

Math 6397 Applied Inverse Problems

Fall 2020, MW 1:00 pm–2:30 pm

Course Math 6397: Applied Inverse Problems (Section 21337)

Instructor Andreas Mang

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Office PGH 614

Office Hours MW 03:00 pm–04:00 pm or by appointment (andreas@math.uh.edu)

Class Time and Place MW 1:00 pm–2:30 pm in SW219

Course Website <https://www.math.uh.edu/~andreas/teaching/math6397-FA20>

Information contained in this syllabus is subject to change without notice. This syllabus provides a general guideline for the course; deviations may be necessary. Students are expected to be aware of any additional course policies presented by the instructor during the course.

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, but several good references for various topics related to inverse problems (which go far beyond the material covered in class) include:

- [Computational Methods for Inverse Problems](#) by C. R. Vogel, SIAM 2002.
- [Statistical and Computational Inverse Problems](#) by J. Kaipio and E. Somersalo. Springer 2005.
- [Discrete Inverse Problems: Insight and Algorithms](#) by P. C. Hansen, SIAM 2010.
- [An Introduction to the Mathematical Theory of Inverse Problems](#) by A. Kirsch, Springer 2011.
- [Inverse Problem Theory](#) by A. Tarantola, SIAM 2005.
- [Optimization with PDE Constraints](#) by M. Hinze, R. Pinnau, M. Ulbrich, and S. Ulbrich. Springer 2009.
- [Perspectives in Flow Control and Optimization](#) by M. D. Gunzburger. SIAM 2003.
- [Convex Optimization](#) by S. Boyd and L. Vandenberghe. Cambridge University Press 2004.
- [Numerical Optimization](#) by J. Nocedal and S. J. Wright. Springer 2006.

3 Course Description

Inverse problems are of paramount importance and can be found in virtually all scientific disciplines with applications ranging from medicine, geophysics, to engineering. In many of these applications the forward or simulation problem, i.e., the solution of an underlying mathematical model to yield outputs given some inputs, is already a challenging task. Many applications require us to go beyond evaluating forward operators; we have to address what is often the ultimate goal: prediction and decision-making. This requires us to tackle mathematical challenges that comprise, and, therefore, are more difficult than the forward problem. One example is the solution of inverse problems. Here, we seek model inputs (or parameters) so that the output of the forward model matches observational data.

This course will introduce the theoretical foundations of inverse problems and strategies to their numerical solution. We will consider applications in data and physical sciences. Starting from first principles we will discuss how to design and analyze direct and iterative methods for efficiently solving different classes of inverse problems. Students will get to explore the design of computational strategies to solve these problems. Examples studied in the class will be selected from different areas of computational sciences and engineering, including deblurring, imaging, and continuum mechanics.

4 Course Content

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

- Introduction to Inverse Problems & Inverse Problem Theory.
 - Examples for Inverse Problems.
 - Ill-Posedness (Hadamard)
- Linear Regression and Least Squares.
- Ill-Posed Operator Equations.
 - Linear Inverse Problems and Compact Operators.
 - Well-Posedness of Operator Equations.
 - SVD of Compact Operators.
- Classical Regularization Techniques.
 - Parameter-Choice Strategies.
 - * A-Priori Parameter Choice Rules.
 - * A-Posteriori Parameter Choice Rules.
 - * Heuristic Parameter Choice Rules.
 - Construction of (Spectral) Regularization Methods.
 - * Truncated SVD.
 - * Tikhonov Regularization.
 - * Asymptotic Regularization.
 - * Landweber Iteration.
- Numerical Optimization.
 - Unconstrained Minimization.
 - * Optimality Conditions.
 - * Line-Search Methods.

- * Large-Scale Unconstrained Minimization.
- Constrained Minimization.
 - * Optimality Conditions.
 - * Lagrange Multipliers and Sensitivity.
 - * Duality.
- Quadratic Programming.
- Sequential Quadratic Programming.
- Inverse Problems with Dynamical Systems (Optimal Control).
 - ODE Constrained Optimization.
 - PDE Constrained Optimization.

5 Syllabus Changes

Due to the changing nature of the COVID-19 pandemic, 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).

6 Attendance Policy

Attendance is not required, but strongly encouraged. Additional information can be found in §20.

7 Dropping Policy

09/09/2020	Official reporting day (ORD); drop a course without receiving a grade.
11/03/2020	Last day to drop a course or withdraw with a 'W'.

8 Homework Assignments

If not noted differently, homework assignments will be made available two weeks before the designated due date on **blackboard**. The homework has to be submitted on the designated due date. The deadline for handing in your homework will be 2:30 pm sharp (i.e., before the class concludes). 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>) are also acceptable. There will be a total of about four 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.

If you are considering to take the prelim, I strongly encourage you to work on all homework assignments. It is your responsibility to be well prepared for the exams and the prelim.

9 Evaluation & Grading

Evaluation will be based on completed homework assignments (50%) and project presentations (50%).

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	$x < 60\%$

The lowest homework score obtained in this course will be dropped to allow for missed assignments. Grades for exams and project assignments can be disputed until **one week** after they have been returned. After that the grade cannot be changed.

10 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.

11 Academic Honesty/Honor Code

In online assignments and tests you will sometimes be asked to make an Academic Honesty Statement. University of Houston students are expected to adhere to the Academic Honesty Policy as described in the UH Undergraduate Catalog. "Academic dishonesty" means employing a method or technique or engaging in conduct in an academic endeavor that contravenes the standards of ethical integrity expected at the University of Houston or by a course instructor to fulfill any and all academic requirements. Academic dishonesty includes, but is not limited to, the following: Plagiarism; Cheating and Unauthorized Group Work; Fabrication, Falsification, and Misrepresentation; Stealing and Abuse of Academic Materials; Complicity in Academic Dishonesty; Academic Misconduct.

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

Refer to UH Academic Honesty website (<http://www.uh.edu/provost/policies/honesty>) and the UH Student Catalog for the definition of these terms and university's policy on Academic Dishonesty. Anyone caught cheating will be reported to the department for further disciplinary actions, receive sanctions as explained on these documents, and will have an academic dishonesty record at the Provosts office. The sanctions for confirmed violations of this policy shall be commensurate with the nature of the offense and with the record of the student regarding any previous infractions. Sanctions may include, but are not limited to: a lowered grade, failure on the examination or assignment in question, failure in the course, probation, suspension, or expulsion from the University of Houston, or a combination of these. Students may not receive a W for courses in which

they have been found in violation of the Academic Honesty Policy. If a W is received prior to a finding of policy violation, the student will become liable for the Academic Honesty penalty, including F grades.

12 Office Hours

Office hours will take place online in one-on-one meetings. Please send me an email to make an appointment for online office hours (andreas@math.uh.edu). I will keep the former schedule for office hours (MW 03:00 pm–04:00 pm) open.

13 Course Delivery Format

This course is being offered in the synchronous online format. Synchronous online class meetings will take place according to the class schedule. There is no face-to-face component to this course. In between synchronous class meetings, there may also be asynchronous activities to complete (e.g., discussion forums and assignments).

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 Center for Students with DisABILITIES (<http://www.uh.edu/csd>). 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 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).

16 Resources for Online Learning

The University of Houston is committed to student success, and provides information to optimize the on-line learning experience through our Power-On website (<https://uh.edu/power-on/learning>). Please visit this website for a comprehensive set of resources, tools, and tips including: obtaining access to the internet, AccessUH, and Blackboard; requesting a laptop through the Laptop Loaner Program; using your smartphone as a webcam; and downloading Microsoft Office 365 at no cost. For questions or assistance contact UHOnline@uh.edu.

17 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 Access UH. They can also be configured on IOS and Android mobile devices. Additional assistance can be found at the [Get Help](#) page. Additional course communications will be announced on TEAMS during synchronous lectures and/or posted on the "Discussion Board."

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 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>).

20 Excused Absence Policy

Regular class attendance, participation, and engagement in coursework are important contributors to student success. Generally speaking, attendance is not required for this class. This is in accordance with general university wide policies: 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. Additional policies address absences related to [military service](#), [religious holy days](#), [pregnancy and related conditions](#), and [disability](#).

21 Students Disability Services/Special Needs

If a student has a disability and would like to request classroom accommodations, please see me after class or during office hours to discuss arrangements as soon as possible (see contact information above).

Academic Adjustments/Auxiliary Aids: The University of Houston System complies with Section 504 of the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990, pertaining to the provision of reasonable academic adjustments/auxiliary aids for students who have a disability. In accordance with Section 504 and ADA guidelines, University of Houston strives to provide reasonable academic adjustments/auxiliary aids to students who request and require them. If you believe that you have a disability requiring an academic adjustments/auxiliary aid, please visit The Center for Students with DisABILITIES (CSD) website at <http://www.uh.edu/csd> for more information.

Accommodation Forms: Students seeking academic adjustments/auxiliary aids must, in a timely manner (usually at the beginning of the semester), provide their instructor with a current Student Accommodation Form (SAF) (paper copy or online version, as appropriate) from the CSD office before an approved accommodation can be implemented.

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Details of this policy, and the corresponding responsibilities of the student are outlined in The Student Academic Adjustments/Auxiliary Aids Policy (01.D.09) document under [STEP 4: Student Submission (5.4.1 & 5.4.2), Page 6]. For more information please visit the Center for Students with Disabilities Student Resources page.

Additionally, if a student is requesting a (CSD approved) testing accommodation, then the student will also complete a Request for Individualized Testing Accommodations (RITA) paper form to arrange for tests to be administered at the CSD office. CSD suggests that the student meet with their instructor during office hours and/or make an appointment to complete the RITA form to ensure confidentiality. RITA forms must be completed at least 48 hours in advance of the original test date. Please consult your counselor ahead of time to ensure that your tests are scheduled in a timely manner. Please keep in mind that if you run over the agreed upon time limit for your exam, you will be penalized in proportion to the amount of extra time taken.

22 Mental Health/CAPS Statement

Counseling and Psychological Services (CAPS) can help students who are having difficulties managing stress, adjusting to college, or feeling sad and hopeless. You can reach CAPS (www.uh.edu/caps) by calling 713-743-5454 during and after business hours for routine appointments or if you or someone you know is in crisis. Also, there is no appointment necessary for the “Let’s Talk” program (<https://www.uh.edu/caps/outreach/lets-talk>), which is a drop-in consultation service at convenient locations and hours around campus.

23 Help

The instructor is available for help during office hours. All the information about this course will be posted regularly on the course website. Material and homework assignments will be posted on blackboard. *Please check these sites often.*