Math 485 – Numerical Methods for Climate Data, Fall 2026 – Course Syllabus

Course Instructor: Mitchell Scott (he/him/his)
Email: mitchell.scott@emory.edu

Lectures:
Monday, Wednesday, 11:30 AM - 12:45 AM, Math & Science Center (MSC)- W201

Some Important Dates and Times:

Nov. 7:	Midterm Exam
Dec. 17:	Final Exam (Tuesday, 11:30 AM-2:00 PM)

Office Hours:
Instructor: Monday, Wednesday, 3:00 PM-4:00 PM MSC E428

Students are always welcome to email the instructor directly to ask questions or to request an appointment.

Prerequisites: Math 315. Math 346/347 and Math 361/362 are recommended but not required.

Learning objectives: In this course, students will learn all about large scale climate data. This data will typically be high dimensional - depending on many independent variables, like temperature, location, altitude, pressure, etc. Many numerical techniques rely on data in matrices - a 2D grid of numbers. However, this might not be the best way to study the data at hand, as we would have to break the underlying high dimensional structure to turn the data in a matrix. To compensate for that, we will teach about the algebraic structure of tensors. First we will teach how to manipulate tensors of any size and dimension. Then we will study the Canonical Polyadic (CP) decomposition, which is well suited for interpreting the any data. Then we will turn our attention to the Tucker decomposition, which shines in compressing large data sets, only using the most necessary components. The course will end with a hands-on project. Using readily available climate data, tensor methods will be used and compared to their matrix counterparts.

Table of Contents:

Textbook

- **Textbook:**
  - *Tensor Decompositions for Data Science*, by Grey Ballard and Tamara Kolda (TD)
- **Content:** We will cover the Appendices (Numerical Linear Algebra, Optimization, Probability) as a review to the course. We will then cover Part 1 of TD (Chapters 1-3), which will cover terminology, indexing/ reshaping tensors, and operations to perform on tensors. This will get us comfortable in thinking in higher dimensions and seeing connections between matrix notation that we are familiar with and tensors. Then we explore Part 2 of TD (Chapters 4-8) which is framed around the Tucker decompositions, one of the big 2 tensor decompositions. We will study variants and see what makes qualities Tucker preserves. Lastly, we will study Part 3 of TD (Chapters 9-11) which is on Canonical Polyadic or CP tensor decompositions. We will end the course with a project where we relate these decompositions to actual climate data.
- **Advice on Reading:** This textbook is very unique in the fact that every single page has a figure. Tensors are notorious to visualize, e.g. how do you envision a 4 dimensional cube? The figures use colors, shapes, arrows, etc. Additionally, there are examples galore, which are really helpful in elucidating thinking in a different way.

Course Structure

- **Lectures:** There will be two lectures each week on Mondays and Wednesdays from 11:30 AM-12:45 PM. While the best way to learn is attend lecture, everyone learns differently, so if you prefer to learn yourself, then lecture attendance is optional. All the lecture notes will be posted before the start of each week. Lecture notes are self-contained and include enough examples. Both lectures and labs will follow these notes.

  The lectures are divided into the following modules

  1. **Module 1:** Tensor Basics – Tensors can be thought of as a higher order analogy of matrices, so just like we learned about ways to reorder and reshape matrices, we must learn how to do that for arbitrary dimensional data. We learn about common terminology such as mode-k fibers, slices, reshaping, unfolding, etc. Using these manipulations to the data, we can define operations such as the Kronecker product, Khatri-Rao product, outer products, and tensor contractions.
  2. **Module 2:** Tucker Decomposition – One of the two most common structures for tensor decompositions, the Tucker decomposition consists of transforming a tensor into a core tensor, which is much smaller than the original tensor and factor matrices. This leads to the Tucker family to be very useful in compression of data and only using the most useful information in each mode. There is an accuracy compression trade off that is to be considered. The algorithms to compute the Tucker decomposition are discussed as well as theoretic guarantees in terms of relative error.
  3. **Module 3:** CP Decomposition – While the Tucker decomposition is very good at compressing data, it is hard to interpret the overall results. That is where the Canonical Polyadic (CP) decomposition comes in. The tensor is factored into just factor matrices, which are a vertical stack of the order d outer products of vectors. This has strong similarities to the matrix SVD; however, there are provable issues with this method such as determining the rank of a tensor is NP-complete. Methods and algorithms are discussed to still get meaningful results from the CP decomposition.

- **Discussion Forum:** It's likely that you will have questions as you review your notes and complete homework assignments. Those that occur to you will likely also occur to other students. You can ask questions on Canvas Discussion Module.

Assessments

- **Grade Distribution:** Grades will be distributed as follows:

Homework	25%	7 assignments, 2 lowest grade dropped
Midterm	35%	1 exam
Projects	40%	2 projects, equally weighted

  Your final grade will be based on a weighted average of all assessed components. There might be an upward adjustment to ensure that the class average aligns at least with a B grade. For every assignment and exam, we will provide the class median, mean, and standard deviation, offering you a clearer understanding of your position. The number of points you earn will be mapped to a letter grade as follows:

A: [93, 100]	A-: [90, 93)	B+: [87, 90)	B: [83, 87)	B-: [80. 83)	C+: [77, 80)
C: [73, 77)	C-: [70, 73)	D+: [67, 70)	D: [63, 67)	D-: [60, 63)	F: [0, 60)

- **Homework:**
  - You will have two homeworks per module and one homework at the beginning to set expectations of the material. There will be 7 total homework assignments. The assignments will be posted on and submitted through Canvas. The homework will be due on Wednesday at 11:30 am, which is the beginning of class, (except for holidays) and will be posted no later than three classes beforehand (Monday the week prior). The number of questions may vary week to week, but the assignments will not be very long. You will upload your written/LaTeX'ed homework to Canvas in PDF format to grade.
  - The lowest two homework grades will be dropped. **No makeup assignments will be given.** If you have to miss an assignment, it will be one that is dropped.
  - Homework assignments will be graded on an individual basis. The instructor allows discussions with other students while solving the problems. The only requirement is that you acknowledge all contributors and sources used. Yes, this does include large language models such as ChatGPT. Identical solutions that are seen as Honors Code violations, will not be graded and will be reported to the Honor Council. The border between acceptable and unacceptable collaboration may be subtle. If you are uncertain whether a particular behavior is acceptable or not, please ask the instructor or teaching assistant as soon as possible.

- **Exams:**
  - There will be **one midterm exam** given in class, on **Nov. 23**. You will be given the full class period (75 minutes) to take the midterm.
  - The **final exam** will be a final presentation to your Module 2 project. It will take place during final week on Monday, **Dec. 17, from 11:30 AM to 2:00 PM**.
  - Conflicts with the final exam time slot must be reported through the Office for Undergraduate Education (OUE). You must notify the instructor at least two weeks before the exam date if you have a conflict, or have a valid excuse verified by the Office of Undergraduate Education (OUE).

- **Projects:**
  - There will be 2 module projects, which will be an individual project based on climate data. There will be a written and oral portion of each project. No project is dropped, and each are weighted equally, i.e. each project is 20% of your final course grade.

  - These projects allow us the flexibility to apply the mathematical topics from class in the broader context of environmentalism, sustainability,
  - There will be some class time dedicated to introducing the project and answering questions, but all work will have to be done outside of class time.

- **Participation:**
  - During the semester, there will be several ways to participate in the course.
  - Attending lectures and office hours, answering discussion questions posed on Canvas, taking practice quizzes, asking me questions, and more are ways of measuring your participation.
  - Just be an active participant in the course!

Emory University Academic Rules

- **Academic Integrity:**

  By participating in this course, you are accepting the Emory Honor Code. Instructors are obligated to report violations to the rules of the honor code.

- **Policy on use of AI and Academic Integrity:**

  There are many good reasons to not use artificial intelligence and large languages models such as ChatGPT. There are numerous resources available to you that, unlike chatGPT,

  - do not drain environmental resources
  - do not pollute communities
  - do not rely on unethical labor for training
  - do not plagiarize the work of others
  - do correctly cite their sources and additional reference material
  - have been verified for accuracy by one or more mathematicians.

  These alternative resources include my class notes and the textbooks listed above. **For these reasons I do not allow the use of ChatGPT or any similar AI model in this course.**

  AI models have no guarantee of accuracy. Moreover, it is usually quite easy to identify when they have been used by students because the answers they generate involve mathematical concepts, language, or notation that haven't been taught yet. Using an AI model to 'think' for you will not help you learn the class material. **If you feel pressured to use an AI model like ChatGPT for any reason, please simply email me and ask for help instead.** I will always be more than happy to provide additional resources or meet with you to help.

  The Faculty of Emory College are required to report suspected cases of academic integrity violations to the Dean of Student Affairs Office. If I suspect that you have cheated or plagiarized in this class, I must report the situation to the dean.

- **Student Accessibility:**

  Emory is committed advancing an accessible and barrier-free environment for students by ensuring that the principles of access, equity, inclusion, and learning are realized in and by the Emory community. If you have a documented disability and have anticipated barriers related to the format or requirements of this course, or presume having a disability (e.g. mental health, attention, learning, vision, hearing, physical or systemic), and are in need of accommodations for this semester, please assist me in accommodating you by registering with the Department of Accessibility Services.

Students who have accommodations in place are encouraged to coordinate sometime with your professor, during the first week of the semester, to communicate your specific needs for the course as it relates to your approved accommodations. All discussions with DAS and faculty concerning the nature of your disability remain confidential.

- **Diversity and Inclusion:**
  Emory University strives to provide a welcoming, diverse, and inclusive campus as an essential part of a community of academic excellence. Dimensions of diversity include sex, race, age, national origin, ethnicity, gender identity and expression, intellectual and physical ability, sexual orientation, income, faith and non-faith perspectives, socio-economic class, political ideology, education, primary language, family status, military experience, cognitive style, and communication style. Please make a personal effort to respect and include all members of our community. See https://www.emory.edu/home/life/diversity.html for more information and resources.
- **Technology Services:** For assistance, please visit https://it.emory.edu/catalog/index.html
- **Office of Undergraduate Education (OUE):** The OUE provides a wide range of academic support for students, including academic advising, peer tutoring, and absentee policies (e.g., if you miss an exam).
- **Academic and Religious Holiday Calendar:** Please review the Academic Calendar for important dates about schedule changes and final exams. Please also review the Religious Holidays Calendar and communicate schedule conflicts with this course as soon as possible.
- **EPASS:** The course moves quickly and online learning can add additional challenges. Emory has an excellent peer-tutoring program that can be extremely helpful. Visit Learning and Peer Assistant Tutoring.

Required Technology

- **Canvas:** All course contents will be hosted on Canvas. This includes lecture notes, homework assignments, solutions, discussions, and more. All announcements will be done through Canvas. In addition, uploading work and grading will be done through Canvas. For information, visit https://canvas-support.emory.edu/
- **Zoom:** While lectures and office hours predominately will be held synchronously in person, there are unexpected time conflicts that might arise, so access to Zoom will be beneficial. Information about meeting rooms and passwords will be provided soon. For information, visit https://it.emory.edu/office365/ZOOM.html
- **CamScanner:** You will be required to upload written work in PDF form for the course. A good, intuitive, free app to do this is CamScanner. For information, visit https://www.camscanner.com/
- **Overleaf:** You will be required to upload written work in PDF form for the course. If you prefer to use LaTeXto type up your assignment, Overleaf Premium is available to Emory students, just log in with your Emory email. 5% extra credit will be added to each assignment that is typeset, as it makes it easier for the professors and TAs to grade. For information, visit https://guides.libraries.emory.edu/main/overleaf_emory/

- **Matlab:** Occasionally visualizations from class will be made available to students. These will be written as MATLAB live scripts (math equations, text, and runnable code in the same document). These will be posted to Canvas and the course website. To actually interact with them, you will need to download MATLAB or run code online using a Mathworks account. Emory provides you access to both, so you can log in using your Emory email. For information, visit https://software.emory.edu/swe/

Tentative Course Schedule

Week	Dates	Sections	Content
Week 1	Aug. 26	TD §A	Introductions; Syllabus; NLA Review
Week 2	Aug. 31, Sep. 2	TD §A, TD §B,C	NLA Review, Probability/Optimization Review
Week 3	Sep. 9	TD §1.1-1.3	Tensors, Slices, Fibers **Homework 0: TD §A,B,C** (due Wednesday, Sep. 9)
Week 4	Sep. 14, Sep. 16	TD §1.4-1.6, TD §2.1,2.2	Mode unfoldings and examples; Vectorization
Week 5	Sep. 21, Sep. 23	TD §2.3,2.4, TD §3.1-3.5	Matricization, Permutations; Tensor Matrix products **Homework 1: TD §1-2** (due Wednesday, Sep. 23)
Week 6	Sep. 28, Sep. 30	TD §3.6-3.8, TD §4.1,4.2	Sparse Tensors and Multi-products; Tucker Decompositions
Week 7	Oct. 5, Oct. 7	TD §4.3-4.5, TD §5.1-5.3	Computing Tucker; Properties of Tucker; Introduce Project **Homework 2: §3-4** (due Wednesday, Oct. 7)
Week 8	Oct. 14	TD §5.4-5.7	Tensor Reconstruction
Week 9	Oct. 19, Oct. 21	TD §6	Tucker Optimization **Homework 3: §5** (due Wednesday, Oct. 21)
Week 10	Oct. 26, Oct. 28	TD §8	Tensor Train
Week 11	Nov. 2, Nov. 4	TD §9.1-9.4	**Presentation 1: Tucker (Nov. 2)** Introduction to CP **Homework 4: §6,8** (due Wednesday, Nov. 4)
Week 12	Nov. 9, Nov. 11	TD §9.5-9.9, TD §10.1-10.4	Extensions of CP; Kruskal Tensors; Introduce Project
Week 13	Nov. 16, Nov. 18	TD §10.5-10.8, Midterm Review	Properties and Operations on Kruskal; Midterm Review **Homework 5: §9-10** (due Wednesday, Nov. 18)
Week 14	Nov. 23	In-class midterm	**Midterm Exam (Nov. 23)**
Week 15	Nov. 30, Dec. 2	TD §11, TD §12	CP Optimization Algorithms
Week 16	Dec. 7	Catch-up Lecture	**Homework 6: §11-12** (due Monday, Dec. 7)

Final Presentation: CP
Monday, Dec. 17, (originally scheduled 11:30 AM - 2:00 PM)