UNIVERSITY OF WATERLOO

Foundations of Multi-agent Systems

ECE.750.T36 Held with ECE.493.T27

1. Course webpage

https://ece.uwaterloo.ca/~smzahedi/crs/ece750/

2. Instructor

Prof. Seyed Majid Zahedi (smzahedi@uwaterloo.ca)

3. Course description

This course is an introduction to the mathematical and computational foundations of modern multi-agent systems, with a focus on game theory, artificial intelligence, and machine learning. The course provides analytical tools to analyze and model multi-agent systems in which an agent's welfare is a function of not only their own actions, but also those of others. Tentative topics include normal-form games, extensive-form games, repeated games, stochastic games, Bayesian games, computation of solution concepts, and learning in multi-agent systems.

4. Prerequisites

There are no formal prerequisites, and it is assumed that most students in the class will be unfamiliar with game theory, mechanism design, and multi-agent systems. Since some of the material is quite mathematically formal, students are expected to have introductory knowledge in probability theory (ECE.203 or equivalents), computational complexity (ECE.208 or equivalents), and algorithms (ECE.250 or equivalents).

5. Antirequisites

Students will not be allowed to take this course if they have completed (or are currently taking) ECON.412, CO.456, CS.886 (Multiagent Systems), and MSCI.700 (Game Theory & Recent App)

6. Textbook

The course does not have a main textbook but there are several optional references.

- Y. Shoham and K. Leyton-Brown, Multi-agent Systems (freely available online)
- N. Nisan, T. Roughgarden, E. Tardos, V. V. Vazirani, Algorithmic Game Theory (freely available online)
- T. Roughgarden, Twenty Lectures on Algorithmic Game Theory (freely available online)
- D. Fudenberg and D. Levine, The Theory of Learning in Games
- D. Fudenberg and J. Tirole, Game Theory
- M. J. Osborne and A. Rubinstein, A Course in Game Theory (freely available online)

7. Tentative topics and schedule

The course tentatively covers the following topics (24 80-minute lectures).

- **Introduction to multi-agent systems (2 lecture)**
  - Overview of game theory and mechanism design, rationality and self-interest, utility theorem, risk attitudes
- **Games in normal form (4 lectures)**
  - Pure and mixed-strategy Nash equilibrium, iterative elimination of dominated strategies, price of anarchy, correlated equilibrium
- **Computing solution concept (2 lectures)**
  - Overview of (mixed-integer) linear programming, computation of solution concepts for normal-form game
- **Games in extensive form (4 lectures)**
  - Perfect and imperfect-information games, finite and infinite-horizon games, subgame-perfect equilibrium, backward induction, one-shot deviation principle
- **Beyond normal and extensive-form games (8 lectures)**
  - Repeated games, stochastic games, Bayesian games, congestion games, trigger strategies, folk theorems, Bayes-Nash equilibrium, auctions, revenue-equivalence theorem, revelation principle, incentive compatibility
- **Learning in multi-agent systems (4 lectures)**
  - Multi-agent reinforcement learning, fictitious play, Bayesian learning, regret-minimization learning

8. Grading

The course has two different grading schemes are as follows.

- Undergraduate: 10% quizzes; 20% assignments; 20% (survey) project; 50% final exam
- Graduate: 5% quizzes; 20% assignment; 45% (research) project; 30% final exam

Quizzes, assignments, and the final exam are the same for both schemes but have different percentage breakdowns in each scheme. The project, however, has different requirements in each scheme (see below for more details). Undergraduate students have the option of choosing the graduate grading scheme when they submit their project proposal. We reserve the right to make changes to the exact percentage breakdowns above.

8.1. Quizzes

There will be an undetermined number of pop-up quizzes.

8.2. Assignments

There will be 4 assignments each with roughly 5 problems. Solutions will be graded on both accuracy and presentation. A correct solution that is poorly presented may not receive full marks. Late submissions will be accepted with 15% penalty per day for only two days after the due date. Students can discuss the class material with other students. Students also can discuss with others about how to formulate assignment problems. However, students must write down their solutions by themselves. In particular, students may not take notes while they discuss assignments with others. Any suspected plagiarism or infractions of this honor code will be reported to the appropriate Associate Dean.

8.3. Survey project (20%)

For the survey project, students will review existing literature in a subarea of multi-agent systems and possibly explore open research questions in that subarea. There will be 2 milestones during the term: proposal (about three weeks into the term) and final written report (end of the term).

8.3.1. Proposal. In the project proposal, students should explain the subarea that will be surveyed, significant research papers in the subarea, and what some of the open research problems might be explored. If necessary, the course instructor can help with finding topics.
Each proposal should include all the following.

- Introduction: introduce and motivate the subarea
- Related work: overview the state-of-the-art by citing significant research papers
- Open research problems: overview some of the open research problems in this subarea

Undergraduate students can choose the graduate grading scheme when they submit their proposals. Those who decide to go with the graduate grading scheme have to follow the proposal format outlined in Section 5.4.1.

8.3.2. Final report. In the final report, each student is expected to submit a written survey paper. The survey paper, as the name suggests, should provide a comprehensive survey of research papers in the proposed subarea. The paper should provide a critical assessment of the work that has been done in the subarea listing strengths and weaknesses of the existing work. If applicable, brief comparisons between (or categorization of) the presented research papers should also be provided. The source for descriptions of existing research work is normally a collection of research papers presented at respected international conferences and in well-known international journals.
The paper should follow the same format that is described in Section 4.5.3. Without references, each survey report should not be less than 7 and not more than 18 pages.

8.4. Research project (40%)

For graduate students, an important part of this course is the research project. For the research project, students can work on the research project alone or in a team of at most three students; of course, teams are expected to work on more significant projects.

The goal of the research project is to try to do something novel, rather than merely a survey of existing work. Projects may be theoretical, experimental (based on simulations), experimental (based on real-world data), a useful software artifact, or any combination thereof. Creativity is encouraged. The only real constraint for the project is that it has to have something to do with the material

covered in the course. Students are encouraged to talk to the course instructor if you are not sure about whether something is an appropriate project.
The final product is a writeup (in the form of a short research paper). Some projects may well lead to publishable papers (perhaps with some additional work). There will be 3 milestones during the course: proposal (roughly three weeks into the course), oral progress report (roughly 7 weeks into the course), and final written report (by the end of the term).

8.4.1. Proposal. In the project proposal, students should explain the topic of their project, what types of results they hope to obtain, and what some of the technical issues are that you will need to address. For graduate students, the course project could be related to their own ongoing research as long as it also has clear connections with the course material. If necessary, the course instructor can help with finding topics.
Each proposal should include all the following.

- Introduction: introduce and motivate the project
- Problem statement: describe the purpose and the objective(s) of the project
- Methodology: describe methods and tools that will be deployed to tackle the problem
- Related work: overview the state-of-the-art by citing related research papers, ideally published recently in top-tier conferences or journals

8.4.2. Progress report. Intermediate oral project progress report is required. This report should explain what results each group has obtained already, what (if any) difficulties the group has encountered, and what the group plans to do to complete the project. Ideally, at this point, each group should already have some good results, so that it can spend the rest of the time on answering questions generated by the results, as well as preparing the writeup.

8.4.3. Final report. Each group will have to prepare and submit a final project report by the end of the term using the ACM Master Article Template. For Microsoft Word, students should use the interim word template, and for Latex they should use the sample-sigconf.tex file in the samples folder. Submitted reports with any other format/style will not be accepted.
Each report has to include (at least) the following sections: abstract, introduction, methodology, experimental results (if applicable), related work, conclusion, and references. Without references, each report should not be less than 5 and not more than 11 pages.

9. Policies

9.1. Academic integrity policy

In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. Check the Office of Academic Integrity for more information.

9.2. Grievance policy

A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4. When in doubt, please be certain to contact the department's administrative assistant who will provide further assistance.

9.3. Discipline policy

A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for his/her actions. Check the Office of Academic Integrity for more information. A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline. For typical penalties, check Guidelines for the Assessment of Penalties.

9.4. Appeals policy

A decision made or penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72, Student Appeals.