ASEN 6412
Uncertainty Quantification (UQ)

Spring 2024

Class meetings: T/Th 10:00 AM - 11:15 AM in AERO 232

Instructor:

Alireza Doostan
Smead Aerospace Engineering Sciences, AERO 363
Tel: 303-492-7572
E-mail: doostan@colorado.edu
Office hours: T/Th 12:00 - 1:30 PM at AERO 363, otherwise by appointment.
Zoom link (only office hours): https://cuboulder.zoom.us/

Prerequisites:

Prerequisite is a B or better in ASEN 5070, APPM 5520, APPM 5570, ECEN 5612, or equivalent courses with instructor consent.

References:

- R. Smith, Uncertainty Quantification: Theory, Implementation, and Applications, SIAM, 2013
- R. Ghanem and P.D. Spanos, Stochastic Finite Elements: A Spectral Approach, Dover, 1991
- D. Xiu, Numerical Methods for Stochastic Computations: A Spectral Method Approach, Princeton University Press, 2010
- O. P. Le Maitre and O. M. Knio, Spectral Methods for Uncertainty Quantification: With Applications to Computational Fluid Dynamics, Springer Verlag, 2010
- R. Aster, B. Borchers, and C. Thurber, Parameter Estimation and Inverse Problems, Elsevier Academic Press, 2005

Grading:

- Homework (35%)
- Mid-term exam (25%)
- Final project (40%) with the following break down: Proposal (20%), Presentation (40%), and Report (40%)

Some notes:

- Homework problems involve combinations of analytical, numerical, or paper review tasks
- Please answer homework problems as clear and clean as possible. 10% of the homework grade goes to clarity
- No late homework submissions will be accepted unless there is an emergency
- Sharing thoughts on homework problems is encouraged; however, every student must submit their homework

Course objectives:

This course will provide an introduction to recent techniques for representation and propagation of uncertainty in PDE/ODE-based systems. Students will be exposed to the state-of-the-art techniques for building probabilistic models (from data) and simulation of random processes, as well as numerical solution of PDEs/ODEs in the presence of uncertainty. A number of case studies from computational solid and fluid mechanics will be discussed.

Course content (tentative):

- (Quick) review of basic probability and statistics:
  - Probability space, random variables, vectors, and processes
  - Convergence of random sequences
- Simulation of random variables, vectors, and processes with *known* distribution:
  - Simulation of random variables: Inversion and rejection techniques
  - Karhunen-Loeve expansion
  - Simulation of Gaussian and non-Gaussian random vectors and processes
- Introduction to modeling/simulation of random processes with *unknown* distribution:
  - Parameter estimation methods – Maximum likelihood and Bayesian
  - Generative modeling – Variational Auto-Encoders (VAEs)
- Solution of PDEs/ODEs with random inputs:
  - Monte Carlo techniques – Standard sampling, Latin Hypercube sampling, and importance sampling
  - Multi-level (and Multi-fidelity) Monte Carlo techniques
  - Polynomial chaos and generalized polynomial chaos expansions
  - Tensor-product and Smolyak sparse grid methods
  - Gaussian process regression (Kriging)
- Advanced topics:
  - Global sensitivity analysis
  - Application of Deep Neural Networks (DNNs) in UQ
  - Application of model reduction techniques in UQ (low-rank, sparse, and multi-fidelity) techniques

Syllabus Statements

Classroom Behavior

Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation, or political philosophy.

For more information, see the classroom behavior policy, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

Requirements for Infectious Disease

Members of the CU Boulder community and visitors to campus must follow university, department, and building health and safety requirements and all applicable campus policies and public health guidelines to reduce the risk of spreading infectious diseases. If public health conditions require, the university may also invoke related requirements for student conduct and disability accommodation that will apply to this class.

If you feel ill and think you might have COVID-19 or if you have tested positive for COVID-19, please stay

home and follow the guidance of the Centers for Disease Control and Prevention (CDC) for isolation and testing. If you have been in close contact with someone who has COVID-19 but do not have any symptoms and have not tested positive for COVID-19, you do not need to stay home but should follow the guidance of the CDC for masking and testing.

Accommodation for Disabilities, Temporary Medical Conditions, and Medical Isolation

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition, see Temporary Medical Conditions on the Disability Services website.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the Honor Code may include but are not limited to: plagiarism (including use of paper writing services or technology such as essay bots), cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty.

All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: honor@colorado.edu, 303-492-5550. Students found responsible for violating the Honor Code will be assigned resolution outcomes from the Student Conduct & Conflict Resolution as well as be subject to academic sanctions from the faculty member. Visit Honor Code for more information on the academic integrity policy.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits protected-class discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. These behaviors harm individuals and our community. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureport@colorado.edu. Information about university policies, reporting options, and support resources can be found on the OIEC website.

Please know that faculty and graduate instructors must inform OIEC when they are made aware of incidents related to these policies regardless of when or where something occurred. This is to ensure that individuals impacted receive outreach from OIEC about resolution options and support resources. To learn more about reporting and support for a variety of concerns, visit the Don't Ignore It page.

Religious Accommodations

Campus policy requires faculty to provide reasonable accommodations for students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. Please communicate

the need for a religious accommodation in a timely manner.

Mental Health and Wellness

The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact Counseling and Psychiatric Services (CAPS) located in C4C or call (303) 492-2277, 24/7.

Free and unlimited telehealth is also available through Academic Live Care. The Academic Live Care site also provides information about additional wellness services on campus that are available to students.