MAE 531: Engineering Design Optimization (DE)
Fall 2024

SYLLABUS AND SEMESTER PLAN

Course summary

- In this class, we focus on best-practices for engineering optimization problem formulation and discuss the strengths, weaknesses, and applicability of various optimization methods.
- Optimization methods will be implemented using hand-calculations, Excel, and MATLAB. Basic coding experience (for loops, while statements, if statements) is required.
- Graded material will consist of six homework assignments and three implementation/reflection projects

Course instructor, times, and location

Instructor: Dr. Scott Ferguson
scott_ferguson@ncsu.edu (smfergu2@ncsu.edu can also be used as they go to the same account)

Lecture: Videos of the live lecture (Mondays and Wednesdays from 4:30 pm – 5:45 pm) will be recorded.
https://ncsu.hosted.panopto.com/Panopto/Pages/Sessions/List.aspx#folderID=a5fc74d5-d278-48a4-ac48-b1c2009e811d
Lecture notes from each class will also be posted on Moodle.

Office hours (Zoom): Mondays and Thursdays from 9:00 pm – 10:00 pm eastern (or by scheduled appointment)
https://ncsu.zoom.us/j/97070635595?pwd=ESVYNh2xNPUVgHVNaPtXyGRvsgMqHf.1

Course description

Optimization involves finding the "best" solution according to specified criteria. In the context of engineering design, the "best" solution may refer to a minimum cost or weight, maximum quality or efficiency, or some other performance index pertaining to a disciplinary objective. However, determining the optimal design involves more than just the minimization or maximization of an objective function. Designers must also identify the design variables that represent the physical form of the system and the constraints that represent limitations on the design space. Typically, the problems of interest in engineering are of a nonlinear nature, in that the objective functions and constraints considered are nonlinear.

This course introduces traditional nonlinear optimization methods that can be used to solve a wide variety of engineering design problems across all engineering disciplines. Additionally, students will study the tradeoffs associated with the design of complex engineering systems. By the end of the semester, students will have gained the ability to create a formal optimization problem, have basic knowledge of numerical optimization algorithms, and will have sufficient understanding of the strengths and weaknesses of these approaches.

Note: Some of the homework and all implementation projects involve programming. A basic programming background is required (for loops, if-else statements, while, etc.). We will cover some MATLAB programming in lecture, and some assignments will require you to program in MATLAB. If you have not written code in a while, it is strongly recommended that you read a MATLAB tutorial or primer (I will post some supplementary material).

Teaching philosophy for this course

"*There is an intimate relationship between the mathematical model that describes a design and the solution methods that optimize it. A basic premise from the start was that a good model can make optimization almost trivial, whereas a bad one can make correct optimization difficult or impossible. Software tools today provide capabilities for intricate analysis of many difficult performance aspects of a system. These analysis models, often referred to as simulations, can be coupled with numerical optimization software to generate better designs iteratively. … The success of such attempts depends strongly on how well the design problem has been formulated …, and on how familiar the designer is with the working and pitfalls of mathematical optimization techniques.*"
Panos Y. Papalambros, 2017, Principles of Optimal Design: Modeling and Computation, Third Edition

"The lasting measure of good teaching is what the individual student learns and carries away."
Barbara Harrell Carson, 1996, *Thirty Years of Stories*

I will try my best to answer all email questions and Piazza forum posts within one business day. If you experience problems with the material, please contact me for help. Finally, constructive course feedback is always encouraged.

Course topics

- Introduction to optimization – design variables, objective functions, constraints, constructing formalized optimization problem statements
- Mathematical foundations of optimality conditions
- Techniques for solving single variable optimization problems
- Techniques for solving unconstrained, multi-variable optimization problems
- Techniques for solving constrained optimization problems
- Metamodeling and response surface generation
- Mathematical foundations of multidisciplinary design optimization (MDO)
- Heuristic-based optimization methods
- Mathematical foundations of multiobjective design optimization

Skills/understanding

At the end of this class, you will have the foundation needed to:

- Formulate optimization problems in standard form
- Assess the optimality of a proposed solution
- Interpret the output of an optimization algorithm
- Assess the sensitivity of an optimal solution
- Compare the advantages and disadvantages of different optimization techniques
- Choose the best optimization technique for meeting your available resources
- Create metamodels using sampled problem data
- Solve multiobjective and multidisciplinary optimization problems
- Construct computer programs for determining the optimal solution for unconstrained and constrained nonlinear optimization problems of multiple variables

Course websites

Moodle: http://wolfware.ncsu.edu
Panopto: https://ncsu.hosted.panopto.com/Panopto/Pages/Sessions/List.aspx#folderID=a5fc74d5-d278-48a4-ac48-b1c2009e811d
Piazza: https://piazza.com/ncsu/fall2024/mae531
Message board where students can ask questions and receive guidance from others and the professor

Text (not required, but useful)

Arora, J., Introduction to Optimum Design, 4th edition, Elsevier, ISBN 978-0-12-800806-5

All students will have free access to the digital book until August 30th. Students wanting to get the All-In materials at the lowest price must place their order for the books before August 30th.

https://shop.ncsu.edu/adoption-search-results?ccid=99128&itemid=196714

Grading

Homework	45%
Implementation/reflection projects (3)	55% (15%, 20%, 20%)

Homework:

Students will submit individual homework. The objective of homework is gaining experience with the concepts/algorithms discussed in class. Homework will involve written work, discussion, some coding, and some graphing.

Implementation/reflection projects:

There will be three (3) implementation/reflection projects. Students will submit individual projects. These projects will involve the computer-based implementation of optimization techniques covered in class. We will use problems that have a larger scale than what we cover in the homework. The focus of these projects will be assessing the effectiveness of the algorithms and comparing their performance in arriving at the optimal solution. In these projects, getting the algorithm to work is only part of the assignment. You will also be asked to provide written reflections that demonstrate what you have learned about problem formulation, algorithm effectiveness, and solution quality.

Submission of homework and projects:
All homework and projects will be submitted via Moodle. A submission link will be created for each assignment. Homework and projects are due by 11:59 pm eastern on the assigned date, unless otherwise stated.

For homework, students are allowed one 24-hour grace period on one assignment. You do not need to contact me about this. Late assignments submitted without communication, and not used as part of the one grace period, will not be accepted without justification. Students are recommended to see the University Attendance Policy for reasons that late homework may be accepted.

For projects, no grace periods are provided. If you need extra time on a project, please contact me so that we can discuss an extension. Communication about illness, travel, challenges, etc. is fundamentally important. Please reach out early so we can develop a plan.

Miscellaneous

Health and participation in class:
If you test positive for COVID-19, you should not attend any face-to-face (F2F) classes. Work with your instructor on any adjustments necessary and follow other university guidelines,

If you are in quarantine or have a personal or family situation related to COVID-19 that prevents you from attending this course in person, please contact me so we can make necessary adjustments.

Course attendance:
NC State attendance policies can be found at: https://policies.ncsu.edu/regulation/reg-02-20-03-attendance-regulations/ . Please refer to this course's attendance, absence, and deadline policies for additional details. If you are quarantined or otherwise need to miss class because you have been advised that you may have been exposed to COVID-19, you should not be penalized regarding attendance or class participation. However, you will be expected to develop a plan to keep up with your coursework during any such absences. If you become ill with COVID-19, you should follow the steps outlined in the health and participating section above. COVID 19-related absences will be considered excused; documentation need only involve communication with your instructor.

Technology requirements:
This course may require particular technologies to complete coursework. Be sure to review the syllabus for these expectations and see go.ncsu.edu/syllabus-tech-requirements to find out more about technical requirements for your course. If you need access to additional technological support, please contact the Libraries' Technology Lending Service: https://www.lib.ncsu.edu/devices.

Academic dishonesty:
Cheating of any kind (copying, plagiarism, etc.) will not be tolerated and will result in an F for the course. Please review the following website (http://www.ncsu.edu/stud_affairs/osc/AIpage/acaintegrity.html) for further information on academic integrity at NCSU. In addition, reasonable accommodations will be made for students with verifiable disabilities. Students must register with the Disability Services Office.

Supporting fellow students in distress:
As members of the NC State Wolfpack community, we each share a personal responsibility to express concern for one another and to ensure that this classroom and the campus as a whole remains a safe environment for learning. Occasionally, you may come across a fellow classmate whose personal behavior concerns or worries you. When this is the case, I would encourage you to report this behavior to the NC State Students of Concern website:http://studentsofconcern.ncsu.edu/. Although you can report anonymously, it is preferred that you share your contact information so they can follow-up with you personally.

Course outline (dates, topics, and assignments all subject to change)

Week	Topic	Notable dates
1	Introduction to optimization *Terminology* *Problem preparation and formalized optimization problem statements* Development of optimality conditions *Existence and uniqueness of solutions*	**FDOC (8/19)**
2	Development of optimality conditions *Necessary and sufficient conditions* *Finding and assessing the optimum using graphical approaches*	**No Class (8/26)**
3	Optimizing functions of a single variable *Bounding phase method* *Point-estimation techniques*	**No Class (9/2)**
4	Optimizing functions of a single variable *Region elimination techniques* Unconstrained functions of multiple variables *Zero-order methods* *Gradient estimation techniques*	**HW 1 due (9/9)**
5	Unconstrained functions of multiple variables *Gradient-based methods* *Second order methods*	**HW 2 due (9/16)**
6	Linear programming and extensions of LP to nonlinear optimization problems	**HW 3 due (9/25)**
7	Linear programming extensions to nonlinear optimization problems Constrained nonlinear optimization *Interior penalty function* *Exterior penalty function*	**Implementation/reflection project 1 due (10/2)**
8	Constrained nonlinear optimization *Augmented Lagrange Multiplier (ALM)* *Generalized Reduced Gradient* *SQP*	**HW 4 due (10/7)**
9	Metamodeling and response surface generation	**No Class (10/14)**
10	Metamodeling and response surface generation	**HW 5 due (10/21)**
11	Multidisciplinary Design Optimization	
12	Multidisciplinary Design Optimization Heuristic optimization techniques *Simulated annealing*	**Implementation/reflection project 2 due (11/6)**
13	Heuristic optimization techniques *Particle swarm optimization* *Genetic algorithms*	**HW 6 due (11/13)**
14	Heuristic optimization techniques *Genetic algorithms* Multiobjective optimization *Pareto sets and tradeoffs* *Basic multiobjective formulations* *NSGA-II*	
15	Multiobjective optimization *NSGA-II*	**Implementation/reflection project 3 due (11/25)**
16	Course conclusion	**LDOC (12/3)**