METHODS OF NUMERICAL SIMULATION IN FLUIDS AND PLASMA (Physics F629) - Spring 2013

Instructor: Antonius Otto

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Course Website: http://how.gi.alaska.edu/ao/sim/index.html

Location and time: REIC 204, MWF 11:45-12:45am

Scope and Contents of the Course:

Numerical simulation has become a frequently used and misused tool in Physics. Many areas in physics employ smaller and larger simulation codes. However, the traditional physics education provides no or little background in simulation techniques and their limitations. Often numerical simulation is used as a black box with little insight into the associated pitfalls and common errors. This course is intended to provide a systematic introduction into the methods and the limitations of computer simulation.

The course will introduce, analyze, and apply methods for the numerical solution of partial differential equations (pde's) which determine the dynamics of fluids and multi particle systems. The elements of this course include (a) classification and applications of partial differential equations, (b) methods for discrete representation of pde's, (c) stability and accuracy of the numerical solution, (d) boundary and initial conditions. The discrete representation of pde's includes finite differences, finite elements, finite volume, and spectral methods. The course address efficiency of various methods, and considers aspects of vector and parallel computer architectures. Applications address the dynamics of fluids, plasmas, and multi particle systems; and consider steady state configurations, convection problems, linear and nonlinear instabilities. Some specific applications can be chosen according to the interest of students enrolled in the course.

(Prerequisites: MATH 310, 421 or equivalent; PHYS 311, 312, 331, 332 or equivalent; experience in programming; graduate standing or permission of instructor; 3 + 0 credits)

Conduct of the Course:

The course will consist of two parts, where the first part provides the methodology of the simulation of convection and diffusion equations which are common in atmospheric, ocean, ionospheric, space plasma, and many technical fluid dynamics applications. The second part will address more specific applications from various areas of physics and includes the generation of appropriate grids, boundary layer flow, shocks and flux corrected transport, and particle/plasma simulation.

The course will be held in a lecture format. The first part of the course will be based on the two volume text by Fletcher, *Computational Techniques for Fluid Dynamics*. No textbook currently available provides all information necessary for the second more specific part of the course.

Homework will be distributed weekly through the class website and problems are analytic and applied, i.e., students are be expected to program and test various algorithms. Program examples will be presented in FORTRAN which is common on supercomputers and the graphics language IDL. However, exercises may be programmed also in C, PASCAL, MATLAB or other languages provided their syntax is sufficiently obvious. Solutions to the homework are distributed through the website. In the second part of the course a portion of the exercises will consist of work on a specific project according to the interest of the student. Enrolled students are expected to obtain their own computer account, and to be/become familiar with a common graphics package for the presentation of results. Programming experience and some background on partial differential equations is recommended for the course. There will be a midterm test and a final exam.

Grading Policy:

Homework: 50%

Project: 15%

Final exam: 35%

Weekly list of Content (tentative)

- Introduction
- Origin of Partial Differential Equations
- Properties of Partial Differential Equations
- Preliminary Computational Techniques
- Theory
- Weighted Residual Methods
- Elliptic Equations and Steady State Problems
- Diffusion Equation
- Convection Equations
- Generalized Curvilinear Coordinates and Grid Generation
- Fluid and Plasma Equations
- Fluid and Plasma Simulation
- Applications and Projects

Textbooks:

Fletcher, *Computational Techniques for Fluid Dynamics, I and II, Springer (1988)*, $ 79.95 per volume: A very good two volume text with very detailed coverage of basic and advanced fluid simulation techniques including finite differences, finite element, spectral and other methods. Many programming examples for illustration and as tutorials. The text addresses dynamic and steady state problems, explicit and implicit treatment, flux corrected transport, boundary conditions, and grid generation. It lacks all aspects of plasma simulation.

Potter: *Computational Physics, John Wiley (1973)*: out of print but available in the GI library): A good text book which covers most of the basics of fluid simulation including theoretical aspects. It also addresses plasma simulation, however because of its age it is slightly outdated, lacks some of the more recent developments and the overall coverage is significantly smaller than in Fletcher's text.

Tajima: *Computational Plasma Physics: With Applications to Fusion and Astrophysics, Addison Wesley (1889)*, $ 52.00: The text focuses on plasma simulation by particle simulation with coverage of explicit, implicit, full electromagnetic, and hybrid models. It also addresses the most important fluid aspects of plasma simulation including finite differences, spectral methods and flux corrected transport.

Birdsall and Langdon, *Plasma Physics via Computer Simulation, IOP (1995, based on 1985 original)*, $ 70.00: Good textbook on plasma simulation but entirely focused on particle simulation techniques. Very detailed presentation with many applications. Good coverage of electrostatic and electromagnetic simulation including theory and physics.

Hockney and Eastwood, *Computer Simulation using Particles, IOP (1994, revised from 1980 edition)*, $ 171.05: Good textbook covering the same range of topics as Birdsall and Langdon. Less detailed regarding the plasma physics applications, however, with additional coverage of simulations of semiconductors and of astrophysical problems.

The following policies and services are included because they are mandated for UAF course syllabi:

- Attendance and class participation (questions, comments etc.) are strongly recommended.
- A make-up exam will be offered if attendance of the final exam was not possible.
- Homework is expected to be handed in on time and plagiarism is strongly discouraged.
- If needed computer access and access to IDL can be provided.
- The instructor will work with the Office of Disabilities Services (203 WHIT, 474-7043) to provide reasonable accommodation to students with disabilities.