EARS 80.03 Technical Computation in the Earth Sciences Fall 2020

Class period: M,W 4:00-5:50 (G)

Instructor:
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Course overview:
Driven by increasing data availability, processing power, and model sophistication, *scientific* or *technical computation* has become increasingly central to basic research in the Earth Sciences. This course aims to provide Earth Science students with a working introduction to scientific computation including (1) hands-on experience applying common, widely applicable sampling and inversion algorithms to classic Earth Science problems; (2) an awareness of the factors limiting efficiency and scalability when working with large datasets; and (3) an introduction to some of the tools and best practices of software engineering used to produce more robust, maintainable software.

Prerequisites: Previous computer programming experience. MATH 3 or greater calculus.

Learning Objectives:
This course is structured to complement the "Quantitative Analysis of Earth Systems" category of courses within the Earth Sciences major. The primary objective of this course, broadly stated, is to provide students with hands-on experience with, and the consequent ability to independently use and understand, a critical range of tools and techniques required to conduct advanced computational research in the Earth sciences. Upon completing this course, students will be able to:

- Solve some common linear and linearizable inverse problems relevant to the Earth sciences.
- Use a Metropolis-style algorithm to sample a posterior distribution.
- Write a simple parallel program, to take advantage of the inherent parallelism of geologic data.
- Use the basic tools of software engineering to write reliable and reproducible code for scientific research.

Readings: Selected readings will be assigned throughout the term, primarily from the following three texts

(1) *Bayesian Data Analysis, 3rd Edition* by Gelman et al.
(2) *Think Julia: How to Think Like a Computer Scientist* by Lauwens & Downey
(3) *Introduction to Applied Linear Algebra – Vectors, Matrices, and Least Squares* by Boyd & Vandenberghe

all three of which are freely available as PDFs courtesy of the authors. You are encouraged to complete the readings before class.

Additional resources:
Linear algebra code examples from Boyd & Vandenberghe
An introduction to basic statistics— see especially the section on summarizing distributions

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Class Schedule:

Week	Date	Class Topic	Assignment	Reading
1	Mon., Sept. 14	Review of programming concepts	Installing Julia. Using the REPL	Lauwens & Downey chapters 1, 2, 5
1	Wed., Sept. 16	Software Engineering 1: Source control with git, commenting your code	“Hello World”	Lauwens & Downey chapters 3, 10, 8, 14
2	Mon., Sept. 21	Data and uncertainty. Datasets as vectors and matrices.	Project 1	Boyd & Vandenberghe Chapters 1, 6
2	Wed., Sept. 23	Solving some linear inverse problems from the Earth sciences	Project 1	Boyd & Vandenberghe Chapter 12
3	Mon., Sept. 28	Software Engineering 2: Package management, debuggers	Project 2	Rackauckas pkg development
3	Wed., Sept. 30	Solving some linearizable inverse problems from the Earth sciences	Project 2	Boyd & Vandenberghe Chapter 18, esp 18.2
4	Mon., Oct. 5	Markov Chain Monte Carlo: The Metropolis algorithm.	Project 3	Gelman et al. chapter 11
4	Wed., Oct. 7	Theory of Markov Chains. Bayes' Theorem.	Project 3	Gelman et al. chapter 1
5	Mon., Oct. 12	Metropolis-Hastings, STAN, HMC, and other modifications.	Project 3	Gelman et al. chapter 12
5	Wed., Oct. 14	Software Engineering 3: Profiling and Optimization	Project 4	Handout
6	Mon., Oct. 19	Shared-memory parallel programming:`@threads`. ILP: `@avx`	Project 4	
6	Wed., Oct. 21	Distributed-memory parallel programming: MPI.jl	Project 4	
7	Mon., Oct. 26	Final project	Final Project	
7	Wed., Oct. 28	Software engineering 4: Building robust programs: interfaces, unit testing, and integration testing.	Final Project	Handout
8	Mon., Nov. 2	Final Project	Final Project	
8	Wed., Nov.4	Neural nets; opportunities and pitfalls thereof.	Final Project	
9	Mon., Nov. 9	Final Project	Final Project	
9	Wed., Nov. 11	Guest lecture: Image analysis	Final Project	
10	Mon., Nov. 16	Final Project	Final Project	
10	Wed., Nov. 18	Final project presentations	Final project due	

Academic Honesty:
The key principle of academic honesty is this: *you must not receive credit for work that is not truly yours*. This simple principle has lead to many difficult situations in collaborative programming; the elaborations below are adapted in part from CS 10, whose instructors have struggled with such issues for many years. In particular:

1. All project code and project reports you turn in must be typed, documented, and output generated by you yourself alone.
2. Students are encouraged to discuss their approach to the problem at hand and help each other with debugging. However, you must clearly acknowledge any point in your program where another student has influenced the design of your code during the course of such lab discussions, and credit them by name.
3. Published open-source code may be used in the course of your assignments if clearly cited and in accordance with the terms of the published license. In principle, you could turn in an entire project composed of properly cited snippets of published code and this would not violate the honor principle; however, in that case you should also not expect to receive full credit for designing an original solution to the problem at hand.
4. You must clearly attribute the source of any code you did not write yourself. Attempting to evade this requirement by, e.g., changing variable names or otherwise "paraphrasing" without attribution is a violation of the Academic Honor Principle.
5. It is not trivial to design good programming assignments; the assignments in this course may be reused with some modification for many years. Attempting to find solutions from previous years, however, is a bad idea that would deeply undercut your learning and present possible honor principle issues.
6. Any figures, data, text, or other material represented as program "output" in your project report must be authentically generated by running your actual program. Misrepresenting such program output is a violation of the Academic Honor Principle.
7. Written lab reports and the final project report must be wholly original and independent; references to previous literature are encouraged but must be properly cited.

More information is available at:
https://students.dartmouth.edu/judicial-affairs/
https://students.dartmouth.edu/judicial-affairs/policy/academic-honor-principle
https://writing-speech.dartmouth.edu/learning/materials/sources-and-citations-dartmouth
https://www.cs.dartmouth.edu/~cs10/ (see sections on Collaboration and Honor code)

Assignments:

This is a hands-on, lab-focused class. After the first week, we will devote most of our efforts each week to one of five programming projects. Nominal "lecture" periods will begin with an introduction and demonstration of new concepts, tools, or algorithms; however, after this introduction we will directly transition into applying this material to the week's lab project in-class.

The five projects are structured as follows:

Project	Description
1	Solving a linear inverse problem
2	Solving a linearizable inverse problem
3	Implementing a Metropolis walker

Project	Description
4	Writing a parallel program
Final	Work with the instructor to find a data analysis or modelling question that can be answered computationally using techniques previously introduced in this class.

For Projects 1-4, you will turn in a folder or archive containing your fully commented code, any relevant data files, as well as a brief lab report with figures describing and interpreting your results as well as describing and justifying any significant code design choices. For the final project, this report will take the form of a more polished lab report, in the style of research paper, presenting your results and the software you developed to obtain them.

Due dates and attendance:
Project reports, both code and text, are due online by midnight the night before the next project is assigned in this syllabus. Grades will be diminished by a (multiplicative) factor of 0.8 per day late, and will not be accepted at all once graded reports have been returned to other students.

Attendance is expected at all regularly scheduled class and lab meetings, except X-Hours; any absences will make it substantially more difficult to complete the class projects successfully. If you miss a class period in which a quiz is conducted, you will only be allowed to make up that assignment if you have notified us of (and the instructor has approved) your planned absence at least two hours before the start of that class.

Grading:
The point breakdown of each assignment is as follows:

Assignment	Weight
Project 1	16.00%
Project 2	16.00%
Project 3	16.00%
Project 4	16.00%
Final Project	28.00%
Quizzes	4.00%
Participation	4.00%
Total	100.00%

In-class quizzes are meant to help me gauge the degree to which the class is on the same page, and are thus not intended to contribute a large proportion of them class grade.
Class projects and project reports will be assessed as follows:

Metric	Weight
Correctness of code: Do you get the right answer?	35.00%
Readability, commenting, and efficiency: Quality of code, beyond correctness?	30.00%
Lab report quality: Do you accurately describe what you've done and why?	30.00%
Presentation: How well does the lab report visually convey your results?	5.00%
Total	100.00%

Accommodations and other considerations:
If you encounter financial challenges related to this class, please let us know. Computing hardware shall be made available for loan or in-lab use to students who do not have a Mac, Linux or BSD laptop or personal computer on which to complete class assignments.

Religious Observances: Some students may wish to take part in religious observances that occur during this academic term. If you have a religious observance that conflicts with your participation in the course, please meet with me before the end of the second week of the term to discuss appropriate accommodations.

Student Accessibility Needs: Students with disabilities who may need disability-related academic adjustments and services for this course are encouraged to see the instructor privately as early in the term as possible. Students requiring disability-related academic adjustments and services must consult the Student Accessibility Services office (205 Collis Student Center, 646-9900, Student.Accessibility.Services@Dartmouth.edu).

Once SAS has authorized services, students must show the originally signed SAS Services and Consent Form and/or a letter on SAS letterhead to the instructor. As a first step, if you have questions about whether you qualify to receive academic adjustments and services, you should contact the SAS office. All inquiries and discussions will remain confidential.

Mental Health:
The academic environment at Dartmouth is challenging, our terms are intensive, and classes are not the only demanding part of your life. There are a number of resources available to you on campus to support your wellness, including your: Undergraduate Dean (http://www.dartmouth.edu/~upperde/);Counseling and Human Development (http://www.dartmouth.edu/~chd/); and the Student Wellness Center (http://www.dartmouth.edu/~healthed/).

Sexual Misconduct:
At Dartmouth, we value integrity, responsibility, and respect for the rights and interests of others, all central to our Principles of Community. We are dedicated to establishing and maintaining a safe and inclusive campus where all have equal access to the educational and employment opportunities Dartmouth offers. We strive to promote an environment of sexual respect, safety, and well-being. In its policies and standards, Dartmouth demonstrates unequivocally that sexual assault, gender-based harassment, domestic violence, dating violence, and stalking are not tolerated in our community.

The Sexual Respect Website (https://sexual-respect.dartmouth.edu) at Dartmouth provides a wealth of information on your rights with regard to sexual respect and resources that are available to all in our community.

Please note that, as a faculty member, I am obligated to share disclosures regarding conduct under Title IX with Dartmouth's Title IX Coordinator. Confidential resources are also available, and include licensed medical or counseling professionals (e.g., a licensed psychologist), staff members of organizations recognized as rape crisis centers under state law (such as WISE), and ordained clergy (see https://sexual-respect.dartmouth.edu/reporting-support/all-resources/confidential-resources).

Should you have any questions, please feel free to contact Dartmouth's Title IX Coordinator or the Deputy Title IX Coordinator for the Guarini School. Their contact information can be found on the sexual respect website at: https://sexual-respect.dartmouth.edu/reporting-support/all-resources/campus-resources

Additional Support for your Learning:

Academic Skills Center (http://www.dartmouth.edu/~acskills/)
The Academic Skills Center is open to the entire Dartmouth Community. Here are some common reasons why you might visit the ASC:
You're getting B's but you want to get A's
You don't feel comfortable talking in class
You're attending class regularly but you feel like you're missing important points
You feel like you're a slow reader
You're having trouble completing tests in the allotted time
You feel like you don't have enough time to get everything done
You're not sure how to take notes
You want to sign up for a tutor or study group
You're not sure if you should get tested for a learning disability

The Research Center for Writing, and Information Technology (RWiT http://writing-speech.dartmouth.edu/learning/support-writing-research-and-composing-technology/rwit)
Located in Berry 183, RWIT is a free service dedicated to helping members of the Dartmouth community develop more effective strategies for generating and organizing their ideas, finding and evaluating research sources, and presenting and revising compositions in a variety of media. Through informal dialogue, RWIT tutors assist writers in developing better compositions and more effective composing strategies. A collaboration between the Institute for Writing and Rhetoric, the Library, and Academic Computing, RWIT brings together faculty, administrators, staff, and students to focus on the art and science of composition.

Dartmouth College Library (http://library.dartmouth.edu/)
A key to successful research is the use of reliable, high-quality information sources. While some information can be found on the open web, the best place to start your research is at the Library's Research Guides, researchguides.dartmouth.edu/guides. These research guides have categorized and organized the library's key resources - including books, databases, scholarly articles, and data sources - for your convenience. The Library's website also has information on useful research tools and services. In addition to the online information, a librarian has been assigned to this class to answer research questions, help you find appropriate resources, and assist with search techniques. Please contact your subject librarian (http://researchguides.dartmouth.edu/subjectlibrarians) for specialized help.