

Stochastic Methods in Engineering (AMCS 308)

INSTRUCTOR: Prof. Raúl Tempone

TEACHING ASSISTANT: Chiheb Ben Hammouda

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CLASS SCHEDULE: Monday and Wednesday from 14:30 to 16:00 in room 4136, Building 1.

Starts on Sunday, January 24, 2016, in room 2131.

OFFICE HOURS:

- TBA (Raúl Tempone, Building 1, room 4109.)
- Thursday from 2 pm to 4 pm (Chiheb Ben hammouda, Campus Library, level 2, sea side, 2rd room.)

Additional office hours may be assigned by appointment.

ELIGIBILITY: The course is organized by AMCS-KAUST. It is the student's responsibility to check and prove eligibility.

PREREQUISITES: The prerequisite for the course is knowledge of basic courses in mathematics, probability, and numerical analysis, or the equivalent. Some experience of computer programming and the use of UNIX/LINUX/WINDOWS systems or personal computers is assumed.

CO-REQUISITES: The homework and computer laboratories constitute a very important part of the course. Computer assignments will be done in MATLAB. Enrolled students will have access to computer facilities with MATLAB at KAUST if needed.

TEXT: The course largely follows the lecture notes from the corresponding Stanford course [3]; additional reading will include parts of the books [1, 5, 6, 4, 2, 7]. Other references will be recommended during the course. The projects at the end of the course may be selected from research papers.

COURSE OBJECTIVES: The student who follows this course will get acquainted with different mathematical models and computational tools used to analyze systems with uncertainty arising in engineering, physics, chemistry, and economics.

COURSE OUTLINE:

Probability Basics [1, 3, 6]

- Probability refresher
- Conditional Expectation
- Bayesian Statistics

The Monte Carlo Method [1, 3, 7]

- Sampling of random variables
- The Central Limit Theorem and related results
- Convergence rates and confidence intervals
- Variance reduction techniques
- Kernel density estimators
- Chernoff inequality and large deviations
- Resampling techniques

Linear and Gaussian Models [6, 3]

Discrete Time Markov Chains [5]

Bayesian Filters, Kalman Filters and state estimation [4]

Continuous-Time Markov Chains [5]

- Pure jump processes
- SSA and Tau leap

Markov Chain Monte Carlo [2, 7]

Additional topics such as, for instance, Bayesian Experimental Design, Stochastic Control, Model Selection and Model Validation, can be covered along the course, if time allows for, or can be the subject of the course project.

GRADING: There will be a closed book, classroom, final examination, as scheduled by the registrar during final week May 15 – 19, 2016.

The grading consists of three parts: homework problems, oral presentations and a written exam. The homework and the presentations are carried out by *groups of students*. Each group hands in a report for each of the assignments, including the final project presentation.

Concerning presentations: Homework problems, book chapters and final projects are presented by lab groups according to a certain schedule. Prepare a presentation of at most 30 minutes with overhead material including the formulation of the problem, theoretical analysis, results from computer simulations, conclusions, open questions etc. Take the presentation seriously and use it as an opportunity of getting some practical training in the difficult art of oral presentation. Remember that presenting a material in a clear and convincing way requires quite a bit of preparation and training to be successful. We all need practice and positive criticism in this respect, both teachers and students. *Rehearse before presenting the material!* Make sure you will fit into the allocated time slot and be ready to answer probing questions about all the content being presented (not necessarily the part you present)!

Concerning Homework:

Each group should hand in a written solution. The homework has two purposes: it poses an exercise on a new mathematical concept or method and gives the opportunity to practice written presentations of solutions. *This means that a solution with just formulas is not acceptable.* The solution should resemble the lecture note's presentation of an

example and not the teacher's shortened version of it when he presents on the blackboard.

The presentation shall be prepared in such a way that a fellow student who has been away for two weeks should be able to understand and be satisfied with it. Describe the formulation of the problem, the theoretical background, the results and some eventual conclusions.

A solution that does not have an acceptable grade can be completed and resubmitted within one week after the corresponding oral presentation. Use this opportunity well.

Numerical course grades will be determined according to the formula

$$\text{Total Score} = (30 * (\text{Final Exam}) + 40 * (\text{Average Homework}) + 10 * (\text{Book Chapter presentation}) + 20 * (\text{Final Project Presentation}))/100$$

SPECIAL ACCOMMODATIONS If you have personal activity, a family, or a religious conflict with the course schedule, you may announce it to the instructor. Please contact the instructor by the end of the second week of the term to discuss appropriate accommodations for any conflicts that can be foreseen. For illness-related absences, there are standard procedures to follow.

EXAM POLICY: No quizzes or tests other than the final exam will normally be given. Acceptable medical excuses must state explicitly that the student should be excused from class.

HONOR CODE: The Academic Honor of KAUST is based on the premise that each student has the responsibility 1) to uphold the highest standards of academic integrity in the student's own work, 2) to refuse to tolerate violations of academic integrity in the University community, and 3) to foster a high sense of integrity and social responsibility on the part of the University community. Please note that violations of this Academic Honor System will not be tolerated in this class. Specifically, incidents of plagiarism of any type or referring to any unauthorized material during examinations will be rigorously pursued by this instructor. Before submitting any work for this class, please make sure you understand the above and ask the instructor to clarify any of its expectations that you do not understand.

References

- [1] S. Asmussen and P. W. Glynn. *Stochastic Simulation: Algorithms and Analysis*. Springer, 2007. A broad treatment of sampling-based computational methods with mathematical analysis of the convergence properties of the methods discussed.
- [2] D. Gamerman and H. F. Lopes. *Markov Chain Monte Carlo*. Chapman & Hall/CRC, second edition, 2006.
- [3] P. W. Glynn. *Stochastic Methods in Engineering*. Stanford University. Lecture Notes for the corresponding course at Stanford.
- [4] J. Kaipio and E. Somersalo. *Statistical and Computational Inverse Problems*. Springer, 2005.
- [5] J. R. Norris. *Markov Chains*. Cambridge University Press, 1997. Discrete-time and continuous-time Markov chains with applications to simulation in Chemistry and Physics, economics, optimal control, genetics, queues and many other topics.
- [6] D. S. Sivia and J. Skilling. *Data Analysis, a Bayesian Tutorial*. Oxford University Press, second edition, 2006. Basic principles of Bayesian probability theory – their use illustrated with examples ranging from elementary parameter estimation to image processing. Other topics covered include reliability analysis, multivariate optimization, least-squares and maximum likelihood, error-propagation, hypothesis testing, maximum entropy and experimental design.
- [7] J. Voss. *An Introduction to Statistical Computing*. Wiley, 2014.