CS 267 Assignment 0

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About me

I am a first year graduate student in the Nuclear Engineering. I haven’t completely identified a research project; however, my interests are in small/medium reactor design and advanced accelerator concepts for the production of medical isotopes. Scientific computing and simulation plays a significant role in the design of nuclear technologies because most systems are too costly and/or dangerous to build prototypes for. I have experience using large-scale parallel systems for Monte Carlo and deterministic methods of nuclear reactor simulation. Over the course of this semester, I’d like to gain a better understanding of parallel systems and computer architecture, and learn how software can be implemented on and optimized for parallel systems. I am also interested in GPU’s especially for radiation imaging applications in either simulation or data analysis.

Computational Methods for Nuclear Reactor Simulation

Parallel computing is used extensively for the modeling and simulation of nuclear reactors. The chain reaction that sustains a nuclear reactor is based on neutron economy; thus characterization of the neutron flux is essential in the design of a nuclear reactor. There are two major approaches to characterizing the neutronics of a reactor:

1) Use various numerical methods to solve the neutron transport equation:
\[
\frac{1}{\nu} \frac{d}{dt} \psi(\vec{r}, E, \vec{\Omega}, t) + \Sigma_t(\vec{r}, E) \psi(\vec{r}, E, \vec{\Omega}, t) + \vec{\Omega} \cdot \nabla \psi(\vec{r}, E, \vec{\Omega}, t) = \\
\int_0^\infty dE' \int_0^{4\pi} d\vec{\Omega}' \Sigma_s(\vec{r}, E \rightarrow E', \vec{\Omega}', \vec{\Omega}) \psi(\vec{r}, E', \vec{\Omega}', t) + \\
\frac{\chi_p(E)}{4\pi} \int_0^\infty dE' \int_0^{4\pi} d\vec{\Omega}' \nu E' \Sigma_f(\vec{r}, E', \vec{\Omega}') \psi(\vec{r}, E', \vec{\Omega}, t) + Q_{ext}(\vec{r}, E, \vec{\Omega}, t)
\]

2) Directly simulate the physics of the system using Monte Carlo methods

Each method has advantages and disadvantages. The deterministic approach generally produces results more quickly, but at a cost to accuracy, and it may not be able to handle more complex problems (e.g., advanced designs featuring high heterogeneity). Monte Carlo methods produce more accurate results, but the run times may be prohibitively long even on powerful cluster computers. In other words, since Monte Carlo simulations are faithful to the true physics of the system, they have the potential to produce the most accurate answer if the statistical error of the problem can be reduced in a reasonable amount of run-time.

Codes currently used in industry (by large core-designers like GE and Westinghouse) rely mostly on deterministic methods which can run quickly. In fact, commercial core designs are so large and complex, that the cost (both in dollars and time) prohibits the use of Monte Carlo methods. Within the nuclear industry, there was a thought experiment proposed by a computer scientist and member of the deterministic community known as the Kord-Smith challenge. The experiment broke down the number of calculations required to simulate a full core using Monte Carlo methods, and using Moore’s law, predicted the time-frame in which the MC methods might be able to complete the challenge on a personal computer (a non-cluster computer). It was originally estimated that this wouldn’t be possible until the 2030; however, one of the assumptions made was that the calculation would be done on a single serial processor (and that clock-speed would continue to obey a Moore’s law-like trend, which we saw in the first few lectures is not true). Professor Bill Martin from the University of Michigan later challenged the analysis saying that the timeframe would be much nearer 2018 based on the increasing prevalence of parallel processing. The efficient implementation of parallel processing will have a great impact on the economics of nuclear reactor design and afford designers more accurate methods.

I have had personal experience with the computational challenges facing designers of nuclear systems. For instance, I worked at Lawrence Livermore National Laboratory last summer, working on a project to verify the accuracy of nuclear cross-section data. The project essentially called for the
construction of a benchmark model based on a small experimental non-power reactor using a Monte Carlo code, and to compare the results of the simulation to the cross-section data acquired from the experiment. The system to be modeled was extremely small when compared to commercial power systems (this reactor had only 71 fuel pins whereas a commercial reactor usually has $17 \times 17$ fuel pins in a single fuel assembly), yet in order to acquire data with an appropriate amount of statistical error, I often had to run for 12 hours on 256 processors (32 nodes with 8 processors/node).

As you can see, parallel processing will play an integral role in the future of the nuclear industry. By taking advantage of parallel computing, the design of nuclear systems will become much cheaper and more efficient, as well as take far less time and provide more data, which will contribute to the safety of future designs. My own experience with parallel computing involved using .mpi, so I would like to learn more about message-passing. One of the unique aspects of neutronics simulations is that the events are 100% independent, in other words, there are no far-field forces involved. There should be no need for each individual processor to pass any data to any other processor when simulating each individual particle trajectory. I feel that distributed memory systems might be especially well-suited for this type of problem, and plan to investigate further systems and methods that are well suited for this unique physical circumstance.

**Class Project Interests**

One of the main reasons I took this class was so that I could learn about parallel architecture and how to efficiently implement algorithms to make the most of the advantages of parallel processing. The obvious application for this in the field of nuclear engineering is in reactor design, as discussed above at length. However, I am also interested in radiation imaging and detection for which GPU’s can be particularly useful. I would like to identify a final project that either involves some novel application of parallel processing to large Monte-Carlo simulations; or the use of GPU’s for analyzing radiation imaging data.