POSITION STATEMENT

INNOVATIVE APPLICATIONS OF MASSIVE PARALLELISM

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The Electric Power Research Institute (EPRI) was formed in 1973 to apply advanced science and technology for the benefit of its member utilities and their customers. Funded through voluntary contributions by some 700 member utilities, EPRI's work covers a wide range of technologies related to the generation, delivery, and use of electricity, with special attention paid to cost-effectiveness and environmental concerns. By far the majority of EPRI research is devoted to the development of products and procedures for the immediate use of its members. However, a portion of its effort, managed by the Office of Exploratory and Applied Research, is directed toward exploring new technological ideas, pursuing advanced concepts, and fostering areas of science with potential for breakthroughs. Current and planned investigations include research in several areas of artificial intelligence and parallel processing including adaptive computation and uniquely parallel algorithms.

Many opportunities for the innovative application of massive parallelism combined with artificial intelligence arise from the needs for computer-aided planning, automated or semi-automated operations, and automatic control in the electric power industry and its customers. These applications range from the control of individual components of a power plant, through efficient operation of the plant itself, to the secure and economical operation of bulk power distribution, and the overall management of the utility as an enterprise. From the point of view of exploratory research, these applications provide the long term goals and the context for investigations into basic science. In the case of large systems such as complete power plants, the electric distribution grid, or the electric utility enterprise itself, both automatic control and human decision aids can appropriately take the form of a concurrent simulation run in parallel to the system being

controlled. In order to be effective for optimization, the simulation must be able to run at many times the speed of the actual system (i.e.: ten to twenty-five times real-time). Parallel computer architectures, possibly of specialized design, as well as the unique algorithms capable of taking advantage of that architecture are required. Adaptive computing techniques (algorithms that "learn" as they operate) may also be required, or may even be able to provide sufficient speed-up on serial machines for some applications.

There is currently a proliferation of computer systems with varying degrees of parallel processing capability and many different architectures. In theory, any of these can improve the efficiency of large computational operations (usually by reducing the computation clock time). However, in order to achieve these gains, it is currently necessary to choose the architecture appropriate to the problem and to solve the problem with algorithms and software that are relatively specific to that architecture. One recent project, undertaken by Performance Processors, Incorporated (PPI), of Palo Alto, CA, on behalf of EPRI, investigated the use of a unique parallel architecture for running an existing code with very little change. The problem involved the economic dispatch of electric power through a transmission network subject to security, safety and environmental constraints. The code requires operations on large, sparse matrices. A speed-up of 30 times, attributable solely to parallelization, was achieved in tests which were run on an emulation of a 64-processor version of PPI's unique (proprietary) parallel architecture.

In this case, the architecture was selected for its conformance with the structure of both the problem and the existing code. Planned research projects in the coming years will investigate alternative approaches to:

- the design of new architectures for specific problems of interest to the electric power industry,
- the automatic (or semi-automatic) reprogramming of existing serial codes for existing parallel architectures,
- the development of inherently parallel algorithms for the solution of problems of particular interest to the electric power industry,

The availability of relatively inexpensive but very high performance computing equipment can also be exploited to improve the precision and/or the completeness of numerical solutions by the use of techniques that would be impractical on conventional serial computers. Examples of this approach are computer-intensive statistical modeling methods such as the "bootstrap" and the "jackknife". Other possibilities include methods that are inherently parallel such as neural networks and genetic algorithms. EPRI has several current and planned research projects in these areas also.

Many systems of concern to the electric power industry can be modeled appropriately in a way that involves the numerical solution of partial differential equations. The generation of meshes for this purpose is one of the greatest consumers of computer time. In order to guarantee that required accuracy is being achieved, mesh generation must be guided by computing estimates of discretization errors in the solution. To compute the solution in an efficient, and ultimately optimal manner, it is desirable to program the adaptive iteration of mesh generation and solution error estimation. This is a particularly difficult challenge in computing moving boundaries and interfaces for problems such as free-surface flows and fluid-structure interactions that characterize many heat-exchanger and similar applications in electric power generation and distribution. An added complication arises from the fact that, while adaptive strategies have been developed that provide much more economical computations on conventional scalar computers, the same degree of success has not yet been achieved with similar adaptive strategies on highly parallel computers. It is planned to investigate application-specific techniques involving component-wise dissection of the domain and the use of different mathematical models of the physical phenomena in different regions of the engineering system. This approach may be of particular value in modeling the fuel depletion problem in a nuclear reactor. These adaptive computing methods may involve embedding artificial intelligence techniques within the numerical solution algorithm.

Massively parallel processing combined with artificial intelligence may be particularly applicable to modeling the planning and operation of an electric power system -- the complete generation, transmission and distribution of electricity throughout the area encompassed by one or more utilities. Operating such a system securely and efficiently requires rapid adaptation to relatively unpredictable equipment failures, changes in loads (customer demands), and the effects of natural phenomena ranging from wind to sun spots. The geographically dispersed nature of electric power systems makes distributed computing especially attractive. Breaks (whether intended or accidental) in the power distribution network are usually accompanied by breaks in the communication of instrument data between the same points. In fact, the instrumentation signals may be sent through the power cables themselves. With a combination of intelligent sensors and intelligent distributed processing, isolated sections of the power grid may be able to continue operating independently in a sub-optimal manner while also being prepared to rejoin the network in an efficient manner without creating unacceptable local conditions either during or after the transition.

Operation of an entire electric power system is a problem of multi-dimensional optimization under a variety of hard and soft constraints. Using a distributed computing architecture, it may be

possible to model individual components as intelligent agents (actors), grouped in a quasi-hierarchical manner at multiple levels, and bidding or negotiating their contributions and/or benefits within the network constraints. In general, existing actor systems operate at a much coarser grain parallel structure than is envisioned here. This approach is complicated by the inherently non-linear dynamics of electric power systems. Very recent investigations have confirmed the existence of chaotic behavior, preceded by bifurcations, in relatively simple models of power systems. Real power systems seem occasionally to exhibit the same phenomena. In addition, equipment is just becoming available which is capable of active control of high voltage, impedance, or phase angle with a response of less than half a cycle. This new ability to "tune" the power grid much like a low power electronic circuit promises to make power transmission more efficient, but the threat of the failure of such devices during their routine operation requires even more rapid analysis and action to bring the network to a new, optimal state of equilibrium.

From a numerical algorithm point of view, analyzing the global stability of an electric power system involves operations with large, sparse matrices. Massive parallelism is also very attractive for solving this kind of problem. However, when the parallel processors are also widely distributed in space, both communications time and the possible disruption of communications must be taken into account. Ideally, the algorithms used for analyzing the network should be designed to adapt both to delays and to disruptions.

Most of the research problems described above imply the use of artificial intelligence as an aid to massively parallel computing rather than the use of massive parallelism to support artificial intelligence. However, they also require studies as to the appropriate representation of knowledge in a distributed and inherently parallel environment, as well as the representation of that distribution (the network topology) itself.

The following are some of recent publications and presentations that provide background to the points discussed above.

"Overview of Neural Network Research Projects at the Electric Power Research Institute." In *Proceedings of the 1992 International Simulation Technology Conference and 1992 Workshop on Neural Networks* (Clear Lake, TX, Nov. 4-7) Society for Computer Simulation, San Diego, CA, pp. 529-534.

"Nuclear Thermal Performance Advisor (NTPA) Expert System." (with M. W. Hunt, J. B. Patton, and E. A. Roache) In *EPRI Nuclear Plant Performance Improvement Seminar* (Miami, FL, Feb. 24-25, 1992) Electric Power Research Institute, Palo Alto, CA, pp. 1-13.

"Power Plant Modeling and Simulation Using Artificial Intelligence and Neural Networks." (with K.A. Hickok) In *Progress in Simulation*, Vol. 1, Chapt. 4, G.W. Zobrist and J.V. Leonard, Eds., Ablex Publishing, Norwood, NJ, 1992, pp. 100-125.

"Object-Oriented Design of an Expert System for Security Analysis." In *Expert System Applications for the Electric Power Industry* (Boston, MA, Sept. 9-11, 1991) Electric Power Research Institute, Palo Alto, CA, unpag.

"Model-Based Reasoning and Neural Networks, Combined in an Expert Advisor for Efficient Operation of Electric Power Plants." In *Proceedings of the Fourth International Conference on Industrial & Engineering Applications of Artificial Intelligence and Expert Systems* (Koloa, Kauai, Hawaii, June 2-5, 1991) The University of Tennessee Space Institute, Tullahoma, TN. Vol. 1, pp. 138-147.

"Expert System Aid for Power System Operators." (with Mark A. Rossi) In *Proceedings of the American Power Conference* (Chicago, IL, April 29-May 1, 1991) Illinois Institute of Technology, Chicago, IL, Vol. 53-I, pp. 33-38.