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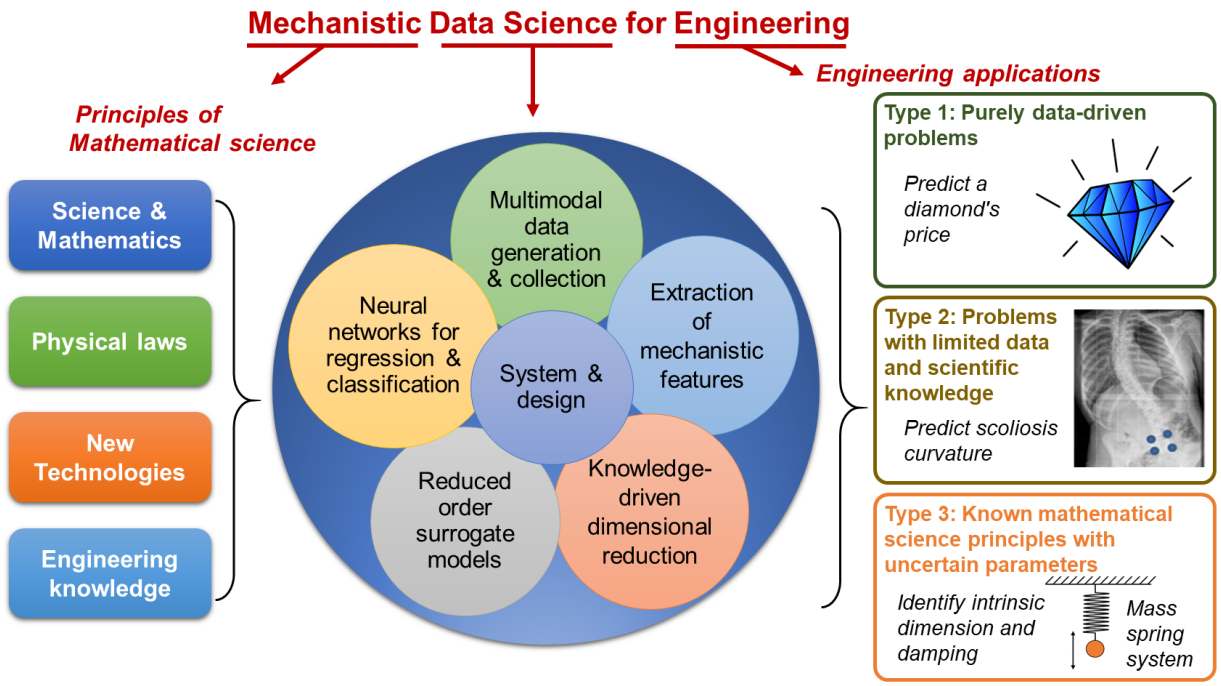
Course ME395 – Mechanistic Data Science for Engineering

Instructors: **Prof. Wing Kam Liu, w-liu@northwestern.edu, Tech A326, 847-491-7094**
Prof. Zhengtao Gan, zhengtao.gan@northwestern.edu
Guest speaker: **Prof. Mark Fleming, mark.fleming@northwestern.edu**
Graders: **Sourav Saha, SouravSaha2023@u.northwestern.edu;**
Chanwook Park, chanwookpark2024@u.northwestern.edu
Meet on **Tu Th 9:30 AM-10:50 AM, Tech LG66**
***Zoom link*:** Meeting ID: 981 8055 5772 https://northwestern.zoom.us/j/98180555772
*Students must login through Canvas
Who should take the class? **Senior and graduate engineering students**

Goals: Introduce mechanistic data science for engineering through the integration of ***mathematical scientific principles*** using ***six basic data science concepts***: multimodal data generation and collection, extraction of mechanistic features, knowledge-driven dimension reduction, reduced order surrogate models, regression and classification models, and system and design. These concepts will be implemented using Python and MATLAB for ***engineering applications***.



Syllabus

Date	Week	Content	Homework Assignment	Instructor
09/21 Tu	1	***Introduction to mechanistic data science*** (a) Basic science and engineering concepts and six modules of data science (b) Diamonds are forever; (c) Coronary artery disease (CAD) diagnosis	HW1: read article on MDS, Describe Mechanistic Data Science (in your own words) – 1 page (Due 09/28)	Wing Liu

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09/23 Th		***Basic examples and tools of data science*** (a) Motion tracker and spring-mass-damper, (b) Sound conversion: piano to guitar	HW2: propose a real-life problem that can be solved by the six modules (Due 10/05)	
09/28 Tu	2	***Multimodal Data generation and collection*** (a) Database (b) Sources of data (c) Data generation using models (d) Programming tools – MATLAB/Octave & Python	HW3: collect data and generate a database for the problem you have proposed (Due 10/12)	Yangfan and Hengyang
09/30 Th		***Linear regression and optimization*** (a) Major League Baseball (MLB) (b) Linear regression (c) Least squares optimization		Yangfan and Hengyang
10/05 Tu	3	***Non-linear Regression*** (a) Bacteria growth (b) Introduce non-linear regression (c) Least-squares optimization (d) Moving least-squares	HW4: perform linear and nonlinear regression using your dataset (Due 10/14) Project proposal submission (Due 10/14)	
10/07 Th		***Extraction of Mechanistic Features: Fourier analysis*** (a) Feature engineering with example (b) Data dependence on relevant features (a) Fourier series and Fourier transformation (b) Gravitational wave detection		
10/12 Tu	4	***Extraction of Mechanistic Features: Convolution*** (a) 1-D convolution (b) 2-D convolution (c) High-D convolution		
10/14 Th		***Extraction of Mechanistic Features: Imaging*** (a) X-ray imaging (b) Construction of 3D geometry from 2D images (c) Adolescent Idiopathic Scoliosis (AIS) example	HW5: use relevant feature extraction techniques on your data. (Fourier/convolution/image features) (Due 10/19)	
10/19 Tu	5	***Knowledge-Driven Dimensional reduction 1: clustering*** (a) Jenks Natural Breaks (b) K-means clustering (c) Clustering for 2D and 3D data (d) Engineering applications		
10/21 Th		***Knowledge-Driven Dimensional reduction 2: SVD/PCA*** (a) Mass-spring oscillator example (b) Singular value decomposition (SVD)	HW6: use relevant dimension reduction techniques (SVD/PCA/ Clustering) to reduce the	

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		(c) Principal component analysis (PCA) (d) Reduced order modeling	dimension of your data. (Due 10/26)	
10/26 Tu	6	***Midterm Presentations***	Presentation on HW up to dimension reduction	
10/28 Th		***Neural Network Fundamentals*** (a) Indentation testing example (b) Basic concepts, terminology, layers (c) Activation functions (d) Forward learning (e) Back-propagation learning through error minimization		
11/02 Tu	7	***Neural Network for Regression and Classification*** (a) Feed Forward Neural Networks (FFNN) for diamond price and nano-hardness prediction (b) Convolutional Neural Networks (CNN)	HW7: use suitable neural network for regression and classification of your data (Due 11/07)	
11/04 Th		***Advanced Manufacturing Application***: 3D printing (a) Predict distribution of mechanical properties using thermal history as input (b) Confidence and prediction intervals based on estimation statistics		
11/09 Tu	8	***Materials Design Application***: Composite material (a) Design of a composite football helmet		
11/11 Th		***Biomechanics Application***: Spine growth prediction (a) Develop a clinically validated patient-specific FEM of the spine. (b) Predict AIS progression using data mining.	HW 8: apply previous HW's knowledge for system and design analysis of your problem. (Due 11/18)	
11/16 Tu	9	***Physics Application***: DimensionNet for dimensional analysis		
11/18 Th		Additional applications		
11/23 Tu	10	Discussion/Presentations		
11/26 Th		Thanksgiving vacation		
11/30 Tu		Discussion/Presentations		
TBD		***Final Projects Presentation***		

Grading: Attendance (15%) Homework assignments (20%), midterm (30%), and final projects (35%)

Grading will be based on homework assignments, a midterm project, and a final project

Homework: there will be one homework set for each of the five modules. Homework will be due 1 week after assignment. Homework must be submitted in the provided report format.

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Midterm project: The midterm project will be based on the integration of modules 1 - 3 proposed by the students.

The midterm project will be due 2 weeks after assignment.

Final project: The final project will be a scientific or engineering application of the integration of all five modules discussed in the class.

The final project will be due during finals week.

Homework and assignment

HW1 (Due Date 09/23): Read article on Mechanistic Data Science (MDS), Describe Mechanistic Data Science (in your own words) – 1 page

HW2 (Due Date 10/05): Propose a real-life problem that can be solved by the six modules of mechanistic data science. For graduate student it can be related to their own research. Undergraduate student can look at common database for finding a problem. (Brief summary and six steps in one page)

We will have some back up problem for the student if you cannot find one.

HW3 (Due Date 10/05): Data collection and database generation on your proposed problem. (Details report with analysis of results)

HW4 (Due Date 10/10): Perform linear and non-linear regression on your collected data. (Details report with analysis of results)

HW5 (Due Date 10/19): Use relevant feature extraction techniques on your data. (Fourier/convolution/image features) (Details report with analysis of results)

HW6 (Due Date 10/26): Use relevant techniques (SVD/PCA/ Clustering) to reduce the dimension of the data. (Details report with analysis of results)

Midterm: Short presentation on Homework 2-6.

HW7 (Due Date 11/07): Use relevant Neural network for regression and classification of your data. (Details report with analysis of results)

HW8 (Due Date 11/18): Apply the previous Homework's knowledge for system and design. (Details report with analysis of results)

Final presentation: Present all the homework results in a presentation and submit a full report (compiled from all previous homework) on the completed project.

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COVID-19 Classroom Expectations Statement

Students, faculty, and staff must comply with University expectations regarding appropriate classroom behavior, including those outlined below and in the COVID-19 Code of Conduct. With respect to classroom procedures, this includes:

- Policies regarding masking and social distancing evolve as the public health situation changes. Students are responsible for understanding and complying with current masking, testing, Symptom Tracking, and social distancing requirements.
- In some classes, masking and/or social distancing may be required as a result of an Americans with Disabilities Act (ADA) accommodation for the instructor or a student in the class even when not generally required on campus. In such cases, the instructor will notify the class.
- No food is allowed inside classrooms. Drinks are permitted, but please keep your face covering on and use a straw.
- Faculty may assign seats in some classes to help facilitate contact tracing in the event that a student tests positive for COVID-19. Students must sit in their assigned seats.

If a student fails to comply with the COVID-19 Code of Conduct or other University expectations related to COVID-19, the instructor may ask the student to leave the class. The instructor is asked to report the incident to the Office of Community Standards for additional follow-up.

COVID-19 Testing Compliance Statement

To protect the health of our community, Northwestern University requires unvaccinated students who are in on-campus programs to be tested for COVID-19 twice per week.

Students who fail to comply with current or future COVID-19 testing protocols will be referred to the Office of Community standards to face disciplinary action, including escalation up to restriction from campus and suspension.

Academic Integrity Statement

Students in this course are required to comply with the policies found in the booklet, "Academic Integrity at Northwestern University: A Basic Guide". All papers submitted for credit in this course must be submitted electronically unless otherwise instructed by the professor. Your written work may be tested for plagiarized content. For details regarding academic integrity at Northwestern or to download the guide, visit: https://www.northwestern.edu/provost/policies/academic-integrity/index.html

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Prohibition of Recording Classes by Students

Unauthorized student recording of classroom or other academic activities (including advising sessions or office hours) is prohibited. Unauthorized recording is unethical and may also be a violation of University policy and state law. Students requesting the use of assistive technology as an accommodation should contact AccessibleNU. Unauthorized use of classroom recordings – including distributing or posting them – is also prohibited. Under the University's Copyright Policy, faculty own the copyright to instructional materials – including those resources created specifically for the purposes of instruction, such as syllabi, lectures and lecture notes, and presentations. Students cannot copy, reproduce, display, or distribute these materials. Students who engage in unauthorized recording, unauthorized use of a recording, or unauthorized distribution of instructional materials will be referred to the appropriate University office for follow-up.

Support for Wellness and Mental Health

Northwestern University is committed to supporting the wellness of our students. Student Affairs has multiple resources to support student wellness and mental health. If you are feeling distressed or overwhelmed, please reach out for help. Students can access confidential resources through the Counseling and Psychological Services (CAPS), Religious and Spiritual Life (RSL) and the Center for Awareness, Response and Education (CARE). Additional information on all of the resources mentioned above can be found here:

https://www.northwestern.edu/counseling/

https://www.northwestern.edu/religious-life/

https://www.northwestern.edu/care/