High Performance Computing Initiative to Enhance Engineering Education

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Abstract

The power and utility of personal computers continues to grow exponentially through (1) advances in computing capabilities through newer microprocessors, (2) advances in microchip technologies, (3) electronic packaging, and (4) cost effective gigabyte-size hard-drive capacity. The engineering curriculum must not only incorporate aspects of these advances as subject matter, but must also leverage technological breakthroughs to keep programs competitive in terms of their infrastructure (i.e., delivery mechanisms, teaching tools, etc.).

An aspect of these computing advances is computer modeling and simulation of engineering problems. Many engineering problems require significant computing power, and some complex problems require massive computing power.

An example of a complex problem is a model that combines several aspects of a flight vehicle. Such a model might include fluid-solid interaction, heat transfer and dynamic loading of structures, all of which are coupled. Such models can easily consume massive computing resources, such as a supercomputer. To provide a conventional supercomputer on a dedicated basis to our faculty and upper level students is not feasible. It is feasible, however, to provide computing power adequate for teaching and student research in the form of clustered personal computers. Clusters can be acquired over time as individual computer purchases and configured by our own departmental personnel. Parallel computing software to exploit the clusters is available for computer operating systems like Unix, Windows NT or Linux. Clusters also have the advantage that they can be used as stand alone computers in a laboratory environment when they are not operating as a parallel computer.

This paper describes how the Mechanical Engineering program introduces engineering students to high performance computing, and parallel computing in particular, without adding courses to the curriculum. The Mechanical Engineering Department at Alabama A&M University has undertaken the High Performance Computing Initiative to Enhance Engineering Education. Under this initiative we not only introduce undergraduate students to high performance computing but also make it an integral part of the undergraduate curriculum.

Our high performance computing initiative was launched with funding from the Department of Energy (DOE) Alliance for Computational Science Collaboration (ACSC) project. A high-performance computing laboratory to support the initiative was established in the Mechanical Engineering Department.

This project provides faculty and students the opportunity to become involved in computational science projects of interest to national laboratories and research institutions. DOE support provides science, engineering and mathematics (SEM) undergraduate majors with scholarships to work under the mentorship of faculty members in projects involving high performance computing. There are currently twelve scholarship recipients. The recipients include students from Mechanical, Electrical, and Civil Engineering, Computer Science and Biology/Chemistry. Seven of them are from the Mechanical Engineering Department. Among these recipients, three multi-disciplinary teams were formed to conduct guided research. The projects include research and training in areas such as computational fluid dynamics, finite element analysis and advanced propellant characterization for propulsion. This paper describes the implementation process for introducing high performance computing to undergraduates and the assessment method to evaluate the effectiveness of this approach to enhance engineering education.

I. Introduction

For problems like global climate modeling, groundwater modeling, human genome mapping, weather forecasting, vehicle dynamics, molecular dynamics, and others., computer power is never sufficient. In the field of computational fluid dynamics (CFD), the problem size grows as the square (2D) or cube (3D) of the grid resolution. Large CFD problems, such as modeling the airflow around a complete aircraft, require hundreds of giga FLOPS (GFLOPS)) and tremendous memory allocations to complete in a reasonable time. Consider the following global climate modeling parameters.

one grid point per square kilometer 15 vertical levels from sea level up to 14 kilometers, six primary time dependent variables (updated once per minute at each grid point

It is estimated that to cover the entire earth surface, it requires the computer to process three Gigabytes of data [1]. To run even higher resolution models than the one described may require an impractical amount of time and memory using a serial high performance computer. In the past few years, computer speeds have increased from Megaherz to GigaHerz, and faster

chips are still to come. However, computer speeds may approach fundamental speed limits, in the next two or three decades. Also associated with the faster chips are problems of heat dissipation. It is generally agreed that continued performance gains beyond these limits can only be achieved by concurrent execution of programs on multiple processors. As indicated by [1], "the greatest gain in computing performance since 1989 has been through the move to large-scale parallelism."

High performance parallel processing can significantly reduce the wall clock time required to execute a program. It also facilitates a huge amount of total memory, which is necessary to solve the largest problems. It can be cost effective to use a cluster of workstations or PCs as a parallel computer. Parallel computing can be achieved through implementation of the Parallel Virtual Machine (PVM) or Message Passing Interface (MPI) libraries on such platforms. Great efforts have been made towards parallel computing applications for engineering in the past few years. Significant achievements have been accomplished in the field of computational fluid dynamics, in particular.

II. Need for Minority Scientists in Computational Science

"There is an urgent need to prepare an increasingly diverse population from a multi-cultural world for academic, government, and industry careers in Science, Mathematics, Engineering and Technology (SMET). According to the US 1990 census, the total US population was 248,709,873 in 1990. Of these, approximately 51% were women, 29,986,060 (or 12%) were African American, 22,354,059 (or 9%) Hispanic, and 1,878,285 (or 1%) Native American. As of 1995, of the total US civilian labor force (132 million), only 627,000 had Ph.D. degrees in SMET and only 341,000 of these were employed in SMET fields. Of these 341,000, only 55,210 (or 16.2%) were women, 7270 (or 2.1%) Hispanic, 5500 (or 1.6%) African American, and 810 (or 0.2%) Native American."

--- DOE Alliance for Computational Science Collaboration (ACSC) FY00 STRATEGIC PLAN [2].

The Department of Energy Alliance for Computational Science Collaboration has operated since October 1997 with the overall goal of training African-American and other minority scientists in computational science for eventual employment with DOE. Strategies designed to help produce future DOE minority scientists are

- to involve HBCU students and faculty members in computational science projects at national laboratories and research institutions;
- to assist HBCU faculty members in integrating interdisciplinary computational science courses into their undergraduate curricula, involving freshmen to senior students; and
- to provide support and expertise to HBCU researchers using state-of-the-art computational science technologies and methodologies.

Historically Black Colleges and Universities (HBCUs) are the primary source of African-American scientists in the US, and HBCU participation is central to the Alliance. Alabama A&M University is one of the HBCU members of the Alliance.

The question at hand is how to introduce engineering students to advanced computational resources without adding courses to the curriculum.

III. Mechanical Engineering Department at Alabama A&M University

Alabama A&M University (AAMU), is a land-grant historically black university. It is located in the northeast outreach of Huntsville, Alabama, an important world center of expertise for advanced missile, space transportation and electronics research and development. Among the leading industry and government organizations located in this area are NASA Marshall Space Flight Center, the Army Aviation and Missile Command (AMCOM), the Redstone Technical Test Center, Boeing, Northrup Grumman, Lockheed Martin and many others associated with high-tech. endeavors. These industries and government agencies require large numbers of highly trained engineers, in the areas of both manufacturing and also propulsion.

To better serve the state of Alabama and in particular the northern part of the state, the Mechanical Engineering program at AAMU was formulated with two options: Manufacturing and Propulsion Systems. To provide additional adaptability in the program, a third option was included and designated the General option. The Mechanical Engineering program strives to provide a strong foundation in engineering design, analysis, and the engineering sciences. Thermodynamics, Fluid Mechanics, and Heat and Mass Transfer are core courses common to all options. Students who pursue one of our more specialized options in Manufacturing or Propulsion Systems are exceptionally well prepared upon graduation. For example, high level propulsion courses include power system integration, power plant performances, analysis and synthesis of gas turbine components, gas dynamics, rocket propulsion, and two consecutive semesters of senior design in propulsion related project. In both options, scientific computing and the intelligent use of computers are given special attention. As part of the vertical and horizontal integration of design and project development, the ME program strongly encourages teamwork in class projects for courses in the major. This helps students to develop a design portfolio starting in their freshman year. Project training continues through their capstone design course. The projects assigned to students are often combined with on-going externally funded research. This aspect of program keeps the students in touch with leading-edge technology and current research activities in the real world.

IV. High Performance Computing Initiative at AAMU

The high performance computing initiative at AAMU was launched in 1999 under the support of the Department of Energy (DOE) Alliance for Computational Science Collaboration (ACSC) project. The key elements of this program at AAMU are to encourage faculty and students to become involved in computational science activities through student scholarships, student internships, student work study, collaborative research projects involving Oak Ridge National Lab (ORNL) scientists, and research proposal submission. The program promotes research and education relative to computational science and high performance computing. It broadens the research and educational capability at AAMU in a manner consistent with our overall growth in sponsored research and with the teaching mission of the University.

A High Performance Computing (HPC) Laboratory using Pentium II PCs that run Linux and PVM, or alternatively Windows NT, has been established. A new Sun Ultra 10 was configured to run high performance computing applications. Current applications include computational fluid dynamics, finite element analysis and grid generation. The Laboratory is located in Carver Complex North, where the school of Engineering and Technology is hosted. This Laboratory is available for use by project participants and by students from Mechanical Engineering, Electrical Engineering, Civil Engineering, and Computer Science Departments, who are either involved in high performance computing projects or enrolled in appropriate classes during the fall 1999 and spring 2000 semester.

The HPC Laboratory is currently connected to the campus network via 10Mbs ethernet and, in turn, to the Internet via a T1 digital circuit. Two projects funded by the National Science Foundation (NSF) plus another funded by the state of Alabama last year supplied critical components of an OC3 Internet feed to our campus.. The OC3 circuit became operational during the summer of 2000.AAMU can arrange to become an Internet 2 affiliate institution when the need arises. These steps will permit campus projects, such as the HPC laboratory, to be connected to their collaborators at other Internet 2 institutions at 155 Mbs provided the departments hosting those projects upgrade their local area networks (LANs) to gigabit ethernet.



Figure 1. High-Performance Computing Laboratory at AAMU, CCN 220.

The initial effort to establish a high-performance computing laboratory was directed by Dr. Scott von Laven and Dr. Deng. Dr. Z.T. Deng was appointed as laboratory director in Fall 1999. The HPC Laboratory is a collaborate efforts among Alabama A&M University, the Alabama Research and Education Network (AREN), and Computer Sciences Corporation. Currently, the high performance computing applications are focused on parallel implementations of computational fluid dynamics codes and finite element structural dynamics codes.

High Performance Computing as a course topic was introduced in one of the Mechanical Engineering classes, ME 300, Mathematical Methods in Mechanical Engineering, taught by the current authors at Mechanical Engineering Department. The HPC laboratory and course elements help prepare students who are selected to participate in the summer internship program in computational science research at ORNL. The high performance computing lab provides access to the course materials and also serve as a teaching platform for other courses in the ME curriculum.

A number of students have benefited from our efforts to promote computational science under DOE sponsorship. Among our past students is a USA Today 1999 Academic Second Team member. Only 20 students nationwide are selected for each team. Another student was a member of the first graduating class (May 1999) to obtain B.S. degrees in ME at AAMU. Under DOE sponsorship so far, two graduate students from Computer Science and one undergraduate student from the Department of Mechanical Engineering have been hired to assist the faculty to conduct research on high performance computing.

AAMU created a DoE Computational Science Scholarship program during FY 2000. The official program announcement was made through the AAMU Admissions Office in November 1999. Scholarship award selection criteria were developed. To apply for the scholarship, a student needs to fill out the application form, write an essay about their goals as they relate to high performance computing, and obtain a faculty recommendation letter. Upon receipt of the application package, a careful selection process is conducted based on the selection criteria. The student needs to agree to maintain GPA of 3.0 or better. Students also need to successfully complete a minimum of 12 credit hours per semester, and maintain a major in science, mathematics, engineering, or computer science. Students will have to pay for any course they fail or in which they receive an incomplete grade. Students are responsible for any fees in excess of the minimum amounts provided by DoE. The student is required to accept employment with the Department of Energy (one-year of employment for each year of scholarship coverage) if offered. The most important part of this scholarship is that students work on interdisciplinary teams to assist faculty in high performance computing research and applications. Twelve students were awarded scholarships for the 2000-2001 academic year. Six are from Mechanical Engineering, two from Computer Science, two from Natural Sciences, one from Civil Engineering and one from Electrical Engineering. Three multi-disciplinary teams were formed to conduct guided research led by the Mechanical Engineering faculty. The student research projects include research and training in areas such as computational fluid dynamics, finite element analysis and advanced propellant characterization for propulsion (biology and chemistry students involved). Four undergraduate students (engineering and computer science majors) were selected to participate in the ORNL RAM Summer Internship program. These students expressed their strong intention to work in the field of computational science after their graduation.

VI. Assessment

The high-performance computing initiative was externally evaluated by a team from Oak Ridge National Laboratory. The project outcome was also evaluated by DOE, and funding was renewed by DoE based on program merit. Each scholarship recipient's performance is evaluated annually by faculty members. Their progress in research is evaluated primarily on project delivery.

VII. Conclusion

The High Performance Computing initiative was established at AAMU to introduce students in science, engineering and mathematics to the state-of-the-art computational science technology. Results indicate that interest in computational science in minority students has increased, particularly among engineering students. The initiative is geared to build stronger competence in modeling and simulation through parallel processing and to provide leading edge computational science resources to both faculty and students at AAMU. The success of the High Performance Computing initiative has been demonstrated, and as a result funding by DOE has been sustained through 2001.

Acknowledgement

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