IE7374 - Generative AI

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Course Description

This **Generative AI course** provides an in-depth exploration of the key principles and cutting-edge techniques driving the field of generative modeling. Students will begin by mastering deep learning fundamentals, including neural networks and optimization methods, before diving into state-of-the-art generative models such as Autoencoders, GANs, Diffusion Models, and Transformers. The course will cover both foundational and advanced topics, including text and image generation, multimodal learning, and reinforcement learning for generative systems. Practical applications such as personalized content generation, text-to-image models like DALL·E, and Retrieval-Augmented Generation (RAG) will be explored, along with essential considerations like fine-tuning, and ethical concerns related to bias and fairness. Additionally, students will explore the role of AI Agents, autonomous systems capable of decision-making and action in dynamic environments, and how they integrate with generative models to create intelligent systems. By the end of the course, students will have the knowledge to design, train, and deploy generative models and AI agents across various domains, preparing them to innovate and solve real-world problems in AI-driven industries.

Prerequisites

- IE-7300, CS-6140, or equivalent machine learning course with minimum grade of C+.
- Proficiency in Python programming.
- Experience with TensorFlow or PyTorch.
- Knowledge of Linear Algebra, Probability, and Statistics.

Course Objectives

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

1. **Understand Deep Learning Fundamentals** - Explain core concepts of neural networks, including architectures like CNNs, RNNs, and optimization.
2. **Develop and Implement Generative Models** - Build and apply models such as Autoencoders, VAEs, GANs, and Diffusion Models for generative tasks.
3. **Master Transformers and Attention Mechanisms** - Analyze how transformer-based models like GPT and BERT are used for text and data generation.
4. **Apply Reinforcement Learning in Generative AI** - Utilize reinforcement learning for content generation in dynamic environments.
5. **Generate and Evaluate Text with Language Models** - Use and fine-tune language models for text generation tasks, with prompt engineering.
6. **Explore Diffusion and Energy-Based Models** - Learn to generate high-quality data with Diffusion Models and EBMs.
7. **Understand Generative Text-to-Image Models** - Develop text-to-image models like DALL·E using multimodal learning.
8. **Address Ethical Concerns in Generative AI** - Discuss ethical challenges, fairness, and adversarial robustness in generative models.

9. **Apply Generative AI to Real-World Applications** - Fine-tune generative models for practical applications in healthcare, entertainment, etc.
10. **Master Fine-Tuning and Transfer Learning** - Adapt pre-trained generative models with few-shot learning for new tasks.
11. **Integrate AI Agents with Generative Models** - Understand AI agents in decision-making and integrate with generative models.
12. **Evaluate and Interpret Generative Models** - Learn evaluation metrics and interpretability techniques for generative models.

Weekly Syllabus

Week	Topic	Description
1	Introduction to Generative AI	Overview of generative models, history, and applications. Deep learning fundamentals including neural networks, backpropagation, gradient descent, and optimization.
2	Batch Normalization, Regularization, and Dropouts	Discussion on methods to improve neural network training and generalization.
3	Convolutional Neural Networks and Autoregressive Models	Exploration of CNNs and models that predict subsequent elements in a sequence.
4	Maximum Likelihood and Representation Learning	Understanding the principles of maximum likelihood estimation and representation learning in AI.
5	Recurrent Neural Networks (RNNs), LSTMs, and Bidirectional Networks	Detailed look at RNNs, Long Short-Term Memory networks, and architectures for processing time-series data.
6	Transformers and Attention Mechanisms	Transformer models, attention mechanisms, and applications in text generation.
7	Fine-tuning and Transfer Learning	Techniques for adapting pre-trained models to new tasks in generative models.
8	Reinforcement Learning for Generative AI	Applying reinforcement learning strategies for policy and content generation.
9	Latent Variable Models	Exploring unsupervised learning with models like VAEs.
10	Normalizing Flow Models	Introduction to flow-based models for density estimation and generation.
11	Generative Adversarial Networks (GANs)	Overview of GANs and their applications in generating realistic images.
12	Energy-Based Models and Score-Based Models	Discussing models that use an energy function or scoring system for sample generation.
13	Diffusion Models	Introduction to diffusion models and their techniques for generating high-quality samples.
14	Evaluation and Ethics in Generative AI	Addressing the evaluation of generative models and ethical concerns such as bias and fairness.

Additional Syllabus Information

Neural Networks: Feedforward NNs, CNNs, RNNs, optimization, regularization, dropout, batch-normalization. **Generative Models:** GANs, VAEs, Transformers for NLP and Vision. **Diffusion Models:** Deep Reinforcement Learning, RLHF, Chat-GPT, Alignment. **Graph Neural Networks:** Applications in generative modeling. **Use Cases:** Lifecycle, pre-training, fine-tuning, vector databases, semantic search, LangChain, RAG, LLM-powered applications.

Course Evaluation

- **Homework:** 10%

- **Midterm and Final Exam:** 30%
- **Final Project:** 50%
- **Labs:** 10%

Grading Scale

Grade	Percentage
A	100 – 94
A-	94 – 88
B+	88 – 82
B	82 – 76
B-	76 – 70
C+	70 – 64
C	64 – 58
C-	58 – 52
F	< 52

Table 2: Grading Scale

Textbooks

To be determined

Software Requirements

Python >= 3.9, TensorFlow, PyTorch

Academic Honesty

Plagiarism, cheating, and any form of unauthorized collaboration are strictly prohibited and will be handled in accordance with University policies as outlined in the Student Handbook. Penalties for academic dishonesty may include, but are not limited to, receiving zero credit on the assignment, being placed on probation, having judicial findings recorded in the student's permanent record, and risking the student's status in the Engineering Program. Acts of academic dishonesty will be referred to OSCCR (Office of Student Conduct and Conflict Resolution). Visit Northeastern University Academic Integrity Policy for additional information on the University's academic integrity policy.

Student Accommodations

Northeastern University and the Disability Resource Center (DRC) are committed to providing disability services that enable students who qualify under Section 504 of the Rehabilitation Act and the Americans with Disabilities Act Amendments Act (ADAAA) to participate fully in the activities of the university. To receive accommodations through the DRC, students must provide appropriate documentation that demonstrates a current, substantially limiting disability. For more information, visit the Northeastern DRC website.

Diversity and Inclusion

Northeastern University is committed to equal opportunity, affirmative action, diversity, and social justice while building a climate of inclusion on and beyond campus. In the classroom, members of the University community work to cultivate an inclusive environment that denounces discrimination through innovation, collaboration, and an awareness of global perspectives on social justice.
It is my intention that students from all backgrounds and perspectives will be well served by this course, and that the diversity students bring to this class will be viewed as an asset. I welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual

orientations, socioeconomic backgrounds, family education levels, abilities – and other visible and nonvisible differences.
All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment for every other member of the class. Your suggestions are encouraged and appreciated.
Please visit the Northeastern University Diversity and Inclusion website for complete information on Diversity and Inclusion.

Title IX

Title IX of the Education Amendments of 1972 protects individuals from sex or gender-based discrimination, including discrimination based on gender identity, in educational programs and activities that receive federal financial assistance. Northeastern's Title IX Policy prohibits Prohibited Offenses, which are defined as sexual harassment, sexual assault, relationship or domestic violence, and stalking. This policy applies to the entire community, including male, female, and transgender students, as well as faculty and staff.
In case of an emergency, please call 911. For a complete list of reporting options and resources available both on- and off-campus, please visit the Northeastern Title IX website.

Contact

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