EIN 6936 Multi-objective Optimization

Spring 2017

Department of Industrial and Management Systems Engineering

University of South Florida

Instructor: Dr. Hadi Charkhgard
Office: ENC 2509
Phone: 813-974-2090
Email: hcharkhgard@usf.edu
Class Meeting Times: Mon and Wed 11:00 – 12:15 at CHE-302
Office Hours: Mon and Wed 4:15-5:15
Final exam: NA

- All contents (and even timeline) in this document may change during the semester.

Course Description:

Many real world-problems involve multiple objectives. Due to conflict between objectives, finding a feasible solution that simultaneously optimizes all objectives is usually impossible. Consequently, in practice, decision makers want to explore and understand the trade-off between objectives before choosing a suitable solution. Thus, generating many or all efficient solutions, i.e., solutions in which it is impossible to improve the value of one objective without a deterioration in the value of at least one other objective, is a primary goal in multi-objective optimization. The focus on the course will be more on an important subclass of multi-objective optimization problems, so-called multi-objective (mixed) integer linear programs. The course is mainly designed for covering recent theoretical and algorithmic developments on solving multi-objective (mixed) integer linear programs.

Textbooks (suggested references):

Prerequisites:

- Good knowledge of linear programming and linear algebra
- Good understanding of mathematical concepts: vectors, matrices, sets, functions, ...
- Good knowledge of at least one programming language (C, C++, Julia, Python, AMPL, MATLAB, etc) and be able to use CPLEX or GUROBI in a programming language.
- Basic knowledge about integer programming: Relaxation, duality, branch-and-bound method, ...
- Basic knowledge about game theory and normal form games

Course Topics:

- Basics of multi-objective optimization: notion of optimality, efficient solutions, nondominated points, ideal solution(s), ideal point, and nadir point
- Weighted sum method
- Multi-criteria linear programming, multi-criteria simplex method*
- Multi-objective pure integer programs vs multi-objective mixed integer programs
- Traditional criterion space search algorithms: epsilon constraint method, perpendicular search method, Chebyshev method, etc
- New criterion space search algorithms: Balanced box method, Triangle splitting method, L-shape search method, Quadrant shrinking method, etc
- Optimization over the set of efficient solutions
- Enhancement techniques for multi-objective 0-1 integer programs: variable fixing, valid inequalities, and pre-processing
- Connection of multi-objective optimization with other fields of study, in particular game theory
- Decompositions techniques for solving single-objective optimization problems*

*Will be covered only if we find enough time.
Course objectives:

At the end of this class, it is expected that every single student to be able

- To explain the difference between the notion of optimality and Pareto-optimality by using simple examples.
- To explain why computing the ideal point seems to be significantly easier than computing the nadir point by using simple examples.
- To explain differences between nondominated frontier of convex optimization problems and non-convex optimization problems by using simple examples.
- To develop and implement algorithms for solving multi-objective optimization problems.
- To develop and implement enhancement techniques for multi-objective optimization problems.
<table>
<thead>
<tr>
<th>Week</th>
<th>Monday (11:00-12:15)</th>
<th>Wednesday (11:00-12:15)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Topic</td>
<td>Date</td>
</tr>
<tr>
<td>1</td>
<td>9-Jan</td>
<td>Introduction; Overview</td>
<td>11-Jan</td>
</tr>
<tr>
<td>2</td>
<td>16-Jan</td>
<td>Weighted sum method</td>
<td>18-Jan</td>
</tr>
<tr>
<td>3</td>
<td>23-Jan</td>
<td>Multi-criteria linear programming</td>
<td>25-Jan</td>
</tr>
<tr>
<td>4</td>
<td>30-Jan</td>
<td>Traditional criterion space search algorithms: epsilon constraint method</td>
<td>1-Feb</td>
</tr>
<tr>
<td>5</td>
<td>6-Feb</td>
<td>New criterion space search algorithms: BBM</td>
<td>8-Feb</td>
</tr>
<tr>
<td>6</td>
<td>13-Feb</td>
<td>Presentation 1 by students (Group A)</td>
<td>15-Feb</td>
</tr>
<tr>
<td>7</td>
<td>20-Feb</td>
<td>New criterion space search algorithms: LSM</td>
<td>22-Feb</td>
</tr>
<tr>
<td>8</td>
<td>27-Feb</td>
<td>Optimization over the set of efficient Solutions</td>
<td>1-Mar</td>
</tr>
<tr>
<td>9</td>
<td>6-Mar</td>
<td>Enhancement techniques for multi-objective 0-1 integer programs</td>
<td>8-Mar</td>
</tr>
<tr>
<td>Week</td>
<td>Date</td>
<td>Monday (11:00-12:15)</td>
<td>Wednesday (11:00-12:15)</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>----------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Topic</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>13-Mar</td>
<td>No Class - Spring Break</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>20-Mar</td>
<td>Presentation 2 by students (Group B)</td>
<td>Presentation 2 by students (Group A)</td>
</tr>
<tr>
<td>12</td>
<td>27-Mar</td>
<td>Other methods: ERM, Sylva-and-Crema</td>
<td>Other methods: p-split, (p-1) split</td>
</tr>
<tr>
<td>13</td>
<td>3-Apr</td>
<td>Possibly no class (Will be Announced)</td>
<td>5-Apr</td>
</tr>
<tr>
<td>14</td>
<td>10-Apr</td>
<td>Multi-objective optimization &amp; Game Theory</td>
<td>12-Apr</td>
</tr>
<tr>
<td>15</td>
<td>17-Apr</td>
<td>Decompositions techniques for solving single-objective optimization problems</td>
<td>19-Apr</td>
</tr>
<tr>
<td>16</td>
<td>24-Apr</td>
<td>Research Project Presentation</td>
<td>26-Apr</td>
</tr>
</tbody>
</table>
The deadlines are **STRICT**, and late submissions will **NOT** be accepted. The **LAST** time that you can submit the requested materials is at **11:00 p.m.** on the specified dates. All submissions **MUST** be done electronically by **E-MAILING**. Also, you should expect to receive a **CONFIRMATION** email from me within **24 hours** of sending your email. So, it is your responsibility to follow up after that time.

I would like to label all the emails for this course to be able to efficiently respond them. Consequently, the title of any email sent to me **MUST** have the following format:

EIN-6936-Spring-2017: `<The Title>`

Instead of ` `<The Title>` `' you should write whatever describes your email best. For example:

EIN-6936-Spring-2017: Appointment request

**Office hours, homework, exams and grades:**

- **Help**: Please feel free to ask for help during the class or office hours. You can also send an email to make an appointment. Please note again that the format of the title of your emails should be as follows:

  EIN-6936-Spring-2017: `<The Title>`

- **Final Grade**: The final grade follows the below rules:

  - **60 – 69.9 = D**
  - **70 – 79.9 = C**
  - **80 – 89.9 = B**
  - **90 – 100 = A**
If the weighted sum of your marks is close to some bound then extra credits will be considered in the final grade.

Class participation (10%), Homework (30%), Presentations (30%), the final project (30%).

Any complains about your marks related to the final project and your homework assignments must be received by me within one week after you receive your marks. For example, if I tell you your mark about homework 1 on date X, and you want to talk to me about it, you should do it by X+7 (days).

- **Class participation:** You will find this course very practical if you fully understand the underlying theoretical and algorithmic concepts of the course. So, you are highly encouraged to **NOT** miss any session. I believe that to get more out of this course, you should **ASK** questions as many as you can in the class, **PARTICIPATE** in discussions, and **BRAINSTORM** your ideas in the class.

- **Homework:** There will be three regular homework assignments (each with ONLY one question) which should be submitted by the specified deadline in the table. The goal of homework assignments is to make your computer programming skill strong, and ready for conducting research in the future. Also, I strongly believe that implementations can help students to deeply understand the workings of an algorithm. So, all homework assignments are **pure computer programming**, and they are time-consuming to do. I am an expert in C++. However, I recommend you to use **JULIA** programming language to implement the algorithms since it seems to be much easier. Also, call **GUROBI** inside your program (written in JULIA) for solving single-objective mixed integer linear programs. Note that you should do homework assignments **YOURSELF**, but that does NOT mean that you cannot obtain help from the others.

- Note that all homework assignments are **already available on CANVAS**. So, you can start to implement them from now. I will
NOT teach how an algorithm should be implemented in the class. It is the responsibility of all students to learn how to implement any algorithm.

- **Presentations**: There will be two presentations (each contributes exactly 15% of your final grade). The students will be divided into two groups with (almost) equal size at the beginning of the semester. Each group will manage two sessions of the class entirely. In other words, each group needs to teach for about 1 hour and 15 minutes in each session. All team members of a group should talk for about the same time. For example, if Group A has three members then each member should talk for about 25 minutes in each session.

  ➢ The teaching materials should come from the recent studies in top-tier journals. In other words, each group in each session should teach one or multiple (but related) papers published in recent years. Teaching materials should be confirmed by me based on the deadline given in the table.

  ➢ The following papers are just some suggestions for Presentation 1. Please feel free to find other algorithmic papers related to bi-objective optimization, extreme supported nondominated points, and multi-objective linear programming.

The following papers are just some suggestions for Presentation 2. Please feel free to find other algorithmic papers related to multi-objective optimization with more than two objectives, nadir point, and optimization over the set of efficient solutions.


Presentations will be mainly evaluated by students that are not presenting. Evaluation will be based on several factors, but the main one is whether the audience could learn anything from your presentations. So, you should teach clearly, make the class interactive, provide enough examples, use your time properly, and be ready for potential questions from the audience. To facilitate your presentation, you may use whiteboard or create slides or etc.
• **Research Project:** A significant proportion of your final grade is based on a research project. You are highly encouraged to work in groups of **two members**. The topic of your research project must be finalized and confirmed (by me) by the **deadline** given in the table. So, one of the members of your group should send an E-MAIL to me and cc the other member (if there is any). In your email, you should introduce your group members (please send your student numbers as well), the topic that you would like to study, and also provide an abstract about the topic. In the abstract, you should describe your topic briefly, and say why you think it is interesting, and what potential questions do you want to answer for this problem. I will try to reply to all emails within **24 hours**.

In this project, you are expected to

- Conduct a comprehensive literature review on the topic.
- Start to ask new questions about the topic, and come up with some new (theoretical or computational) results.
- Present your work in the class in **30 minutes**.
- (Hopefully) write a journal publication.

- All groups should prepare **PowerPoint slides** for their projects, and be ready for an oral presentation.
- The **presentation part** of your research project will be **mainly** evaluated by students that are not presenting. So, you should teach clearly, and all members of a group should be involved in presenting.

The topic of your research project is your own choice. The following list is just some suggestions for the problem that you may choose:

- Find a single-objective optimization problem, and try to solve the multi-objective version of the problem
• Develop a new algorithm for an arbitrary class of multi-objective optimization problems
• Try to improve existing algorithms
• Develop a heuristic or meta-heuristic algorithm for a class of multi-objective optimization problems
• Develop an approximation algorithm for a class of multi-objective optimization problems
• Work on parallelization of an algorithm for solving multi-objective optimization

You should E-MAIL your final projects by the specified deadline. Your e-mail should contain two files:

(1) Your PowerPoint slides.
(2) A document with a comprehensive literature review, and your new results.

Please choose the name of your files as follows:

<Student Number1>-<Student Number2>-Project.pdf
<Student Number1>-<Student Number2>-Slides.pptx

Please replace ‘<Student Number1>’ and ‘<Student Number2>’ with the student numbers of your group members. If your group has only one member simply replace ‘<Student Number1>-<Student Number2>’ with your student number.

General:

• I highly recommend to all students who still use WORD for preparing their text files to switch to LATEX TODAY. LATEX is FREE, easy to use, nicer, more professional, and (more importantly) it is specifically designed for users that need to work with mathematics a lot. There are two steps to install LATEX:
(1) Step 1 (Install a Tex distribution for instance TeXLive):

http://www.tug.org/texlive/acquire-netinstall.html

(2) Step 2 (Install an editor for instance TeXstudio):

http://texstudio.sourceforge.net/

A minimal working example can be found here:

http://www.electronics.oulu.fi/latex/examples/example_1/

- It is very important that you frequently check your mails, massages and calendars on CANVAS system. Important announcements, and dates will be posted there.
- If USF suspends normal operations due to an EMERGENCY event, it is your responsibility to monitor your emails, CANVAS, all related websites (main USF, college, department and etc), and in general any other related tools for important information. Also, during this time, the delivery of instruction may be done differently for instance through online tools (SKYPE, ...) , or even we may have to reschedule the class.

Academic Integrity

- This class follows "USF System Regulation 3.027: Academic Integrity of Students". Academic dishonesty is a very serious matter, and will not be tolerated. Plagiarism, cheating, or any form of academic dishonesty will have serious consequences, and will be reported. The minimum penalty would be a “Zero” grade in the assessment instrument, and also an “F” in the class.

- You must respect to all intellectual property rights of the others. If you want to use materials from the Internet, libraries, and etc, you must make sure that you have the right permission (or license) from the owner(s) for the particular type of the work that you want to do.
Mandatory Reporter:

- This class follows "USF System Policy 0.004: an environment free from sex discrimination, including sexual harassment and sexual violence". The USF Center for Victim Advocacy and Violence Prevention is a confidential resource where you can talk about incidents of sexual harassment and gender-based crimes including sexual assault, stalking, and domestic/relationship violence. However, based on the laws, if you disclose any of these situations in class, in papers, or to me personally, I MUST report it.

Teaching Improvement:

- I would like to improve myself and my teaching style as much as possible. Therefore, I highly appreciate all your comments and feedback, regarding my teaching style or anything related to this class. You can freely tell me what you think about the class in any way that you feel is the best: face-to-face conversations, emails, notes, and etc. Your comments and suggestions are very valuable for me, and will definitely JUST have positive impacts. In addition to the formal survey that will be carried by the department (at the end of the semester), some informal teaching surveys will also be conducted by me to hopefully help me to improve my teaching skills during the semester.