



Course Information

Course Number:	CSCE 631
Course Title:	Intelligent Agents: Computational Game Solving
Section:	600
Time:	TR 11:10-12:25
Location:	HRBB 126
Credit Hours:	3

Instructor Details

Instructor:	Alan Kuhnle
Office:	421 Peterson Building (PETR)
Zoom:	<u>https://tamu.zoom.us/my/kuhnle</u>
E-Mail:	<u>kuhnle@tamu.edu</u>
Office Hours:	MW 4:00 - 4:50 PM, in PETR 421
	or by appointment

Course Description

Delve into the world of intelligent agents and explore the design and implementation of coordination mechanisms among multiple agents. This advanced course bridges theoretical principles and practical methods for implementing intelligent agents in complex, strategic environments. In most real-world strategic settings, games are characterized by multi-step imperfect information, presenting unique challenges such as signaling, deception, and interpreting the deceptive actions of others. Since 2003, significant advancements in the AI community have revolutionized the way these games are approached and solved. This course aims to provide a comprehensive understanding of both the foundational theories and the cutting-edge techniques in this field.

Course Prerequisites

CSCE 420 or CSCE 625

Special Course Designation

None.

Course Learning Outcomes

Upon completion of this course, students should be able to:

- Understand fundamental concepts and techniques used in Multi-Agent Systems, including the elements of game theory
- Analyze strategic interactions among rational agents in diverse settings such as auctions, voting systems, and resource allocation.



- Design algorithms that optimize outcomes in strategic environments and account for the incentives and motivations of rational agents.
- Communicate effectively about Multi-Agent Systems concepts and ideas to other students and professionals.

Textbook and/or Resource Materials

Resources:

The course will be lecture based. At the end of the course there will be a few lectures of project presentations by students. Readings will consist of a mixture of papers and course notes.

- Textbook: Shoham and Leyton-Brown. Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations (MAS)

Course Webpage: https://www.alankuhnle.com/teaching/f24-631/index.html

Grading Policy

Homework Assignments. There will be four homework problem sets. Your assignments must be submitted in LaTeX. Submit assignments by the beginning of class on the due date. Submissions may be paper or electronically via email.

Paper presentations. Students will complete a paper presentation. It may be done individually or in groups of 2-3 students. It can be theoretical or experimental, or a combination. The students can pick the paper to present subject to instructor approval.

Grading Distribution.

Paper presentations, 50%. Homework Assignments, 40%. Attendance, participation in class discussions, 10%

The grading scale will be: $A \ge 90\% > B \ge 80\% > C \ge 70\% > D \ge 60\% > F$.

Late Work Policy

Assignments are due at date and time indicated on the assignment. No late work is accepted unless it is because of a documented, excused absence. Please refer to Student Rule 7 for information about excused absences. Course Schedule

Lecture 1, 8/20	Introduction Reading: MAS, Ch. 3.1,3.2
	Course organization. Introduction to game theory. Game representations. Normal form, examples
Lecture 2,	Solution concepts



8/22	Reading: MAS, Ch. 3.3
	Solution concepts. Maxmin strategies, Minimax theorem, Nash's theorem
Lecture 3, 8/27	Further solution concepts Reading: MAS, Ch. 3.4
	Correlated equilibria, dominated strategies, minimax-regret, other concepts, rationalizability
Lecture 4, 8/29	Computing nash equilibria Reading: MAS, Ch. 4.1,4.2,4.3
	2player zero-sum, LCP formulation, Lemke-Howson, complexity
Lecture 5, 9/3	Extensive-form representation Reading: MAS, Ch. 5.1,5.2 Homework 1 out
	Definition, strategies, backward induction, subgame-perfect equilibria, imperfect information
Lecture 6, 9/5	Sequence-form representation Obvious (but often inappropriate for optimization) behavioral representation of a strategy. Sequence-form representation. Examples of sequence-form strategies, and computation of expected utilities given the sequence-form representation (multilinearity of expected utilities). Kuhn's theorem: relationship between normal-form and sequence- form strategies. Bottom-up decomposition of the sequence-form polytope.
Lecture 7, 9/10	Regret minimization and hindsight rationality Reading: <u>[Gordon et al., ICML '08]</u> Homework 1 due
	Phi-regret minimization. Special cases: external regret minimization, internal regret minimization, swap regret. External-regret dynamics lead to Nash equilibrium in 2-player O-sum games, and to NFCCE in general multiplayer games. Internal regret minimization leads to Nash equilibrium in 2-player O-sum games, and NFCE in general multiplayer games. For other choices of Phi transformations, we can arrive to EFCE and EFCCE. Special role of external regret minimization. Solution to convex-concave saddle-point problems via regret minimization; applications to bilinear saddle-point problems such as Nash equilibrium, optimal correlation, etc.
Lecture 8,	Blackwell approachability and external regret minimization for simplex domains
9/12	Blackwell game approach and construction of regret matching (RM), RM+.
Lecture 9, 9/17	Regret circuits and counterfactual regret minimization (CFR)



	Treeplex case: regret circuits for Cartesian products and for convex hull. Construction of CFR and pseudocode; proof of correctness and convergence speed.
Lecture 10, 9/19	Provably correct techniques for speeding up CFR algorithms. Reading: [Brown & Sandholm, ICML '17], [Brown & Sandholm, AAAI '19] Alternation. Reweighted updates of regrets and strategies, LCFR, DCFR. Dynamic
Lecture 11, 9/24	Optimistic/predictive regret minimization via online optimization Reading: [Syrgkanis et al., NeurIPS '15]
	Online projected gradient descent. Distance-generating functions. Predictive follow-the- regularized-leader (FTRL), predictive online mirror descent (OMD), and RVU bounds. Notable instantiations, e.g., optimistic hedge/multiplicative weights update. Accelerated convergence to bilinear saddle points. Dilatable global entropy.
Lecture 12, 9/26	Predictive Blackwell approachability Reading: [Abernethy et al., COLT '11]
	Blackwell approachability on conic domains. Using regret minimization to solve a Blackwell approachability game. Abernethy et al.'s construction. Predictive Blackwell approachability.
Lecture 13, 10/1	Predictive regret matching and predictive regret matching plus
	Connections between follow-the-regularized-leader / online mirror descent and regret matching / regret matching plus. Construction of predictive regret matching and predictive regret matching plus.
Lecture 14, 10/3	Monte-Carlo CFR and offline optimization methods for two-player zero-sum games Regret minimization with unbiased estimators of the utilities. Game-theoretic utility estimators (external sampling, outcome sampling). Offline optimization methods for two- player zero-sum games. Accelerated first-order saddle-point solvers (excessive gap technique, mirror prox). Linear programming formulation of Nash equilibrium strategies. Payoff matrix sparsification technique.
Lecture 15, 10/10	Game abstraction 1: Practical state of the art Reading: [Brown et al., AAMAS '15]
	Lossless abstraction: GameShrink. Lossy state abstraction. Potential-aware, earth-
Lecture 16, 10/15	Game abstraction 2 Reading: [Kroer & Sandholm, NeurIPS '18]



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	Reverse mapping. Abstraction pathology. Lossy abstraction with solution-quality bounds. Application of the theory to game modeling.
Lecture 17, 10/17	State-of-the-art for two-player no-limit Texas hold'em: Libratus Reading: [Brown & Sandholm, Science '18]
	Subgame solving in imperfect-information games. Self-improver. Time allowing: Deep CFR as an alternative to abstraction, and Supremus improvements to DeepStack.
Lecture 18, 10/22	State-of-the-art for multi-player no-limit Texas hold'em: Pluribus Reading: [Brown & Sandholm, Science '19]
	Depth-limited subgame solving.
Lecture 19, 10/24	"Endgame" solving without a blueprint strategy: ReBeL Reading: [Brown et al., NeurIPS '20]
Lecture 20, 10/29	Simulator-access games 1: State-of-the-art for StarCraft: <i>AlphaStar</i> Reading: [<u>Vinyals et al., Nature '19]</u>
Lecture 21, 10/31	Simulator-access games 2: (Near)optimality certificates and how to learn them Reading: [Zhang & Sandholm, AAAI '21]
Lecture 22, 11/5	Opponent exploitation Reading: [Ganzfried & Sandholm, AAMAS '11]
	Different approaches to opponent exploitation. Hybrids with game theory. Safe opponent exploitation.
Lecture 23, 11/7	Equilibrium refinements Reading: <u>[Farina & Sandholm, NeurIPS '18]</u>
	Sequential irrationality. Trembling-hand equilibrium refinements: quasi-perfect equilibrium (QPE) and extensive-form perfect equilibrium (EFPE). Relationships among refinements. Computational complexity. Trembling-hand linear program formulation of QPE and EFPE. Scalable exact algorithms for QPE, and EFPE.
Lecture 24, 11/12	Correlated strategies and team coordination Reading: <u>[Farina et al., NeurIPS '18]</u> , <u>[Zhang & Sandholm, arXiv '21]</u>
	Team maxmin equilibrium and TMECor; why the latter is often significantly better. Realization polytope: low dimensional but only the vertices are known and not the constraints; ways around that in practice.
Lecture 25, 11/14	Cooperation and competition in strategic games Reading: [<u>Kuhnle et al., arXiv '23]</u>



Lecture 26, 11/19	Paper presentations
Lecture 27, 11/21	Paper presentations
Lecture 28, 11/26	Paper presentations

University Policies Attendance Policy

The university views class attendance and participation as an individual student responsibility. Students are expected to attend class and to complete all assignments.

Please refer to <u>Student Rule 7</u> in its entirety for information about excused absences, including definitions, and related documentation and timelines.

Makeup Work Policy

Students will be excused from attending class on the day of a graded activity or when attendance contributes to a student's grade, for the reasons stated in Student Rule 7, or other reason deemed appropriate by the instructor.

Please refer to <u>Student Rule 7</u> in its entirety for information about makeup work, including definitions, and related documentation and timelines.

Absences related to Title IX of the Education Amendments of 1972 may necessitate a period of more than 30 days for make-up work, and the timeframe for make-up work should be agreed upon by the student and instructor" (<u>Student Rule 7, Section 7.4.1</u>).

"The instructor is under no obligation to provide an opportunity for the student to make up work missed because of an unexcused absence" (<u>Student Rule 7, Section 7.4.2</u>).

Students who request an excused absence are expected to uphold the Aggie Honor Code and Student Conduct Code. (See <u>Student Rule 24</u>.)

Academic Integrity Statement and Policy

"An Aggie does not lie, cheat or steal, or tolerate those who do."

"Texas A&M University students are responsible for authenticating all work submitted to an instructor. If asked, students must be able to produce proof that the item submitted is indeed the work of that student. Students must keep appropriate records at all times. The inability to authenticate one's work,



should the instructor request it, may be sufficient grounds to initiate an academic misconduct case" (<u>Section 20.1.2.3, Student Rule 20</u>).

Texas A&M at College Station

You can learn more about the Aggie Honor System Office Rules and Procedures, academic integrity, and your rights and responsibilities at <u>aggiehonor.tamu.edu</u>.

Texas A&M at Galveston

You can learn more about the Honor Council Rules and Procedures as well as your rights and responsibilities at <u>tamug.edu/HonorSystem</u>.

Texas A&M at Qatar

You can learn more about academic integrity and your rights and responsibilities at Texas A&M University at Qatar by visiting the <u>Aggie Honor System</u> website.

Americans with Disabilities Act (ADA) Policy

Texas A&M University is committed to providing equitable access to learning opportunities for all students. If you experience barriers to your education due to a disability or think you may have a disability, please contact the Disability Resources office on your campus (resources listed below) Disabilities may include, but are not limited to attentional, learning, mental health, sensory, physical, or chronic health conditions. All students are encouraged to discuss their disability related needs with Disability Resources and their instructors as soon as possible.

Texas A&M at College Station

Disability Resources is located in the Student Services Building or at (979) 845-1637 or visit <u>disability.tamu.edu</u>.

Texas A&M at Galveston

Disability Resources is located in the Student Services Building or at (409) 740-4587 or visit <u>tamug.edu/counsel/Disabilities</u>.

Texas A&M at Qatar

Disability Services is located in the Engineering Building, room 318C or at +974.4423.0316 or visit <u>https://www.gatar.tamu.edu/students/student-affairs/disability-services</u>.

Title IX and Statement on Limits to Confidentiality

Texas A&M University is committed to fostering a learning environment that is safe and productive for all. University policies and federal and state laws prohibit gender-based discrimination and sexual harassment, including sexual assault, sexual exploitation, domestic violence, dating violence, and stalking.



With the exception of some medical and mental health providers, all university employees (including full and part-time faculty, staff, paid graduate assistants, student workers, etc.) are Mandatory Reporters and must report to the Title IX Office if the employee experiences, observes, or becomes aware of an incident that meets the following conditions (see <u>University Rule 08.01.01.M1</u>):

- The incident is reasonably believed to be discrimination or harassment.
- The incident is alleged to have been committed by or against a person who, at the time of the incident, was (1) a student enrolled at the University or (2) an employee of the University.

Mandatory Reporters must file a report regardless of how the information comes to their attention – including but not limited to face-to-face conversations, a written class assignment or paper, class discussion, email, text, or social media post. Although Mandatory Reporters must file a report, in most instances, a person who is subjected to the alleged conduct will be able to control how the report is handled, including whether or not to pursue a formal investigation. The University's goal is to make sure you are aware of the range of options available to you and to ensure access to the resources you need.

Texas A&M at College Station

Students wishing to discuss concerns in a confidential setting are encouraged to make an appointment with <u>Counseling and Psychological Services</u> (CAPS).

Students can learn more about filing a report, accessing supportive resources, and navigating the Title IX investigation and resolution process on the University's <u>Title IX webpage</u>.

Texas A&M at Galveston

Students wishing to discuss concerns in a confidential setting are encouraged to make an appointment with the Counseling Office in the Seibel Student Center, or call (409)740-4587. For additional information, visit <u>tamug.edu/counsel</u>.

Students can learn more about filing a report, accessing supportive resources, and navigating the Title IX investigation and resolution process on the Galveston Campus' <u>Title IX webpage</u>.

Texas A&M at Qatar

Texas A&M University at Qatar students wishing to discuss concerns in a confidential setting are encouraged to visit the <u>Health and Wellness</u> website for more information.

Students can learn more about filing a report, accessing supportive resources, and navigating the Title IX investigation and resolution process on the University's <u>Title IX webpage</u>.

Statement on Mental Health and Wellness



Texas A&M University recognizes that mental health and wellness are critical factors that influence a student's academic success and overall wellbeing. Students are encouraged to engage in healthy self-care by utilizing available resources and services on your campus

Texas A&M College Station

Students who need someone to talk to can contact Counseling & Psychological Services (CAPS) or call the TAMU Helpline (979-845-2700) from 4:00 p.m. to 8:00 a.m. weekdays and 24 hours on weekends. 24-hour emergency help is also available through the 988 Suicide & Crisis Lifeline (988) or at 988lifeline.org Links to an external site..

Texas A&M at Galveston

Students who need someone to talk to can call (409) 740-4736 from 8:00 a.m. to 5:00 p.m. weekdays or visit <u>tamug.edu/counsel</u> for more information. For 24-hour emergency assistance during nights and weekends, contact the TAMUG Police Dept at (409) 740-4545. 24-hour emergency help is also available through the 988 Suicide & Crisis Lifeline (988) or at 988lifeline.org Links to an external site..

Texas A&M at Qatar

Texas A&M University at Qatar students wishing to discuss concerns in a confidential setting are encouraged to visit the <u>Health and Wellness</u> website for more information.

Campus-Specific Policies

Texas A&M at Galveston

Classroom Access and Inclusion Statement

Texas A&M University is committed to engaged student participation in all of its programs and courses and provides an accessible academic environment for all students. This means that our classrooms, our virtual spaces, our practices and our interactions are as inclusive as possible and we work to provide a welcoming instructional climate and equal learning opportunities for everyone. If you have an instructional need, please notify me as soon as possible.

The Aggie Core values of respect, excellence, leadership, loyalty, integrity and selfless service in addition to civility, and the ability to listen and to observe others are the foundation of a welcoming instructional climate. Active, thoughtful and respectful participation in all aspects of the course supports a more inclusive classroom environment as well as <u>our mutual</u> responsibilities to the campus community.