McGill School of Computer Science
www.cs.mcgill.ca

Course Outline

Course Name: Multi-Agent Robotics
COMP-599 – Fall 2024

Instructor: Joseph Vybihal
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Website: www.cs.mcgill.ca/~jvybihal Office hours: Th 4PM & Fr 9AM, 60 mins.
Discussions: UAsk

Pre-Requisites: COMP 251, COMP 310.

Course Objectives:

A 4-credit full semester course in multi-agent robotics that introduces the problems and techniques when integrating more than one agent in a cooperative activity.

By the end of the course, students will be able to:

- Use game theory strategies in multi-agent robotics.
- Use swarm intelligence strategies in multi-agent robotics.
- Solve group planning problems.
- Integrate multi-agent perception in world modelling considering sensor noise.
- Decide between networking and communication strategies.
- Use robot simulators to implement solutions to problems in multi-agent robots.

The course assumes basic systems knowledge in low-level programming and operating systems. Some networking background is an asset; however, the course will introduce basic networking concepts. Some background in machine learning is also an asset. Some self-study required.

Course Description: Introduction to multi-agent robotics problems and techniques. Focus on multi-agent problem solving, perception, sensor modeling, coordination, and communication. Students will use robotic simulators.

Texts:

Primary Text:

Research papers and chapters as handed out during class.

Supplementary Texts:

- Game Theory: An Introduction; Steven Tadelis; Princeton University Press; E-Book
- Graph Theoretic Methods in Multiagent Networks; Mehran Mesbahi and Magnus Egerstedt; Princeton University Press; E-Book
- https://www.roboticsbook.org/intro.html
- Computational Principles of Mobile Robotics; Gregory Dudek & Michael Jenkin; Cambridge University Press; ISBN 978-1-108-73638-1

Teaching Method: Traditional in-person lectures with readings. Presentation of material will happen through slides and blackboard. At times simulators will be used in class.

Evaluation:

Assignments	30%	3 Assignments
Late Midterm	30%	In-person test
Project	40%	Due end of exam period with presentation.
Tournament	Glory	Optional competition after exam period. https://ssim.robocup.org/

Late work: You will be notified in advance of assignment due dates. All assignments are due on My Courses at the indicated time and date. Late assignments will lose **10%** of its grade per day late. Assignments beyond **2 days** late will not be accepted. You may not submit assignments via e-mail without the permission of the instructor.

Additional Work: Students with grades of D, F or J will not be given the opportunity to complete additional work to upgrade their grade.

Supplemental Exam: There will be no supplemental exam for this course.

Re-grading: Mistakes can occur when grading. Not surprisingly, requests for re-grading always involve those mistakes in which the student received fewer points than they deserved, rather than more points than they deserved. With that in mind: if you wish me to re-grade a question on an exam or assignment, I will do so. I reserve the right to re-grade other questions as well. All regrading requests must happen within 7 days after the submission was graded.

Cheating/Collaboration: Collaboration is encouraged but your discussions should be public in the sense that anyone including the professor should be allowed to listen in, and no code is shared (including through conversation). Assignments are original works created by the student alone. You are permitted and encouraged to have conversations with other students concerning the meaning of the assignments, but your work must be original. If two or more assignments are found to be identical (or portions of assignments) then all parties will lose points. This includes the student who permitted their assignment to be copied. This includes written solutions and software source code. **ChatGPT is an example of cheating.**

Grading: All software solutions must compile with zero errors and must run to be graded. It does not need to run correctly for grading, but it must run. If your program compiles with errors or does not run at all then you will receive zero points. The grader will not fix your code or look at the source code to give you partial grades.

Communication

My Courses**:** All official communication, including announcements, lecture material, assignments, grades will be found on My Courses.

Course Discussions: UAsk.

Private Email: The professor and TA have private email accounts that you may also use, however these communication channels are for personal queries. For example: if you have a problem with your grade then email the TA who graded you directly, do not email the prof and do not use the course email address.

Appointments: Please email directly the one you want to communicate with to book an appointment outside office hours.

Office Hours: Consult the posted office hours and come to those times without appointment.

After lecture: Some optional time will be available just after class to ask questions. I do not guarantee the length of this time since other constraints may interfere.

TA

The full details about your TA can be found on myCourses: **TA/Prof Coordinates**.

TENTATIVE SCHEDULE
COMP 599: Multi-agent Robotics

Day	Lecture	Readings	Work
Jan 7	**Introduction** Agents in AI generally. Swarm vs multi-agents. The perception problem. Control strategies & environmental constraints. Special topics. Final project.		
	Unit 1 – Introduction to Swarm Robotics		
Jan 9	**What is Swarm?** Insects as a model of a swarm. Exploration of different insect strategies and how they can be applied to robotics. Expending our ideas about perception and seeing the world around us.		
Jan 14	**Cooperative gathering: Part 1 – Search & Retrieval** Adapting insect models to solve combinatorial optimization and routing problems. Searching for food and bringing it back to the nest.	Chapter reading 1 Paper reading 2	
Jan 16	**Cooperative gathering: Part 2 – Cooperative Transport** Adapting insect modeling to solve cooperative obstacle removal and transport of heavy structures.		
Jan 21	**Division of labour & Task Allocation: Part 1 - Thresholds** Self organization around response thresholds and needs.		
Jan 23	**Division of labour & Task Allocation: Part 2 – Sorting** Special examples of division of labour: centralized collections and specific collections.		
Jan 28	**Division of labour & Task Allocation: Part 3 – Building** Special examples of building structure and self-assembling structures.		Assignment 1 handed out
	Unit 2 – Introduction to Modeling and Managing Sensory Perception		
Jan 30	**The Problem Space** The different environments in modeling and their properties: The World and Physics, Sensor Space, Live Map Space, Memory Map Space, expected values, projections. A-priori info vs discovery with uncertainty.		
Feb 4	Sensor 1: **The fluctuation problem** – windows, averaging, cropping upper/lower bound issues, decision making, robotic perception, immediate perception vs. area modeling vs world modeling. Sensor detection models: sensor arrays & data structures. Review: maps, occupancy grid mapping, particle filtering, SLAM.		
Feb 6	Sensor 2: **The next step problem**. – Reactive vs Proactive planning. Sensor integration in planning. Stereovision, depth, tracking self/others/space. Motion vector estimation.		
Feb 11	Sensor 3: **Did I complete the action problem**. Hinderances to move completion. Awareness of self. Map/model management. Feedback issues. Multiple attempt cycle. When to call for help or trying Plan B.		Assignment 2 handed out.
	Unit 3 – Introduction to Game Theory for Multi-agent Robotics		
Feb 13	**Introduction to Game Theory** Famous problems. Composing a Discrete Game. Executing the game by hand. Using the sandbox to execute a game.		
Feb 18	Case studies and how they apply to robotics		
Feb 20	Case studies and how they apply to robotics		

	Unit 4 – Multi-agent Cooperation and Modeling		
Feb 25	**Introduction to cooperation** The mapping of an input space with an output space (sensors to motors). Control methods: Score functions (individual, group), probability graphs, state transition functions, shared state-graph with role assignment (sports, risk), and democratic decision making. Handling communication issues & recovery: security, signal drop, run-time errors, no reply).		Assignment 3 handed out
Feb 27	Type 1: **Centralized Control**. Algorithm. Risks. Benefits. Decision making. Single and multi-agent states: Internal, external, and group states. Network loss.		
Mar 3 – Mar 7	**READING WEEK**		
Mar 11	Type 2: **Decentralized coordination - Peer-to-peer**. Communication is key. Communication methods. Distributing information. Missing information. Decision making. Local Consensus control.		
Mar 13	Type 3: **Decentralized coordination – Blackboard**. Algorithm. Fallback methods. Risks. Benefits. Decision making. Global Consensus control. Task assignment.		
Mar 18	Type 4: **Decentralized coordination – Coach**. How/when is this helpful? What is good to compute locally? What is good to compute remotely? Decision making. Coverage and Formation control.		
Mar 20	**Distributed perception** Building the model using a shared server. Building and sharing local model under Peer-to-peer architecture. Techniques and issues, building a group eye, building a group representation, populating the group model.		**Project handed out**
Mar 25	Case studies: Amazon, driverless cars, RoboCup, distant space exploration, unstructured package delivery.		
Mar 27	**MIDTERM EXAM**		
	Unit 4 – Special Topics in Applying Multi-agent Robotics		
April 1	**Special Topic 1 - Robo-cup** Introduction to the software and the run-time environment. How to write a client application.		
April 3	Discussing an example application. Sensor processing and motor commands.		
April 8	**Special Topic 2 – Multi-agent Reinforcement Learning** Multi-agent Reinforcement Learning		
April 10	Multi-agent Reinforcement Learning		
End of Exams			Project Due
After Exam Period			Tournament

Project:

We will use the RoboCup application to implement a fun multi-agent robotics game. Students will work in pairs. Together they will build the client API to communicate with the soccer physics server. Then, individually, each team member will program their own unique AI (or strategy) for their soccer team. They will then test their algorithm against their teammate's soccer algorithm. You must use techniques covered in class or in the literature. This is for grades.

Tournament:

After the lectures are over, all the teams will disband. Optionally, an individual can register their AI (or strategy) to compete in the Tournament to find which student created the best multi-agent robotic soccer team. Rules about improving your code and playing in the tournament will be published later. This is for glory only, but I think it will be a lot of fun. It will be a great way to competitively improve your multi-agent strategy.

General Course Information

Course Requirements: The pre-requisite for this course is COMP-202 or COMP-250.

Right to submit in English or French written work that is to be graded.

In accord with McGill University's Charter of Students' Rights, students in this course have the right to submit in English or in French any written work that is to be graded.

Classroom Rules: All electronic devices (cell phones and beepers) must be turned off or left on silent mode during class time.

Assignments Pickup: All assignments are submitted to and picked-up from My Courses.

Computing Resources: Trottier 3rd floor.

Examinations and Grading:

Students are responsible for all materials for the tests and exams, whether it is covered in class. Exams will be a combination of all types of questions based on all sources, and students may be required to integrate theoretical concepts from the text to substantiate their arguments.

No make-up tests or make-up assignments are allowed in this course.

If you are not satisfied with the grading of an assignment or mid-term test, you may request a review within 7 days of return. Indicate in writing or during a meeting with the instructor where and why you feel the marks are unjustified and give it back to your instructor for re-grading. Note that the entire assignment or mid-term test will be re-graded and your grade can go up or down (or stay the same) accordingly.

Calculators
Only non-programmable, no-tape, noiseless calculators are permitted. Calculators capable of storing text are not permitted in tests and examinations.

Dictionaries
Dictionaries are not permitted, but translation dictionaries are.

Handheld Devices
Handheld devices capable of storing text and having calculator functionality (e.g. Palm, etc.) are not permitted.

Additional Information: The course slides are not meant as a complete set of notes or a substitute for a textbook, but simply constitute the focus of the lecture. Important gaps are left in the slides that are filled in during class, thus **l**ecture attendance should be considered essential.

The material covered in the classroom will be used to supplement textbook readings.

Academic Integrity: *Code of Student Conduct*

McGill University values academic integrity. Therefore all students must understand the meaning and consequences of cheating, plagiarism and other academic offences

under the Code of Student Conduct and Disciplinary Procedures (see www.mcgill.ca/integrity for more information).

L'université McGill attache une haute importance à l'honnêteté académique. Il incombe par conséquent à tous les étudiants de comprendre ce que l'on entend par tricherie, plagiat et autres infractions académiques, ainsi que les conséquences que peuvent avoir de telles actions, selon le Code de conduite de l'étudiant et des procédures disciplinaires (pour de plus amples renseignements, veuillez consulter le site www.mcgill.ca/integrity).

Final Exam Policy:

Regulations

Students should not make other commitments during the final exam period. Vacation plans do not constitute valid grounds for the deferral or the rescheduling of examinations. See the Centre Calendar for the regulations governing Examinations:
http://www.mcgill.ca/student-records/exams/regulations/
Students are required to present their I.D. Card (with photo) for entrance to their examination.

Conflicts

If you are unable to write your final examination due to scheduling conflicts, you must submit a Final Exam Conflict Form with supporting documentation at least **one month** before the start of the final examination period. Late submissions will not be accepted. For details, see
http://www.mcgill.ca/student-records/exams/conflicts/

Exam Timetable

Examination schedules are posted at the Centre and on the following page approximately 6-8 weeks before the examination period commences
http://www.mcgill.ca/student-records/exams/
The Centre cannot provide examination dates over the telephone.

Email Policy:

E-mail is one of the official means of communication between McGill University and its students. As with all official University communications, it is the student's responsibility to ensure that time-critical e-mail is accessed, read, and acted upon in a timely fashion. If a student chooses to forward University e-mail to another e-mail mailbox, it is that student's responsibility to ensure that the alternate account is viable.

Please note that to protect the privacy of the students, the University will only reply to the students on their McGill e-mail account.

Students Rights and Responsibilities:

Regulations and policies governing students at McGill University can be downloaded from the website:
http://www.mcgill.ca/deanofstudents/rights/

Students Services and Resources:

Various services and resources, such as email access, walk safe, library access, etc., are available to students:
http://www.mcgill.ca/stundet-records

Minerva for Students: http://www.mcgill.ca/minerva-students/

Important Note:

In the event of extraordinary circumstances beyond the University's control, the evaluation scheme in a Course is subject to change, provided that there be timely communications to the students regarding the change.

Land acknowledgement:

McGill University is on land which has long served as a site of meeting and exchange amongst Indigenous peoples, including the Haudenosaunee and Anishinabeg nations. We acknowledge and thank the diverse Indigenous people whose footsteps have marked this territory on which people of the world now gather. Please see here for more details: https://www.mcgill.ca/edu4all/other-equity-resources/traditional-territories .