PHYS/ASTR 8150
NUMERICAL METHODS FOR PHYSICS AND ASTRONOMY
FALL 2025

Instructor: Dr. Fabien Baron
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Course classroom: Aderhold 303
Course hours: Tuesdays/Thursdays 12:45 PM – 2:00 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.

Assessments: There will be three take-home assignments during the semester. They cover the material discussed in class, and are aimed at assessing the theoretical and algorithmic knowledge of the student. You may be asked to write a mock computer program. In-class participation accounts for 10% of your grade, and is meant to measure how active you will have been in interacting during the course.

Grading: The course grade will be determined as follows:

Take-home assignments:	90%	A+: 97-100%	A: 93-96%	A-: 90-92%
Class participation:	10%	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 and time series processing (6 hours):
- Fourier Transforms (DFT, FFT, NUFFT)
- Convolution/Correlation
- Inverse methods (denoising, deconvolution, regularization)
- Image registration and comparison
- Wavelet analysis

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

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

"Old" Machine Learning (3 hours)
- Clustering
- Expectation Maximization & Variational Inference

"New" Machine Learning (3 hours)
- Neural networks: perceptron, backpropagation, stochastic gradient descent
- Examples: Diffusion models, Inverse Networks, Neural Radiance Fields

Parallel processing: a quick overview (3 hours)
- Multi-threading, Multi-process, OpenMP vs MPI, GPU computing

Legal disclaimer: 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/.

AI usage: The use of artificial-intelligence (AI) tools – including but not limited to text, image, video, or code generators, research assistants, or problem-solving systems – is permitted unless the instructions for an assignment, activity, or assessment explicitly state otherwise. Unauthorized use of AI may constitute academic misconduct under the university's Policy on Academic Honesty. If you are unsure whether an action constitutes AI use, ask me before proceeding.

Accommodations: Students who wish to request accommodation for classwork or tests may do so by registering with the Access and Accommodation Center (https://access.gsu.edu/). Students may only be accommodated upon issuance by the Access and Accommodation Center of a signed Accommodation Plan and are responsible for providing a copy of that plan to instructors of all classes in which accommodations are sought.