Using TOP-C for Commodity Parallel Computing in Cosmic Ray Physics Simulations

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TOP-C (Task Oriented Parallel C) is a freely available package for parallel computing. It is designed to be easy to learn and to have good tolerance for the high latencies that are common in commodity networks of computers. It has been successfully used in a wide range of examples, providing linear speedup with the number of computers. A brief overview of TOP-C is provided, along with recent experience with cosmic ray physics simulations.

1. Introduction

Ultra high energy cosmic rays are observed indirectly through detection of the extensive air showers that are produced when they travel through the atmosphere. To adequately interpret the measured observables and to be able to infer the properties of the incident primary particle, a full Monte Carlo treatment of the extensive air shower is needed. The CPU time required rises with the primary energy. For example, for primary energies around $10^{20}$ eV a shower contains about $10^{11}$ secondary particles. The amount of computing time required to follow all the particles seems to be prohibitive. Traditionally, sampling techniques are used to reduce the number of particles tracked\textsuperscript{[1]}. In this article we describe an ongoing program to use commodity parallel computing for fast Monte Carlo simulations\textsuperscript{[3]}. The aim is to go beyond the simple event-level parallelism which is commonly used today and actually run individual events faster than would be possible on a single workstation or PC.

2. GEANT4

For a variety of reasons, in no small part driven by the wish to work with software which is likely to see use in the future, we decided to try to parallelize GEANT\textsubscript{4}\textsuperscript{[4]}, the C++ rewrite of the older (FORTRAN77) GEANT3. GEANT\textsubscript{4} is an object-oriented simulation package that provides general-purpose tools for defining and simulating detector geometry, material properties, particle transport and interactions, visualization, and all relevant physics processes. Its versatility allows it to be employed in applications beyond its traditional usage in High Energy Physics experiments, from the medical and biological sciences to Cosmic Ray Physics\textsuperscript{[5]}.

3. TOP-C

TOP-C (Task Oriented Parallel C)\textsuperscript{[5]} was initially designed with two goals in mind:

1. to provide a framework for easily developing parallel applications;
2. to build in the ability to tolerate the high latency typically found on Beowulf clusters\textsuperscript{[6]}

The package is freely available\textsuperscript{[5]}. The same application source code has been run under shared

\textsuperscript{9}The term “Beowulf cluster” refers to a cluster of systems running Linux and connected by ethernet.
and distributed memory (SMP, IBM SP-2, NoW, Beowulf cluster). A sequential TOP-C library is also provided to ease debugging. The largest test to date was a computer construction of Janko’s group over three months using approximately 100 nodes of an IBM SP-2 parallel computer at Cornell University.

The TOP-C programmer’s model is a master-slave architecture based on three key concepts:

1. **tasks** in the context of a master/slave architecture;
2. global shared data with lazy updates; and
3. actions to be taken after each task.

Task descriptions (task inputs) are generated on the master, and assigned to a slave. The slave executes the task and returns the result to the master. The master may update shared data on all processes. Such global updates take place on each slave after the slave completes its current task. The programmer’s model for TOP-C is graphically described below.

4. **Parallelization of GEANT4 Using TOP-C**

   The task-oriented approach of TOP-C is ideally suited to parallelizing legacy applications. The tactic in parallelizing GEANT4 was to perturb the existing software as little as possible and to modify just the section of the code which handles particle tracking and interaction (a frequent operation) to allow it to run on multiple CPU’s. The largest difficulty was in marshalling and unmarshalling the C++ GEANT4 track objects that had to be passed to the slave processes. Marshalling is the process by which one produces a representation of an object in a contiguous buffer suitable for transfer over a network, and unmarshalling is the inverse process.

   We developed a 6-step software methodology to incrementally parallelize GEANT4, allowing us to isolate individual issues. The six steps were:

   1. the use of .icc (include) files to isolate the code from the original GEANT4 code;
   2. collecting the code of the inner loop in a separate routine, **DoTask()**, whose input was a primary particle track, and whose output was the primary and its secondary particles;
   3. marshalling and unmarshalling the C++ objects for particle tracks
   4. integrating the marshalled versions of the particle tracks with the calls to **DoTask()**;
   5. adding calls to TOP-C routines such as **TOPC_init()**, **TOPC_submit_task_input** and then testing as the marshalled particle tracks were sent across the network;
   6. and finally adding **CheckTaskResult()**, which inspected the task output, and added the secondary tracks to the stack, for later processing by other slave processes.

   Prior to the fifth step, all debugging was in a sequential setting. The maturity of the TOP-C library then allowed us to create fully functioning parallel code in less than a day.
5. Discussion

GEANT4 (approximately 100,000 lines of C++ code) was successfully parallelized using TOP-C. In the future we plan to perform timing tests on a long run using many processors. Initial results for the example described indicate that a single task in an application requires approximately 1 ms of CPU time. Hence, it will be essential to submit approximately 100 particles for a single slave process to compute in order to overcome network overhead. Optimization of the parallel implementation is underway.

TOP-C seems to be well-suited to the problem of parallelizing GEANT4, and would likely be well-suited to other high energy physics and cosmic ray applications as well. Its flexibility and simplicity makes it possible to envision enormous speedups for GEANT4 within a single event, something not often considered in high energy experiments, but offering advantages over the usual event-by-event parallelism, especially during interactive data analysis and code or hardware design.

Of particular interest is the parallelization of existing cosmic ray simulation programs such as AIRES and CORSIKA. Although written in FORTRAN, such programs are in fact often converted to C for compilation using f2c, and can certainly be linked with other C programs, so we anticipate no major obstacles. We are always interested in collaboration with other groups who may have needs for the speedups that our methodology offers.

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