Computational Methods for Data Driven Earth Science
HWRS 640 - Spring 2026 (3 credits)

General Information

Course Meeting Times:
Location Harshbarger 232 (Kisiel Room)
MWF 11am - 11:50am

Office Hours:
Location: Harshbarger 322B
Date and time: Wednesdays, 10-10:50am

Course Prerequisites or Corequisites:
Python, or similar (R, Julia, Javascript) programming skills.
A strong background in numerical computing is recommended.

Instructor and Contact Information
Dr. Andrew Bennett
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Office: Harshbarger 322B

Catalog & Course Description
This course aims to provide students with concepts, skills, and applications for understanding and modeling the complex Earth system using advanced computational methods. We will survey fundamental mathematical methods for large-scale data analysis and modeling including topics such as optimization, reduced order modeling, dimensionality reduction, deep learning, and connections to numerical modeling via partial differential equations. A large focus of the course will be on the topics of scientific machine learning (SciML) and building skills for working with real-world datasets across a multitude of modalities.

Required Texts and Materials

Required Texts

None

Equipment and Software Requirements

All of the work for this class will be done on personal computers using free software packages. You will need daily access to a laptop or other web-enabled device with a webcam and microphone, regular access to reliable internet signal; ability to download and free software including python. Linux, Mac, and Windows computers are all fine for this course.

Learning Objectives, Outcomes, and Assessment

Course Objectives

- **Understand Computational Foundations**: The course will cover the basics of computer architecture, floating-point arithmetic, and key concepts in concurrent execution. There will be a strong emphasis on practical implications of these concepts and their relationship to the mathematical methods.
- **Strengthen Mathematical Foundations**: Students will revisit crucial mathematical concepts such as linear algebra, optimization, and numerical methods through the lens of Earth systems science.
- **Use Deep Learning Techniques**: Students will gain hands-on experience with machine learning models including convolutional neural networks and recurrent neural networks.
- **Integrate Hybrid Modeling Approaches**: The course will explore hybrid modeling techniques, including physics-informed neural networks and differentiable models.
- **Develop Practical Skills**: Through practical tasks and projects, students will learn to implement computational methods for real-world Earth science problems.

Expected Learning Outcomes

Students will be able to:

1. Interpret how physical hardware and software constraints affect data analysis and modeling workflows.
2. manipulate large, heterogeneous datasets representing Earth system processes.
3. generate summaries and statistically analyze said datasets using computational techniques.
4. build and explain modeling workflows to predict key areas of the Earth system through computational modeling.

5. Analyze, validate, and visualize the results of computational models, including the analysis of uncertainty and potential risks of model use.

Assessments and Grading Breakdown

- **Class participation (20%):**
  Active engagement in class discussions, coding activities, will form the basis of this component. Students are encouraged to ask questions and contribute to our in class discussions. Participation will be assessed through a combination of attendance, in-class exercises, and the quality of interactions.
- **Weekly assignments (60%)**
  Weekly assignments will comprise a mix of short-answer questions, problem sets, and coding exercises designed to reinforce the concepts covered in lectures. They will provide students with hands-on experience in applying computational methods to Earth science problems. Expect approximately 12-14 assignments throughout the semester, with varying levels of complexity and time commitment.
- **Final project (20%)**
  This project will offer students the opportunity to explore topics of interest and showcase their ability to integrate and apply the knowledge and skills acquired in the course. The projects will involve a combination of research, data analysis, modeling, and presentation. Detailed guidelines and evaluation criteria will be provided well in advance.

Grading Scale and Policies

This course will be graded using the regular university grading system (https://catalog.arizona.edu/policy/courses-credit/grading/grading-system) with the A-E scale. Grades will be assigned as follows:

A >= 90%
B >= 80%
C >= 70%
D >= 60%
E < 60%

The lowest scored assignment during the course will be omitted from the final grade.

Final Exam:

This course will not include a final exam and will be completed on the last day of regular classes. For reference to the final exam schedule for other courses, however, see: https://registrar.arizona.edu/finals?audience=students&cat1=10&cat2=31

Incomplete or Withdrawal:

These requests must be made in accordance with University policies, which are available at this link.

Late work policy:

No late assignments will be accepted without prior approval from the instructor. Late assignments will receive a zero. The lowest scored assignment will be dropped from the overall grade.

Policy on teamwork and collaboration:

All of the assignments in this course will be submitted and graded individually. It is expected that you will be responsible for your own writing, code, and figures. However, teamwork is still highly encouraged. You are welcome to share your work with others, consult classmates for help debugging and follow their examples for how to approach a problem. You will only be penalized if it is clear that you are copying others' work without also doing your own.

Scheduled Topics and Activities

Week	Dates	Topic	Assignments	Due Date
1	Jan 14-16	Overview of computer architecture: Memory hierarchy, floating point numbers	Reading assignments, short answer questions	Jan 23
2	Jan 19-23	Key concepts in concurrent/parallel computing: Scaling, Flynn’s taxonomy	Problem set, coding exercise	Jan 30
3	Jan 26-30	Linear algebra refresher: Vector spaces, transforms, eigenvalues/eigenvectors	Coding exercise	Feb 6
4	Feb 2-6	Introduction to numerical methods: Nonlinear solvers, ODE methods	Problem set	Feb 13
5	Feb 9-13	Statistics refresher: Parameter estimation,	Data analysis exercise	Feb 20

		Maximum likelihood		
6	Feb 16-20	Tensor decomposition methods I: Singular value decomposition	Regression Exercises	Feb 27
7	Feb 23-27	Tensor decomposition methods II: Dynamic mode decomposition	ENSO PCA/DMD Exercises	Mar 6
8	Mar 2-6	Optimization methods I: Back propagation, gradient descent	Problem set, optimization exercise	Mar 13
9	Mar 9-13	Optimization methods II: First order methods, numerical methods revisited	Coding exercises	Mar 20
10	Mar 16-20	Deep learning: The multilayer perceptron	Coding exercises, final project proposal	Mar 27
11	Mar 23-27	Deep learning: CNNs and RNNs	Coding exercises	Apr 3
12	Mar 30-Apr 3	Deep learning: Transformers	Coding exercises	Apr 10
13	Apr 6-10	Deep learning: Diffusion models	Coding exercises	Apr 17
14	Apr 13-17	Deep learning: Physics informed neural networks	Coding exercises, final project dataset report	Apr 24
15	Apr 20-24	Deep learning: Operator learning	Report on data and model inductive biases	May 1
16	Apr 27-May 1	Deep learning: Hybrid and differentiable modeling techniques	Project presentation, final report	Date of final exam
17	May 4-6	Final project presentations & course discussion	N/A	N/A

Class Format, Communication, and Policies

Course Format

This course will consist of a mixture of lectures, discussion and interactive coding activities. Every week, I will present new material, students will present their work and we will have group discussions and code walkthroughs. This is a very interactive course and students are expected to participate in discussions and come prepared to share their work and help others.

Course Communication

- Course communications will take place using your official UA email address.
- I will attempt to reply to all email inquiries in a timely manner but please be advised that if your question will take more than 5 minutes to reply to, I will request that you come to office hours or schedule an appointment. For coding questions related to homework or projects, I prefer that you come to office hours or make an appointment as debugging can be difficult over email.
- Emails will generally be handed in normal business hours so do not expect to get a response if you send your question out late the night before an assignment is due.
- Course grades and announcements will be posted through D2L
- All other course materials will be shared through GitHub

Class recordings

For any lecture recordings, which are used at the discretion of the instructor, students must access content in D2L only. Students may not modify content or re-use content for any purpose other than personal educational reasons. All recordings are subject to government and university regulations. Therefore, students accessing unauthorized recordings or using them in a manner inconsistent with UArizona values and educational policies are subject to suspension or civil action.

Makeup Policy for Students Who Register Late

Students may register late with the instructor's permission but will be expected to make up all assignments that they missed within one week of their registration.

University Resources and Policies

University-wide policies are available at this link.

**Syllabus Subject to Change Clause: Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor*