

Math 567: Integer and Combinatorial Optimization (Spring 2023)

Credits	3
Time	Tue+Thu 10:35–11:50 AM
Location	CUE 114 (Pullman), VECS 209 (Vancouver)
Instructor	Bala Krishnamoorthy
Check-in Hours	Tue 2–3 PM, Wed 2:30–3:30 PM (Zoom)
Email	kbala@wsu.edu
Web page	http://www.math.wsu.edu/faculty/bkrishna/Math567.html
Text	Class notes and handouts
References	Dimitris Bertsimas and Robert Weismantel: Optimization over Integers Dynamic Ideas, ISBN: 0-9759146-2-6. Laurence A. Wolsey: Integer Programming John Wiley and Sons, ISBN: 0-471-28366-5.

Description of the Course

Solving optimization problems with variables restricted to take integer values, as opposed to real values, is called integer optimization. The subject, also commonly called integer programming (IP), uses concepts from various areas of mathematics and computer science including linear algebra, combinatorics, geometry of numbers, algorithms and data structures, and more recently, machine learning. IP techniques have been used to model and solve problems in electrical power systems, airline crew scheduling, economic lot-sizing, transportation and logistics, treatment of tumors using radiation, computational biology, and many other areas.

This graduate level course will provide a detailed treatment of the theory, solution methods, and applications of integer and combinatorial optimization. Topics covered could include IP formulations, binary expressions and conjunctive normal form (CNF), enumerative methods (branch-and-bound), theory of cutting planes, lattice-based approaches including basis reduction, basics of computational complexity, and [machine learning approaches for branching, cutting planes, and other hard combinatorial optimization problems](#). We will also emphasize the use of state-of-the-art software packages to model and solve real-life problems. The packages AMPL and solvers Gurobi/Cplex will be introduced through homework problems and a project.

As a prerequisite, students should have taken an undergraduate level course in Linear Optimization (MATH 364, MATH 464, or equivalent), **or obtain the permission of the instructor** ([exceptions for this requirement may be made on a case-by-case basis](#)). Some familiarity with computer programming languages or packages such as Matlab or Python will be helpful.

Organization and Grading

The course will have around six homework assignments. These assignments will include theoretical problems as well as ones that involve the use of software packages. Apart from the homework assignments, there will be two course projects that will involve the use of software packages AMPL (with Gurobi/Cplex) and/or Matlab/Python. The total score for the course will be calculated using the weights: homework: 60% and projects: 40%. There will be no exams. This total score for the course will be curved to assign grades.

Software: The modeling language AMPL (www.ampl.com) along with the solvers Gurobi and Cplex will be used in the course. Students will model several examples as well as real-life integer optimization problems using this software. Further analysis could be done using Matlab or Python. The course projects will involve creating a complete model for one or two real-life instances of integer optimization problems, interpreting the solutions obtained, or implementing heuristic algorithms for large scale combinatorial optimization problems.

Academic Integrity: I encourage discussion of homework problems with others. But each student should submit their own (hand or type) written solutions and/or computer programs (codes). You might search the internet for materials to enhance your understanding. If you use such material to assist in your homework submission, you **should** cite the relevant sources. Plagiarism or cheating will **not** be tolerated. In particular, do not copy blindly from internet sources! Such behavior is easy to detect, and will result in a zero grade for the item in question and possibly a failing grade for the entire course.

Tentative List of Topics Covered

1. Integer programming basics and formulations: 7 lectures
 - IP formulations, modeling with binary variables, facility location, traveling salesman and other network problems, disjunctive constraints
 - binary expressions - conjunctive normal form (CNF)
 - strength of formulations, aggregated and disaggregated formulations
2. Solvers and applications: 3 lectures
 - Introduction to commercial software packages (AMPL + Cplex/Gurobi)
 - p -median/ p -center problems, fixed charge network flow, local area network (LAN) planning
3. Enumerative methods, branch-and-bound: 3 lectures
4. Integral polyhedra, matching, other topics: 6 lectures
 - totally unimodular matrices
 - network matrices, maximum-cardinality/maximum-weight matching, total dual integrality
5. Theory of valid inequalities: 4 lectures
 - Chvátal-Gomory (CG) cuts, mixed-integer rounding, disjunctive cuts
 - knapsack cover inequalities, Lovász-Schrijver procedure
6. Lattices and applications: 4 lectures
 - Hermite normal form (HNF) and Diophantine equations
 - basis reduction (BR), Lenstra's algorithm, BR-based reformulation techniques
 - shortest vector problem (SVP), closest vector problem (CVP)
7. Machine learning and IP: 3 lectures
 - Learning to branch, learning to select cuts
 - Learning hard optimization problems

WSU Systemwide Policies and Statements

Reasonable Accommodation

Reasonable accommodations are available for students with documented disabilities or chronic medical or psychological conditions. If you have such a condition and need accommodations to fully participate in this class, please visit your campus' Access Center/Services website to follow published procedures to request accommodations. Students may also contact their campus offices to schedule an appointment with an Access Advisor. All disability related accommodations are to be approved through the Access Center/Services on your campus. It is a university expectation that students connect with instructors (via email, Zoom, or in person) to discuss logistics within two weeks after they have officially requested their accommodations.

For more information, contact an Access Advisor on your home campus:

- Pullman, WSU Global Campus, Everett, Bremerton, and Puyallup: 509-335-3417 Access Center (<https://www.accesscenter.wsu.edu>) or email at access.center@wsu.edu
- Vancouver: 360-546-9739 Access Center (<https://studentaffairs.vancouver.wsu.edu/access-center>) or email van.access.center@wsu.edu.

Religious Accommodation

Washington State University reasonably accommodates absences allowing for students to take holidays for reasons of faith or conscience or organized activities conducted under the auspices of a religious denomination, church, or religious organization. Reasonable accommodation requires the student to coordinate with the instructor on scheduling examinations or other activities necessary for course completion. Students requesting accommodation must provide written notification within the first two weeks of the beginning of the course and include specific dates for absences. Approved accommodations for absences will not adversely impact student grades. Absence from classes or examinations for religious reasons does not relieve students from responsibility for any part of the course work required during the period of absence. Students who feel they have been treated unfairly in terms of this accommodation may refer to Academic Regulation 104 – Academic Complaint Procedures.

Academic Integrity

All members of the university community share responsibility for maintaining and promoting the principles of integrity in all activities, including academic integrity and honest scholarship. Students are responsible for understanding the full [Academic Integrity Statement](#). Students who violate WSU's Academic Integrity Policy (identified in [WAC 504-26-010\(3\) and -404](#)) will receive a failing grade for the assignment or for the whole course, will not have the option to withdraw from the course pending an appeal, and will be reported to the Center for Community Standards. If you have any questions about what is and is not allowed in this course, ask your course instructor.

Safety and Emergency Notification

Classroom and campus safety are of paramount importance at Washington State University, and are the shared responsibility of the entire campus population. WSU urges students to follow the "Alert, Assess, Act," protocol for all types of emergencies and the "[Run, Hide, Fight](#)" response for an active shooter incident. Remain ALERT (through direct observation or emergency notification), ASSESS your specific situation, and ACT in the most appropriate way to assure your own safety (and the safety of others if you are able). Please sign up for emergency alerts on your account at MyWSU. For more information on this subject, campus safety, and related topics, please view the FBI's [Run, Hide, Fight video](#) and visit the [WSU safety portal](#).

Full details can be found at <https://provost.wsu.edu/classroom-safety/>.

Severe Weather

For severe weather alerts, see <http://alert.wsu.edu/> and <https://oem.wsu.edu/emergency-procedures/severe-weather/>. In the event of severe weather affecting university operations, guidance will be issued through the alert system.

WSU Vancouver Statement: In the event that an adverse weather event (e.g., snow or ice) or natural hazard that poses a safety risk occurs, you should take personal safety into account when deciding whether you can travel safely to and from campus, taking local conditions into account. If campus remains open and your instructor decides to cancel the face-to-face meeting and substitute an alternative learning activity, you will be notified by your instructor via email or through Blackboard within a reasonable time after the decision to open or close campus has been made. Instructions regarding any alternative learning options or assignments will be communicated in a timely manner. If travel to campus is not possible due to adverse regional conditions, allowances to course attendance policy and scheduled assignments, including exams and quizzes, will be made. Students who attempt to gain advantage through abuse of this policy (e.g., by providing an instructor with false information) may be referred to the Center for Community Standards for disciplinary action. If a student encounters an issue with an instructor, the student should first talk with the instructor. If the issue cannot be resolved, the student should follow the reporting violations of policies outlined on the student affairs website.

Discrimination and Harassment

Discrimination, including discriminatory harassment, sexual harassment, and sexual misconduct (including stalking, intimate partner violence, and sexual violence) is prohibited at WSU (See [WSU Policy Prohibiting Discrimination and Harassment](#) (Executive Policy 15) and [WSU Standards of Conduct for Students](#)). If you feel you have experienced or have witnessed discriminatory conduct, you can contact the WSU Compliance & Civil Rights (CCR) and/or the [WSU Title IX Coordinator](#) at 509-335-8288 to discuss resources, including confidential resources, and reporting options. (Visit ccr.wsu.edu for more information). Most WSU employees, including faculty, who have information regarding sexual harassment or sexual misconduct are required to report the information to CCR or a designated Title IX Coordinator or Liaison. (Visit ccr.wsu.edu/reporting-requirements for more info).

Lauren's Promise

I will listen and believe you if someone is threatening you. Lauren McCluskey, a 21-year-old honors student athlete, was murdered on Oct. 22, 2018, on the University of Utah campus by a man she briefly dated. *We must all take actions to ensure that this never happens again.*

If you are in immediate danger, call 911.

If you are experiencing sexual assault, domestic violence, stalking, discrimination or harassment, you have support and options. If you share information with me, please know that I am required to reach out to the Title IX Coordinator in WSU Compliance and Civil Rights (CCR), and CCR will reach out to you with information about on and off campus reporting options and resources. CCR is a system-wide resource (all campuses) which is available for intake consultations for you to learn more about available support. You can reach them directly at 509-335-8288, ccr@wsu.edu, or report online (anonymous reports accepted).

You can also speak to a victim advocate, a medical provider, or counselor confidentially about your concerns. Advocates help survivors of crime determine their own needs in regards to their physical and emotional health, reporting options, and academic concerns. At no cost, advocates connect survivors to campus and community services, and provide accompaniment to important appointments (court, hospital, and police) and support throughout the process. For a list of confidential victim advocates and medical providers, please visit CCR Resources.

WSU Police Department (WSU PD) officers and campus security will treat victims of sexual assault, domestic violence, stalking, hate crimes, and other crimes with respect and dignity. WSU PD, campus security departments, CCR, and victim advocates can also help you with safety planning.

Resources for Students

In Pullman

- Student Care Network: studentcare.wsu.edu
- Cougar Transit: 978 267-7233
- WSU Counseling and Psychological Services (CAPS): 509 335-2159
- Suicide Prevention Hotline: 800 273-8255
- Crisis Text Line: Text HOME to 741741
- WSU Pullman Police: 509 335-8548
- Pullman Police (Non-Emergency): 509 332-2521
- WSU Office of Civil Rights Compliance & Investigation: 509 335-8288
- Alternatives to Violence on the Palouse: 877 334-2887
- Pullman 24-Hour Crisis Line: 509 334-1133

In Vancouver

- Students may apply for grant assistance to cover technology or COVID-19 related educational costs through the Student Emergency Funding request form: <https://studentaffairs.vancouver.wsu.edu/financial-aid>
- The Laptop Loaner Program will continue in Spring 2022. To apply, students should visit: <https://www.vancouver.wsu.edu/information-technology/new-student-tech-guide>
- Tech Help for Students: <http://wsuvtech4students.org/>
- Access Campus Software Remotely with AppStream: <https://www.vancouver.wsu.edu/information-technology/access-campus-software-remotely-appstream>
- Cougar Food Pantry: We know that it can be hard for students to make ends meet when paying for college and living on a tight budget. The Cougar Food Pantry can help. The pantry provides free, nonperishable food items for WSU Vancouver students in need. The process is simple, anonymous and judgement-free. Learn more and request food at <https://studentaffairs.vancouver.wsu.edu/cougar-food-pantry>.