Many supercomputing applications involve complex data sets and massive amounts of potentially visual information that lends itself to sophisticated imaging and graphics techniques for effective analysis. Model and simulation validation, interactive exploration of multidimensional data sets, and dissemination of results to larger audiences are examples of new applications of graphics and imaging technologies. Specialized image computing architectures are being used in conjunction with fast, general-purpose "compute engines" to provide new ways of visually interacting with data and communicating results.

This article looks at a variety of supercomputing applications, selected primarily from the atmospheric and earth sciences, showing how visualization aids play an important role in understanding data. We will show by example some of the trade-offs (both technical and economic) encountered when applying these technologies to given problems and, conversely, how to best exploit the particular strengths of given technologies.

Within the TASC Computing Technology Center (CTC), a variety of computing technologies are being applied to a diverse range of applications in remote sensing, image processing and image understanding, expert system prototyping, meteorology, geology and geodesy, nondestructive testing, sensor simulation, scene generation, and simulation of complex systems. The CTC currently supports computing, imaging, and graphics systems, including two Alliant computers, a Pixar Image Computer, a Silicon Graphics IRIS system, several VAX computers, Gould Image Processing Systems, and various workstations such as Symbolics and Sun. In this article the Alliant and Pixar will serve as the supercomputer-image computer paradigm to illustrate the main themes: the synergy of supercomputing and powerful visualization tools, the cost-performance benefits of these emerging technologies, and strategies for distributing a given application across these technologies.

Host architectures

Over the past several years there has been an explosion of commercially available parallel-architecture computers, ranging from those with relatively few processors (Cray, Alliant, Elxsi) to medium-grained systems (Butterfly) to fine-grained architectures (Connection Machine). The medium- and fine-grained architectures have demonstrated important successes in various applica-

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Supercomputing and Graphics in the Earth and Planetary Sciences

Within the last few years, cost-effective vector- and multiprocessor-based "mini-supercomputers" have found wide-ranging applications in many new fields. Sophisticated computer graphics are being used to facilitate many of these applications that involve large, multidimensional data sets and outputs of complex computer simulations. This article explores the synergism between massive analytic engines such as the Alliant FX/8 and the Cray X-MP, and imaging and graphics systems such as the Pixar Image Computer and the Silicon Graphics IRIS. Examples from meteorology, geodesy, and remote sensing are used as illustrations. Image processing, image understanding, and image synthesis techniques are described for presenting and interacting with complex data sets.
tions but have required new algorithms and/or programming approaches. Course-grained systems with relatively few but powerful processors and shared memory architectures, such as the Cray X-MP supercomputer and the Alliant FX/8 mini-super, have been quite successful with existing codes.

Figure 1 shows price versus performance for a number of systems running the Linpack benchmark for the solution of a system of 100 linear equations. While no single benchmark can adequately measure the performance of a given system, this benchmark does illustrate several important trends. Two price-performance curves are given: One is associated with the VAX 11/780, a uniprocessor minicomputer in wide use in universities and laboratories; the other is for the Cray X-MP. A factor of about 10 separates the two curves. For applications with inherent parallelism, the supercomputer and minisupercomputer architectures are considerably more cost-effective than traditional minicomputer architectures.

The Alliant FX/8 is a multiprocessor architecture with up to eight computational elements (processors). Each CE also supports vector processing. The Alliant Fortran compiler automatically searches code for vectorization and concurrency opportunities and distributes (micro-tasks) a given job across both vector registers and computational elements. Theoretical peak speed for a fully loaded Alliant is currently about 94 MFLOPS, and actual performance in the 20-40 MFLOP range is not unusual. Figure 2 shows the relative performance as a function of the number of Alliant FX/8 processors for a sensor simulation program. Note that for this application the processing time increases almost linearly to about four computing elements and then trails off as we approach eight. This may indicate a resource limitation (for example, cache size) or may simply reflect Amdahl's law in