CSC 535: Probabilistic Graphical Models

MW 11am-12:15pm : Live Online

Description of Course

Probabilistic graphical modeling and inference is a powerful modern approach to representing the combined statistics of data and models, reasoning about the world in the face of uncertainty, and learning about it from data. It cleanly separates the notions of representation, reasoning, and learning. It provides a principled framework for combining multiple sources of information, such as prior knowledge about the world, with evidence about a particular case in observed data. This course will provide a solid introduction to the methodology and associated techniques, and show how they are applied in diverse domains ranging from computer vision to computational biology to computational neuroscience.

Course Prerequisites or Co-requisites

MATH 223 and MATH 313or equivalent math background.MATH 464 or alternative course that covers basic discrete and continuous probability. CSC 345or equivalent preparation in algorithms, data structures, and programming.

Instructor and Contact Information

Instructor:

Jason Pacheco, GS 724, Email: pachecoj@cs.arizona.edu

Office Hours: Tuesday, 10:00-11:30am

Web Information:

Course Homepage: http://www.pachecoj.com/courses/csc535_fall20

D2L: https://d2l.arizona.edu/d2l/home/937505

Piazza: https://piazza.com/arizona/fall2020/csc535

Instructor Homepage: http://www.pachecoj.com

CSC COVID 19 Policy:

All Fall 2020 CSC courses, whether In-Person, In-Person Flex, or Live Online, will provide recorded lectures for students along with office hour accommodations via Zoom. Additionally, In-Person and In-Person Flex courses will accommodate students who cannot attend class to take midterm exams and attendance will not be factored into final grades.

Course Format and Teaching Methods

Live synchronous online lectures only.

Live Online:

This class is scheduled to be taught in the LIVE ONLINE modality.

- **Meeting Times:** The class will meet Monday and Wednesday at 11am-12:15pm via Zoom. Our synchronous meetings will consist of lectures by the professor and will allow for real-time question and answering.
- **Class attendance:**
    - If you feel sick, or may have been in contact with someone who is infectious, stay

home. Except for seeking medical care, avoid contact with others and do not travel.
- Campus Health is testing for COVID-19. Please call (520) 621-9202 before you visit in person.
- Visit the UArizona COVID-19 page for regular updates.

Pandemic-Related Information for All Modalities

- **Advising:** If you have questions about your academic progress this semester, or your chosen degree program, consider contacting your graduate program coordinator and faculty advisor. Your program coordinator, faculty advisor, and the Graduate Center can guide you toward university resources to help you succeed.**Computer Science students** are encouraged to email gradadvising@cs.arizona.edu for advising related questions.
- **Life challenges:** If you are experiencing unexpected barriers to your success in your courses, please note the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office can be reached at 520-621-2057 or DOS-deanofstudents@email.arizona.edu.
- **Physical and mental-health challenges**: If you are facing physical or mental health challenges this semester, please note that Campus Health provides quality medical and mental health care. For medical appointments, call (520-621-9202. For After Hours care, call (520) 570-7898. For the Counseling & Psych Services (CAPS) 24/7 hotline, call (520) 621-3334.
- **Exams**: The course will consist of a take-home midterm and final exam available through D2L / Gradescope.
- Final exam information: The take-home final exam must be returned by the end of the scheduled exam period on Dec. 14.
- **Equipment and software requirements**: For this class you will need daily access to the following hardware: laptop or web-enabled device with webcam and microphone; regular access to reliable internet signal; ability to download and run the following software: zoom, Matlab.
- **Staying current:** You are required to complete regular homework assignments and exams on your own time to ensure comprehension of the material and meet course requirements.
- **Remote / online only after Thanksgiving:** After the Thanksgiving holiday, we are scheduled to move to remote teaching. Synchronous Zoom lectures will continue to be offered at normal meeting times. Additional efforts will be made to accommodate expected timezone constraints, such as ensuring asynchronous availability to class recordings.
- **Class Recordings:** For lecture recordings, students must access content in D2L only. Students may not modify content or re-use content for any purpose other than personal educational reasons. All recordings are subject to government and university regulations. Therefore, students accessing unauthorized recordings or using them in a manner inconsistent with UArizona values and educational policies are subject to suspension or civil action.

Course Objectives

The broad objectives of this course are to develop a solid fundamental understanding of probabilistic graphical models, learn how to apply them to diverse problems, and build a toolkit of useful statistical models and related algorithms. Assignments and exams will develop and evaluate both conceptual understanding and applying the methodology to practical problems.

Concepts that students are expected to learn include: Bayesian methodology, conditional

independence, modeling and inference as distinct activities, model selection, Bayesian decision making, directed graphical models (Bayes nets), sampling probability distributions from Bayes nets (ancestral sampling), undirected graphical models (Markov random fields, factor graphs), relationships between model types and the space of probability distributions, causality, statistical clustering, statistical inference, exact inference on graphs using message passing, expressing model learning as inference, approximate inference for missing value problems using expectation maximization (EM), variational inference, sampling probability distributions using Markov chain Monte Carlo (MCMC), and how MCMC can used for inference.

Commonly used models that students will learn about include Naïve Bayes, Gaussian mixture models (GMM), hidden Markov models (HMM), and linear dynamic systems (LDS). Generally applicable algorithms that students will learn about include sum-product (includes forward/backward for HMM as a special case), max-sum (includes Viterbi as a special case), K-means clustering, expectation-maximization (EM), variational inference, Kalman filter, Metropolis Hastings, Gibbs sampling, and particle filter.

Specific skills that students will develop through homework assignments include:

1) Creating both directed and undirected graphical models for data
2) Identifying conditional independencies in graphical models
3) Specifying distributions for parameters of model components that link the model to data
4) Applying exact inference methods to compute marginal probabilities and maximally probable configurations given a model (sum-product and max-sum algorithms, respectively)
5) Applying approximate inference to learn model parameters using expectation maximization (EM algorithm), variational inference, and various Markov chain Monte Carlo methods including Metropolis Hastings sampling, Gibbs sampling, and Hamiltonian Monte Carlo.

Topics

- Introductory foundations
  - Probabilistic foundations
  - Introduction to the Bayesian methodology and introductory examples
  - Actions and decisions
  - Model selection
- Graphical representation of probabilistic models
  - Representing models using directed graphs (Bayes nets)
  - Representing models using undirected graphs (Markov Random fields)
  - Causality
  - Factor graphs
- Examples of graphical models
  - Naïve Bayes
  - Gaussian Mixture Models (GMM)
  - Hidden Markov Models (HMM)
  - Linear Dynamical Systems (LDS)
- Inference for graphical models
  - Sum product algorithm
  - Max sum algorithm
  - Expectation maximization (EM)

Markov chain Monte Carlo (MCMC) methods including Metropolis Hastings, Gibbs sampling, and Hamiltonian Monte Carlo.

Absence and Class Participation Policy

Participating in the course and attending lectures and other course events are vital to the learning process. As such, attendance is required at all lectures and discussion section meetings. Due to the current COVID-19 pandemic, however, absences will not affect the student's final course grade. If you anticipate being absent, are unexpectedly absent, or are unable to participate in class online activities, please contact me as soon as possible. To request a disability-related accommodation to this attendance policy, please contact the Disability Resource Center at (520) 621-3268 or drc-info@email.arizona.edu. If you are experiencing unexpected barriers to your success in your courses, the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office is located in the Robert L. Nugent Building, room 100, or call 520-621-7057.

The UA's policy concerning Class Attendance, Participation, and Administrative Drops is available at http://catalog.arizona.edu/policy/class-attendance-participation-and-administrative-drop

The UA policy regarding absences for any sincerely held religious belief, observance or practice will be accommodated where reasonable: http://policy.arizona.edu/human-resources/religious-accommodation-policy.

Absences pre-approved by the UA Dean of Students (or dean's designee) will be honored. See https://deanofstudents.arizona.edu/absences

Course Communications

Online communication will be conducted using D2L, Piazza, and official UA email addresses.

Required Texts or Readings

This class will select material from the following two textbooks:

1) Bishop, Chris, "Pattern Recognition and Machine Learning" (https://www.microsoft.com/en-us/research/uploads/prod/2006/01/Bishop-Pattern-Recognition-and-Machine-Learning-2006.pdf)
2) Murphy, Kevin, "Machine Learning: A Probabilistic Perspective"

Neither book is required as all course material will be available within the lecture notes, assignments, and supplementary readings.

Required or Special Materials (if any)

Matlab Most students will use Matlab for most assignments. While there will be some flexibility in the choice of programming languages, unless there is a reason to do otherwise (please consult with the instructor), students are advised to use Matlab.Matlab is available on a number of student accessible computers across campus including the CS machine general purpose instructional computer "lectura". Students wishing to use Matlab on a personal computer can download and install it through the U. Arizona web pages (http://softwarelicense.arizona.edu/mathworks-matlab).
Zoom will be required for attending synchronous course lectures.

Assignments and Examinations: Schedule/Due Dates

There will be 10 assignments, one midterm, and a final, as detailed in the table below.For maximum flexibility, I will post assignments as soon as we have covered material that enables students to start on them. Due dates are nominally midnight, with grace until 8am the following

morning.

	DESCRIPTION	WEIGHT
HW1	Introduction	4
HW2	Bayesian probability	7
HW3	Directed PGMs (Baye's Nets)	7
HW4	Undirected PGMs (MRFs, Factor Graphs)	7
HW5	Sum-product, max-sum	7
Midterm	Up-to-and-including HW5 & Week 7	10
HW6	Loopy Belief Propagation	5
Withdrawal deadline : Nov 2		
HW7	Gaussian mixture models & EM	7
HW8	Linear dynamical systems	7
HW9	Switching State-Space Models	7
HW10	MCMC	7
Final		25

Final Examination or Project

Final exam information: The take-home final exam must be returned by the end of the scheduled exam period on Dec. 14. See the final exam schedule, *http://www.registrar.arizona.edu/schedules/finals.htm* and regulations, *https://www.registrar.arizona.edu/courses/final-examination-regulations-and-information* .

Grading Scale and Policies

Assignment grading. Assignment deliverables will generally consist of two parts: 1) all code developed in response to the assignments; and 2) a report, in PDF format explaining what has been done, what the results were, commenting on the results, and answering any questions posed in the assignment. The instructor will provide a document that details the expectations of the report. Assignments will be graded with respect to four criteria: 1) reproducibility (the ease by which the grader can run the code to get the reported results); 2) completeness (the extent that the work done and sufficient effort was applied); 3) correctness; and 4) the exposition (clarity, insight, and conformance to the guidelines provided). The weight of these four criteria will vary among the assignments, but students are advised that the fourth criterion will generally have substantive weight.

Grading breakdown

Assignments: 65%
Midterm: 10%
Final Exam: 25%

90% guarantees an A, 80% guarantees a B, 70% a C, and 60% a D.

Requests for incomplete (I) or withdrawal (W) must be made in accordance with University policies, which are available at http://catalog.arizona.edu/policy/grades-and-grading-system#incomplete and http://catalog.arizona.edu/policy/grades-and-grading-system#Withdrawal, respectively.

Dispute of Grade Policy. Students wishing to dispute a grade on an assignment or exam should contact the instructor within two weeks of the date that the assignment or exam was returned to the students

Scheduled Topics/Activities

Week 1: Probability Primer
Week 2: Bayesian Probability and Statistics
Week 3: Bayesian Probability and Statistics (Cont'd)
Week 4: Probabilistic Graphical Models
Week 5: Exponential Families
Week 6: Message Passing Inference Algorithms
Week 7: Parameter Learning
Week 8: Expectation Maximization
Week 9: Monte Carlo Methods
Week 10: Monte Carlo Methods (Cont'd)
Week 11: Dynamical Systems
Week 12: Dynamical Systems (Cont'd)
Week 13: Variational Methods
Week 14: Variational Methods (Cont'd)
Week 15: Topic Models
Week 16: Bayesian Nonparametrics

Bibliography

C. M. Bishop, Pattern recognition and machine learning: Springer, 2006.

Wainwright, Martin J., and Michael I. Jordan. "Graphical models, exponential families, and variational inference." *Foundations and Trends® in Machine Learning* 1.1–2 (2008): 1-305.

Andrieu, Christophe, N. d. Freitas, A. Doucet, M. I. Jordan. "An introduction to MCMC for machine learning." *Machine learning* 50.1-2 (2003): 5-43.

Blei, David M., Andrew Y. Ng, and Michael I. Jordan. "Latent dirichlet allocation." *Journal of machine Learning research* 3.Jan (2003): 993-1022.

Murphy, Kevin P. *Machine learning: a probabilistic perspective*. MIT press, 2012.

Neal, Radford M. "MCMC using Hamiltonian dynamics." *Handbook of markov chain monte carlo* 2.11 (2011): 2.

Hoffman, Matthew D., and Andrew Gelman. "The No-U-Turn sampler: adaptively setting path lengths in Hamiltonian Monte Carlo." *Journal of Machine Learning Research* 15.1 (2014): 1593-1623.

Snoek, Jasper, Hugo Larochelle, and Ryan P. Adams. "Practical bayesian optimization of machine learning algorithms." *Advances in neural information processing systems*. 2012.

Shahriari, Bobak, et al. "Taking the human out of the loop: A review of Bayesian optimization." *Proceedings of the IEEE* 104.1 (2015): 148-175.

Kingma, Diederik P., and Max Welling. "Auto-encoding variational bayes." *arXiv preprint arXiv:1312.6114* (2013).

Rezende, Danilo Jimenez, Shakir Mohamed, and Daan Wierstra. "Stochastic backpropagation and

approximate inference in deep generative models." *arXiv preprint arXiv:1401.4082* (2014).

Rasmussen, Carl Edward. "Gaussian processes in machine learning." *Summer School on Machine Learning*. Springer, Berlin, Heidelberg, 2003.

Teh, Y., M. Jordan, M. Beal, et al. Hierarchical Dirichlet processes.Journal of the American Statistical As-sociation, 101(476):1566–1581, 2007.

Department of Computer Science Code of Conduct

The Department of Computer Science is committed to providing and maintaining a supportive educational environment for all. We strive to be welcoming and inclusive, respect privacy and confidentiality, behave respectfully and courteously, and practice intellectual honesty. Disruptive behaviors (such as physical or emotional harassment, dismissive attitudes, and abuse of department resources) will not be tolerated. The complete Code of Conduct is available on our department web site. We expect that you will adhere to this code, as well as the UA Student Code of Conduct, while you are a member of this class.

Classroom Behavior Policy

To foster a positive learning environment, students and instructors have a shared responsibility. We want a safe, welcoming, and inclusive environment where all of us feel comfortable with each other and where we can challenge ourselves to succeed. To that end, our focus is on the tasks at hand and not on extraneous activities (e.g., texting, chatting, reading a newspaper, making phone calls, web surfing, etc.).

Students are asked to refrain from disruptive conversations with people sitting around them during lecture. Students observed engaging in disruptive activity will be asked to cease this behavior. Those who continue to disrupt the class will be asked to leave lecture or discussion and may be reported to the Dean of Students.

Threatening Behavior Policy

The UA Threatening Behavior by Students Policy prohibits threats of physical harm to any member of the University community, including to oneself. See http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students.

Accessibility and Accommodations

At the University of Arizona, we strive to make learning experiences as accessible as possible. If you anticipate or experience barriers based on disability or pregnancy, please contact the Disability Resource Center (520-621-3268, https://drc.arizona.edu/) to establish reasonable accommodations.

Code of Academic Integrity

Students are encouraged to share intellectual views and discuss freely the principles and applications of course materials. However, graded work/exercises must be the product of independent effort unless otherwise instructed. Students are expected to adhere to the UA Code of Academic Integrity as described in the UA General Catalog. See http://deanofstudents.arizona.edu/academic-integrity/students/academic-integrity.

The University Libraries have some excellent tips for avoiding plagiarism, available at http://new.library.arizona.edu/research/citing/plagiarism.

UA Nondiscrimination and Anti-harassment Policy

The University is committed to creating and maintaining an environment free of discrimination; see http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy

Additional Resources for Students

UA Academic policies and procedures are available at http://catalog.arizona.edu/policies

Student Assistance and Advocacy information is available at http://deanofstudents.arizona.edu/student-assistance/students/student-assistance

Subject to Change Statement

Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor.

Campus Pantry

Any student who has difficulty affording groceries or accessing sufficient food to eat every day, or who lacks a safe and stable place to live and believes this may affect their performance in the course, is urged to contact the Dean of Students for support. In addition, the University of Arizona Campus Pantry is open for students to receive supplemental groceries at no cost. Please see their website at: *campuspantry.arizona.edu* for open times.

Furthermore, please notify me if you are comfortable in doing so. This will enable me to provide any resources that I may possess.

Title IX

The University of Arizona is committed to removing educational barriers created by sex discrimination and sexual harassment. Sex discrimination under Title IX can include acts of violence based on sex, such as sexual assault, domestic violence, dating violence, and stalking. If you (or someone you know) has experienced or experiences any of these incidents, you have options for help at the University. The University of Arizona has staff members trained to support you in navigating campus life, accessing health and counseling services, providing academic and housing accommodations, helping with legal protective orders, and more.

Please be aware that UA faculty and instructors who work with students are required to report allegations of sex discrimination to the Title IX Office. This means that if you tell me about a situation involving sexual harassment, sexual assault, dating violence, domestic violence, or stalking that involves another student or employee, or that happens on campus or in a UA program, I **must** share that information with the Title IX Coordinator. Although I have to make that notification, you will have choices regarding whether or not you want to pursue a formal complaint against anyone on campus. Our goal is to make sure you are aware of the range of options available to you and have access to the resources you need.

If you wish to speak to someone privately, you can contact any of the following on-campus resources:

- Counseling & Psych Services (CAPS), https://health.arizona.edu/counseling-psych-services, 520-621-6490, 520-570-7898 (after hours)
- Oasis Sexual Assault, Relationship Violence, and Trauma Services, https://health.arizona.edu/counseling-oasis (same phone as CAPS)
- Campus Health, https://health.arizona.edu/home, (520) 621-6490
- University of Arizona Ombuds, https://ombuds.arizona.edu/, (520)-626-5589

- Title IX section on sexual assault support & resources (https://titleix.arizona.edu/title-ix/sexual-harassment-violence) has more information, as well as a link explaining options if you have a concern, need assistance/support, or would like to file a complaint.

Preferred Gender Pronoun

This course affirms people of all gender expressions and gender identities. If you prefer to be called a different name than what is on the class roster, please let me know. Feel free to correct instructors on your preferred gender pronoun. If you have any questions or concerns, please do not hesitate to contact me directly in class or via email (instructor email). If you wish to change your preferred name or pronoun in the UAccess system, please use the following guidelines:

Preferred name: University of Arizona students may choose to identify themselves within the University community using a preferred first name that differs from their official/legal name. A student's preferred name will appear instead of the person's official/legal first name in select University-related systems and documents, provided that the name is not being used for the purpose of misrepresentation. Students are able to update their preferred names in UAccess.

Pronouns: Students may designate pronouns they use to identify themselves. Instructors and staff are encouraged to use pronouns for people that they use for themselves as a sign of respect and inclusion. Students are able to update and edit their pronouns in UAccess.

More information on updating your preferred name and pronouns is available on the Office of the Registrar site at https://www.registrar.arizona.edu/.

Confidentiality of Student Records

http://www.registrar.arizona.edu/personal-information/family-educational-rights-and-privacy-act-1974-ferpa?topic=ferpa

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The University of Arizona sits on the original homelands of indigenous peoples who have stewarded this land since time immemorial. Aligning with the university's core value of a diverse and inclusive community, it is an institutional responsibility to recognize and acknowledge the people, culture, and history that make up the Wildcat community. At the institutional level, it is important to be proactive in broadening awareness throughout campus to ensure our students feel represented and valued.