Course Syllabus

## ESI 6448: Discrete Optimization Theory
Fall 2022

*Instructed by Aleksandr M. Kazachkov*

**Overview**

| | |
|---|---|
| *Credits* | 3 (no pass/fail allowed) |
| *Meetings* | Tues. 4:05–6:00pm ET (pds. 9–10) in Weil 401 |
| | Thurs. 4:05–4:55pm ET (pd. 9) in Weil 401 |
| *Virtual* | https://ufl.zoom.us/j/91979933355, password: 32611 |
| *Website* | Canvas through elearning.ufl.edu |

**Instructor:** Aleksandr M. Kazachkov (he/him/his)

| | |
|---|---|
| *Email* | akazachkov@ufl.edu (see Communication Guidelines below) |
| *Office* | Weil 401B or https://ufl.zoom.us/j/91979933355, password: 32611 |
| *Office hours* | Wed. 10:40–11:30am ET (pd. 4), Thurs. 5:10–6:00pm ET (pd. 10), |
| | or by appointment |
| *Phone* | +1.352.273.4902 |

# Syllabus Contents

# 1    Course Description and Objectives

> **Catalog Description of ESI 6448**                    **3 Credits (Letter Grade)**
>
> Modeling with integer variables; enumeration and cutting plane methods; decomposition algorithms; branch and bound methods; computational complexity and software issues; special combinatorial optimization problems; parallel algorithms for integer programming.
>
> **Prerequisite:** Linear programming and nonlinear optimization or equivalent.

**Instructor's Description of the Class**   *This class is not likely to be taught every year.*

Integer programming is a powerful and flexible modeling technique, widely used in industrial and academic settings, such as allocating organs to patients while ensuring high-quality transplants, or efficiently dispatching and routing vehicles in ridesharing applications and during emergencies. These contexts require *discrete variables* that can capture "either-or" requirements, "on-off" decisions, or selecting from a countable set of options. In general, it is theoretically difficult to solve problems with integrality restrictions; nevertheless, in practice, large-scale instances are now regularly solved, due to theoretical, algorithmic, and engineering advances that are the subject of the course. We cover the fundamentals of integer programming, emphasizing the core components of modeling and solving an integer program through both proof-based theoretical development and hands-on computational exercises. Later in the semester, recent and ongoing research topics are covered.

**Learning Outcomes**   By the end of this course, you will be expected to:

- Define integer variables to model a variety of discrete decisions and constraints

- Derive inequalities to tighten a linear programming relaxation of a given integer program, including proving a particular inequality is valid, analyzing whether a valid inequality defines a facet of the integer hull, and computing common cuts

- Explain the key steps and engineering decisions in a branch-and-bound algorithm and the interplay of enumeration with cutting plane methods

- Decompose an integer programming problem based on row / column generation techniques

- Write code to solve an integer programming problem with optimization software

The course objectives will be pursued through exercises in various forms to help you understand and communicate these concepts, including assignments asking you to implement or analyze discrete optimization models and to prove basic integer programming properties.

**Disclaimer**   The content of this syllabus, particularly the course schedule, is subject to change throughout the semester. The latest version will be posted on Canvas.

# 2    Guidelines on Communication and Class Meetings

**Communication Guidelines**

*Canvas*     Please use Canvas Discussions to ask all nonconfidential course questions.
*Email*      Emails regarding this course should have "[**ESI 6448**]" in the beginning of the Subject line, so your email can be answered more quickly.

## 3   Tentative Course Schedule

| Wk | Day | Topics | Reading | Assignments |
|---|---|---|---|---|
| 1 | Aug 25 | Course introduction | W 1.1 | HW 0 out (ungraded) |
| 2 | Aug 30 | Terminology and basic concepts | W 1.2–1.3; CCZ 1.1, 1.4 | HW 0 due |
|   | Sep 01 | Complexity | W 1.4, 6.1–6.4; CCZ 1.3 | HW 1 out |
| 3 | Sep 06 | Solving an integer program in practice | Gurobi Python interface | |
|   | Sep 08 | Formulations and models | W 1.5–1.7; CCZ 2 | |
| 4 | Sep 13 | Relaxations | W 2.1–2.2 | HW 1 due |
|   | Sep 15 | Branch-and-bound | CCZ 1.2.1; W 7.1–7.4 | HW 2 out |
| 5 | Sep 20 | Duality and Farkas's lemma | W 2.5–2.6; CCZ 3.2–3.3 | |
|   | Sep 22 | **Early course feedback** | | |
| 6 | Sep 27 | Valid inequalities / cutting planes | W 8.1–8.3 | HW 2 due |
|   | Sep 29 | Gomory's fractional cuts | W 8.6; CCZ 1.2.2, 5.2.4 | HW 3 out |
| 7 | Oct 04 | Mixed-integer, intersection, and split cuts | W 8.7; CCZ 5.1–5.3, 6.1–6.2 | |
|   | Oct 06 | Disjunctive and lift-and-project cuts | W 8.8; CCZ 5.4 | |
| 8 | Oct 11 | Implementing cutting planes | W 9.6; Wesselmann+Suhl'12 | |
|   | Oct 13 | Exam review | | HW 3 due |
| 9 | Oct 18 | **In-class midterm** | | |
|   | Oct 20 | Strong valid inequalities 1 | W 9.1–9.2; CCZ 3.8–3.9 | HW 4 out |
| 10 | Oct 25 | Strong valid inequalities 2 | W 9.1–9.2; CCZ 3.8–3.9 | |
|   | Oct 27 | Lifting, tilting, coefficient strengthening | W 9.3; CCZ 7.1–7.2 | |
| 11 | Nov 01 | Dantzig-Wolfe decomposition | W 11.1–11.3; CCZ 8.2 | HW 4 due |
|   | Nov 03 | Branch-and-price | W 11.4; CCZ 8.2.3 | HW 5 out |
| 12 | Nov 08 | Benders' algorithm | W 12; CCZ 8.3 | |
|   | Nov 10 | TBD | | |
| 13 | Nov 15 | TBD | | HW 5 due |
|   | Nov 17 | Irregular cuts | | HW 6 out |
| 14 | Nov 22 | $\mathcal{V}$-polyhedral disjunctive cuts | | |
|   | Nov 24 | **Thanksgiving: no class** | | |
| 15 | Nov 29 | TBD | | HW 6 due |
|   | Dec 01 | Paper presentations | | |
| 16 | Dec 06 | Paper presentations | | |
|   | Dec 08 | Reading days | | |
| 17 | Dec 12 | Exam week start | | **Take-home final** |
|   | Dec 16 | Exam week end | | |

# 4   Class Materials

There is no required textbook or materials & supplies fee. I suggest the following references:

- Michele Conforti, Gérard Cornuéjols, Giacomo Zambelli, *Integer Programming*, Springer, 2014. ISBN 978-3-319-11008-0 (free online access).

- Michael Jünger, Thomas M. Liebling, Denis Naddef, George L. Nemhauser, William R. Pulleyblank, Gerhard Reinelt, Giovanni Rinaldi, Laurence A. Wolsey, *50 Years of Integer Programming 1958–2008* , Springer, 2010. ISBN 978-3-540-68279-0 (free online access).

- Laurence A. Wolsey, *Integer Programming*, 2nd Ed., Wiley, 2020. ISBN 9781119606536.

Other references that you might find useful for different perspectives or background:

- Laurence A. Wolsey, George L. Nemhauser, *Integer and Combinatorial Optimization*, 2nd Ed., Wiley, 1999. ISBN 978-0-471-35943-2. Free online access: `https://ebookcentral.proquest.com/lib/ufl/detail.action?docID=1776322`.

- Jon Lee, *A First Course in Linear Optimization*, 4th Edition (Version 4.01), Reex Press, 2013–21. `https://github.com/jon77lee/JLee_LinearOptimizationBook`

- Arkadi Nemirovski, *ISyE 6661 Lecture Notes: Introduction to Linear Optimization*, 2016. `https://www2.isye.gatech.edu/~nemirovs/OPTILectureNotes2016.pdf`

- Alexander Schrijver, *Theory of Linear and Integer Programming*, Wiley, 1997. ISBN 978-0-471-98232-6.

- Dimitris Bertsimas and John N. Tsitsiklis, *Introduction to Linear Optimization*, Athena Scientific, 1997. ISBN 1-886529-19-1.

   You are expected to take your own class notes, but any slides that are prepared for the course will be made available to you. These are not intended to replace the actual lecture, but rather to serve as an outline. *Any material I distribute to the class should be kept strictly within this class; without my express permission, you cannot share course content (aside from this syllabus) to anyone not enrolled in the class.*

**Software Use**   We will use the software Gurobi, for which you can request a free academic license, primarily through its Python interface. It will be required to learn to use Jupyter notebooks. All faculty, staff, and students of the University of Florida are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

# 5  Grading Policy, Assignments, Exams, and Effort

Your course grade will be based on the following components (your unweighted score, prior to any curving, will be the maximum of the two criteria):

| Component | Criterion 1 | Criterion 2 |
|---|---|---|
| Participation | 5% | 5% |
| Homework assignments | 45% | 35% |
| Midterm exam | 15% | 20% |
| Paper presentation | 15% | 20% |
| Final exam | 20% | 20% |

You should expect to spend ~6 hours on this class per week, on average, outside of lectures.

The (tentative) grading scale is: A = $[93.\bar{3}, 100]$, A– = $[90, 93.\bar{3})$, B+ = $[86.\bar{6}, 90)$, B = $[83.\bar{3}, 86.\bar{6})$, B– = $[80, 83.\bar{3})$, C+ = $[76.\bar{6}, 80)$, C = $[73.\bar{3}, 76.\bar{6})$, C– = $[70, 73.\bar{3})$, D+ = $[66..\bar{6}, 70)$, D = $[63.\bar{3}, 66.\bar{6})$, D– = $[60, 63.\bar{3})$, E = $[0, 60)$. Some assignments or exams may be curved if the average is too low. See also the Graduate Academic Regulations on Grading at `gradcatalog.ufl.edu/graduate/regulations`.

## 5.1  Attendance & Participation

Attendance is mandatory, but will not be directly recorded. Participation will be based on in-class activities and Canvas discussions; active involvement in both is highly encouraged. In-class activities will include ungraded work in small groups approximately once a week to reinforce class concepts and gain hands-on experience. You will be able to use your notes.

## 5.2  Homework Assignments

You must submit your own homework. You *are* allowed to discuss problems with other students in the class, such as on Canvas, but you *cannot* share complete answers with each other. If you have attempted a problem on your own but could not find a solution, your next step should be to talk to your classmates, the TA(s), or me. You may also refer to online resources, but do not abuse this policy: if you find a solution or partial solution to a problem, leave it aside and only refer to it as a last resort, after exhausting the options of seeking help via Canvas, the TA(s), and me. Even at that point, the best thing to do is to use that outside resource partially, to get a sense of a path to the solution, and then to attempt the problem on your own again. If you do read a solution from an external source, I advise you to internalize *how* and *why* the solution works, possibly with the help of the TA(s)/me. In that situation, you should write your own solution while not looking at the external source, to ensure you really understood it.

**You *must* properly attribute your sources** at the start of your solution to each problem, even if it is yourself (via "Attribution: self"). For example, if Bob asks Alice for advice on question 3, then Bob would write at the beginning of their solution to question 3: "Attribution: Discussed with Alice". You will not lose points for telling the truth.

**Late Assignment Policy**  For the homework assignments, late submissions are allowed with no penalty for up to a week after the official due date, but their grading may be substantially delayed. Any assignments submitted more than 7 days after the due date will not be graded. Special arrangements will be made in the event of an *excused absence*. Excused absences must be in compliance with University policies in the Graduate Catalog (`gradcatalog.ufl.edu/graduate/regulations`) and require appropriate documentation.

## 5.3  Exams

There will be a midterm and a final exam. The midterm exam is scheduled to be during class on *Tuesday, October 18, 2022*. The final will be a take-home exam. You are not allowed to consult other people or any online sources for the tests, but you are permitted to use your class notes. Please check the course website for the latest exam schedule.

**Exam Make-Up Policy**  If you are unable to take an exam due to a family or medical emergency, and you notify the instructor in advance of the exam, then a make-up exam will be organized as soon as it is feasible for both you and the instructor.

## 5.4  Paper Presentation

At the end of the semester, you will present a research paper from the integer programming literature to the class. You will be given a selection of suggested papers, though you will also be given the opportunity to propose a discrete optimization article to present.

## 5.5  Regrade Policy

Every student may request a regrade of their assignments and exams. Only one regrade will be considered per assignment/exam. The deadline for requesting a review is two weeks after the graded work is returned to the class, even if you were not present that day. The request for regrading must be done in writing together with a detailed description of the reasons why you believe there was a mistake in your grade. Note that requesting a regrade implies that the *entire* assignment may be reviewed. This means points could actually be *deducted*.

# 6  Honor Code

All course participants (myself and students) must abide by the requirements and spirit of the University of Florida Student Honor Code, which can be found at

`https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/`.

Every University of Florida student is subject to the following Honor Pledge:

> We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honesty and integrity by abiding by the Student Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment."

You are obligated to report any condition that facilitates academic misconduct to appropriate personnel. Any honor code violations will be handled by the University's honor code process.

**In this course, collaboration on exams is expressly forbidden, as is the exchange of complete answers to homework assignments prior to submission.** Please ask if at any point you need clarification regarding the honor code expectations, or you need assistance in any way in complying with the honor code.

# 7    Course Evaluation

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback is available at `gatorevals.aa.ufl.edu/students`. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via `ufl.bluera.com/ufl`. Summaries of course evaluation results are available to students at `gatorevals.aa.ufl.edu/public-results`.

# 8    Course Recording

**Instructor Recording of Class Sessions**
Class sessions may be audiovisually recorded and made available for private review.    **If you participate in class, you acknowledge that your voice and potentially your image, such as your video or profile picture, may be captured on this recording. If you do not consent, you must inform the instructor(s) as soon as possible, to discuss alternatives.**    As in all courses, unauthorized recording and unauthorized sharing of recorded materials is prohibited. In particular, you are not permitted to distribute recordings of this class to anyone not enrolled.

**Student Recording of Class Sessions**
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are: (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format

or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

## 9    Special Accommodations

If you require special accommodations, you should reach out as early as possible in the semester to discuss how we can ensure accessibility for you, and you should connect with the Disability Resource Center by visiting `disability.ufl.edu/students/get-started`.

## 10    Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see the Notification to Students of FERPA Rights and visit `registrar.ufl.edu/ferpa`.

## 11    Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture. If you feel like your performance in class is being impacted by discrimination or harassment of any kind please contact your instructor or any of the following:

- Your academic advisor or Program Coordinator
- Jennifer Nappo, Director of Human Resources, 352-392-0904, `jpennacc@ufl.edu`
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, `taylor@eng.ufl.edu`
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, `nishida@ufl.edu`

## 12    Land Acknowledgement

A land acknowledgement is a formal statement that recognizes and respects Indigenous Peoples as traditional stewards of this land, as well as their enduring relationship with it. Specifically, the University of Florida is located on the traditional territory of the Potano (part of the Timucua people) tribe, and later lived on by Seminole tribes. It is important to recognize and reflect on the context in which our (land grant) institution of higher learning

exists, and that we are not only acknowledging the history, but also identifying an ongoing process of marginalization and colonialism. I encourage you to read the history of Indigenous Peoples in Florida and the rest of the United States, and consider what you can do to support current indigenous populations. You may also read more about the significance of a land acknowledgment at nativegov.org/news/a-guide-to-indigenous-land-acknowledgment.

# 13 Campus Resources

## 13.1 Health and Wellness

Take care of yourself by paying attention and devoting time to your physical and mental wellbeing. Do not hesitate to reach out to me or a qualified professional if you are ever in need of support. Resources that are available to you include:

- University Police Department: 352-392-1111 (call 911 for emergencies).

- U Matter, We Care: If you or someone you know is in distress, please contact umatter@ufl.edu or call 352-392-1575 (a nighttime and weekend crisis counselor is available). The U Matter, We Care Team can help connect students to many other helping resources available including, but not limited to, Victim Services, Housing Staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. `https://umatter.ufl.edu`

- Counseling and Wellness Center: Visit the center or call 352-392-1575 for information on crisis and non-crisis services. `https://counseling.ufl.edu`

- Student Health Care Center: Visit the SHCC website or call 352-392-1161 for 24/7 information to help you find the care you need. `https://shcc.ufl.edu`

- UF Health Shands Emergency Room / Trauma Center: For immediate medical care call 352-733-0111 or go to the emergency room at 1515 SW Archer Road, Gainesville, FL 32608. `https://ufhealth.org/uf-health-shands-emergency-room-trauma-center`

- **Sexual Discrimination, Harassment, Assault, or Violence** If you or someone you know has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence, contact the Office of Title IX Compliance, located at Yon Hall Room 427, 1908 Stadium Road, 352-273-1094, `title-ix@ufl.edu`. `https://titleix.ufl.edu`

- Sexual Assault Recovery Services (SARS): Sexual assault counseling available through the Student Health Center, 352-392-1161.

## 13.2 Academic Resources

- e-Learning Technical Support: 352-392-4357 (option 2) or `learning-support@ufl.edu`.

- Career Resource Center: Career assistance and counseling, Reitz Union, 352-392-1601.

- Library Support: Receive assistance with using the libraries or finding resources.

- Teaching Center: General study skills and tutoring, Broward Hall, 352-392-2010 or 352-392-6420.

- Writing Studio: Help brainstorming, formatting, and writing papers, 302 Tigert Hall, 352-846-1138.

- The Care Area: Address student complaints, create success plans and ongoing support for students in distress, and help students complete necessary medical petition paperwork for all courses or medical withdrawals from a course.

- Distance Learning Complaints: Student complaints for online distance learning programs.