ASTR/PHYS 8150
NUMERICAL METHODS FOR PHYSICS AND ASTRONOMY

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Location: Spark 307 12:45 PM – 14:00 PM

Course description: Solving physics and astronomical problems using modern signal and image analysis techniques, with a practical "hands-on" approach to code-writing. A wide range of subjects will be covered.

Objectives: providing a basic understanding of algorithmic design; covering a broad range of algorithms and methods used in astronomy; providing the students with the tools required to understand the computational aspect of papers in the literature.

Prerequisites: some prior experience in programming is required.

Lectures: 2:30 hours per week. Lectures will mix hands-on programming and numerical analysis as needed, using Julia examples. Because of the wide range of techniques covered by this course, and of the focus on physics/astronomical applications, no book covers the full material. Therefore, there will not be an official/required textbook. Instead the slides and the code samples will serve as your textbook. They can be found at https://github.com/fabienbaron/numericalmethods. In addition you may find the following books useful:

Computer Age Statistical Inference, Efron & Hastie
Numerical methods in Astrophysics: an introduction, Bodenheimer et al.
Statistics, Data Mining and Machine Learning in Astronomy, Ivezic, Connoly, VanderPlas & Gray.
Numerical recipes (3rd edition), Press et al.
Numerical Optimization, Nocedal et al.
Introduction to computational physics, Pang
Computational Physics, Newman
Numerical methods for Physics, Garcia
Data Analysis: A Bayesian Tutorial, Sivia & Skilling
Computational Hydrodynamics for Astrophysics, Zingale, Open Astrophysics Bookshelf.

Tests, Homework & Final Project: While several assignments will be given as homework, involving writing computer programs for given tasks, they will not be graded. The grade for this course will come from a final project directly related to the student's research. This final project will consist in a presentation in class plus a detailed report covering the algorithmic choices and the code written to solve the problem.

Grading: the final grade will be computed from 15% of oral participation + 85% for the final report & presentation. The focus will be on the clarity, depth of knowledge and understanding displaying in the final presentation and report. The course grade will be determined as follows:

Oral Participation: 15%
Final Project: 85%

A+: 97-100%	A: 93-96%	A-: 90-92%
B+: 87-89%	B: 83-86%	B-: 80-82%
C+: 77-79%	C: 73-76%	C-: 70-72%
D: 60-69%	F: 0-59%	

Tentative Schedule (42 hours, 14 weeks)

Probabilities (4 hours)
- Introduction to statistics and probabilities

Error analysis (2 hours):
- Classic error propagation
- Probabilistic approach

Modeling and Fitting (5 hours):
- Bayesian framework
- Maximum likelihood
- Maximum a posteriori
- Bayesian Model selection

Image processing (6 hours):
- Convolution/Correlation
- Inverse methods (denoising, deconvolution, regularization)
- Image registration and comparison
- Wavelet analysis

Monte Carlo (3 hours)
- Error propagation
- Optimization
- Integration

Time series analysis (4 hours):
- Fourier Transforms (DFT, FFT, NUFFT)
- Least-square spectral analysis methods (Lomb-Scargle)
- Principal component analysis
- Wavelets

Directed Optimization (5 hours):
- Global vs local, constrained vs unconstrained, convexity, smoothness, large vs small scale
- Simple root finding: Newton/Householder, Brent
- Convex optimization:
  - Simplex method, Interior point method
  - Conjugate gradients, Newton and semi-Newton, Trust region, Levenberg-Marquardt
- Non-smooth optimization:
  - proximal methods, ADMM
- Non-convex optimization

Basic Machine Learning (3 hours)
- Clustering
- Expectation Maximization (example: patch priors for denoising)
- Introducation to neural networks

Overview of parallel processing (3 hours)
- Multi-threading, Multi-process, OpenMP vs MPI
- Introduction to GPU computing

The course syllabus provides a general plan for the course; deviations may be necessary. Students are responsible for adhering to the GSU academic honesty policy, which can be found at http://studenthandbook.gsu.edu/ and http://codeofconduct.gsu.edu/. Students who wish to request accommodation for a disability may do so by registering with the Office of Disability Services. Students may only be accommodated upon issuance by the Office of Disability Services of a signed Accommodation Plan and are responsible for providing a copy of that plan to instructors of all classes in which an accommodation is sought." The Office of Disability Services is located in the Student Center, Suite 230.