Course 02443: Stochastic Simulation, June 2020

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Textbook: Suggested reading material is:

- Simulation, Sheldon M. Ross, Elsevier, 2013.
- Simulation Modeling and Analysis, Søren Asmuussen and Peter W. Glyn Springer, 2015.
- Introducing Monte Carlo Methods with R, C.P. Robert and G. Casella, Springer, 2010.
- Numerisk Simulation), Villy Bæk Iversen, DTU, 2007.

Supplementary reading: Some other books I consult, copies of selected material available at DTU Inside

- Simulation Modeling and Analysis, Averill M. Law, Mcgraw-hill, 2013 (5ed). Chapter 5 of edition 4.
- Modern Simulation and Modeling, Reuven Y. Rubinstein and Benjamin Melamed, Wiley, 1998. Selected material.

You do not necessarily have to study this wealth of material, indeed the course is experimental by nature, so ideally you should be able to solve exercises and problems by following the lectures and reading the slides. However, most students probably aim for more than that, particularly students who are already quite familiar with the basic concepts of probability and statistics. The course relies to a high degree on the Danish phrase ``Ansvar for egen læring" (own responsibility of learning). In case you find the course too easy you are highly encouraged to dig deeper into the reading material and solve additional exercises from the text books.

Lectures will be online. If time permits, all lectures will be prerecorded. As for now lectures are prerecorded for the first two teaching days. starting Thursday 4/6, 9.00. Lectures will continue until Monday 15/6.

Computer exercises are carried out online individually by each student. However, students assist each other in groups of three and overlap of code is accepted as long as each student demonstrate individual contribution and understanding. This approach is necessary as a heavy workload on the TA's is expected.

When help is needed it is the group that requires help rather than the individual student. When you need help, please you the form

Teaching assistant help request form.

We hope this will be an efficient way for the supervision process, but changes might be needed as the course progresses. We hope for your understanding, even if the wait for help in cases might end up being unacceptably long.

You are highly encouraged to form groups of three students in advance in case you already know other course participants, which you would like to work with. There is a group hand-in created at DTU Inside, where you have to register as soon as you have formed a group. It is important that all students "hand in" under the group name. You can upload an additional file with group member names, but it is not necessarey. All such groups should be formed and registered not later than 1 pm (13.00) Thursday June 4. After the deadline the teachers will form groups for students, who are not in a group yet. We will try to team you up with other students following the same or supposedly similar study lines.

The computer exercises can be found at the end of their associated slideshow. The computer exercises must be documented in reports and handed in not later than Wednesday 17/6, preferably Monday 15/6. Each group of three students write a common report with the individual coding attached as appendices. The report should document that the exercises have been solved. It is sufficient to provide extended lab notes, which is to be interpreted as computer code intertwined with plots and tables. The conclusions and lessons learned should be added in text. Nice hand writing of this textual explanation is acceptable.

Simulation project From Monday 15/6 until Thursday 25/06, students will work on a specific topic. A report of this work must be handed in on Thursday 25/06, with a possibility for an extension. Team sizes can vary. However, teams of 4-5 students are considered most adequate.

Any **language** implementing the most common probability and statistics functions (e.g. R, Matlab, Python) can be used. See e.g. R for Beginners by Emmanuel Paradis 76 pp.

Course plan:

- All videos.
- Day 1 - June 4, **Introduction and Generating Random Numbers**
  - Reading: Slides are intended to be reasonably sufficient
    Ross (R13) Chapter 3 (C3) (limited information), R13C11, Asmussen and Glynn (AG07) Chapter 1 Section 1 (C1S1), (Iversen (I07) Kapitel 3 (K3)) Supplementary: Law (L07) Chapter 7,
  - 9.00 - 10.00 : Introduction. Slide show.
    - Introduction (video).
    - Continuous random variables (video).
    - Conditional densities and covariance/correlation - Apparently problem with blackboard, although live streaming seemed to work (video).
  - 10.00 - 11.00 : Generating Random Numbers. Slide show.
    - Generating random numbers (video).
  - 11.00 - 12.00 : Testing Random Numbers. Slide show.
    - Testing random numbers (video).
    - Chi-square test (video).
    - Kolmogorov-Smirnov test (video).
    - Test for correlation (video).
  - 13.00 - 17.00 : Computer exercise 1: Generation and testing of random numbers.

- Day 2 - June 8, **Sampling from Discrete & Continuous Distributions**
  - Reading: Slides are intended to be reasonably sufficient
    R13C4, R13C5, AG07C2S2, AG07C2S3, I07K4
  - 9.00 - 10.00: Sampling from Discrete Distributions. Slide show.
    - Generation of discrete random variables (video).
    - Simple rejection method for discrete random variables (video).
    - Alias method (video).
    - General acceptance/rejection for discrete random variables NB! Camera signal lost, but this one should work anyway (video).
  - 10.00 - 12.00: Computer exercise 2: Sampling from discrete distributions.
  - 13.00 - 14.00: Sampling from Continuous Distributions. Slide show.
    - Generating continuous random variables - the inverse transformation technique (video).
    - Generating continuous random variables - the inverse transformation technique - some examples (video).
    - Generating normal random variables (video).
    - Generating hyperexponential and Erlang random variables (video).
  - 14.00 - 17.00: Computer exercise 3: Sampling from continuous distributions.

- Day 3 - June 9, **Discrete Event Simulation**
  - Reading: R13C7, RM98C1, I07C6
  - 9.00 -10.00: Discrete event simulation. Slide show.
    - Discrete Event Simulation - event by event principle (video).
    - Discrete Event Simulation - queueing systems (video).
    - Discrete Event Simulation - output analysis (video).
  - 9.00 -10.00: Discrete event simulation - ferry simulation example. Slide show.
    - Discrete Event Simulation - ferry simulation example NB! Camera signal lost, but this one might work anyway (video). Drawing from blackboard to compensate for lost camera signal.
  - 11.00 - 12.00: Computer exercise 4: Discrete event simulation.
  - 13.00 - 17.00: Computer exercise 4 continued

- Day 4 - June 10, **Simulation Software and Variance Reduction Methods**
  - Reading: R13C9, AG07C5
  - 9.00 - 10.00: Simulation Software. Slide show (draft) I decided not to record a lecture. It is a soft topic. I suggest you read the slides, which might give you the main message. Another set of slides from a guest lecturer on discrete event simulation Guest lecturer Daniel Karnøe Svendsen Integrate
  - 10.00 - 11.00: Variance Reduction Methods. Slide show
    - Variance reduction methods, the crude Monte Carlo estimator (video).
    - Antithetic variables (video).
    - Control variates(video).
    - Stratified sampling, imprtance sampling, common random numbers(video).
  - 11.00 - 12.00: Computer exercise 4 continued & computer exercise 5: Variance reduction methods.
  - 13.00 - 17.00: Computer exercise 4 & computer exercise 5 continued.

- Day 5 - June 11, **Markov Chain Monte Carlo & Simulated Annealing**
  - Reading: R13C12
  - 9.00 - 10.00: Markov chains. Slide show.
    - Markov chains (video).

        - Markov chains - example (I forgot to stop streaming - you should skip from 12:22, will edit when time permits) (video).
    - 10.00 - 11.00: Markov chain monte carlo. Slide show.
        - Markov Chain Monte Carlo (MCMC) introduction (video).
        - MCMC Metropolis-Hastings algorithm (video).
        - MCMC ibbs sampling and wrap up (video).
    - 11.00 - 12.00: Computer exercise 6: Markov chain monte carlo.
    - 13.00 - 14.00: Computer exercise 6 continued.
    - 14.00 - 15.00: Simulated Annealing. Slide show. Kirkpatrick et. al. Science 1983.
        - Simulated annealing an optimisation problem (MCMC) introduction (video).
        - Simulated annealing Metropolis-Hastings algorithm (video).
        - Simulated annealing travelling salesman problem (video).
    - 15.00 - 17.00: Computer exercise 7: Simulated annealing. The matrix needed can be download here. Prepared for Matlab.

- Day 6 - June 12, **Bootstrap**
    - Reading: R13C8S7.3
    - 9.00 - 10.00 Bootstrap. Slide show.
        - Boostrap motivation (video).
        - Boostrap empirical distribution (video).
        - Boostrap replicate NB! Camera signal lost, but this one should work anyway(video).
    - 10.00 - 12.00: computer exercise 8:Bootstrap.
    - 13.00 - 17.00: Computer exercise 6,7 & 8 continued.

- Day 7 - June 15, **Project suggestions**
- Presentation of projects Project list.

- Day 8 - June 16, **Simulation Modeling, Statistical Design of Simulation Experiments Projects**
    - Reading: Law and Kelton Chapter 5
    - 15.00 - 15.30: Simulation modeling. Slide show (draft)

Last change: 15/6 2020, by bfn