MATH 4650 / MSSC 5650 – Theory of Optimization – Spring 2021

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Lectures: MWF 9-9:50am, Cudahy Hall 417
Course Website: D2L https://d2l.mu.edu/d2l/home/427717

Office Hours: Mon 2-3, Wed 3-4, Fri 12-1, or by appointment.
Note: Office hours will be held virtually on Teams.

Course Description

Introduction to the theory of numerical optimization with applications. This course will cover fundamentals of continuous optimization: gradient methods, Newton and quasi-Newton methods, nonlinear least squares, constrained optimization theory, and basics of non-smooth convex optimization. A special focus will be given to applications arising in data science, machine learning, and imaging.

Course Objectives

Upon successful completion of the course, the student should be able to:

1. Give definitions of key mathematical terms (e.g., objective function, feasible point, global and local minimizers, etc).
2. Classify a continuous optimization problem according to whether it is linear/nonlinear, constrained/unconstrained, convex/nonconvex, and identify a suitable algorithm to solve the optimization problem.
3. Implement algorithms using numerical computing software, such as MATLAB, Julia, or Python/numpy.
4. Understand the optimality conditions for unconstrained and constrained smooth optimization.
5. Understand basic convergence theory for selected algorithms.

Textbook

Required:

- *Numerical Optimization* by Jorge Nocedal and Stephen J. Wright (Second Edition). Springer, 2006.

Optional, but recommended:

- *Introduction to Nonlinear Optimization: Theory, Algorithms, and Applications with MATLAB* by Amir Beck. SIAM, 2014. (Selected chapters available online at: https://sites.google.com/site/amirbeck314/books)

I have put one physical copy of each book on course reserve at the Raynor Memorial Library for a 4 hour loan period. If you have difficulty obtaining one or both of these books, please contact me.

I will also occasionally post additional notes and supplementary materials on D2L. You are not responsible for textbook material or any other material that is not covered in lecture.

Grading Policy

- For students in **Math 4650**, the final grade is earned out of 500 total points distributed as follows:
  - Homework: 320 pts
  - Midterm Exam: 80 pts
  - Final Exam: 100 pts
  - (Optional) MSSC Problems: Up to 50 pts Extra Credit
- For students in **MSSC 5650**, the final grade is earned out of 600 total points distributed as follows:
  - Homework: 320 pts
  - Midterm Exam: 80 pts
  - Final Exam: 100 pts
  - MSSC Problems: 100 pts
- The grading scale for both Math 4650 and MSSC 5650 is given by:

A	$93\% \leq$ Percentage $\leq 100\%$	**C**	$73\% \leq$ Percentage $< 77\%$
A-	$90\% \leq$ Percentage $< 93\%$	**C-**	$70\% \leq$ Percentage $< 73\%$
B+	$87\% \leq$ Percentage $< 90\%$	**D+**	$67\% \leq$ Percentage $< 70\%$
B	$83\% \leq$ Percentage $< 87\%$	**D**	$60\% \leq$ Percentage $< 67\%$
B-	$80\% \leq$ Percentage $< 83\%$	**F**	Below 60% Percent
C+	$77\% \leq$ Percentage $< 80\%$		

Homework

- There will be 8 graded hand-in written homework assignments. Unless otherwise noted, these will be due on *Friday 5:00pm* by upload to a D2L dropbox. Solutions will be posted on D2L.
- On average, each assignment will be worth roughly 40 points with 6-8 problems per assignment. Each problem will be graded out of a possible 6 earned points. With a few possible exceptions, the 6 points will be divided as follows: 4 points for the mathematical content of the solution, 2 points for communication.
  - For mathematical content, the scale is:
    - *4 Points*: The solution is 100% correct.
    - *3 Points*: The solution demonstrates a good understanding of the problem, but some small details are incorrect or missing.
    - *2 Points*: The solution is largely incorrect, but there are some good ideas in it.
    - *1 Point*: The problem was attempted, but no real progress was made towards a solution.
    - *0 Points*: No attempt was made at a solution.
  - The communication scale is:
    - *2 Points*: The solution is clear (in terms of both step-by-step logic and overall organization) and justified in sufficient detail. Written explanations are grammatical and given in complete sentences.
    - *1 Point*: The solution is mostly clear, but some details are missing and/or written explanations are ungrammatical or given in sentence fragments.
    - *0 Points*: The solution is mostly unclear and/or many details are missing and/or the solution is unprofessionally written.

  - The communication points will only be assigned if at least 2 points are earned on the mathematical content.

- Format for Written Work: Each problem writeup must begin on a new sheet of paper and must begin with the full statement of the problem. Failure to do so with be may result in points taken off. While you are encouraged to work through confusion with your classmates, your work must be written in your own words unless otherwise stated.

- **Your homework must be uploaded as a single pdf file to the D2L dropbox.** There are several free apps to help with this including Genius Scan and CamScanner among others. Please make sure your scanned homework is legible before uploading. Scanned homework that cannot be read or that is uploaded as multiple files and/or in the wrong format (i.e., not a single pdf) will not be graded and given an automatic 0. Occasionally you may need to merge pdfs before uploading to D2L. There are several free online apps to do this as well, such as combinepdf.com.

- **No late homework is accepted.** However, your single lowest homework score will be dropped at the end of the semester.

Exams

- There will be one midterm exam and a comprehensive final.

- The midterm exam will be in-person and is (tentatively) scheduled for March 8 during the regular class period. I reserve the right to adjust the midterm exam schedule as needed. If you are unable to attend class on the day of the midterm due to quarantine/illness, please let me know and I can arrange for the exam to be taken synchronously online.

- The Final Exam will be a take-home exam and due by upload to a D2L dropbox on May 13. You will have roughly a week to work on the final exam.

- An absence from an exam is recorded as a score of 0. Make-up exams will not be given unless the student informs, and has a come to a written agreement with, the instructor regarding the absence no later than the day before the exam day. The student is responsible for scheduling their make-up exam.

MSSC Problems

- Students enrolled in the graduate-level version of this course (MSSC 5650) will be assigned a few additional homework and exam problems that require extra mathematical rigour. These will be labelled as "MSSC Problems". Students in Math 4650 will be able to attempt the MSSC Problems for extra credit, however they will only get half-points for these problems. For example, if an MSSC Problem is listed as worth 6 pts, then a MSSC 5650 student will be graded out of the full 6 pts, while a Math 4650 student can earn up to 3 pts toward extra credit.

Course Technology

MATLAB

- Several assignments will use the MATLAB computing toolbox. However, no previous experience with MATLAB is expected or required.

- Marquette University students may download MATLAB onto their personal computers: `http://www.marquette.edu/its/help/matlab/`. MATLAB is also available in the computer labs of Cudahy Hall and in Engineering and the library. Note, most of you will not need all of the extra toolboxes

which significantly add to the size of the program on your computer as well as the download time. You are encouraged to check access to MATLAB by Friday Jan 29, 2021 to ensure proper access moving forward. Please contact ITS with questions about downloading and installing MATLAB on your device.

One-Minute Reflection

- At the end of each class period, I will assign a "one-minute reflection" consisting of a 2-3 short answer questions on a Google Forms survey. Filling out the survey is optional, and you may fill it out anonymously if you wish, but I would really appreciate any feedback you are willing to give.

Course Policies

Class Conduct

- **COVID-19 Specific Rules**: All students (and the instructor) will be required to wear a face mask that covers the mouth and nose, and engage in social distancing by six feet or more. Students who do not comply will be asked to leave the classroom – no exceptions.
- Norms for classroom conduct are based on respect for the instructor and your fellow students. While in class, please silence your cell phones. If for some good reason you need to be reachable by phone during the class please let me know in advance. Behaviors such as texting, reading newspapers, sleeping, watching videos, or otherwise distracting your fellow students are inappropriate.

Attendance Policy

Students are expected to attend the in-person lectures. However, due to the COVID-19 pandemic, I realize that this may not be possible for all students at all times. To accommodate students that miss an in-person lecture, I will be recording videos of the lectures which will be posted on D2L shortly after the lecture ends. In the event that a student requires a prolonged absence (two or more consecutive in-person lectures), please contact me as soon as possible so I can make reasonable accommodations, especially if the absence includes an exam date.

Grading Disputes

If you have any issue with the grading of your homework or in-class exams you must inform me in writing via e-mail within seven days of the day the assignments were returned to the class; otherwise I cannot promise that I will consider the issue.

Accommodations for Disabilities

If you have a disability and will require accommodations under the Americans with Disabilities Act, you need to provide appropriate documentation to the Office of Disability Services. They will supply you with a letter to give to me detailing the accommodations. If you are unsure of whether or not you qualify for services, visit the Office of Disability Services' website, `http://www.marquette.edu/disability-services`, or contact them at (414) 288-1645. If you qualify for special accommodations you must work with the course instructor and come to an agreement no less than 7 days prior to the needed accommodation.

Academic Support

It is your responsibility to keep abreast of the course, to master the material covered, and to take the initiative for getting any help you may need. *You are encouraged to obtain help from the course instructor by*

attending office hours. If you need additional support outside of class and office hours, the Office of Student Education Services (http://www.mu.edu/oses) is available to help.

Academic Integrity and Honesty

Academic dishonesty will not be tolerated. In particular, representing another person's work as your own is academic dishonesty. This applies to all homework, project work, assignments, take-home exams, etc. Any time you use and present ideas that are not your own you must cite your sources. Failure to abide by the university "Academic Integrity Policy"(http://bulletin.marquette.edu/undergrad/academicregulations/) may result in disciplinary action.

Tentative Course Schedule

The schedule below is tentative and subject to change.

Monday	Wednesday	Friday
Jan 25th **1** Intro to Optimization	27th **2** Linear Algebra and Calculus Review	29th **3** Linear Algebra and Calculus Review
Feb 1st **4** Optimality Conditions for Unconstrained Optimization	3rd **5** Optimality Conditions for Unconstrained Optimization	5th **6** Optimality Conditions for Unconstrained Optimization
8th **7** Least Squares	10th **8** Least Squares	12th **9** Least Squares
15th **10** Gradient Methods	17th **11** Gradient Methods	19th **12** Gradient Methods
22nd **13** Gradient Methods	24th **14** Gradient Methods	26th **15** Gradient Methods
Mar 1st **16** Gradient Methods	3rd **17** Gradient Methods	5th **18** Midterm Review
8th In-class Midterm Exam	10th Mental Health Day – No Class	12th **19** Newton's Method
15th **20** Newton's Method	17th **21** Newton's Method	19th **22** Newton's Method
22nd **23** Newton's Method	24th **24** Newton's Method	26th **25** Least Squares Revisited
29th **26** Least Squares Revisited	31st **27** Least Squares Revisited	Apr 2nd Holiday – No Class
5th **28** Constrained Optimization	7th **29** Constrained Optimization	9th **30** Constrained Optimization
12th **31** Constrained Optimization	14th **32** Constrained Optimization	16th **33** Constrained Optimization
19th **34** Convex Optimization	21st **35** Convex Optimization	23rd **36** Convex Optimization
26th **37** Convex Optimization	28th **38** Stochastic Optimization	30th **39** Stochastic Optimization
May 3rd **40** Final Exam Review	5th Mental Health Day – No Class	7th No Class – Final Exam Released

May 13th - Take-home Final Exam due by upload to D2L Dropbox.