AEROSP 729
Data-driven Analysis and Modeling of Complex Systems

3 Credits, Winter 2017, Tu/Thu 1:30-3:00pm, FXB 1012.

Instruction:

Instructor: Karthik Duraisamy, FXB 3009, kdur@umich.edu.

Guest Lecturers:

Prof. Nathan Kutz, Applied Mathematics, University of Washington.

Prof. Steve Brunton, Mechanical Engineering, University of Washington.

Course goals:

The objective of this course is to learn to effectively use data in the analysis and modeling of complex, real-world problems. Specifically, we will study the use of data to

1. Augment existing models to improve predictive accuracy,
2. Discover the structure of the underlying physical system,
3. Decompose the system into a simpler form to aid our understanding,
4. Develop mathematically formal reduced-order models to enable efficient prediction.

While this course is focused on applications, we will study the basics of several mathematical tools and techniques.

Course materials:

No text book is required. Handouts will be provided to supplement in-class teaching. Additional reading material and homework will be posted on Canvas. We will also study a few journal papers in detail. The following are excellent references:

1. *Data-driven Modeling and Scientific Computation*, Kutz, Oxford University Press, 2013.
2. *Parameter Estimation and Inverse Problems*, Aster/Borchers/Thurber, Wiley, 2013.
3. *Approximation of Large-Scale Dynamical Systems*, Antoulas, SIAM 2005.

Pre-requisites:

Exposure to scientific computing, adequate programming skills and basic command of linear algebra and differential equations.

Course contents (Some topics may not covered):

<u>Introduction</u>

- Modeling, data, uncertainty & predictive science
- Overview of tools & techniques

<u>Math basics</u>

- Functional analysis
- Linear algebra & Spectral theory
- Adjoint operators and dual space
- Least-squares and L1-regression
- Basic probability & statistics

<u>The idea of augmenting models with data</u>

- Sensitivity analysis using adjoints
- Parameter and function estimation
- Bayesian inversion

<u>The idea of data-driven discovery</u>

- Regression in feature space
- Sparse identification of dynamical systems

<u>Dynamical systems & observables</u>

- Phase portraits, equilibria, bifurcations

- Normal forms
- Lyapunov exponents and chaos
- Probabilistic properties of deterministic systems
- Koopman and Perron-Frobenius operators

Data-driven decompositions & modeling

- Proper orthogonal decompositions
- Dynamic mode decomposition
- Koopman decomposition
- Kernel methods

Reduced-order modeling

- Projection-based Model Reduction
- Balanced truncation and balanced residualization
- Techniques for Non-linear Model Reduction

Grading:

Homeworks/projects : 70 %,
Written mid-term : 15 %,
Oral final exam : 15 %