Course Syllabus

GE 413: Engineering Design Optimization

Tuesday/Thursday 5-6:20 pm

1103 Siebel Center for Comp Science

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. **Prerequisites: Math 241, Math 415, or equivalent**.

Click here 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. 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 options 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:

GE 413 is an intense course. It involves significant mathematical depth (but not proof-based), 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 benefit.

While GE 413 requires significant effort, students who complete it and master the material will be in a strong position to use design optimization techniques in actual engineering practice. It encompasses not only 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.

Prerequisites:

While the only formal prerequisites are Math 241 (multivariate calculus/calculus III) and 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 tools they need for this class. Quantitative analysis experience in other domains is valid as 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 construct models that predict system behavior based on system design. As this is a senior-level engineering course, some experience with computer programming is assumed.

MATLAB and Programming:

GE 413 does not have any specific prerequisite course for programming, but many 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 cover 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 are not recommended to 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). A student without any programming experience would need to be a self-starter, have significant time available (5-10 hours/week for the first several weeks), and extremely dedicated early in the semester to develop adequate programming skill.

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 using numerical methods for optimization. In supporting this primary objective, the following objectives should be met by students:

- 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.

Textbook:

- **Required:** **Optimization in Practice with MATLAB** (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:** **Principles of Optimal Design: Modeling and Computation** (http://www.optimaldesign.org/) (Second Edition, Papalambros and Wilde, 2000)
- **Optional Additional Reference:** **Numerical Methods for Unconstrained Optimization and Nonlinear Equations** (http://epubs.siam.org/doi/book/10.1137/1.9781611971200) (Dennis and Schnabel, 1996)
- **Optional Additional Reference:** **Nonlinear Programming** (http://www.athenasc.com/nonlinbook.html) (Bertsekas, 1999)

Exams are closed-book, so electronic 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 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)
- **Unconstrained Optimization - Geometric Interpretations** (read along with Ch. 12)
- Unconstrained Optimization Notes: **Part 1**, **Part 2** (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)

Lecture slides 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 (files > Lecture Examples). Some videos of MATLAB and other examples are available from the **lecture videos page**.

Office Hours:

Professor Allison: Wednesdays 4:30 pm - 6:30 pm. Office: 313 Transportation Building. Also available by appointment.

Albert Patterson (TA): TBD

Grading:

The final course grade is based primarily 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 often 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). Exam questions will focus on topics covered in class (attend and take notes!), although students are expected to know all material from the assigned chapters of the required textbook, as well as the material from the required additional materials (listed above).

Homework Submission: Unless otherwise instructed, submit homework electronically through Canvas. Submit MATLAB code, output, and plots as appropriate. The instructor should be able to replicate your results based on the files submitted. The MATLAB publish command may be especially useful for preparing homework submissions. Please type essay assignments. Please scan handwritten derivations/solutions.

- 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.
- For submissions that require multiple files, please put all of the files into a single zip file, and upload that zip file. Please label the individual file names in a way that makes it easy to identify where your solutions to particular problems are. For example: HWK1_Probs_2.6-.2.16.pdf. Within the files please make very clear what problem solutions your are presenting, especially if multiple problem solutions are contained in a single file.

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

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

Several in-class activities will be used throughout the semester. Some may be announced beforehand, some may be impromptu (so be sure to attend class). No makeup is allowed for class activities. In most cases class activities will be graded on a completion basis (i.e., each student makes a genuine effort to complete the activity as well as possible in the time given). Completing unannounced class activities provides a small amount of extra credit to 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. There will be two options: a **standard project** and 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. 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 project deliverable submission, except for individual intensive projects, a short description of **how each group member contributed** should be included. Please see the [project information pag]e 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 justify the need for multiple students if a group project is proposed (e.g., what is the role of each student). Significant modeling and analysis effort outside the normal scope of the class is expected for intensive projects (e.g., finite element analysis, state-space models, or other advanced modeling tools). Students participating in the intensive project will enroll in 1 credit hour of independent study (GE/IE 497). Because the project counts toward independent study credit, you will receive two separate grades: one for independent study (the intensive project) one for GE 413. Project quality is still a factor in the 3-credit GE 413 grade. A project proposal approved by the instructor is required for GE/IE 497 registration. This registration should be completed by 2/1/2017.

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.

The [first class participation assignment] 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 (1/17,19): Introduction to design optimization

Week 2 (1/24,26): MATLAB problem implementation, mathematics background

Week 3 (1/31,2/2): Problem formulation

Week 4 (2/7,9): Modeling for design, introduction to multi-objective optimization

Week 5 (2/14,16): Multi-objective optimization, global optimization, numerics fundamentals

Week 6 (2/21,23): Numerics, exam review

Week 7 (2/28,3/2): Exam 1, Unconstrained optimization

Week 8 (3/7,9): Unconstrained optimization

Week 9 (3/14,16): Unconstrained optimization

Week 10: Spring Break

Week 11 (3/28,30): Constrained optimization

Week 12 (4/4,6): Constrained optimization,

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

Week 14 (4/18,20): Evolutionary algorithms, pattern search, hybrid methods

Week 15 (4/25,4/27): Simulation-based design optimization, integrative examples, exam review

Week 16 (5/2): Exam 2

Week 17: Final project deliverables

Resources for Students With Disabilities

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail **disability@illinois.edu (mailto:disability@uiuc.edu)** or go to the **DRES website (http://disability.illinois.edu/)**. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available on campus that can help diagnosis a previously undiagnosed disability by visiting the DRES website and selecting “Sign-Up for an Academic Screening” at the bottom of the page.

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/)***