Math 6397 Computational and Mathematical Methods in Data Science

Fall 2025, TT 8:30 am–10:00 am

Course MATH 6397: Computational and Mathematical Methods in Data Science (Section 19706)

Instructor Andreas Mang

✉ andreas@math.uh.edu

☎ 713.743.7409

🌐 https://www.math.uh.edu/~andreas

Office PGH 614

Office Hours TT 10:00 am–11:00 am or by appointment (andreas@math.uh.edu)

Class Time and Place TT 8:30 am–10:00 am in AH 301

Course Website https://www.math.uh.edu/~andreas/teaching/math6397-SP24

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1 Prerequisites

Credit for or concurrent enrollment in MATH 4331 and MATH 4377/4378, or consent of instructor. Students are expected to have a good grounding in basic real analysis and linear algebra. Basic knowledge about optimization theory (MATH 6366/6367) is helpful but not required.

2 Textbooks

No particular textbook is required. The following lists several good references for various topics related to this course (which go far beyond the material covered in class). Aside from these, we'll also discuss more recent published in papers.

- Mathematics of Data Science: A Computational Approach to Clustering and Classification by D. Calvetti & E. Somersalo. SIAM 2021.
- Data Clustering: Theory, Algorithms, and Applications by G. Gan, C. Ma, & J. Wu. SIAM 2020.
- Deep Learning Architectures: A Mathematical Approach by O. Calin. Springer 2020.
- First-order and Stochastic Optimization Methods for Machine Learning by G. Lan. Springer 2020.
- Modern Nonconvex Nondifferentiable Optimization by Y. Cui & J.-S. Pang. SIAM 2021.
- Numerical Optimization by J. Nocedal and S. J. Wright. Springer 2006.
- Lectures on Convex Optimization by Yurii Nesterov. Springer 2018.

3   Course Description

Recent advances in machine learning and data science have been driven by significant progress in computing technologies. In the era of big data, there is a growing demand to integrate model-based and data-driven approaches to enable real-time decision-making. This has led to the development of digital twin technologies—computational representations of real-world systems that enable continuous monitoring, inference, prediction, and uncertainty quantification in near real-time.

This course equips students with the mathematical and computational foundations essential for analyzing, implementing, and developing numerical methods central to data-enabled science. It is intended for students seeking to deepen their theoretical understanding while building practical skills as computational scientists and applied mathematicians working at the interface of data science and machine learning. We will review classical techniques and explore state-of-the-art methods, with an emphasis on their mathematical underpinnings and practical implementation. The course is designed as a hands-on learning experience: while lectures will address both theoretical and computational aspects, assignments will primarily focus on implementing key concepts. Rather than applying pre-built libraries or black-box tools, students will write mathematical code from scratch to solve fundamental problems in data science. This approach will help develop an intuition for when modern machine learning methods are expected to perform well—and when they may fail.

Topics will include elements of numerical analysis, numerical linear algebra, and optimization, with applications to machine learning and data-driven modeling. Students are welcome to use the programming language of their choice.

4   Tentative Course Content

Course material will be made available section by section on Canvas. The tentative content of this course is as follows:

- Overview
    - Linear Regression
    - Logistic Regression
    - Generalized Linear Models
    - Support Vector Machines
    - Regularization, LASSO, and Ridge Regression
    - Population Risk Minimization
    - Neural Networks

- Optimization Formulation of Data Analysis Problems
    - Least Squares
    - Matrix Completion
    - Non-negative Matrix Factorization
    - Sparse Inverse Covariance Estimation
    - Sparse Principle Components
    - Sparse Plus Low-Rank Matrix Decomposition

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- Smooth Convex Optimization (Short Intro)

    - Convex Sets
    - Convex Functions
    - Representer Theorem and Kernel Representations
    - Lagrange Duality
    - Legendre Fenchel Conjugate

- Non-Smooth Convex Optimization

    - Calculus of Subgradients
    - Subgradient Method
    - Projected Subgradient Method
    - Subgradient Method for Constrained Optimization
    - Primal Dual Subgradient Method
    - Mirror Descent and Variable Projection
    - Variable Metric Subgradient Methods
    - Proximal Methods
    - Moreau Decomposition
    - Proximal Gradient Method
    - ADMM

- Spectral Clustering

- Numerical Methods for Deep Learning

    - Intro do DNNs
    - Linear Least Squares
    - Linear Classification
    - Single Layer Nueral Networks
    - Variable Projection
    - Sample Average Approximation
    - Stochastic Gradient Descent
    - Convolutional Neural Networks
    - Deep Neural Networks
    - Residual Neural Networks

- Deep Generative Models

    - Autoregressive Models
    - Variational Autoencoders
    - Variational Inference
    - Parameterizing Distributions via DNNs
    - Normalizing Flows

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5 Course Delivery Format

This course will be delivered face-to-face (in person). In between class meetings, there may also be asynchronous activities to complete (e.g., homework assignments).

6 Syllabus Changes

Please note that the instructor may need to make modifications to the course syllabus and may do so at any time. Notice of such changes will be announced as quickly as possible through (specify how students will be notified of changes).

7 Attendance Policy

Attendance is not required, but strongly encouraged. Additional information can be found in §17. Coming to class late or leaving early is disruptive and thus discouraged.

8 Office Hours

Office hours will take place either in person or online in one-on-one meetings (based on the student's preference). Please send me an email to make an appointment for office hours. I will keep a fixed schedule for office hours (MoWe 10:00 AM–11:00 AM) but am flexible to meet a student's availabilities.

9 Dropping Policy

01/31/2024 Official Reporting Day (ORD; withdraw without receiving a grade or drop a course)

04/17/2024 Last day to drop a course or withdraw with a 'W'.

04/29/2024 Last day of class.

If you stop participating in assignments, and do not drop, and your name appears on the final class roll, you will *receive a grade of F* at the end of the semester.

10 Technical Equipment Needed

Students will need the following equipment to be able to follow classes: • internet connection, • ability to sign into Canvas to access course material and assignments, as well as to submit homework assignments, • ability to access MS Teams for communications relevant for this class, and • a scanner or certain smartphone apps so that you can submit your homework as a PDF file. For technical problems, please contact UH IT Help Desk; your instructor might not be able to help with technical issues. Students that do not have access to the required equipment can find the needed computer equipment in the library. Additional information and technical support is available at `https://www.uh.edu/infotech`.

11 Evaluation Criteria

This is a research-oriented graduate course. Students will be evaluated through homework assignments (mix of paper and pencil and computations). The grading criteria are described in §11.2.

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11.1 Homework Assignments

If not noted differently, homework assignments will be made available two weeks before the designated due date on Canvas . The deadline for handing in your homework will be 10:00 pm sharp on the designated due date. Late homework will **not** be accepted. The homework will be a combination of practical (computing) exercises and analysis. Computing will be done in Matlab (https://www.mathworks.com/products/matlab.html). If desired, solutions in Julia (https://julialang.org) or Python (https://www.python.org) (or any other programming language of your choosing) are also acceptable. There will be a total of about four to five homework assignments. Homework scores cannot be changed after one week after they have been returned.

It is expected that you express your ideas clearly, legibly, and completely, which often requires complete English sentences (i.e., a justification) rather than a long string of equations or unconnected mathematical expressions.

Homework can and should be worked on and discussed with others. Collaboration is a big part of learning and of scholarship in general. I strongly encourage you to participate in study groups with fellow students attending this course. However, the write-up of the homework has to be independent, and in your own words. Your homework needs to be complete, neatly written, and stapled. If you use any external source (e.g., books or internet) you must acknowledge the source in your submission. Penalty for not reporting your sources will be a score of zero for the homework. Your coding solutions have to be submitted by email as instructed in the homework assignments. I reserve the right to deduct points if these rules are not followed.

11.2 Grading

Evaluation will be based on completed homework assignments and project presentations.

letter grade	percentage	letter grade	percentage
A	$93\% \leq x \leq 100\%$	C	$73\% \leq x < 77\%$
A−	$90\% \leq x < 93\%$	C−	$70\% \leq x < 73\%$
B+	$87\% \leq x < 90\%$	D+	$67\% \leq x < 70\%$
B	$83\% \leq x < 87\%$	D	$63\% \leq x < 67\%$
B−	$80\% \leq x < 83\%$	D−	$60\% \leq x < 63\%$
C+	$77\% \leq x < 80\%$	F	$x < 60\%$

Grades for homework assignments can be disputed until **one week** after they have been returned. After that the grade cannot be changed.

11.3 Makeup Policy

Not turning in homework by the assigned due date or not being present for a project presentation will result in a **score of zero**. There will be **no makeup assignments**. Technology failures will not be accepted as reason for missed assignment due dates. Therefore, do not leave anything to the last minute. It is the student's responsibility to identify alternative ways to complete or submit an assignment.

Exceptions are possible in the case of extreme circumstances, such as a documented, serious illness. In the event that a student cannot turn in homework or participate in a project presentation on the day it is held the student needs to speak to me in advance, and make every attempt to do the work before (and not after) the rest of the class.

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12   Office Hours

Office hours will take place online in one-on-one meetings or in person. Please send me an email to make an appointment for online office hours (andreas@math.uh.edu). I will keep a fixed schedule for office hours (MW 10:00 am–11:00 am) open.

13   Dissemination of Course Material

The materials provided by the instructor in this course are for the *use of the students enrolled in the course only*. Course materials and course recordings (if permission was warranted) may not be further disseminated without instructor permission. This includes sharing content to commercial course material suppliers or public domain platforms. Students are also prohibited from sharing materials derived from the instructor's content (e.g., a student's lecture notes).

14   Recording of Class

Students may not record all or part of class, livestream all or part of class, or make/distribute screen captures, without advanced written consent of the instructor. If you have or think you may have a disability such that you need to record class-related activities, please contact the Justin Dart, Jr. Student Accessibility Center. If you have an accommodation to record class-related activities, those recordings may not be shared with any other student, whether in this course or not, or with any other person or on any other platform. Classes may be recorded by the instructor. Students may use instructor's recordings for their own studying and notetaking. Instructor's recordings are not authorized to be shared with anyone without the prior written approval of the instructor. Failure to comply with requirements regarding recordings will result in a disciplinary referral to the Dean of Students Office and may result in disciplinary action.

15   Cell Phones and Electronic Devices

During class and exam periods, all cell phones and other electronic devices must be turned off and kept in a secure location away from the students immediate view. The use of laptop computers in class is only permitted if students are using the computers to take notes or for purposes related to the class.

16   Academic Honesty/Honor Code

High ethical standards are critical to the integrity of any institution, and bear directly on the ultimate value of conferred degrees. All UH community members are expected to contribute to an atmosphere of the highest possible ethical standards. Maintaining such an atmosphere requires that any instances of academic dishonesty be recognized and addressed. The UH Academic Honesty Policy is designed to handle those instances with fairness to all parties involved: the students, the instructors, and the University itself. All students and faculty of the University of Houston are responsible for being familiar with this policy.

Posting answers for homework assignments online (at group chats or other online tools) is considered an academic honesty violation. Students are expected to know the difference between "getting and/or giving help on a problem" and "getting/giving answers to a problem." If a student is caught sharing answers (in person or online), they might be reported to the departmental hearing officer for an academic

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honesty violation. If a student becomes aware of cheating or any other violations; that student is responsible for informing the instructor.

17   Excused Absence Policy

Regular class attendance, participation, and engagement in coursework are important contributors to student success. Absences may be excused as provided in the University of Houston Undergraduate Excused Absence Policy and Graduate Excused Absence Policy for reasons including: medical illness of student or close relative, death of a close family member, legal or government proceeding that a student is obligated to attend, recognized professional and educational activities where the student is presenting, and University-sponsored activity or athletic competition. Under these policies, students with excused absences will be provided with an opportunity to make up any quiz, exam or other work that contributes to the course grade or a satisfactory alternative. Please read the full policy for details regarding reasons for excused absences, the approval process, and extended absences. Additional policies address absences related to military service, religious holy days, pregnancy and related conditions, and disability.

18   Late Registration

No special accommodations will be made for students who register late for this class, miss class, or are denied access to Blackboard owing to late registration. It is the sole responsibility of the student to seek out and obtain course materials or announcements if they miss class or cannot access these items through Blackboard. No make-up exams or extensions on assignments will be granted for late registration. If you do encounter problems accessing the course material, please contact the TA and instructors immediately for help, in person and via email. We are best able to help you the sooner you let us know.

19   Communications and Announcements

Email communications related to this course will be sent to your Exchange Email Account, which each University of Houston student receives (or whichever email address is linked to your student ID on ACCESS UH). Exchange email accounts can be accessed by logging into Office 365 with your Cougarnet credentials or through Acccess UH. They can also be configured on IOS and Android mobile devices. Additional assistance can be found at the Get Help page.

20   UH Email

Please check and use your Cougarnet email for communications related to this course. Faculty use the Cougarnet email to respond to course-related inquiries such as grade queries or progress reports for reasons of FERPA. To access this email, login to your Microsoft 365 account with your Cougarnet credentials.

Please check and use your Cougarnet email for communications related to this course. To access your Cougarnet email, login to your Microsoft 365 account with your Cougarnet credentials. Visit University Information Technology (UIT) for instructions on how to connect your Cougarnet e-mail on a mobile device.

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21   Reasonable Academic Adjustments/Auxiliary Aids

The University of Houston is committed to providing an academic environment and educational programs that are accessible for its students. Any student with a disability who is experiencing barriers to learning, assessment or participation is encouraged to contact the Justin Dart, Jr. Student Accessibility Center (Dart Center) to learn more about academic accommodations and support that may be available to them. Students seeking academic accommodations will need to register with the Dart Center as soon as possible to ensure timely implementation of approved accommodations. Please contact the Dart Center by visiting the website: https://uh.edu/accessibility calling (713) 743–5400, or emailing jdcenter@Central.UH.EDU.

22   Mental Health and Wellness Resources

The University of Houston has a number of resources to support students' mental health and overall wellness, including CoogsCARE and the UH Go App. UH Counseling and Psychological Services (CAPS) offers 24/7 mental health support for all students, addressing various concerns like stress, college adjustment and sadness. CAPS provides individual and couples counseling, group therapy, workshops and connections to other support services on and off-campus. For assistance visit https://uh.edu/caps, call 713-743-5454, or visit a Let's Talk location in-person or virtually. Let's Talk are daily, informal confidential consultations with CAPS therapists where no appointment or paperwork is needed.

The Student Health Center offers a Psychiatry Clinic for enrolled UH students. Call 713-743-5149 during clinic hours, Monday through Friday 8 a.m. - 4:30 p.m. to schedule an appointment.

The A.D. Bruce Religion Center offers spiritual support and a variety of programs centered on well-being.

Need Support Now? If you or someone you know is struggling or in crisis, help is available. Call CAPS crisis support 24/7 at 713-743-5454, or the National Suicide and Crisis Lifeline: call or text 988, or chat 988lifeline.org.

23   Title IX/Sexual Misconduct

Per the UHS Sexual Misconduct Policy, your instructor is a "responsible employee" for reporting purposes under Title IX regulations and state law and must report incidents of sexual misconduct (sexual harassment, non-consensual sexual contact, sexual assault, sexual exploitation, sexual intimidation, intimate partner violence, or stalking) about which they become aware to the Title IX office. Please know there are places on campus where you can make a report in confidence. You can find more information about resources on the Title IX website at https://uh.edu/equal-opportunity/title-ix-sexual-misconduct/resources.

24   Security Escorts and Cougar Ride

UHPD continually works with the University community to make the campus a safe place to learn, work, and live. Our Security escort service is designed for the community members who have safety concerns and would like to have a Security Officer walk with them, for their safety, as they make their way across campus. Based on availability either a UHPD Security Officer or Police Officer will escort students, faculty, and staff to locations beginning and ending on campus. If you feel that you need a

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Security Officer to walk with you for your safety please call 713-743-3333. Arrangements may be made for special needs.

Parking and Transportation Services also offers a late-night, on-demand shuttle service called Cougar Ride that provides rides to and from all on-campus shuttle stops, as well as the MD Anderson Library, Cougar Village/Moody Towers and the UH Technology Bridge. Rides can be requested through the UH Go app. Days and hours of operation can be found at https://uh.edu/af-university-services/parking/cougar-ride.

25   Religious Holy Days

Students whose religious beliefs prohibit class attendance or the completion of specific assignments on designated dates may obtain an excused absence. To do so, please make a written request for an excused absence and submit it to your instructor as soon as possible, to allow the instructor to make arrangements. For more information, see the Student Handbook (http://catalog.uh.edu/index.php).