Parallel computing in reliability and stochastic analysis of structures

by marco broccardo

Bio

I am fourth year Ph.D. student in Civil Engineering working in the Structural Engineering, Mechanics and Materials (SEMM) group. My research focuses on stochastic dynamics and structural reliability analysis. Most of my programming experience has been serial programming in Matlab (very familiar) and Fortran (sufficient familiar but rusty). The core of my research is to determine the reliability of strategic infrastructures under stochastic excitations. This oftentimes requires a large number of structural response simulations and a lot of computational time. Indeed, writing a parallel computing code seems the right strategy to tackle this class of problems. I have not had any experience on parallel programming and this lack of knowledge is the main reason to take this class.

Project Proposal

The object of this project is to use parallel computing to determine the reliability of civil facilities. Safety analysis of structures subjected to general excitations, such as live loading, wind or earthquakes is a primary goal for structural engineers. A considerable amount of effort in the last few decades has been made to provide mathematical models, which are able to predict with fairly good approximation the response of complex structures under specific excitations.

The discipline that aims to predict the response of structural systems to a defined excitation is structural analysis. Historically, it was developed in parallel with the well-known finite element method, FEM, and is presently classified as a subset of that method. The rapid improvement of computational power in the past decades has spread the use of structural analysis from academia to industry until to become a standard procedure.

In structural analysis a structural system is described as a collection of structural components. A large sparse matrix expresses the connectivity between the components and the structural system response is obtained by its inversion. The computational efforts usually depend on the size of the system and for large problems the time required can be considerably important.

While structural analysis is a robust and standard method for predicting responses of linear elastic systems, it still remains an open research field for nonlinear and inelastic systems. This field is crucial in earthquake engineering, where buildings can be damaged under severe excitations such as a strong ground motion. Nonlinear and inelastic problems are much more difficult tasks to address and their computational time increases significantly. Some analyses can take days, weeks, or even months, indeed the computational power is crucial. For multiple or large scale analysis, parallel and cloud computing is the natural or the only choice available.

These mathematical models assume a perfect knowledge of the structure and of the excitation, however typical problems of structural engineering lack this knowledge. The first one is due to construction procedures, uncertainties on the material proprieties and additional non-structural elements. The second one is an inherent characteristic of particular loads. Earthquakes, wind and ocean waves, although governed by physical laws, are inherent random phenomena. The predicted responses can be far from the real ones due to these uncertainties. Indeed a mathematical framework that accounts for these uncertainties is a more consistent approach for the structural engineering field. Random vibration and structural reliability analysis aim to provide a probabilistic framework to solve this class of problem. In this context each defined failure event is equipped with a "measure", the probability of the event, which can be used later in risk-based decision-making context. Estimating this event probability can be rather difficult due to the nonlinear behaviour of the structural system under extreme excitation that has to be taken into account in the analysis.

There are different methods to approach the problem; the more intuitive one is the Monte Carlo method, or the broad family of simulation methods. The general framework requires modelling the structural uncertainties with a joint probability distribution and the input with a stochastic process, which describes the family of all possible inputs for a particular excitation. The failure event is selected among the structural responses of interest as the one that is believed to be crucial for a target structural behaviour. Once this probabilistic framework is defined, a sample from the joint distribution will give a particular structure configuration and one sample of the stochastic input will define a particular excitation. Once the input and the structural configuration are defined, the output is derived with standard structural analysis theory. The probability of failure is estimated by defining an indicator variable, which will assume a unitary value if the response exceeds the failure threshold and a null value, otherwise. Once several simulations have been run, the probability of failure is obtained by the arithmetic average of the indicator variable. The sample size needed to accurately estimate the probability of failure depends from the magnitude of the latter. The product of the total number of simulations and the time required to solve a structural analysis gives the total computational cost.

Civil engineering facilities usually require high reliability standards and a large number of simulations are needed to estimate low level of probability. Parallel to the classical Monte Carlo, other simulation methods such as important sampling, subset methods, etc. have been developed to tackle this class of problems. Although the number of simulations can be drastically reduced the total computational time for large-scale systems or highly nonlinear systems can still remain unfeasible unless parallel or clouding computation is used.

The goal in this project consists in the development of a software that make use of parallel computing to estimate small probabilities of failure for large engineering systems.

Specifically we focus on earthquake excitations, which are critical for the Bay Area. A stochastic model developed by S. Reazian and A. Der Kiureghian is used to describe the family of all possible seismic events for a given location. The structural system is either a single building or multiple strategic buildings and each structural analysis is carried throughout Open Sees open source software introduced in UC Berkeley.

While beyond the scope of this initial project, the ultimate goal, is to create a complex graphical model of entire neighbourhoods or cities in order to get both large scale realistic hazard maps and accurate estimations of failure probability for specific buildings or components. We strongly believe that this approach will play a crucial role in the management of risk for large and small-scale problems.

In conclusion this project focuses on the development of a software that makes use of the current knowledge in the earthquake engineering fields and the parallel computing facilities of UC Berkeley. This will be a key part of a rational and robust methodology for risk assessment, which is under development in UC Berkeley.