CS886: Theory and Applications of Generative Models

Fall 2026

Web: https://cs.uwaterloo.ca/~y328yu/teaching/886/

Learn: https://learn.uwaterloo.ca/d2l/home/1288925

Piazza: https://piazza.com/uwaterloo.ca/fall2026/cs886

Syllabus

Instructor

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Course Description

Generative modeling is a rapidly developing area of machine learning concerned with learning complex data distributions and generating new samples from them. They have become a central component of modern machine learning, underlying advances in image and video generation, language modeling, scientific discovery, and many other applications. This graduate course explores both the theoretical foundations and recent developments in modern generative models.

The course consists of two parts. In the first part, lectures will be given to introduce the foundations of major classes of generative models, including distribution transportation (GANs and optimal transport), diffusion and score-based models, flow-based models, and their discrete counterparts. We will focus on the mathematical principles underlying these models, their training objectives, and their sampling algorithms.

The second part of the course will be seminar-based and centered on recent research papers. Students will present and discuss selected papers covering topics such as training and inference, sampling and guidance, model distillation and acceleration, memorization and generalization, data purification, and applications of generative models. Through these presentations and discussions, students will develop a broader understanding of current research directions, open problems, and emerging applications in generative modeling.

Course Objectives

At the end of the course, students should have the ability to

- understand the mathematical foundations of major families of modern generative models, including GANs, diffusion models, flow-based models, and others;
- derive and explain their principal training objectives and sampling or inference procedures;
- articulate theoretical and practical trade-offs among different generative modeling approaches;
- read, analyze, and critically evaluate recent research papers in generative modeling;
- clearly communicate technical ideas through research presentations and discussions;

- identify open questions and potential research directions in generative modeling.

Course Overview (Tentative)

- Transport (first lecture: Sep 14, 2026)
- Diffusion
- Flow
- Discrete Models
- Training (second part)
- Inference
- Guidance
- Distillation
- Memorization
- Deconvolution
- Purification
- Applications

Prerequisites

Good knowledge of linear algebra (vector space, eigenvalue, matrix multiplication, etc.) and basic probability (random variable, distribution, expectation, conditional probability, Bayes rule, etc.). Exposure to machine learning or Python is a plus but not required.

Textbooks

There is no required textbook. We will post lecture notes or slides before class. Please refrain from uploading any course material (notes, slides, assignments) to any generative AI tool or website.

The following fine books are recommended:

- *Generative AI and Stochastic Thermodynamics*. Max Welling, Sirui Lu and Lars Holdijk. Cambridge University Press, 2026.
- *Probabilistic Machine Learning: Advanced Topics*. Kevin Patrick Murphy. MIT Press, 2023.
- *Deep Learning*. Ian Goodfellow, Yoshua Bengio and Aaron Courville. MIT Press, 2016.

Grading (30% + 20% + 10% + 40%, Tentative)

Each student will give two presentations in the second part of the course, together worth 30%. We reserve 20% for course participation (engaging in discussion, asking questions, additional readings / experimentations, etc.).

There will be a final course project that

- relates to generative models (either algorithmic, theoretical or applied)
- allows you to learn something new (and hopefully significant)
- is interesting and nontrivial, preferably publishable in a top machine learning conference

You need to submit a project proposal (10%) by November 9, 2026. Please elaborate the following:

- What is the project about? What is the goal?
- Initial literature search: what has been done? What remains open?
- Feasibility study: convince us your proposal is within reach. If possible, include simple toy examples or quick experiments.
- Dataset, evaluation and computing (if applicable): make sure you have all the resource for your project. Talk to me if you need help.

Please write your proposal using the provided template and limit yourself to 2 pages + 1 page solely for figures and tables (if needed) + 1 page solely for reference.

You need to submit a project report (40%) by December 18, 2025 that summarizes all your findings (empirical, algorithmic, theoretical). We expect the report to be less than **8 pages** (excluding references). Refer to the course webpage for more instructions on the report writing. Your project report will be evaluated by its clarity, significance, rigor, presentation, and completeness.

Use of Artificial Intelligence Tools

The use of generative AI tools (such as ChatGPT, Claude, Gemini, GitHub Copilot, and similar tools) is permitted in this course as a learning aid. However, all submitted work must reflect your own understanding and intellectual effort. You are responsible for completing the assigned work independently and for being able to explain and justify everything you submit.

AI tools may be used, for example, to clarify concepts, obtain feedback on your work, improve writing, or assist with debugging. They should not be used to generate solutions or substantial portions of an assignment that you then submit as your own work.

Whenever you use an AI tool in completing an assignment, you must include a brief declaration stating which tool(s) you used and how you used them. If you did not use any AI tools, no declaration is necessary.

You remain fully responsible for the correctness, originality, and integrity of all work you submit. Undeclared or inappropriate use of AI may be treated as a violation of the course's academic integrity requirements.

Academic Integrity

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 university website for more information.

Grievance

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

Discipline

A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for hisher actions. 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.

Appeals

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).

Students with Disabilities

AccessAbility Services collaborates with all academic departments to arrange appropriate accommodations for students with temporary or permanent disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations, please register with the AccessAbility Services at the beginning of each academic term.

Intellectual Property

Students should be aware that this course contains the intellectual property of their instructor, TA, and/or the University of Waterloo. Intellectual property includes items such as:

- Lecture content, spoken and written (and any audio/video recording thereof);
- Lecture handouts, presentations, and other materials prepared for the course (e.g., PowerPoint slides);
- Questions or solution sets from various types of assessments (e.g., assignments, quizzes, tests, final exams); and
- Work protected by copyright (e.g., any work authored by the instructor or TA or used by the instructor or TA with permission of the copyright owner).

Course materials and the intellectual property contained therein, are used to enhance a student's educational experience. However, sharing this intellectual property without the intellectual property owner's permission is a violation of intellectual property rights. For this reason, it is necessary to ask the instructor, TA and/or the University of Waterloo for permission before uploading and sharing the intellectual property of others online (e.g., to an online repository).

Permission from an instructor, TA or the University is also necessary before sharing the intellectual property of others from completed courses with students taking the same/similar courses in subsequent terms/years. In many cases, instructors might be happy to allow distribution of certain materials. However, doing so without expressed permission is considered a violation of intellectual property rights.

Please alert the instructor if you become aware of intellectual property belonging to others (past or present) circulating, either through the student body or online. The intellectual property rights owner deserves to know (and may have already given their consent).