High-Performance Martian Space Radiation Mapping

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Abstract—To ensure safe operation of deep space missions, UHCL researchers performed a preliminary investigation to apply high-performance computer techniques to enable better space radiation analysis for Mars and other space missions. After study of the space radiation problem and methodology in 2004, the urgent need became apparent to modernize the NASA radiation code. Having obtained the HZETRN source code from NASA in 2005, researchers are currently seeking support to restructure the computation to match the newly developed computer resource of the parallel, multithread network cluster and reconfigurable parallel FPGA platforms. The top-down optimization will involve splitting up the task for parallel computation. As to the bottom-up optimization, the bottleneck functions taking up 70 percent of the run-time are identified for porting to FPGA, which will work as a co-processor with the rest of the non-bottleneck computation. Other optimization steps include modernization to current computing platforms, design for ease of use, exploring sparse matrix opportunities in data, and increasing accuracy. The success of applying parallel techniques to enhance both complementing deterministic HZETRN and stochastic FLUKA Monte Carlo radiation transport analysis/simulation code used by NASA scientists will greatly enhance space radiation understanding which is also vital to safer nuclear energy, anti-aging programs, and cancer treatment.

Space Radiation Modeling

NASA's mission to Mars with its Martian Radiation Environment Experiment (MARIE) project seeks to model the space radiation environment on Mars to determine when and where the astronauts can land safely. NASA scientists have used the HZETRN program for calculating transport of radiation particles. The HZETRN model has been developed as an accurate scientific model, but the implementation of the model in FORTRAN code using VAX machines is inefficient. Radiation exposure is underestimated by 15 to 30 percent. In addition to underestimation, the code takes a considerable length of time to execute, about one day to analyze three days of data collection.

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High-Performance Space Radiation Computation

Research is being performed to mathematically model high-energy particles as they pass through the walls of a spacecraft. This technology can also study high energy particles as they pass through parts of the human body. Data have been collected over the years on the effects of space radiation on humans, but to understand the effects for many different cases, a mathematical model needs to be created to simulate different conditions in space. The current execution mode is cumbersome in that the current HZETRN parameters in the source code have to be changed and recompiled between runs. The following statement summarizes the continuous diagnosis work of HZETRN. We are seeking support to explore ways to include parallel reconfigurable FPGA and cluster/Grid to modernize the NASA HZETRN code.

High-Performance Space Radiation Analysis with FPGA

Spring 2005

Before the actual HZETRN source code was available to us in Spring 2005, an FPGA approach was attempted based on HZETRN documentation analysis to implement bottleneck interpolation and integration routines. Implementing the HZTERN bottleneck routines on an FPGA, we had the advantage of its parallelism and its improvements of floating-point arithmetic to enhance the performance and efficiency of the HZETRN Program.

In this project, we used the Digilent D2-SB System Board as the FPGA and the Digilent DIO2 Peripheral Board to display results. The FPGA was programmed using the Xilinx Project Navigator; the platform we were using was the VHDL. The bottlenecks (interpolation and integration) were improved in order to improve the accuracy and speed of the HZTERN code. A pre-

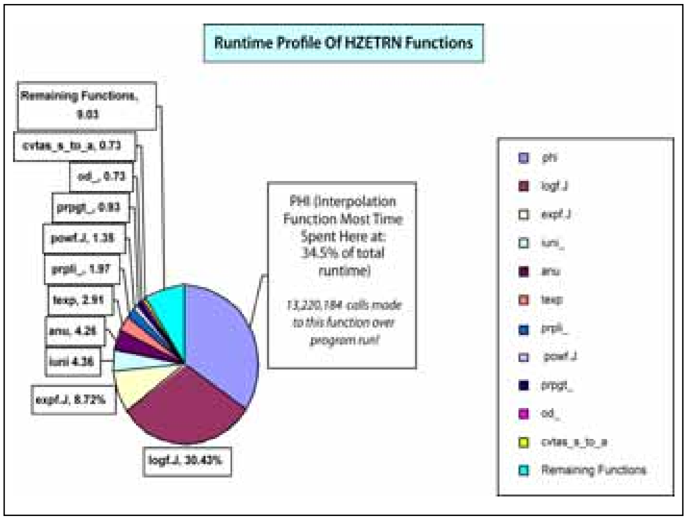

Figure 1. Runtime Analysis

liminary, non-optimized FPGA module showed a 200-to-600 time speed above the speed of equivalent HZETRN routines running on Sun Sparc 5 systems.

HZETRN Portability Check, Performance Profile, and Optimization

Fall 2005

After the new NASA software release procedure was followed, the HZETRN source code was finally obtained for analysis from NASA Langley in April 2005. In the past few months, the code was test-run on various platforms, and its performance was also detail-profiled by software tools. HZETRN code was found not portable to all systems tested. Only half of the six compilers would work with the code. Only two of the six machines tried would run the code. Only one machine seemed to get results.

Software performance profiling tools confirmed previous hand analysis that one-third of the run time was spent on a PHI function that performs interpolation (which is also used in integration). If the PHI routine could be updated, HZETRN execution time could be shortened by up to one third. Both logf and expf routines took another third of the run time. Both may also be updated with fast approaches such as FPGA or table "look-up" within the specific parameter range used in HZETRN, if the extra memory access time is tolerable.

HZETRN code has been evolved throughout the years. The code was not originally programmed with computer efficiency in mind, perhaps for readability reasons. After a preliminary effort cleaning out some redundant code and inefficient use of operations, HZETRN code was increased by about 10 percent in speed. After this detailed performance in the profiling and diagnosis of the HZETRN, we are planning to attack these bottlenecks with the treatment of both top-down parallel grid computing approach among the particles tracking and the bottom-up FPGA approach in time-consuming routines.

Photo provided by L. Shih

RADIATION MAPPING—(*l.* to *r.*) Karthik Katikaneni, UHCL M.S. Computer Science; Dr. Robert Singleterry, Jr., NASA Administrator's Fellow, Langley Research Center; Dr. Liwen Shih, professor of computer engineering (UHCL); Sergio J. Larrondo, graduate student in computer engineering (UHCL); and Ahmed Khan, UHCL B.S. Computer Science, NSF Student Scholar, performed preliminary investigation and applied high-performance computer techniques to enable better space radiation analysis for Mars and other space missions.

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Presentations

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"HZETRN," access to NASA Langley Space Radiation source code, April 2005. (*Granted*.)

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