probability for a team to win in a given pairing.
- Calculate the probability for a given team to win a tournament by running many stochastic simulations of the whole tournament.
- Report statistical probability for a given team to end up in $N$-th place, and report most probable tournament outcomes.
- Compare to those historical results that you didn't use to derive your model.

Disclaimer: If you make money from this project, it's all yours.