MSAI-337: DEEP LEARNING FOR NATURAL LANGUAGE PROCESSING

Winter 2025

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Teaching Assistants: Jacob John and Karan Garkel	**Place:** Technological Institute, Room #L211
Time: Tuesdays and Thursdays 12:30PM to 1:50PM	2145 Sheridan Rd, Evanston

Course Description: Natural Language Processing (NLP) is a branch of artificial intelligence that focuses on techniques that enable computers to understand, interpret and manipulate human language. Common NLP tasks include question answering, text classification (including fakes detection), text summarization, text generation (including dialogue, translation and program synthesis), natural language inference and knowledgebase completion, among others. Statistical language models are an essential component in modern approaches to these tasks.

In the first half of this course, we will explore the evolution of deep neural network language models, starting with n-gram models and proceeding through feed-forward neural networks, recurrent neural networks and transformer-based models. In the second half of the course we will apply these models to a variety of NLP tasks, and explore associated datasets, evaluation metrics, use cases and open research questions.

Office Hours: By appointment via Zoom (https://northwestern.zoom.us/j/93429505268).

Course Materials: No textbook. The course material will be comprised of class slides and periodic research papers/external readings.

Course Goals: The goal of this course is to familiarize students with a variety of NLP tasks including their motivation, methodologies, evaluation metrics and the current state-of-the-art. After completing this course, students will be able to generalize these fundamental techniques to a wide variety of applied and research problems in natural language processing.

Prerequisites: MSAI-349 and intermediate proficiency with Python.

Grading Policy: Grades are assigned using the standard scale (given in the "introduction" lecture notes), such that 93%-100% is an A, 90%-93% is an A-, etc. Points will be allocated as follows:

HW #1: Bengio (NNLM) and Transformer (GPT) Language Models	10 pts
HW #2: Generative Question Answering	10 pts
HW #3: Architecture Modification	10 pts
HW #4: To Be Determined	10 pts
Final Project - Proposal	5 pts
Final Project - Report	25 pts
In-class Final Exam (Individual)	30 pts

Students will form groups of up to four members for the homework assignments. You can drop from a group, but you may not join another group. You cannot drop from a group within one week of a deadline.

There are four homework assignments for the course. Each assignment focuses on a specific deep-learning task performed on a given dataset, and will consist of (i) a coding component in which the group will implement models in Python using a Jupyter notebook and (ii) a short question and answer part in which the group will demonstrate their understanding of the material. All group members should participate in all aspects of the homework assignments -- allocating specific activities to individual group members is inconsistent with the academic integrity policy. You may be asked to identify and rate other group members' contribution to each assignment. If individual group members are not contributing, you are responsible for promptly bringing this to my attention.

The final project accounts for approximately one-third of your grade. Final projects can be applied or research-focused on a topic of your choosing. I am available to discuss potential topics and project parameters. The final projects will consist of two deliverables: (a) a project proposal and (b) a final presentation. The proposal is typically about one page and describes the project, rationale, anticipated data source(s), and proposed deep learning models. The format of the final project report is to be determined.

Since most of the deliverables for the class are group assignments/projects, there will also be an in-class final exam. Exams will be "closed-book and closed-notes". Any material covered in class or homework assignments is fair game for the final exam.

Other Class Policies:

- You are responsible for making me aware in a timely manner of any accommodation that you may have through AccessibleNU so that they can be implemented appropriately,
- Video and/or audio recordings are not permitted unless performed by the instructor (sorry),
- Students are strongly encouraged to attend class in-person, and
- Students are expected to adhere to the University's Academic Integrity Policy.

Northwestern University Syllabus Standards

This course follows the Northwestern University Syllabus Standards (https://www.registrar.northwestern.edu/registration-graduation/northwestern-university-syllabus-standards.html). Students are responsible for familiarizing themselves with this information.

Calendar:

Week #1: Course Overview, Foundations of Language Models and N-Grams Models

- Introduction of class policies
- Overview of natural language processing tasks and final projects
- Definition and use cases of statistical language models
- Tokenization and corpus construction
- N-gram language models, cardinality, smoothing and back-off techniques, and perplexity calculations

Week #2: Neural Network Language Models

- Embedding spaces, distance metrics, the softmax function and temperature
- Word embedding analogy and similarity tasks, interpreting results and limitations
- Introduction of feed-forward neural network language models (Bengio model)
- Introduction of recurrent architectures (including LSTMs), and back propagation through time
- Training techniques for recurrent models: hidden state, drop-out and gradient clipping

Week #3: Transformer-Based Language Models

- Introduction of transformer-based models and encoder/decoder stacks
- Attention mechanism, key-query value calculations, multi-head attention and position encoding
- BERT: encoder-only stack, masked language modeling and next sentence prediction training objectives
- GPT-2: decoder-only stack, autoregressive training objective, web-scale corpora and multi-task learning

Week #4: Decoding and Text Classification

- Greedy decoding, beam search, constrained generation (NeuroLogic), BLEU, ROUGE and BERTScore
- Atomic feature representations: bag-of-words, tf-idf and knowledgebase encodings
- Using hidden states, sentence embeddings, label prediction and latent features
- Sentiment analysis, fakes detection (fact checking, stylometric and Grover) and associated datasets

Week #5: Question Answering

- Text summarization and simplification, evaluation metrics and limitations
- Multiple-choice, extractive and abstractive question answering
- Representative datasets (SQuAD 2.0, commonsenseQA, Winogrande and OpenBookQA, among others)
- Semantic parsing (logical forms, SQL and question decomposition meaning representations)

Week #6: Text Generation (Machine Translation, Program Synthesis and Dialogue)

- Statistical machine translation, neural machine translation, parallel corpora and low resource languages
- Program synthesis, differentiable beam search and data augmentation
- Dialogue generations, practical considerations and opportunities

Week #7: Large Language Models and Architectural Enhancements

- Review of large language model architectures and training corpora
- Instruction fine-tuning, Reinforcement Learning with Human Feedback
- Post-processing techniques: neural-cache, ensemble models and alternative evaluation metrics
- Insertion transformers, adapter modules, LoRA distillation model and NeuroLogic decoding

Week #8: Working with Large Language Models

- Chain-of-Thought prompting, Scratchpads for Intermediate Calculation, and other techniques
- Retrieval-Augmented Generation
- Rotary Position Embeddings (RoPE) and Attention with Linear Biases (ALiBi)
- Quantized language models and QLoRA

Week #9: Knowledgebase Completion and Natural Language Inference

- Information and relationship extraction, regular expressions and knowledgebase triples
- Abductive reasoning, implicit vs. explicit knowledge and knowledge augmentation
- Natural language inference, semantic equivalence, dataset construction and artifacts

Week #10: Course Review and Final Exam

- Course review
- In-class Final Exam

Finals Week

Final Project Presentations