CSCE 52803 Graph and Combinatorial Algorithms (3 credit hours)

Catalog Description: Advanced topics in graph and combinatorial optimization problems. Traditional approach section: P and NP problems, proof of NP-completeness, approximation algorithms for solving NP hard problems. Machine learning-based approach section: graph neural networks, deep reinforcement learning, state-of-the-art machine learning approaches for solving graph and combinatorial optimization problems, and learning-augmented algorithms.

Prerequisites: Graduate standing in CSCE.

Textbook / Required material: No textbook is required. The following materials are good references.

- Guichard, D. (2017). An introduction to combinatorics and graph theory. Whitman College-Creative Commons.
- Vazirani, V. V. (2001). Approximation algorithms (Vol. 1). Berlin: Springer.
- L. Wu, P. Cui, J. Pei, and L. Zhao. (2022). Graph Neural Networks: Foundations, Frontiers, and Applications. Springer, Singapore. Available online: https://graph-neural-networks.github.io/index.html
- Aston Zhang and Zachary C. Lipton and Mu Li and Alexander J. Smola (2020). Dive into Deep Learning. Available online: https://d2l.ai/
- Richard S. Sutton and Andrew G. Barto (2018). Reinforcement learning: An introduction. A Bradford Book, Cambridge, MA, USA.

Goals: This course will teach how to analyze the complexity of graph and combinatorial optimization problems and how to solve these problems from both heuristics/approximation algorithms and machine learning perspectives.

Student Learning Outcomes. By the end of this course, students will be able to:

- Determine and apply appropriate algorithms for solving classic tractable graph problems.
- Distinguish between P and NP problems.
- Analyze if a graph or combinatorial problem is NP-complete.
- Describe three methodologies for designing approximation algorithms.
- Design approximation algorithms for solving NP hard problems.
- Calculate the gradient of neural networks using backpropagation.
- Explain the architecture and update functions of different graph neural networks.
- Explain state, action, reward, etc. in reinforcement learning.
- Explain three deep reinforcement learning algorithms.
- Critically review the literature of research on machine learning for solving graph and combinatorial optimization problems.

Topics covered:

- Introduction and basics of graph theory (1 week)
- Tractable graph problems (shortest path, minimum spanning tree, bipartite matching, Euler tour) (1 week)
- P and NP (1 week)
- Approximation algorithms (greedy algorithms, LP relaxation and randomized rounding, analysis of approximation ratio) (2 weeks)

- Machine learning and neural network basics (1.5 week)
- Graph neural networks (1.5 week)
- Deep reinforcement learning (2 weeks)
- Learning-augmented algorithms (1 week)
- Traveling salesman problem (1 week)
- Paper presentation and discussion (3 weeks)
- Wrap up (1 week)

Grading
The grading in this course will be distributed as follows.

- Assignment: 45%
- Presentation and discussion: 25%
- Final exam: 30%

Assignment Description:
There will be 4 assignments which are closely related to the materials and topics covered in the class.

- Exercise questions about graph theory.
- Exercise questions about NP problem proven using polynomial reducibility.
- Exercise questions about designing greedy algorithms and computing approximation ratios.
- Programming in Colab about graph mining and graph neural networks.
- Exercise questions about neural networks.

Paper Presentation and Discussion Description:
A list of state-of-the-art research papers on solving intractable graph problems using machine learning will be provided. Students need to form groups and each group will be assigned one paper for presenting and leading the discussion. Other students also need to read the paper and involve in the discussion.

Academic Dishonesty Policy
As a core part of its mission, the University of Arkansas provides students with the opportunity to further their educational goals through programs of study and research in an environment that promotes freedom of inquiry and academic responsibility. Accomplishing this mission is only possible when intellectual honesty and individual integrity prevail. Each University of Arkansas student is required to be familiar with and abide by the University's 'Academic Integrity Policy' at honesty.uark.edu. Students with questions about how these policies apply to a particular course or assignment should immediately contact their instructor.

Class/laboratory schedule: Meets either 3 times a week for 50 minutes or 2 times a week for 75 minutes for 15 weeks.