1 Final Project

A final research project will be required for this course in place of a final exam. This project should involve a significant amount of engineering physics and a significant amount of numerical programming similar to the homework problems given throughout the semester. A list of possible projects is given below. You may choose one of these or make up your own. You are strongly encouraged to use the library to research your project and to explore new ideas. Many of the reserve books for this course contain useful ideas for projects. You may use subroutines or procedures from published sources but the majority of the program(s) used for your project must have been written by you (i.e. simply typing in a program listed in a book is not sufficient). This course has focused on using the computer to numerically solve engineering physics problems that cannot be solved analytically. In keeping with this approach, final projects involving data analysis, digital signal processing or pure math as a principle theme are discouraged (but not strictly forbidden).

Where appropriate you may combine this project with work from other courses (if approved by all instructors involved) as long as the total amount of work is approximately the same as you would have done if you did not combine this project with other course work. This is meant to be an opportunity to pursue a specific topic in more depth than you might otherwise have the time for and NOT a way of reducing your total amount of work.

2 Report Format

A formal written report on your final project should be turned in at the end of the semester (the exact time will be announced later). You will be required to hand in an outline of your proposed project about a month or so before the end of the semester. This outline should be about one page in length with one or more references and must be approved before handing in your final project. The final project itself should be a formal report of about 10-20 pages (not including appendices or program listing) submitted in electronic pdf format. More than 20 pages will not be read or graded. A formal report means that it should start with a section labeled **Introduction** and end with a section called **Conclusions**, and contain various other sections in between describing the theory, how your program works, your results, and the references you used. The introduction section should contain a brief discussion of the background for the project and introduce important concepts and references. The conclusions should summarize your results and contain your physical interpretation of the meaning of your results. The theory (detailed in English and mathematical equations) and program documentation should be in the main body of the report and the program listing should be included as an appendix (all rules governing program documentation in the homework apply here as well).

In general when you are writing a technical paper you do not get to choose your audience. Some people will not be familiar with the topic and you should explain in a clear and concise manner all of the basic underlying concepts. Other people may be experts and require a precise and detailed discussion of all the areas. It is important to strike a balance between these two extremes. There should be enough general background that a person who is not familiar with the details of your project may understand your work, and there should also be enough detail to convince the experts. The report for your final project should follow these guidelines. In a practical sense there will be a large variety of topics for the class as a whole. I will not be familiar with all possible topics so there should be enough background for me to understand what you did. On the other hand there are some things that I may understand in detail and there should be enough detail to convince me that you did it correctly. Because you will not know before hand what I know and don't know this exercise is in fact very similar to writing a paper for publication.

3 Grading

The grade for your final project will be a combination of the written presentation, the programming and numerical methods used and your physical interpretation of the meaning of your results. I will try to take into account the level of difficulty of your project as much as possible. The final project will count 20% toward your final course grade.

4 Typical Projects

Many of the books on reserve for this course (see below) contain possible ideas for final projects. You are encouraged to look through these books for ideas. The following brief titles would be appropriate types of projects:

1. **Chaotic Motion.** With many degrees of freedom and possibly nonlinear terms, motion may become very chaotic. F. C. Moon's book also describes many different physical systems that are chaotic. Use automatic step size Runge-Kutta.

2. **N-Body Motion.** If there are many moons orbiting Jupiter, what is required to produce stable orbits over a long period of time. Also some interesting pictures result from the study of colliding galaxies (see for example Hockney and Eastwood or Potter or Schroeder and Comins Astronomy, Dec. 1988, pg. 91-96 or `ssd.jpl.nasa.gov/` on solar system dynamics). Or you might investigate the stability of a planet orbiting a binary star. What do two suns do to the planets orbit? Use automatic step size Runge-Kutta. Can also make a movie of the result using matlab. For large N, you might try using a particle-mesh approach to rapidly calculate the gravitational potential on a mesh using an FFT to solve Poison's equation from mass distribution (Dawson, Rev. Mod. Phys. 55, 1983, p.403)

3. **Charged Particle Focusing.** The electrode system in HW 6 forms a lens for charged particles. After solving for the fields use the Runge-Kutta method to trace the trajectories through the lens to see if it really focuses (i.e. this could be used in an electron microscope or old fashion TV screen).

4. **Hartree-Fock Calculation of Helium Atom Energy Levels.** This is a very common method of calculating energy levels in many-electron atoms and can be applied to large atomic number atoms. Hartree-Fock for He is a reasonable amount of work. Atoms like carbon may be somewhat more challenging (see Koonin chapter 3). R. D. Cowan, "The Theory of Atomic Structure and Spectra", (Univ. of Cal. Press, 1981) is an advanced treatment if you are interested.

5. **2D Ising Model.** Apply numerical Monte Carlo methods to the study of the magnetic properties of a collection of spins using statistical mechanics (see Koonin section 8.4 or Wong section 7.5 page 434).

6. **Diffusion Limited Aggregation.** Some aggregates (such as snowflakes) grow by a random collection of small particles that randomly diffuse near by. The shape may vary in subtle ways (i.e. fractal curves etc.). Use Monte Carlo methods (see Wong section 7.8 page 479 and fig.7-27; Witten and Sander, Physical Review Letters, Vol 47, 1981, p. 1400-1403; Niemeyer et al, Phys. Rev. Let. Vol 52, 1984, p. 1033-1036). For snowflake formation see Vicsek, Phys. Rev. Lett. Vol. 53, 1984, p. 2281.

7. **Steady State Hydrodynamics.** The flow of a fluid around an object can be calculated in 2D using relaxation as described on pg. 158-168 of Koonin (also see the books by Fletcher and Chow). This might illustrate the airflow over an airplane wing etc. with translational invariance in one direction. It might be interesting to calculate the pressure difference and hence lift of an airplane wing.

8. **Mission to Mars.** Using the known orbits and masses of the Sun, Earth and Mars find the conditions necessary to get a spacecraft from the Earth to Mars using the automatic step size Runge-Kutta. (C. D. Murray and S. F. Dermott, Solar System Dynamics, Camb. Univ. Press., 1999; `www.seds.org/`; `ssd.jpl.nasa.gov/`; `www.stjarnhimlen.se/comp/ppcomp.html`).

9. **Multigrid Techniques.** Compare the convergence of multigrid relaxation methods for solving for electrostatic field to the normal overrelaxtion method discussed in class. See section 19.6 of Numerical Recipes, or "A Multigrid Tutorial", 2nd edit, by Briggs, Henson and McCormick (SIAM 2000, QA377.B75x2000, Math Library).

10. **Finite Element Calculations.** The finite element method is an alternative to the finite difference method discussed in class. It is described in section 7.11 and 8.7 of Gerald and Wheatley. You may calculate electrostatic fields or other continuum mechanics problems such as elasticity etc. The finite element method is a convenient way of including things like a dielectric block in the electrostatic field. (K. H. Huebner, "The Finite Element Method for Engineers", Wiley, 1975)

11. **Semiconductor Device Modeling.** Apply finite difference and relaxation techniques to model the fields and current inside a transistor. (Mayergoyz, J. Applied Physics, Vol. 59, 1986, p.195-199, and Korman, Mayergoyz, J. Applied Physics, Vol. 68, 1990, p.1324-1334.)

12. **Light Propagation in Fibers.** Use the spit step method with FFT's to propagate light in fibers. (Feit and Fleck, Applied Optics 17, 1978, p.3990; 18, 1979, p. 2843).

RESERVE READING LIST:

(should be in the Math Library)

Computational Physics:

J. D. Anderson, Computational Fluid Dynamics, McGraw-Hill 1995. (QA911.A58 x1995, - in Engin. Library))

A. D. Boardman, edit., Physics Programs, A Manual of Computer Exercises for Students of Physics and Engineering , Wiley 1980. (QC21.2 P57)

Chuen-Yen Chow, An Intro. to Computational Fluid Mechanics, Wiley 1979 (TA357.C53 - in Engin. Library).

C. A. J. Fletcher, Computational Techniques for Fluid Dynamics, Vol. 1 and 2, Springer 1991 2nd edit QC 151.F58x 1991.

A. Garcia, Numerical Methods for Physics, Prentice-Hall 1994, (QC 20.G37x)

H. Gould and J. Tobochnik, An Introduction to Computer Simulation Methods, Applications to Physical Systems, Part 1 and Part 2, 2nd edit. Addison-Wesley 1988. (QC21.2 G68)

R. W. Hockney, J. W. Eastwood, Computer Simulation Using Particles, McGraw-Hill 1981,1989. (QA76.9.C65 H68 1989 in Engineering Library)

Y. Jaluria, K. E. Torrance, Computational Heat Transfer, 1986 (TJ260.J26 in Engineering Library)

S. E. Koonin and D. C. Meredith, Computational Physics, Fortran Version, Addison-Wesley 1990. (QC20 K82 C7).

F. C. Moon, Chaotic and Fractal Dynamics, Wiley 1992, Q172.5.C45 M66x, 1992.

D. Potter, Computational Physics, Wiley 1973 (QC20.P86)

E. W. Schmid, G. Spitz, W. Losch, Theoretical Physics on the Personal Computer, 2nd edition, Springer-Verlag 1990 (QC20.7 E4 S3513 1990).

Samuel S. M. Wong, Computational Methods in Physics and Engineering, Prentice Hall 1992 (ISBN 0-13-155953, QC 52 W66 1992).

Numerical Methods:

S. C. Chapra and R. P. Canale, *Numerical Methods for Engineers, 4th edit.*, (McGraw-Hill, 2002) (TA345.C47x 2002)

G. E. Forsythe, M. A. Malcolm, C. B. Moler, Computer Methods for Mathematical Computations, Prentice-Hall 1977. (QA297.F73 C6 in Engineering Library)

C. F. Gerald and P. O. Wheatley, Applied Numerical Analysis, 5th edit., Addison-Wesley, 1994 (QA297.G35)

R. W. Hornbeck, Numerical Methods, Quantum Publishers 1975. (QA297.H81 in Engineering Library)

W. H. Press, B. P. Flannery, S. A. Teukolsky, W. T. Vetterling, Numerical Recipes in C, The Art of Scientific Computing (2nd edit.), Cambridge Univ. Press, 1992, (ISBN 0-521-43108-5, QA 76.73.C15 N97).

R. D. Richtmyer and K. W. Morton, *Difference Methods for Initial-Value Problems*, Interscience Publishers, 1967, (QA431.R53 1967)

Programming:

L. Ammeraal, C++ for Programmers, 1991, (QA76.73.C153 A46x)

B. W. Kernighan, D. M. Ritchie, The C Programming Language, 2nd edit., Prentice Hall 1988. (ISBN 0-13-110362-8; QA 76.73 C15 K39 1988)

H. Kopka and P. W. Daly, *A Guide to LaTeX, 2nd Edit.*, Addison-Wesley 1995. (Z253.4.L38 K66x 1995).