ENGG*6140 Optimization Techniques for Engineering

Winter 2023
Section(s): 02

School of Engineering
Credit Weight: 0.50
Version 1.00 - December 21, 2022

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1 Course Details

1.1 Calendar Description

This course serves as a graduate introduction into combinatorics and optimization. Optimization is the main pillar of Engineering and the performance of most systems can be improved through intelligent use of optimization algorithms. Topics to be covered: Complexity theory, Linear/Integer Programming techniques, Constrained/Unconstrained optimization and Nonlinear programming, Heuristic Search Techniques such as Tabu Search, Genetic Algorithms, Simulated Annealing and GRASP.

1.2 Course Description

The course provides the basic concepts and fundamentals of optimization. It covers the main and core methods of optimization which can be used in practice. We start with **preliminaries** including sets, norms, functions, local/global minimizer, derivatives, gradient, Jacobian, Hessian, convexity of sets, and convexity of functions. We introduce the **standard problems** (e.g., convex problem, linear programming, quadratic programming, semidefinite programming, etc). Then, we cover **linear programming** (the Simplex algorithm) and **integer programming** for continuous and discrete linear problems, respectively. Then, we introduce the **Karush-Kuhn-Tucker (KKT) conditions** along with the **Lagrangian** function and the method of Lagrange multipliers. We cover **unconstrained and constrained first-order optimization** which are gradient methods. Then, the **unconstrained and constrained second-order optimization** techniques, including the **interior-point method**, are covered in order to be able to solve all convex optimization problems (this method also works fairly well on nonconvex problems). Some mathematical models may be so complex that it becomes impossible to solve them by any of the available optimization algorithms. In such cases, it may be necessary to abandon the search for the optimal solution and simply seek a good solution using **metaheuristic optimization**. We cover important metaheuristic methods such as genetic algorithm, particle swarm optimization, and simulate annealing. If time allows, we

will also go through **distributed optimization** (such as **ADMM**) in order to solve complex multivariate optimization problems.

The course will address and cover the above topics.

1.3 Timetable

Lectures:

Tuesday 07:00PM - 09:50PM Synchronous, Online via Zoom/Teams.

1.4 Final Exam

No final Exam. A presentation and a final project will be used instead. Instructor will post the exact date and time on CourseLink. Moreover, the course has a midterm exam.

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2 Instructional Support

2.1 Instructional Support Team

Instructor: Benyamin Ghojogh
Email: bghojogh@uoguelph.ca
Office Hours: By appointment and via Zoom/Teams.

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3 Learning Resources

3.1 Required Resources

Courselink (Website)
https://courselink.uoguelph.ca
Course material, news, announcements, and grades will be regularly posted to the ENGG*6410 (section 2) Courselink site. You are responsible for checking the site regularly.

Required Reading (Readings)

1. Lecture notes (which are provided to students).
2. Benyamin Ghojogh, Ali Ghodsi, Fakhri Karray, and Mark Crowley. "KKT Conditions, First-Order and Second-Order Optimization, and Distributed Optimization: Tutorial and Survey." arXiv preprint arXiv:2110.01858 (2021), web: https://arxiv.org/abs/2110.01858
3. Stephen Boyd and Lieven Vandenberghe. "Convex optimization." Cambridge

university press, 2004. web:
https://web.stanford.edu/~boyd/cvxbook/bv_cvxbook.pdf

3.2 Recommended Resources

Recommended Readings (Other)

1. Additional resource for interested students: Convex Optimization I and II at the YouTube channel of Stanford University, web:
   https://www.youtube.com/watch?v=McLq1hEq3UY&list=PL3940DD956CDF0622
   - Optimization I of Stanford: mostly focused on second-order optimization
   - Optimization II of Stanford: mostly focused on non-convex optimization and first-order optimization
2. The books of Yurii Nesterov (mostly focused on first-order optimization):
   - Introductory lectures on convex optimization: A basic course, 2003
   - Introductory Lectures on Convex Optimization
   - Lectures on Convex Optimization
3. Research articles in the literature

3.3 Additional Reasources

- Lecture Information: All the lecture notes are posted on the web page (week #1-#12).
- Assignments: Assignments will be posted in CourseLink along with their due dates.
- Miscellaneous Information: Other information related to the course may be posted on the web page.

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4 Learning Outcomes

The main goal of this course is to learn the core concepts and methods of optimization, including the simplex algorithm, KKT conditions, first-order optimization, second-order optimization, metaheuristic optimization, and possibly distributed optimization.

4.1 Course Learning Outcomes

By the end of this course, you should be able to:

1. Understand basics of optimization techniques and the mathematics behind them.
2. Learning linear programming (Simplex algorithm) and integer programming.
3. Learning the Karush-Kuhn-Tucker (KKT) conditions for optimization.
4. Learning first-order optimization including gradient methods

5. Learning second-order optimization including unconstrained and constrained Newton's method
6. Learning some important algorithms in metaheuristic optimization, including genetic algorithm (evolutionary optimization), particle swarm optimization, and simulated annealing.
7. If time allows, distributed optimization (including ADMM) will be learned.

4.2 School of Engineering - Graduate Degree Learning Outcomes

Successfully completing this course will contribute to the following:

#	Outcome	Learning Outcome
1	Literacy	1, 2, 3, 4, 5, 6
1.1	Information Literacy	1, 2, 3, 4, 5, 6
1.2	Quantitative Literacy	1, 2, 3, 4, 5, 6
1.3	Technological Literacy	1, 2, 4, 5, 6
1.4	Visual Literacy	1, 2, 3, 4, 5, 6
2	Global Understanding	2, 3, 5
2.1	Global Understanding	2, 3, 5
2.2	Sense of Historical Development	2, 3
3	Communication Skills	5
3.1	Oral Communication	5
3.2	Written Communication	5
3.3	Reading Comprehension	5
3.4	Integrative Communication	5
4	Professional and Ethical Behaviour	5
4.1	Teamwork	5
4.2	Ethical Reasoning	5
4.3	Leadership	5
4.4	Personal Organization/Time Management	5
4.5	Intellectual Independence	5
5	Critical and Creative Thinking	3, 4, 5, 6
5.1	Independent Inquiry and Analysis	4, 6

#	Outcome	Learning Outcome
5.2	Problem Solving	3, 4, 5, 6
5.3	Creativity	4, 5, 6
5.4	Depth and Breadth of Understanding	4, 5, 6

5 Teaching and Learning Activities

5.1 Lecture

Week 1 - 2

Topics: Preliminaries (sets, norms, functions, gradient, Jacobian, Hessian, etc). Convexity of sets and functions. Introduction to standard optimization problems.

Learning Outcome: 1

Week 2 - 3

Topics: Linear Programming, the Simplex method, and Integer linear programming.

Learning Outcome: 2

Week 4 - 5

Topics: Karush-Kuhn-Tucker (KKT) conditions, the Lagrangian function, dual variables, primal and dual feasibility, the dual problem, and the method of Lagrange multipliers

Learning Outcome: 3

Week 6

Topics: The midterm exam.

Week 6 - 7

Topics: Unconstrained an constrained first-order optimization: gradient descent, line-search, steepest descent, backpropagation and neural networks, stochastic gradient descent, proximal mapping, proximal gradient method, projected gradient method

Learning Outcome: 4

Week 8 - 9

Topics: Unconstrained and constrained second-order optimization: unconstrained Newton's method, equality constrained Newton's method, interior-point and barrier methods, quasi-Newton's methods

Learning Outcome: 5

Week 10

Topics: Metaheuristic optimization: genetic algorithm, particle swarm optimization, simulate annealing, etc.

Learning Outcome: 6

Week 10

Topics: If time allows: distributed optimization: alternating optimization, dual decomposition methods, augmented Lagrangian method, Alternating Direction Method of Multipliers (ADMM).

Learning Outcome: 7

Week 11 - 12

Topics: Group final project presentations.

5.2 Disclaimer

The instructor reserves all right to change any or all of the above in the event of appropriate circumstances, subject to the University of Guelph academic regulations. Base on the class situation, some of the topics may be changed slightly during the semester.

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6 Assessments

6.1 Marking Schemes & Distributions

Name	Scheme A (%)
Assignments	20
Midterm Exam	30
Project	40
Group presentation	10

Name	Scheme A (%)
Total	100

6.2 Assessment Details

Assignments (20%)
Assignments will be posted on CourseLink along with the due dates. They are performed individually.

The midterm exam (30%)
Date: Week 6
Details to be discussed in class.

Course project (40%)
Date: Week 6 - 11

More details will be discussed in class. Report will be electronic submission due in CourseLink.

- The number of people in each group will be announced in the class.
- Pick a Topic after 6 weeks.
- Send me the title and objectives to approve it.

Group Presentation (10%)
Date: Week 11 - 12
During class time.

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7 School of Engineering Statements

7.1 Instructor's Role and Responsibility to Students

The instructor’s role is to develop and deliver course material in ways that facilitate learning for a variety of students. Selected lecture notes will be made available to students on Courselink but these are not intended to be stand-alone course notes. Some written lecture notes will be presented only in class. During lectures, the instructor will expand and explain the content of notes and provide example problems that supplement posted notes. Scheduled classes will be the principal venue to provide information and feedback for tests and labs.

7.2 Students' Learning Responsibilities

Students are expected to take advantage of the learning opportunities provided during lectures and lab sessions. Students, especially those having difficulty with the course content, should also make use of other resources recommended by the instructor. Students who do (or may) fall behind due to illness, work, or extra-curricular activities are advised to keep the instructor informed. This will allow the instructor to recommend extra resources in a timely

manner and/or provide consideration if appropriate.

7.3 Lab Safety

Safety is critically important to the School and is the responsibility of all members of the School: faculty, staff and students. As a student in a lab course you are responsible for taking all reasonable safety precautions and following the lab safety rules specific to the lab you are working in. In addition, you are responsible for reporting all safety issues to the laboratory supervisor, GTA or faculty responsible.

8 University Statements

8.1 Email Communication

As per university regulations, all students are required to check their e-mail account regularly: e-mail is the official route of communication between the University and its students.

8.2 When You Cannot Meet a Course Requirement

When you find yourself unable to meet an in-course requirement because of illness or compassionate reasons please advise the course instructor (or designated person, such as a teaching assistant) in writing, with your name, id#, and e-mail contact. The grounds for Academic Consideration are detailed in the Undergraduate and Graduate Calendars.

Undergraduate Calendar - Academic Consideration and Appeals
https://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-ac.shtml

Graduate Calendar - Grounds for Academic Consideration
https://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/index.shtml

Associate Diploma Calendar - Academic Consideration, Appeals and Petitions
https://www.uoguelph.ca/registrar/calendars/diploma/current/index.shtml

8.3 Drop Date

Students will have until the last day of classes to drop courses without academic penalty. The deadline to drop two-semester courses will be the last day of classes in the second semester. This applies to all students (undergraduate, graduate and diploma) except for Doctor of Veterinary Medicine and Associate Diploma in Veterinary Technology (conventional and alternative delivery) students. The regulations and procedures for course registration are available in their respective Academic Calendars.

Undergraduate Calendar - Dropping Courses
https://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-drop.shtml

Graduate Calendar - Registration Changes
https://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/genreg-reg-regchg.shtml

Associate Diploma Calendar - Dropping Courses
https://www.uoguelph.ca/registrar/calendars/diploma/current/c08/c08-drop.shtml

8.4 Copies of Out-of-class Assignments

Keep paper and/or other reliable back-up copies of all out-of-class assignments: you may be asked to resubmit work at any time.

8.5 Accessibility

The University promotes the full participation of students who experience disabilities in their academic programs. To that end, the provision of academic accommodation is a shared responsibility between the University and the student.

When accommodations are needed, the student is required to first register with Student Accessibility Services (SAS). Documentation to substantiate the existence of a disability is required; however, interim accommodations may be possible while that process is underway.

Accommodations are available for both permanent and temporary disabilities. It should be noted that common illnesses such as a cold or the flu do not constitute a disability.

Use of the SAS Exam Centre requires students to make a booking at least 14 days in advance, and no later than November 1 (fall), March 1 (winter) or July 1 (summer). Similarly, new or changed accommodations for online quizzes, tests and exams must be approved at least a week ahead of time.

For Guelph students, information can be found on the SAS website
https://www.uoguelph.ca/sas

For Ridgetown students, information can be found on the Ridgetown SAS website
https://www.ridgetownc.com/services/accessibilityservices.cfm

8.6 Academic Integrity

The University of Guelph is committed to upholding the highest standards of academic integrity, and it is the responsibility of all members of the University community-faculty, staff, and students-to be aware of what constitutes academic misconduct and to do as much as possible to prevent academic offences from occurring. University of Guelph students have the responsibility of abiding by the University's policy on academic misconduct regardless of their location of study; faculty, staff, and students have the responsibility of supporting an environment that encourages academic integrity. Students need to remain aware that instructors have access to and the right to use electronic and other means of detection.

Please note: Whether or not a student intended to commit academic misconduct is not relevant for a finding of guilt. Hurried or careless submission of assignments does not excuse students from responsibility for verifying the academic integrity of their work before submitting it. Students who are in any doubt as to whether an action on their part could be construed as an academic offence should consult with a faculty member or faculty advisor.

Undergraduate Calendar - Academic Misconduct
https://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-amisconduct.shtml

Graduate Calendar - Academic Misconduct
https://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/index.shtml

8.7 Recording of Materials

Presentations that are made in relation to course work - including lectures - cannot be recorded or copied without the permission of the presenter, whether the instructor, a student, or guest lecturer. Material recorded with permission is restricted to use for that course unless further permission is granted.

8.8 Resources

The Academic Calendars are the source of information about the University of Guelph's procedures, policies, and regulations that apply to undergraduate, graduate, and diploma programs.

Academic Calendars
https://www.uoguelph.ca/academics/calendars

8.9 Disclaimer

Please note that the ongoing COVID-19 pandemic may necessitate a revision of the format of course offerings, changes in classroom protocols, and academic schedules. Any such changes will be announced via CourseLink and/or class email.

This includes on-campus scheduling during the semester, mid-terms and final examination schedules. All University-wide decisions will be posted on the COVID-19 website (https://news.uoguelph.ca/2019-novel-coronavirus-information/) and circulated by email.

8.10 Illness

Medical notes will not normally be required for singular instances of academic consideration, although students may be required to provide supporting documentation for multiple missed assessments or when involving a large part of a course (e.g.. final exam or major assignment).

8.11 Covid-19 Safety Protocols

For information on current safety protocols, follow these links:

- https://news.uoguelph.ca/return-to-campuses/how-u-of-g-is-preparing-for-your-safe-return/
- https://news.uoguelph.ca/return-to-campuses/spaces/#ClassroomSpaces

Please note, these guidelines may be updated as required in response to evolving University, Public Health or government directives.
