On the Role of Monte Carlo Methods in Swedish M. Sc. Engineering Education

Andreas Svensson, Department of Information Technology, Uppsala University

ABSTRACT

Monte Carlo methods have quite recently become well-established tools for scientific computations in many different fields. We raise the question whether the education has followed this development, and investigate to what extent Monte Carlo methods are present in Swedish M. Sc. engineering education today. By studying the course syllabuses, we conclude that 11% of the Swedish M. Sc. engineering students are admitted to a program with a mandatory course containing Monte Carlo methods. Further, 60% of all students have the option to actively choose a course which at least mentions Monte Carlo methods. Courses containing Monte Carlo methods are mostly on advanced level with a clear application focus, and tend to be given at the bigger universities. We thus conclude that Monte Carlo methods have found their way into the M. Sc. Engineering education, but the question about level and to what extent has perhaps not yet reached maturity among the Swedish universities.

1. INTRODUCTION

Monte Carlo methods are a class of probabilistic numerical methods, which during the last decades has become an important tool for, e.g., computing integrals, sampling from nontrivial probability distributions, and optimization (Robert & Casella, 2004; Kroese, Brereton, Taimre, & Botev, 2014). Usually no explicit definition of a Monte Carlo method is given in the literature, but the uniting idea is to perform computations using samples rather than analytical expressions, as illustrated in Figure 1.

The origin of the Monte Carlo methods is to be found in physics research during the 1940s. Since then, computational power has become cheaper and more accessible for every year, which most likely is the reason to the rapid development of Monte Carlo methods. Today, advanced Monte Carlo methods are well established tools in as different areas as signal processing, particle physics, statistical physics, econometrics, computer graphics, Bayesian inference, machine learning and computational biology. In addition to the applications, Monte Carlo methods are also an active research field itself.

In this article, we will try to examine whether the reach of Monte Carlo methods in the research has been reflected in the Swedish M. Sc. engineering education (sv. civilingenjörsutbildning). Most such programs have a basic course on numerical methods, containing tools such as Euler methods for differential equations, Newton-Rhapson methods for optimization, etc. Due to the widespread use and increasing importance of

---

Figure 1, the Monte Carlo idea. Consider a function (purple line), that is of interest to study in some application. The idea is to represent the function with a finite set of randomly generated samples (black dots), somehow describing the properties of the function. The function is typically defined by some expression or procedure that is hard to manipulate and analyze with a computer. The samples, however, can be represented by numbers, and are easier to manipulate and analyze by a computer. Monte Carlo methods are designed so that the properties of the function of interest are with high probability resembled if using sufficiently many samples.
Monte Carlo methods, it might appear natural also for Monte Carlo methods to take such a prominent place in the education. However, Monte Carlo methods have been developed fairly recently (in contrast to most part of mathematics that is taught in M. Sc. engineering education), and might therefore not have made its way into the basic courses yet. There might also be other reasons not to include them, such as their probabilistic nature.

With these questions in mind, the aim of this study is to survey the role that Monte Carlo methods have today in the Swedish M. Sc. engineering education. There exists literature on how Monte Carlo methods can be used in teaching, e.g., (Billinton & Wang, 1999; Genevieve & Hill, 2013). However, to the best of author’s knowledge, no study on the role of Monte Carlo methods in higher education has been published.

2. Method

The method chosen was to study all course syllabuses for courses included in all Swedish M. Sc. engineering programs, and note the occurrence of Monte Carlo methods. By also grouping the courses containing Monte Carlo methods into (i) scientific subject, and (ii) the share of Monte Carlo methods in the course (mentioned/ a not negligible share/ a substantial share), a more detailed analysis can be made.

The study was performed during March 2016, and the most recent version of the syllabuses available on the internet was studied for each course. In a few cases, ambiguities in the syllabus were clarified using additional course information available. A M. Sc. engineering program was considered to be defined by its current program syllabus, and hence only courses included in any such program syllabus were included in the study. To interpret and put the results in perspective, the number of admitted students per program to fall semester 2015 was also taken into account. Indeed, the number of admitted students to a program is not the number of students graduating, but assuming the share of drop-outs is comparable for all M. Sc. engineering programs, the relative sizes between the programs remain unaffected.

3. Results

In total, 60% of all Swedish M. Sc. engineering students are studying a program whose syllabus includes at least one course to some degree containing Monte Carlo methods. Obviously, this implies that 40% are studying a program not mentioning Monte Carlo methods in any course in the syllabus. In most syllabuses, however, these courses are optional, and 11% of the students are studying a program with a mandatory course containing Monte Carlo methods to some degree. All data collected will be available at the author’s homepage.

A more detailed summary of all courses in the study is presented in Figure 2, where all courses containing Monte Carlo methods are grouped per subject and the share of Monte Carlo methods in the course. It is important to note that the numbers in Figure 2, in the case of optional courses, reflects the course offer to the students, not the actual number of students taking such courses. An illustrative situation is that the number 35.3% for courses in statistical inference with a substantial Monte Carlo share corresponds to only three courses at advanced level, however offered to a very broad range of different M. Sc. engineering at Lund University, KTH Royal Institute of Technology and Chalmers University of Technology.

---

1 In detail, the number of students after the second round of admittance for the fall semester 2015 was considered (UHR, Swedish Council for Higher Education, 2016)
Uppsala University is the only university where Monte Carlo methods are treated in a course mandatory for all M. Sc. engineering programs. That course is also the only course on basic level found in the study.

In Figure 3, another summary of the results is presented by considering the number of course instances given per student and year for each university and share of Monte Carlo methods. If a course is given once a year, it counts as one course instance per year, and if it is given twice a year, it counts as two, etc. Assuming the cost for providing each course instance is somewhat comparable, the figure gives an idea of how different universities prioritize differently on providing courses with Monte Carlo methods, adjusted for the number of students.
4. **Discussion**

From the results, we conclude that Monte Carlo methods are by most universities considered to be an important topic, as it apparently is offered to a majority of the Swedish M. Sc. engineering students. It is interesting that almost all courses containing Monte Carlo methods are offered on an advanced level. Provided that Swedish M. Sc. engineering education is a traditional subject, this is suggesting that

(i) Monte Carlo methods are not deemed relevant to be included in basic courses, or
(ii) Monte Carlo methods are too advanced and does not fit into a course on basic level, or
(iii) there is more room to introduce new material in courses on advanced level, whereas inclusion of new material in basic courses is a more heavy and lengthy, process.

The overall impressive course offering of Monte Carlo related courses in many different subject areas, disqualifies (i) as an argument. Further, (ii) is disproved by the course at basic level given by Uppsala University (however, (ii) might still be used as an argument, albeit it is invalid). This suggests that (iii) might be a reasonable explanation. If (iii) is the reason, it implies it is only a matter of time before Monte Carlo methods are introduced in basic courses in a larger scale at more universities than Uppsala. A similar study in some years could determine whether this is the case or not.

The spread over different subject is also notable. It seems to be common to mention Monte Carlo methods in biostatistics, whereas the in-depth treatment is lacking in that subject. In statistical inference, the situation is somewhat opposite. The topic of statistical inference has the peculiarity that the topic concerns the study of randomness, and randomness is vital also within Monte Carlo methods themselves, which perhaps provides a particular good ground for understanding Monte Carlo methods. Finance is not a major topic in M. Sc. engineering education, but offers nonetheless a non-negligible possibility for the students to study Monte Carlo methods. With the historical background of Monte Carlo methods being developed within the physics community, the mandatory computational physics courses mentioning Monte Carlo methods is also interesting.

The variance in the course offerings between different universities is also worth considering. There is clearly a correlation between the size of the M. Sc. engineering education and the presence of courses containing Monte Carlo methods; the Monte Carlo related course offerings (per student) are very weak at, e.g., Blekinge Institute of Technology and Halmstad University, in sharp contrast to, e.g., KTH Royal Institute of Technology and Linköping University. Two exceptions, however, are Umeå and Lund University, where the former offers twice as many course instances, even though the number of M. Sc. engineering students in Umeå is only a third of the number in Lund.

An appealing explanation for this discrepancy would be a correlation between active research groups working with Monte Carlo methods, and the inclusion of Monte Carlo methods in the education, but it is beyond the scope of the study to confirm this.

To summarize, it can be said that Monte Carlo methods indeed are present today in the Swedish M. Sc. engineering education. They seem, though, not to have a mature, well established role in the education: the variance between universities is considerable, and there is a bias towards courses on advanced level with a clear application focus. Best possibilities to study Monte Carlo methods for M. Sc. engineering students are in general given at the bigger universities.
BIBLIOGRAPHY


