ECE 580: Optimization Methods for Systems and Control

Instructor

- Stanislaw (Stan) Henryk Żak, *Professor of Electrical and Computer Engineering, Purdue University*

Course Description

An introduction to various methods of obtaining the extremum (minimum or maximum) of a non-dynamical system and the use of these methods in real-life applications. Computational methods for nonlinear optimization; unconstrained optimization. Constrained optimization; linear programming; simplex method for solving linear programs; Lagrange's conditions, the Karush-Kuhn-Tucker (KKT) conditions, Least squares, Convex optimization, Global optimization methods: Genetic algorithms and Particle swarm optimization (PSO) method.

Course Learning Outcomes

After completing this course, you will be able to:

- Use various methods to compute minimum or maximum of nonlinear functions of many variables
- Solve linear programming problems
- Find minimum or maximum of nonlinear functions of many variables using population-based methods
- Apply various optimization methods learned in the course to real-life design problems

Required Tools

Textbook

An Introduction to Optimization by E. K. P. Chong and S. H. Żak (4th edition), published by Wiley & Sons, Inc., New York 2013, available in two forms:

- Wiley E-Text, ISBN: 9781118515150 (available online through Purdue Libraries; log in with your Purdue career account)
- Hardcover, ISBN: 9781118279014

MATLAB

You will need to have access to MATLAB in this course. To access MATLAB, you may either:

1. Purchase a student version of MATLAB for $99
   Link to student version
2. Use MATLAB via Software Remote. Note that there are a limited number of licenses for this, and during busy times students may not be able to use MATLAB via Software Remote.

Prerequisites

- MA 511 or equivalent (first graduate course in linear algebra)
- Linear algebra, calculus of several variables. In particular: matrix manipulation, linear spaces, quadratic forms, tangent planes. Elements of multivariable calculus, in particular, differentiation of real-valued functions of n variables, gradients, and the chain rule.
- You can review your linear algebra at your leisure by viewing video lectures by Professor Gilbert Strang.

Grading

This course will be graded based on the following criteria:

Assessment Type	Description	% of Final Grade
FunWork	I'm sure that these assignments will be a source of fun for you – thus, we have named them "FunWork" instead of your everyday, basic "homework". There will be five FunWork assignments that will be averaged out to be worth 100 points.	20%
Midterm Exams	There will be two midterm exams each weighted 100 points. The midterm exams will test your understanding of the course material. The midterms will be available to access for 48 hours (see the schedule below), but you will only have 1.5 hours to complete it once you have started.	40%
Final Exam	The final exam will be comprehensive and worth 200 points. The final exam will be available to access for 48 hours (see the schedule below), but you will only have 2.5 hours to complete the final exam once you have started.	40%

Grading Scale

98% - 100%	A+
90% - 98%	A
84% - 90%	A-
78% - 84%	B+
72% - 78%	B
68% - 72%	B-
63% - 68%	C+
58% - 63%	C
53% - 58%	C-
48% - 53%	D+
45% - 48%	D
40% - 45%	D-
<40%	F

Regrades

In order to receive consideration, all requests for re-grades, regardless of type, will have to be submitted within one week of the return of the exam or homework in question.

Course Schedule

Week	Dates	Modules	Assignments and Exams
1	8/24 – 8/30	1. Welcome, Introduction, and Motivation 2. Differentiation of functions of many variables 3. Taylor series expansion and feasible directions	• FunWork 1 posted
2	8/31 – 9/6	4. First-order necessary condition (FONC) 5. Necessary and sufficient conditions for a point to be a minimizer 6. Quadratic forms	
3	9/7 – 9/13	7. Quadratic forms and second-order sufficient condition (SOSC) 8. Proof of the second-order sufficient condition (SOSC) 9. Golden section search and Fibonacci method	• **FunWork 1 Due** ○ Due Date: **9/12 at 11:59 PM ET** *(9/13 at 3:59 UTC)*
4	9/14 – 9/20	10. The Fibonacci line search method and Newton's methods 11. Introduction to the method of steepest descent (SD) 12. Performance analysis of the steepest descent (SD) gradient method	• FunWork 2 posted
5	9/21 – 9/27	13. Further analysis of the steepest descent (SD) gradient method 14. Newton's method to minimize functions of many variables 15. The asymptotic symbols and the conjugate directions (CD) method	• **FunWork 2 Due** ○ Due Date: **9/26 at 11:59 PM ET** *(9/27 at 3:59 UTC)*
6	9/28 – 10/4	16. Linear independence of conjugate directions 17. Implementation of the Conjugate Gradient (CG) algorithm 18. Review for Midterm 1	• FunWork 3 posted
Midterm 1		19. Midterm 1	• **Midterm 1** ○ Exam Opens: **10/1 at 12:00 AM ET** *(10/1 at 4:00 UTC)* ○ Exam Due Date: **10/2 at 11:59 PM ET** *(10/3 at 3:59 UTC)* ○ Time Limit Once Started: **1.5 hours**

Week	Dates	Modules	Assignments and Exams
7	10/5 – 10/11	20. An introduction to quasi-Newton methods 21. The rank one correction and Davidon-Fletcher-Powell methods 22. The Broyden-Fletcher-Goldfarb-Shanno algo	• **FunWork 3 Due** ○ Due Date: **10/10 at 11:59 PM ET** *(10/11 at 3:59 UTC)*
8	10/12 – 10/18	23. The least-squares method development and its applications 24. The least squares and the recursive least-squares (RLS) methods 25. Underdetermined systems of linear equations	• FunWork 4 posted
9	10/19 – 10/25	26. Solving a general system of linear equations 27. The pseudo-inverse and population based optimization methods 28. Particle Swarm Optimization and Canonical Genetic Algorithms	
10	10/26 – 11/1	29. The canonical genetic algorithm (GA) development 30. The canonical genetic algorithm implementation and analysis 31. The canonical genetic algorithm MATLAB implementation	• **FunWork 4 Due** ○ Due Date: **10/31 at 11:59 PM ET** *(11/1 at 3:59 UTC)*
11	11/2 – 11/8	32. The schema theorem and the real-number genetic algorithms 33. Real-number genetic algorithms and linear programming 34. Fundamental theorem of linear programming	• FunWork 5 posted
12	11/9 – 11/15	35. Fundamental theorem of linear programming and convex sets 36. Basic feasible solutions and extreme points of the feasible set	
Midterm 2		37. Midterm 2	• **Midterm 2** ○ Exam Opens: **11/12 at 12:00 AM ET** *(11/12 at 5:00 UTC)* ○ Exam Due Date: **11/13 at 11:59 PM ET** *(11/14 at 4:59 UTC)* ○ Time Limit Once Started: **1.5 hours**

Week	Dates	Modules	Assignments and Exams
13	11/16 – 11/22	38. Simplex method for solving linear programming problems 39. The two-phase simplex method and an introduction to duality 40. An introduction to nonlinear optimization subject to constraints	• **FunWork 5 Due** ○ Due Date: **11/21 at 11:59 PM ET** *(11/22 at 4:59 UTC)*
14	11/23 – 11/29	41. Nonlinear optimization subject to equality constraints 42. The Lagrange multiplier theorem 43. Nonlinear optimization subject to inequality constraints	
15	11/30 – 12/6	44. Convex functions and convex optimization problem	
Final Exam	12/7 – 12/13	45. Final Exam	• **Final Exam** ○ Exam Opens: **12/10 at 12:00 AM ET** *(12/10 at 5:00 UTC)* ○ Exam Due Date: **12/11 at 11:59 PM ET** *(12/12 at 4:59 UTC)* ○ Time Limit Once Started: **2.5** hours

Course Help

To get help with course content, comment in the discussion forums located in each unit. By commenting in the unit discussion forums, the course team will be able to respond to your question more quickly.

Discussion Guidelines

Please follow the Discussion Guidelines when contributing to discussions in this course. Here are a few of the key points you should remember:

- Do not use offensive language. Present ideas appropriately.
- Be cautious in using Internet language. For example, do not capitalize all letters since this suggests shouting.
- Avoid using vernacular or slang language. This could possibly lead to misinterpretation.
- Do not hesitate to ask for feedback.
- Be concise and to the point.
- Think and edit before you push the “Send” button.

Technical Help

If you experience technical difficulties with the edX platform, contact edX Support using:

- The email address: support-masters@edx.org
- edX's Contact Us form

Accessibility Information

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: drc@purdue.edu or by phone: 765-494-1247.

The **Office of Institutional Equity**, which is responsible for ensuring Americans with Disability Act compliance, can be contacted with any accessibility concerns at:

Phone: (765) 494-7253
Email: equity@purdue.edu
TTY: (765) 496-1343
Website

- Purdue's Disability Resource Center Website
- Purdue's Web Accessibility Policy
- edX's Website Accessibility Policy
- MATLAB's Accessibility Policy
- Proctortrack's Web Accessibility Policy

Academic Integrity

Academic integrity is one of the highest values that Purdue University holds. Individuals are encouraged to alert university officials to potential breaches of this value by either emailing or by calling 765-494-8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

The Purdue Honor Pledge

"As a Boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue"

Nondiscrimination Statement

Purdue University is committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Link to Purdue's nondiscrimination policy statement.

Academic Guidance in the Event a Student is Quarantined/Isolated

If you become quarantined or isolated at any point in time during the semester, in addition to support from the Protect Purdue Health Center, you will also have access to an Academic Case Manager who can provide you academic support during this time. Your Academic Case Manager can be reached at acmq@purdue.edu and will provide you with general guidelines/resources around communicating with your instructors, be available for academic support, and offer suggestions for how to be successful when learning remotely.

If you find yourself too sick to progress in the course, notify your academic case manager and notify me via email or Brightspace. We will make arrangements based on your particular situation. The Office of the Dean of Students (odos@purdue.edu) is also available to support you should this situation occur.

Attendance Policy during COVID-19

The following information is for on-campus students. Students should stay home and contact the Protect Purdue Health Center (496-INFO) if they feel ill, have any symptoms associated with COVID-19, or suspect they have been exposed to the virus. In the current context of COVID-19, in-person attendance will not be a factor in the final grades, but the student still needs to inform the instructor of any conflict that can be anticipated and will affect the submission of an assignment or the ability to take an exam. Only the instructor can excuse a student from a course requirement or responsibility. When conflicts can be anticipated, the student should inform the instructor of the situation as far in advance as possible. For unanticipated or emergency conflicts, when advance notification to an instructor is not possible, the student should contact the instructor as soon as possible by email, through Brightspace, or by phone. When the student is unable to make direct contact with the instructor and is unable to leave word with the instructor's department because of circumstances beyond the student's control, and in cases of bereavement, quarantine, or isolation, the student or the student's representative should contact the Office of the Dean of Students via email or phone at 765-494-1747.

Classroom Guidance Regarding Protect Purdue

The following information is for on-campus students. The Protect Purdue Plan, which includes the Protect Purdue Pledge, is campus policy and as such all members of the Purdue community must comply with the required health and safety guidelines. Required behaviors in this class include: staying home and contacting the Protect Purdue Health Center (496-INFO) if you feel ill or know you have been exposed to the virus, wearing a mask in classrooms and campus buildings, at all times (e.g., no eating/drinking in the classroom), disinfecting desk/workspace prior to and after use, maintaining proper social distancing with peers and instructors (including when entering/exiting classrooms), refraining from moving furniture, avoiding shared use of personal items, maintaining robust hygiene (e.g., handwashing, disposal of tissues) prior to, during and after class, and following all safety directions from the instructor.

Students who are not engaging in these behaviors (e.g., wearing a mask) will be offered the opportunity to comply. If non-compliance continues, possible results include instructors asking the student to leave class and instructors dismissing the whole class. Students who do not comply with the required health behaviors are violating the University Code of Conduct and will be reported to the Dean of Students Office with sanctions ranging from educational requirements to dismissal from the university.

Any student who has substantial reason to believe that another person in a campus room (e.g., classroom) is threatening the safety of others by not complying (e.g., not wearing a mask) may leave the room without consequence. The student is encouraged to report the behavior to and discuss next steps with their instructor. Students also have the option of reporting the behavior to the Office of the Student Rights and Responsibilities. See also Purdue University Bill of Student Rights.