University of Illinois at Urbana-Champaign

COURSE OUTLINE

This proposal is for [X] A new course Proposed effective date Fall 2013

[ ] A revised course Proposed effective date

1. College/School: Engineering Department: Nuclear, Plasma and Radiological Engineering

2. Rubric and course Number: NPRE 498MC Title: **Monte Carlo Simulation, Science and Engineering Applications**

a. If revision involves change of number or title, give number and title of existing course:

b. If this course replaces existing course(which should be dropped), indicate number and title:
NE490S: Numerical Transport Methods for Fission and Fusion. The course when taught covered the Monte Carlo Method as well as the Discrete Ordinates method. Evaluation of the course suggested the need to devote the course exclusively to the Monte Carlo Method.

c. If course is to be cross-listed, indicate department(s) and course numbers): CSE 4**

d. If cross-listed, indicate controlling department responsible for scheduling and staffing: Nuclear Engineering

3. Catalog description: (Include special requirements, such as field trips, special equipment, etc.)

The objectives of this work is not just to provide general coverage of the fundamental aspects of the Monte Carlo Method for readers who are using existing Monte Carlo codes, but also to delve deeper into its sophisticated applications concerning variance reduction and error estimation, enabling them to become the developers and writers of their own future codes. A unique feature of the present work is to supplement the theoretical coverage with coding templates for the readers to build on their own coding. It is not meant to train the users of existing Monte Carlo codes, which is best covered in other forums.

The Monte Carlo Simulation Method or the Method of Statistical Sampling was developed as part of the Manhattan Project and the subsequent Super project for the design of thermonuclear devices.

Initially used for particle and radiation interactions simulations, it was instrumental in the development of digital computers, as we know them today. This became a major spin off of the effort to carry out these simulations. With the advent of current computer architectures and platforms, its realm of application has recently drastically enlarged in most fields of Science and Engineering.

Even though the readers may have been introduced to Monte Carlo in topics using numerical simulations, by covering the basic subject matter, some find that they need more time to delve deeper into the basic theoretical concepts as well as the practical methodologies of Monte Carlo. This work thus supplements and augments such coverage for those desiring it, by considering the Monte Carlo Method as the primary subject matter, and not as a subset of another more important topic. Consequently it concentrates on the theoretical and the practical programming fundamentals, and move beyond analog simulations to the realm of variance reduction methods. These include, among others, importance sampling, correlated sampling, and antithetic variates. It also gives adequate coverage on the methodologies for error estimation, primary and secondary estimators, bias avoidance, as well as both probabilistic and possibilistic sampling. It also provides the opportunity for actual hands-on programming simulations.

For those students in Nuclear, Plasma and Radiological Engineering interested in particle transport simulations, fault tree analysis in probabilistic risk assessment, and other related fields such as heat transfer, plasma physics, material science, who desire emphasis and deep coverage of the Monte Carlo methodology as the primary subject per se, this course provides motivation and sets direction of further and deeper study by emphasizing the basic and fundamental Monte Carlo theories and methodologies.

4. Prerequisites:

Adequate mathematical background: calculus (Math 280 or equivalent), Junior-Senior or graduate standing, and computer programming experience, or consent of instructor

5. Credit: SEMESTER HOURS: 3 UNITS: 3/4 - 1
Summer Credit: SEMESTER HOURS: 3 UNITS: 3/4 - 1

5. Credit(continued)

a. Restrictions on credit:

1. May this course be repeated in separate semesters? No If so when appropriate, please complete the following:
May be repeated to a maximum of hours or units.

2. May students register in this course more than once in the same term? (This is called "duplicate registration.") No________If so, for how many total hours and/or units?

Hours Units

3. Other restrictions on credit? If so, specific. (Example: "Students may not receive credit for both (this course) and ________.")

b. For a graduate course permitting variable credit, e. G. 1/2 or 1 unit, specify the additional work required for the higher credit.

Graduate students enrolled in this course for 1 unit will be required to complete more advanced homework sets and/or carry out an individual study project in their area of specialization using Monte Carlo methods in order to earn the extra 1/4 unit of credit.

c. For 300-level courses only One unit is normally considered the equivalent of 4 semester hours of undergraduate credit. If for example, 1 unit is to be equivalent to 3 semester hours in this course, explain why the graduate credit is not 3/4 unit.

6. For revised courses, summarize the nature of the changes and the reason for them

7. Purpose of the course:

a. Prerequisite for:

b. Required in the following curricula for majors:

c. Required in the following areas: Any.

d. Meets the general education requirements (for 100- through 300- level courses):

7. Purpose of the course: (continued)

e. For 300- and 400- level courses, describe the following:

1. Course Objective.
2. How the course relates to the overall pattern of courses in your department and/or to other courses in the area of specialization.
3. Justify a new course in terms of deletion of other courses, new subject matter, and evidence of course need, e. g., enrollment in special topics offering, enrollment increase, expanded staff, etc.
4. Justify why this course should award graduate credit in terms of level of content, previous knowledge required, relevance to current research, methodology, etc. (See graduate College statement of criteria for judging graduate courses.)

1. This course is designed to provide an introduction and a broad coverage of the Monte Carlo method across the engineering disciplines. It provides motivation and sets directions of further study for many students in different fields of engineering, by emphasizing the potential importance of Monte Carlo simulation methods in their respective fields.

2. This course is one of a number of advanced courses in the computational area. The Monte Carlo method has been historically developed within the Nuclear Engineering and Science field, but has now spread to many other disciplines. It is an choice for the students exercising the Computational Science and Engineering (CSE) option in Nuclear Engineering and other engineering disciplines.

3. This new course builds up on the increased interest in the Monte Carlo method, with the advent of new computer hardware and architectures. Monte Carlo simulations is becoming a very important aspect of current and future computing. In other universities courses at the undergraduate and graduate levels are devoted to the Monte Carlo method.

4. This course is advanced material for both majors and non-majors, and is thought suitable for graduate credit.

8. Overlap with other courses. Identify and justify duplication or overlap of content with other courses, either in your department or other departments. If overlap with a course in another department has been identified, please attach letters from that department's representative indicating appropriateness of overlap.

This is the only course on our campus devoted specifically to the theory and the implementation aspects of Monte Carlo simulations, although aspects of the Monte Carlo method are also covered in other courses as single topics. Some two hours of background will be developed in probability theory, variance estimation, set theory, linear systems of equations and Markov chains concepts. Minimum overlap with NE 357 (Safety Analysis of Nuclear Reactor Systems), on the Monte Carlo sampling of Fault Trees. Some overlap with NE 457 (Advanced Reactor Analysis) in the coverage of particle transport, as well as with NE 441 (Nuclear Radiation Shielding) in the design of radiation shields. ECE 439 (Advanced Theory of Semiconductors and Semiconductor Devices) uses the Monte Carlo method for device simulation. ECE 371 UR (Introduction to Computational Electronics) uses drift-diffusion and Monte Carlo methods for the simulation of conductor devices and gas phase plasmas. Physics 398/ Material Science 390 (Computer Simulation Methods of Many-Particle Systems), uses molecular dynamics and Monte Carlo for the simulation of phase transitions(e. g. melting-freezing temperatures), calculation of free energies, and Brownian motion. These overlaps show the wide use of the Monte Carlo method in varied disciplines, and underscore the need for covering it in depth as a single topic for the benefit of our students at the undergraduate and graduate levels.

9. If the course will serve students in other departments, summarize discussions with other departments.

Consultation about cross-listing of the course for the CSE option in engineering was discussed with the Computational Science and Engineering steering committee, and with Prof. Prith Banerjee, Director, CSE Program.

10. For both new and revised courses, list the principal topics covered in this course, including minor headings as well. The topics outline should be specific enough to make the contents of the course clear to an outsider. Include examinations and total the number of contact hours. (If Available, attach the complete topics outline from the syllabus for the course.)

Topic	Hours(Approximate)
1. Introduction, history and general description. Monte Carlo as a numerical experiment: Analog Monte Carlo. Generation of random, pseudo-random and quasi-random numbers.	(4 hours)
2. Sampling methods: mathematical expectation and variance of a random variable, sampling continuous and discrete probability density functions, the inversion and rejection methods. Error estimation procedures for Monte Carlo Computations.	(3 hours)
3. Variance reduction methods, as applied to the evaluation of integrals. Analog, Hit or miss, or Poor Man's Sampling Crude Monte Carlo sampling Correlated Sampling or Control variates Importance Sampling Weighted Uniform Sampling Antithetic variates Sequential Monte Carlo Stratification method Overbiasing and underbiasing	(6 hours)
4. Markov Chains, solution of linear systems of equations. Continuous and discrete random walks	(3 hours)
5. Mathematical formulation of particle transport in Monte Carlo Theory, Neumann solution to the transport equation Multigroup and continuous energy cross sections treatment Adjoint formulation and reciprocity relations Monte Carlo statistical weighting methods, source iteration method for criticality calculations Estimation methods in Particle transport: comparing the collision, track length, and last event primary estimators Secondary estimators for particle fluxes, reaction rates, heating rates, and radiation damage parameters Particle tracks scaling and chain segmentation, solution of deep penetration problems Variance reduction using coupled symbolic-procedural programming, and applied artificial intelligence concepts.	(7 hours)
6. Complex geometries generation: combinatorial geometries and the inverse problem of analytical geometry	(2 hours)
7.Applications: Shielding, Dosimetry, Fault Tree Analysis in probabilistic safety analysis Radiative and conductive heat transport calculations.Optimization and random search algorithms, Connectionist Systems: Training of Neural Networks and estimation of weight matrices, Percolation processes	(7 hours)
8. Programming exercises in students respective fields with instructor's supervision of	

computing assignments. Exercises in writing programs for direct simulations and variance reduction methods, and error estimation. Use of the SAMPLE Monte Carlo code for fault tree analysis. Use of a particle transport code for a shielding problem(MORSE or MCNP), backpropagation for neural network training, or other problems of particular interest to students on different computer platforms. (10 hours)

9. Tests (3 hours)

Total *(45 hours)*

11. Basic texts: Complete list of texts (give author, title, year of publication): If a long bibliography of articles or chapters from books is to be used, attach the complete list and indicate required and recommended articles.

1. M. Ragheb, "Lecture Notes on Monte Carlo Simulations," FSL-65, Department of Nuclear Engineering, University of Illinois, 2007.
2. M. H. Kalos and P. A Whitlock, "Monte Carlo Methods: Vol 1, Basics, John Wiley, 1986.
3. J. M. Hammersley and D. C. Handscomb, "Monte Carlo Methods, " Methuen's Monograph on applied probability and statistics, London: Methuen and Co. Ltd., 1967
4. J. Spanier and E. M. Gelbard, "Monte Carlo and Neutron Transport Problems," Addison-Wesley Publishing Co., 1969.
5. R. Y. Rubistein, "Simulation and the Monte Carlo Method," J. Wiley and Sons, 1981.
6. R. Siegel and J. R. Howell, "Thermal Radiation Heat Transfer," Hemisphere Publishing Corporation, 1992.

12. Additional comments:

APPROVALS
(Signatures required unless otherwise specified)

Request prepared by:	M. Ragheb, 223 NEL, (217)333-6569 ________________________ (Print or type. Signature not required.)	Date:	8/23/2007 _______
Faculty member who will teach the course	M. Ragheb, 223 NEL, (217)333-6569. ________________________ (Print or type. Signature not required.)	Date:	8/23/2007 _______
Departmental Approval	________________________ (Head of Department)	Date	_______
School Approval (if applicable)	________________________ (Director of School)	Date	_______
Undergraduate college approval	________________________ (Dean of College)	Date:	_______
Graduate College approval (if applicable)	________________________ (Dean of Graduate College)	Date:	_______

Approved by the
Chancellor   Date:

_______________________________ (Assistant Vice Chancellor for Academic Affairs)   ________

IMPORTANT: If a course is to be CROSS-LISTED, the written approval (or signatures thereof) of all concerned departments, schools, and colleges must be obtained.