Spring 2024 ME495: Applied Computational Intelligence for Engineering
Instructor: Professor Wing Kam Liu (w-liu@northwestern.edu), Walter P. Murphy Professor and Co-Founder of HIDENN-AI, LLC
Days and Times: Tuesday/Thursday -- 9:30 to 11:00
Location: TBD
Office hours: Before or after the class
Who should attend: Graduate students and senior undergraduate students with a background in applied mathematics and an interest in data science applications.
Graders/Computer Instructors: TBD

This course will introduce students to computational intelligence methodologies for converting scientific or engineering problems into data-driven *optimization* problems with solution obtained by *training and/or solving* using available data from mathematical scientific principles and *auto differentiation*. Materials, manufacturing, and multiphysics problems will be discussed and demonstrated, showing how large-scale problems in these fields can be reformulated using the new paradigm of *deep-learning-based* computations.

Project: Students must complete a final project. The proposal is due in the 5th week.

Homework: Four computer assignments related to the subject materials will be given.

Grading: Reading assignments (15%) + Homework (HW) (30%) + Midterm Project Proposal (20%) + Final project presentation and report (35%)

Prerequisites: Multivariate calculus, MATLAB, introductory knowledge of Python programming.

Week	Date (day)	Topic	Contents	Homework and Reading Assignments
Module 1: Training and optimization using kernel learning				
1		Opportunities in next generation of data-driven scientific computation: Tools of computational intelligence	Papers/lecture notes will be provided	Reading assignment assigned-1
2		Introduction to kernel, convolution, and integral transform *Discussion Topic: Determining mathematical operators with kernel learning*	Papers/lecture notes will be provided	Reading assignment assigned-2
		Feature extraction with Kernels: Fourier Transform; Short time Fourier transform	Papers/lecture notes. programs will be provided	Reading assignment-1 due. **HW1 (assigned)**
3		Feature extraction with Kernels: Fourier Transform; Short time Fourier transform *Discussion Topic: Short time Fourier transform in Signal Analysis*	Papers/lecture notes, programs will be provided	**HW2 (assigned)**
		Kernel feature extraction: Wavelet transform.	Papers/lecture notes. programs will be provided	**HW1 (due)**
4		Interpolation using reproducing kernel	Papers/lecture notes, programs will be provided	

		Kernel Learning: Formulation of the method	Papers/lecture notes, programs will be provided	
5		Kernel Learning: Applications *Discussion Topic: Wavelet transform and learning features in Additive Manufacturing Process Design*	Papers/lecture notes, programs, data will be provided	**HW 2 (Due)**
		Midterm Proposal Presentation		
Module 2: Hierarchical Deep Learning Neural Networks				
6		From Interpolation to Neural Network and Hierarchical deep learning neural network (HiDeNN)	Papers/lecture notes, programs, data will be provided	**HW 3 (assigned)**
		Solving and Training Partial Differential Equations (PDE) using HiDeNN *Discussion Topic: Applying Pruning and HiDeNN for Efficient Construction of Neural Network*	Papers/lecture notes, programs, data will be provided	
7		Convolution-HiDeNN (C-HiDeNN) for space-time-parametric problems	Papers/lecture notes, programs, data will be provided	**Reading Assignment 3 assigned**
		Solving and training Partial Differential Equations (PDE) using HiDeNN	Papers/lecture notes, programs, data will be provided	
8		Solving and training Partial Differential Equations (PDE) using C-HiDeNN	Papers/lecture notes, programs, data will be provided	**HW 3 (Due)**
Module 3: Parameterized physics-based reduced-order methods for large-scale problems				
8		Introduction to dimensionality reduction: Singular value decomposition (SVD)	Papers/lecture notes will be provided	**Reading Assignment 3 due**
9		Proper generalized decomposition (PGD) and tensor decomposition (TD) *Discussion Topic: Applying Tensor Decomposition for compressing a Neural Network*	Papers/lecture notes, programs, data will be provided	**HW 4 (assigned)**
		Convolution-HiDeNN-TD: parameterized physics-based reduced order method	Papers/lecture notes, programs, data will be provided	
10		Application of C-HiDeNN-TD for design and topology optimization	Papers/lecture notes will be provided	**HW 4 (Due)**
		Lecture and Discussion on Integrating three modules to solve a design problem	**Summary**	
		Final project review and presentation		

- Each HW will involve a theoretical analysis and computer implementation. HW will be announced at the beginning of the module, and the relevant concepts will be discussed in the class.
- The reading assignments will be designed to expose the students to the broader application of the methods and some necessary materials for comprehension of the lectures. These will be in written report format.
- **Final project:** students are encouraged to propose a project based on their own research using the methods taught in this course. Students without research projects will be given ideas for projects.