Incorporation of Simulation-Based Science in the Engineering Curriculum through integration of high-performance/soft computing techniques

Alexandros Taflanidis, University of Notre Dame

Introduction and Objectives

Advances over the last decade in computer and computational science, especially the popularity of high-performance computer clusters and of soft-computing techniques, have considerably reduced the computational burden traditionally associated with simulation-based approaches[1] making ***Simulation-Based Engineering Science*** a powerful framework for addressing challenging problems of the 21st Century.

The meaningful integration of the relevant computational tools within engineering curriculum faces, however, challenges. Though many specialized courses exist that focus on individual tools within this greater framework little is done to efficiently integrate such tools within ***traditional*** engineering courses, primarily because the necessary background is currently not a fundamental component of the engineering curriculum (as such one cannot assume exposure of all students to the required tools).

This educational initiative focuses on incorporating Simulation-Based Science tool in the Engineering Curriculum through integration of high-performance/soft computing techniques in a traditional course on uncertainty quantification/propagation.

[1][approaches that adopt complex, black-box, numerical models to assess the performance of engineering systems]

Developmental History of Innovation

The proposed integration is utilized within is a senior undergraduate elective/graduate course on "Applied/Computational Probability for engineers", discussing uncertainty quantification/propagation (UQ). This course attracts a multidisciplinary group of students, from Civil, Mechanical, Aerospace, Chemical Engineering and Computer Science. This year will be the third year the innovation is (further) integrated within the course.

Motivation is the realization that even though Simulation-Based Engineering Science is developing as a very powerful tool, we do not actively leverage all its potential as educators within traditional courses. Many of the examples and projects within such courses are selected based on convenience (numerically simple) and correspond to "toy-problems". UQ enjoys great benefits from simulation-based science as such it offers a great test-bed to evaluate the proposed innovation.

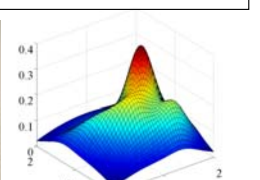
Learning Activities and Materials

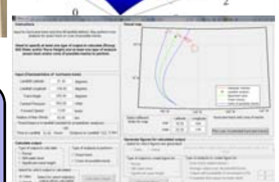
Resources: The computational resources of the HIgh Performance system Analysis and Design laboratory (HIPAD) at Notre Dame are used. This includes, Persephone a 336 core high-performance cluster, Prometheus a 1536 CUDA enabled personal supercomputer, as well as a number of state-of-the art workstations.

Workshops: For exposing the students to the additional techniques required, since many students lack the necessary computational and soft computing background, a couple of two hour workshops[2] are offered during the semester, aimed to provide the students with the necessary knowledge on Simulation-Based tools.

Project-based approach: To further engage students, each of them is required to choose a challenging system from his/her discipline and assess its probabilistic performance implementing high-performance or soft-computing techniques for the analysis. This offers a valuable understanding of the potential of simulation-based tools for providing solutions to very challenging engineering application

[2][The first one (that have been already offered twice) focuses on simulation-based modeling and on parallel computing. The second (that will be offered for the first time next year) discusses kernel-based approximations and surrogate modeling focusing on their utility as soft-computing tools in supporting development of standalone apps]





Project-based learning approach & use of supplemental Workshops (fill knowledge gaps)

Advocacy for Simulation-Based Science for solving 21st century challenges

Execution

Workshop details: Workshops are open to the entire college of Engineering but any student taking the class is required to participate in them. Offering the workshops as open to the college has distinct advantages as: a) it helps with the popularity of the class itself as students not yet enrolled in it get interested in taking it the following year, viewing it as an opportunity to get further exposure to these tools, b) it creates is no "direct" additional requirement for the students already registered for the class.

Project-implementation details: Since for some students (especially undergraduates students) it is not always straightforward to develop on their own the required models, a few practical examples from recent research projects are provided, such as a) real-time estimation of storm surge, b) evaluation of the energy capacity of wave energy extraction devices, c) seismic risk assessment.

Major Issues to Resolve (Challenges)

Focusing on the additional materials unavoidably detracts from the main course subject (reduced focus on science, increased focus on implementation of computational tools). It is crucial to maintain a good balance between these two objectives. Exposure to tools for solving challenging problems does not justify ignoring the foundation behind them.

Workshops are viewed as additional work and proper motivation (or even reward) is required, especially if in the number of such workshops increases (which needs to happen). It is crucial to find the right motivation to maintain a strong interest.

Computational resources poses still a challenge. Personal desktops will typically not suffice for most practical problems within a simulation-based science framework. Considering the advances in computer science and the increasing popularity of workstation computers this will not be a problem in the near future, but currently it is. Relying on resources from a specific lab does not scale well, whereas any advanced computational resources college has are typically given priority to specialized courses (as they should)

Discussion

Simulation-Based Engineering Science offers a powerful framework but integrating it within traditional courses in the Engineering Curriculum requires some innovative approaches. The main challenge is the fact that educators cannot rely on prior exposure of the entire student body on the required techniques. This innovation focuses on integration of high-performance/soft computing techniques in a traditional course on uncertainty quantification/propagation, utilizing workshops and a project-based learning approach. Workshops provide the students enrolled in the class with the additional computational background needed. The project-based approach targets challenging engineering applications and provides tangible proof to the students of the power of simulation-based science, aiming at creating strong advocates among them.

Future extensions will focus on soft-computing and will incorporate an additional stage in the project where each student will be required to develop a standalone app (with proper user interface, developed in MATLAB). This is aimed at providing a tangible proof to the students of the capabilities these techniques have to offer to cross-over technology adoption barriers towards non-technical audiences. Some of the standalone apps will be further utilized to spearhead interest within K-12 classrooms settings.

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