Course Syllabus

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SE 413: Engineering Design Optimization

Tuesday/Thursday 3:30-4:50 pm

Location: 112 Transportation Building

UIUC Course Description

Application of optimization techniques to engineering design problems. Emphasis on problem formulation, including applications in structural, mechanical, and other design domains. Important theoretical results and numerical optimization methods. Matlab programming assignments to develop software for solving nonlinear mathematical programming problems. 3 undergraduate hours. 3 graduate hours. **Prerequisites: MATH 241 and MATH 415.**

Click here to for a 1-page course description.

Course Summary:

This course focuses on the connection between practical engineering design problems and mathematical optimization. Students will learn how to model engineering systems in a way that is appropriate for design optimization, formulate engineering design problems as optimization problems, and how to solve and analyze these optimization problems. Emphasis will be on gradient-based optimization theory and algorithms (nonlinear programming) as opposed to gradient-free methods. Select gradient-free methods will be covered, and students will explore hybrid methods that combine the complementary properties of two or more algorithms. Students will complete an integrative semester project to help solidify their understanding of how principles learned in class can be used in engineering practice. This course is open to both undergraduate and graduate students. An optional intensive project can be completed for an additional credit hour (independent study credit). This option is provided primarily for graduate students who are looking for a deeper experience and who need a four-credit course, but is also open to ambitious undergraduate students with deep interest in design optimization.

General Note About Course:

SE 413 is an intensive course. It involves significant mathematical depth (but is not proof-based), lengthy MATLAB programming assignments with increasing complexity, and an integrative semester project. It is **important not to get behind with topics in class**. This class is targeted specifically for senior undergraduate students (it is more applied than IE 513), although graduate students who would like to use design optimization as a tool in their research, or take the class as a first introduction to design optimization, would likely find this course to be valuable.

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optimization theory and algorithms, but a practical knowledge of how to formulate design optimization problems, and an understanding of what to do when things go wrong with design optimization efforts.

See this page for general advice to be successful in SE 413.

Prerequisites:

While the only formal prerequisites are Math 241 (multivariate calculus/calculus III), Math 415 (linear algebra), it is important that students are able to model and analyze some type of physical system to be designed. For example, students having taken basic courses in statics, dynamics, solid mechanics, or other engineering analysis domains will have the physics-based modeling background needed for this class. Quantitative analysis experience in many other domains will work equally well (e.g., electrical engineering, fluid dynamics/aerodynamics, materials science, heat transfer, physics majors, etc.). Students interested in participating in the optional intensive course project will need to have strong background in analysis so that they can rapidly construct more involved design-appropriate models (i.e., models that can predict how system behavior changes when system design is adjusted).

MATLAB and Programming:

Many SE 413 assignments and the project will involve a significant amount of MATLAB programming. These assignments go beyond interactive command-line use of MATLAB, requiring a moderate level of programming skill. Knowledge of object-oriented programming is not required.

This is a senior-level engineering course, and it is expected that upper-division engineering students will have some basic understanding of programming (algorithm logic, function definitions, data types, etc.). We will review the basics of MATLAB programming at the beginning of class. Elementary examples will be provided in lecture, and additional MATLAB learning resources will be provided (written tutorial __(http://www-personal.umich.edu/~jtalliso/Teaching/matlab.pdf), Ch. 1 from the textbook, lecture videos, more). This basic assistance is intended to help students who have programming experience in another language and need to learn MATLAB syntax and programming conventions, as well as to help students who have learned MATLAB but have not used it for some time. Students who do not have recent experience with MATLAB should plan to devote significant time early in the semester to ramping up MATLAB programming skills. In addition to completing programming assignments, you should spend time doing your own exploration and learning until you feel comfortable with basic MATLAB programming.

Students who have no programming experience at all should not take this course. Assignments in this course will build up to implementing your own optimization algorithms and solving practical engineering design optimization problems (please look through upcoming assignment definitions, especially the last 2-3 homework sets, to get a sense of how involved the programming is).

Course Objectives:

The primary objective of this course is for students to gain the knowledge and creative skill required to translate practical engineering design problems into mathematical optimization problems that can be solved

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- Demonstrate an understanding of how design optimization fits into the overall engineering design process.
- Learn how to formulate practical engineering design problems as well-posed optimization problems.
- Understand continuous optimization theory and its implications for algorithm development, problem formulation, and system modeling.
- Develop a detailed understanding of numerical methods for optimization through both theoretical development and implementation in MATLAB.

The final course grade for each student is based on how well these learning objectives have been met as assessed through homework, exams, the semester project, and other class assignments and activities.

Textbook:

- Required: <u>Optimization in Practice with MATLAB</u>
 (<a href="http://www.cambridge.org/us/academic/subjects/engineering/control-systems-and-optimization/optimization-practice-matlab-engineering-students-and-professionals?format=HB) (Messac, 2015)
- Optional Additional Reference: <u>Principles of Optimal Design: Modeling and Computation</u>
 (http://www.optimaldesign.org/) (Third Edition, Papalambros and Wilde, 2017)
- Optional Additional Reference: <u>Numerical Methods for Unconstrained Optimization and Nonlinear</u>
 <u>Equations</u> (http://epubs.siam.org/doi/book/10.1137/1.9781611971200) (Dennis and Schnabel, 1996)
- Optional Additional Reference: <u>Nonlinear Programming</u> (<u>http://www.athenasc.com/nonlinbook.html</u>)
 (Bertsekas, 1999)

Exams are closed-book, so e-book copies of the textbook are acceptable for this class.

Required Additional Reading:

Several other resources will be provided that complement the textbook. The assigned chapters of the textbook and the required additional reading are all fair game when it comes to exam questions. Below is a list of important additional required reading materials:

- Mathematical Preliminaries (read along with Ch. 2) (handwritten notes 🗟) (revised typed notes)
- Design Optimization Paradigm (read along with Ch. 3-5)
- Problem Formulation and Monotonicity (read along with Ch. 3-5)
- Optimization Numerics (read along with Ch. 7)
- <u>Unconstrained Optimization Geometric Interpretations</u> (read along with Ch. 12)
- Unconstrained Optimization Notes: Part 1 notes: Part 2 notes
 Part 2 notes
 (read along with Ch. 12)
- Constrained Optimization Notes: Part 1 , Part 2 (read along with Ch. 13)
- Least Squares Regression (read along with Ch. 15)

See the <u>Reading Assignments Page</u> for more details and the most up-to-date and comprehensive list of additional reading materials.

<u>Lecture slides</u> are posted on Canvas after each lecture (go to files > Lecture Slides and Notes). The code from MATLAB examples used in class is often posted in the <u>Lecture Examples folder</u> in the files section of

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Office Hours:

Professor Allison: Tuesdays 1:30-3:00 pm. Office: 313 Transportation Building. Also available by appointment.

Satya Peddada (TA): Wednesdays 3:00-5:00 pm, 406 TB. Also available by appointment.

Grading:

The final course grade is based on how well students have met the stated course objectives. Course assessments (e.g., homework assignments and exams) aid the instructor in determining how well each students has met the course objectives. Please refer to the assignment page for a detailed breakdown of homework assignments, exams, and weighting for final grades.

The general grade breakdown is:

- 94%-100%: A (A+ possible for exceptional mastery of material)
- 90%-93%: A-
- 87%-89%: B+
- 83%-86%: B
- 80%-82%: B-
- 77%-79%: C+
- 73%-76%: C
- 70%-72%: C-
- 67%-69%: D+
- 63%-66%: D
- 60%-62%: D-
- <60%: F

Your final grade will be at least as high as the above scale indicates based on your overall class score. The instructor may curve either individual assessments or final grades if needed to more accurately reflect how well students met course objectives. Specifically, if implemented, the curve would only improve student grades.

The two lowest **homework** grades will be dropped (use this opportunity wisely). Homework is due at the beginning of class on the due date specified on the course website. Please submit homework **electronically** through Canvas by the due date/time. This will usually be at the beginning of class. Please scan any handwritten notes for electronic homework submission. **Late homework is not accepted** as we may discuss homework solutions in class.

Two midterm **exams** will be given during class time. No final exam will be given (the semester project fills the role of an integrative assessment). Exams are closed-book except for one side of an 8 1/2" × 11" sheet of paper allowed for notes and a calculator (no other electronic devices). For Exam 2, you may bring both your notes from Exam 1 (one side of one sheet) and one side of one sheet of new notes. Exam questions will

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Homework Submission: Submit homework **electronically through Canvas**. Please submit 1) a main answer document, and 2) supporting files (e.g., code). Please use the following instructions:

- The main answer document should be a single pdf file that contains, in order, the answers to all homework problems. You may need to form this document by concatenating multiple pdf files. Please name this file so that it is easy to identify (e.g., HWK1_Answers_NETWORKID.pdf). The purpose of creating this file is to make it possible to grade all homework problems by viewing this single file. Having this as a separate file (not inside a zip file) will make it possible to view using the Canvas grading utility.
- All supporting files, such as MATLAB code, should be submitted as a single zip file. Please name this file
 appropriately (e.g., HWK1_supporting_NETWORKID.pdf). These should be included so that, if needed,
 the instructor/TA/grader can replicate your results and award partial credit when appropriate.
- For any derivations or other work written out by hand, please scan these pages and include them in the main answer document.
- Please type any essay assignments and include them in main answer document.
- When homework assignments include programming problems, please include in the main answer
 document a pdf generated using the **publish** command that displays 1) appropriate headings and
 comments, 2) MATLAB code organized into sections to improve readability and interpretation of outputs,
 and 3) command line and figure output.
- For programming problems, please include all MATLAB files required to replicate the results displayed in the main answer document (generated using publish). These .m files should be included in the supporting file zip file. Please ensure that all code is **well-commented** so that we can understand the logic of your code. Please organize these files (in subfolders if it makes sense) and name them appropriately so that it is easy to make sense of them. Within the files please make very clear what problem solutions your are presenting, especially if multiple problem solutions are contained in a single file. The instructor should be able to replicate your results based on the files submitted.

Notes regarding Canvas homework submissions:

- When submitting assignments electronically through Canvas, click on the assignment in Canvas. You will
 then see a button to click for making your submission. You can resubmit if needed before the assignment
 deadline.
- Canvas allows resubmission of homework up to the homework deadline (if you need to update your submission). If your latest submission is submitted after the deadline, your assignment will be marked late.

Class participation is a significant portion of the final grade. Please be sure to attend class and be engaged. The class participation grade will be comprised of three main components:

- 1. Self evaluation
- 2. Instructor evaluation
- 3. Class activities (most are extra credit)

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activity as well as possible in the time given). Completing unannounced class activities provides a small amount of extra credit toward the class participation grade. Attending regularly and participating in these activities will help your grade, but there is not a penalty for missing unannounced activities as they are extra credit. Class activities that are announced ahead of time are required (not extra credit).

Software:

Course examples and assignments will make use of MATLAB, particularly the Optimization and Global Optimization toolboxes. Information on how to use MATLAB is located on the MATLAB information page along with other useful links to help you get started. Term projects may be done entirely in MATLAB, or students may choose to incorporate other engineering analysis software they have experience with into their project work.

Term Project:

Students will be required to complete an integrative project as a means to tie together topics covered in class. Students must choose ahead of time one of two project options: 1) a **standard project**, or 2) an **intensive project**. All projects *must* connect in some way to a design problem that involves a **physical engineering system**. Scheduling, supply chain, or other operations research type problems are not appropriate as a term project for this course. Projects must involve non-trivial problem formulations (explained in class in more detail, and on **this page**). All standard projects **must be group projects** (2-3 students, group size should be justified, >3 requires approval). Intensive projects may be individual projects with approval. With each *group* project deliverable submission, a short description of **how each group member contributed** should be included. Project group members will submit peer evaluations at midterm and at the end of the semester. Please see the **project information page** for more details.

Standard projects are projects based on an engineering design application of interest to student groups. Students propose their own projects that must consist of system modeling, design space exploration, problem formulation, multiple optimization studies, iterative improvement of optimization formulation and solution, and analysis of results. Standard projects may be based on appropriate advanced homework problems in the textbook, or an appropriate project defined by the students. If the project is based on a textbook example or problem, it must include a creative extension that helps to generate additional understanding about the system design beyond what is covered in the textbook problem. Students should **make this extension clear** in project proposals, as well as in subsequent project deliverables as appropriate. Individual standard projects are not permitted.

Intensive projects are available for students who desire a deeper experience with design optimization. These are primarily intended for graduate students who plan to use design optimization in their research, who are preparing for qualifying exams, or who need to increase total credit for this course to 4 credit hours. The deliverables are on the same schedule as for the standard project, but have much higher expectations. Intensive projects may be individual or small group projects. In project proposals, students should explain the role of each student if a group project is proposed. Significant modeling and analysis effort outside the normal

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two separate grades: one for independent study (the intensive project) one for SE 413. Project quality is still a factor in the 3-credit SE 413 grade. A project proposal approved by the instructor is required for SE 497 registration. This registration should be completed by 1/29/2018 (the drop/add deadline). The project proposal (PD1) will be included as part of the independent study registration form.

All students, whether participating in a standard or intensive project, should meet with the instructor during office hours to discuss their project proposal before submission. Students should discuss their project progress with the instructor during office hours regularly throughout the semester. It is imperative not to get behind with project milestones, especially construction of a successful design-appropriate model.

The <u>first class participation assignment</u> will aid students in identifying potential project group members. Homework sets and exams are designed to help students be successful in term projects. The term project requires submission of several intermediate deliverables to help groups stay on track. Final project deliverables include a final comprehensive report and a recorded video presentation that will be reviewed by peers and the instructor.

Schedule Overview:

Week 1 (1/15, 17): Introduction to design optimization, MATLAB

Week 2 (1/22, 24): MATLAB problem implementation, mathematics background

Week 3 (1/29, 31): Problem formulation

Week 4 (2/5, 7): Modeling for design, introduction to multi-objective optimization

Week 5 (2/12, 14): Multi-objective optimization, global optimization, numerics fundamentals

Week 6 (2/19, 21): Numerics, exam review

Week 7 (2/26, 28): Exam 1, Unconstrained optimization

Week 8 (3/5, 7): Unconstrained optimization

Week 9 (3/12,14): Unconstrained optimization

Week 10: Spring Break

Week 11 (3/26, 28): Constrained optimization

Week 12 (4/2, 4): Constrained optimization,

Week 13 (4/9, 11): Constrained optimization, surrogate modeling

Week 14 (4/16, 18): Evolutionary algorithms, hybrid methods

Week 15 (4/23, 25): Simulation-based design optimization, integrative examples, exam review

Week 16 (4/30): Exam 2

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Safety Information

- What to do in an emergency (pdf) (http://police.illinois.edu/dpsapp/wp-content/uploads/2016/08/syllabus-attachment.pdf).
- Preparedness video (run/hide/fight).
- Sign up for emergency texts at: emergency.illinois.edu (http://emergency.illinois.edu

Course Summary:

Date	Details	
Fri Jan 18, 2019	Class Activity 1 - Student Survey - Announced (not extra credit) (https://canvas.instructure.com/courses/1431956/assignments/9695560)	due by 11:59pm
Tue Jan 22, 2019	PD0 - Group Formation (https://canvas.instructure.com/courses/1431956/assignments/9695579)	due by 11:59pm
Sun Jan 27, 2019	PD1 - Project Proposal (https://canvas.instructure.com/courses/1431956/assignments/9695580)	due by 11:59pm
Tue Jan 29, 2019	HWK 1 - MATLAB Programming (https://canvas.instructure.com/courses/1431956/assignments/9695569)	due by 3:30pm
Thu Feb 7, 2019	HWK 2 - Mathematical preliminaries and introduction to optimization (https://canvas.instructure.com/courses/1431956/assignments/9695570)	due by 3:30pm
Thu Feb 14, 2019	HWK 3 - Optimization problem formulation, system modeling, and optimization in engineering design (https://canvas.instructure.com/courses/1431956/assignments/9695571)	due by 3:30pm

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Date	Details	
Fri Feb 22, 2019	HWK 4 - Multiobjective optimization, numerics, and global optimization (https://canvas.instructure.com/courses/1431956/assignments/9695572)	due by 11:59pm
Tue Feb 26, 2019	Exam 1 - Through HWK 4 (https://canvas.instructure.com/courses/1431956/assignments/9695567)	due by 4:50pm
Fri Mar 15, 2019	HWK 5 - Unconstrained optimization (https://canvas.instructure.com/courses/1431956/assignments/9695573)	due by 11:59pm
	PD3 - Modeling Report (https://canvas.instructure.com/courses/1431956/assignments/9695582)	due by 11:59pm
Tue Mar 26, 2019	PD4 - Midterm Peer Evaluations (https://canvas.instructure.com/courses/1431956/assignments/9695583)	due by 11:59pm
Tue Apr 2, 2019	HWK 6 - Unconstrained optimization implementation (https://canvas.instructure.com/courses/1431956/assignments/9695574)	due by 3:30pm
Tue Apr 9, 2019	HWK 7 - Constrained optimization 1 (https://canvas.instructure.com/courses/1431956/assignments/9695575)	due by 3:30pm
Tue Apr 16, 2019	PD5 - Progress Report (https://canvas.instructure.com/courses/1431956/assignments/9695584)	due by 11:59pm
Thu Apr 18, 2019	HWK 8 - Constrained optimization 2 (https://canvas.instructure.com/courses/1431956/assignments/9695576)	due by 3:30pm
Thu Apr 25, 2019	HWK 9 - Surrogate modeling, simulation-based design optimization, and gradient-free and hybrid methods (https://canvas.instructure.com/courses/1431956/assignments/9695577)	due by 1:00pm
Tue Apr 30, 2019	Exam 2 - HWK 5-9 Topics (https://canvas.instructure.com/courses/1431956/assignments/9695568)	due by 4:50pm
Fri May 3, 2019	Self Evaluation (https://canvas.instructure.com/courses/1431956/assignments/9695588)	due by 5pm
	PD6 - Virtual Project Presentation (https://canvas.instructure.com/courses/1431956/assignments/9695585)	due by 11:59pm
Wed May 8 2019	Permission Survey (https://canvas.instructure.com/courses/1431956/assignments/9695559) Resetting the test student will clear all	due by 11:59pm

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Date	Details
Thu May 9, 2019	PD8 - Peer Evaluation (https://canvas.instructure.com/courses/1431956/assignments/9695587) due by 11:59p
	Instructor Evaluation (https://canvas.instructure.com/courses/1431956/assignments/9695578)

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