High Energy and Nuclear Physics

The field of High Energy and Nuclear Physics (HENP) will soon be acquiring more experimental data, and with it more chances to observe new phenomena and make new discoveries. DOE projects nearing completion are the BaBar detector at the SLAC B-Factory, new experiments at Brookhaven Relativistic Heavy-Ion Collider (RHIC), upgraded experiments at the Fermilab Tevatron, and at Jefferson Lab. These experiments, as well as U.S. participation in the Large Hadron Collider at CERN in Geneva, have the opportunity to increase knowledge of the physical world in unprecedented ways, through unprecedented amounts of data. The volume of data, however, absolutely demands new computer science tools for data management at scales previously unheard of. The Strategic Simulation Initiative (SSI) will provide the cross cutting computational infrastructure to propel science to new levels and scientists in HENP can help given their background in data management.

But answers to fundamental questions about the nature of the universe will not simply leap out from these laboratories. They will be subtly hidden in the raw data. Large-scale numerical simulations of theoretical models are needed to compare data with theory, test the Standard Model and exciting new physics beyond it. These simulations will require computing power of the scale envisioned for SSI to allow theorists to discover new possibilities.

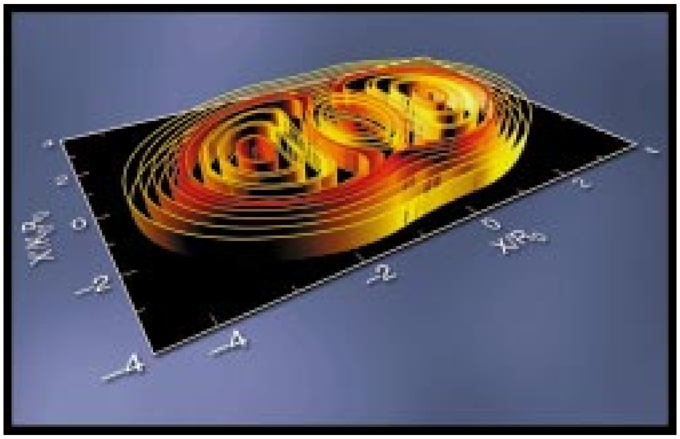
Beyond the upcoming generation of experiments, other future facilities will be needed. SSI offers dramatically new levels of performance and capability for accelerator modeling to design compact, high-energy accelerators of the future, involving 3D geometry and large beam-generated fields, for example. Components could be designed with significantly improved performance and cost effectiveness, and accelerator simulations might eventually approach the level of a complete accelerator system. HNEP has a long history of designing and building their own supercomputer systems to support their studies, so physicists can make valuable contributions.

Collaborations increasingly involve geo–graphically distributed colleagues. Current and planned network capabil–ities will free researchers from the need to be physically located near their data or computers. Hardware and software tools to facilitate effective collaborations at a distance and the network capability to sustain them are crucial for sustaining synergy among highly motivated researchers.

At the end of the 19th century, J. J. Thompson measured the electron and developed his "plum-pudding" model of the atom. At the end of the 20th century, we have the Standard Model but some tantalizing questions. With SSI computational science ability, high energy and nuclear physicists can make unprecedented advances in the next century.

Computational Needs for Future Accelerators

Charged–particle accelerators are fundamental tools used for a broad spectrum of important research and development in all four of DOE’s mission areas: science, energy, national security, and environmental restoration. In the science programs they are central to a large fraction of the work that includes the giant accelerators of the High Energy and Nuclear Physics (HENP) Program, the synchrotron light sources and the spallation neutron sources of Basic Energy Sciences, Biological and Environmental Sciences, and the Fusion Sciences. In the energy area there are the neutral beam injectors of the plasma fusion program and the heavy ion drivers of the inertial confinement fusion program. In the national security area there are the neutron sources, flash radiographic systems and pulsed-power systems. In the environmental restoration area, increasing use is being made of the synchrotron light sources. Accelerators for transmutation of nuclear waste are under consideration. There are many other applications of accelerators and accelerator science that extend far beyond the broad mission of the DOE. These include such things as electron microscopy, proton microprobes, charged-particle beam lithography, ion implantation, medical isotope production, radiation therapy, x-ray lithography, and free-electron lasers.



Computer modeling and simulation have been a key element in the design and understanding of all modern accelerators. Computer programs have been written and used to study a wide variety of problems ranging from microwave component design to the long-term stability of particles in nonlinear magnetic fields. This modeling has been as sophisticated and extensive as the available computers would support, and has allowed the development of far more complex and innovative accelerators of all energies as computer capabilities have increased.

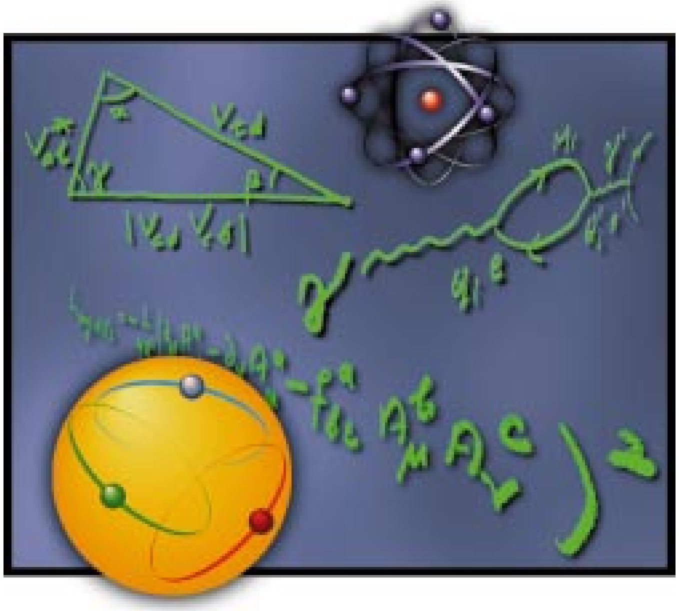
The interplay between simulation, experiment, and theory has been of great importance. Together they have provided a framework for calculation, design, verification, discovery, and understanding The Strategic Simulation Initiative (SSI) offers dramatically new levels of performance and capability for accelerator modeling and simulation which could qualitatively change the complexity of the physics incorporated and greatly extend the scale of the problems studied. Components could be designed with significantly improved performance and cost effectiveness, and accelerator simulations might eventually approach the level of a complete accelerator system. SSI could result in significant reductions in design cost and time for particle accelerators for high energy and nuclear physics, could also open up new applications in material science, biology and medicine and have broad impact an accelerator devices used in industry.

Tools for Theory — High Performance Computing

Recent advances in understanding the basic building blocks of nature have led to a unified, but qualitative, description of physical processes from the smallest size scale, internal hadronic structure, to the largest scale, intergalactic structure. Scientists are now asking for a quantitative description, but such a description will require a very large increase in computer power. Presently, large investments are being made in basic research experiments. However, these investments will only yield their full return when corresponding, but much smaller, investments are made in the computational infrastructure.

An increase in computing capabilities of many orders of magnitude would enable major advances in fields such as high energy and nuclear physics, astrophysics, and general relativity, to name only a few. Increases in raw processor power need corresponding increases in memory, storage, data movement and input-output capabilities. Improvements in algorithms and software have advanced computational research as much as computing power. To take advantage of more powerful hardware, substantial efforts in algorithm and software development must be undertaken.

For example, in High Energy and Nuclear Physics, lattice gauge theory has made the greatest use of high performance computers. Currently, lattice simulations provide the only means of obtaining accurate predictions of quantum chromodyanics (QCD). These predictions are important in order to make precise determinations of the parameters of the Standard Model, and to search for new physics within and beyond it. Recent improvements in algorithms and computational techniques, coupled with massively parallel computers, have brought QCD simulations to a new level of accuracy. More detailed predictions of the required accuracy for the properties of elementary particles and quark-gluon plasmas will require much more computer power.



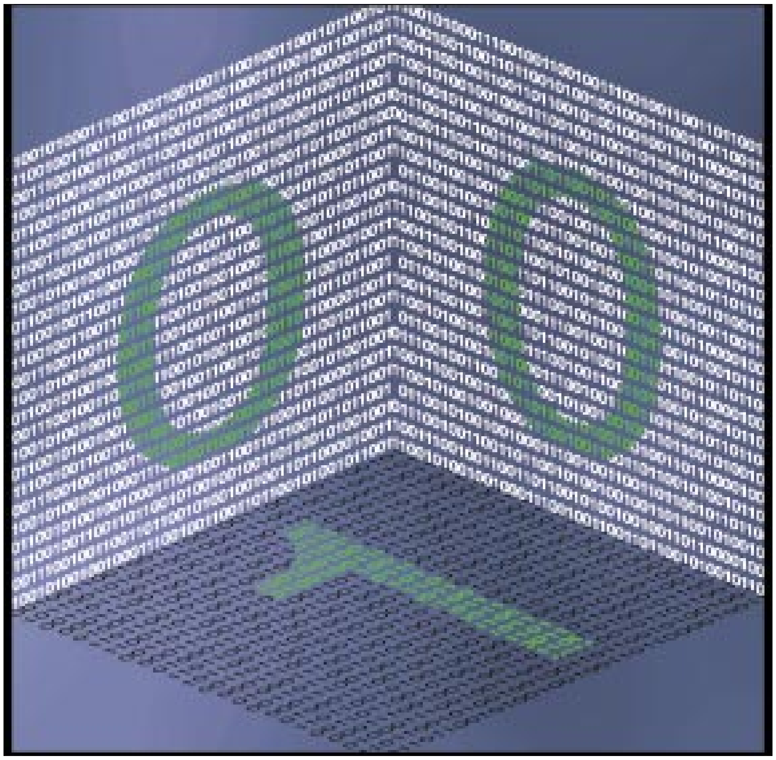
Cosmology involves the study of the origin, structure, and evolution of the universe as a whole. New instruments have allowed detailed observations of the structure of the early universe. Computer simulations are required to understand fully the mechanisms that created this structure.

Lastly, theorists need increased computational power to solve the equations of the Einstein theory of gravity, since they are considered to be the most complex in all of physics. Gravitational wave observatories presently being built or planned are increasing the interest in this area. The separation of gravity waves from background noise demands precise calculations. Investment in the Strategic Simulation Initiative will bring great progress in a variety of theoretical areas mentioned above, but only if we make the corollary investment in the necessary data analysis.

Data Management in High Energy and Nuclear Physics

God, it appears, does play dice: fundamental physical truth cannot be determined by single measurements. To probe deeper into fundamental physics we must record and analyze ever greater numbers of collisions between particles. Like the science of particle accelerators, the science of data analysis is integral to progress in experimental fundamental physics.

Data management in high-energy and nuclear physics (HENP) is unique in its combination of scale and complexity. Each HENP experiment requires the intellect and labor of hundreds or thousands of physicists at universities and laboratories all over the nation or the world. Our data analysis capability limits the number of collisions that can be studied. Today's limit for the complex and granular HENP data is around one petabyte. At this limit, it can take many months for a student to try a simple new analysis idea.



We propose a revolutionary advance in the science of distributed data management and analysis in high-energy and nuclear physics. The goal is to give data-management intelligence to networked computers and storage such that queries that might have taken months or years could be completed in minutes or hours. We also propose an increasingly rigorous approach to the design and exploitation of HENP data-management systems. Systems are built from mass storage (tape), caches (disk), wide-area networks, computers and HENP-specific or commercial software components. The rigorous approach requires that existing systems be instrumented and that models be developed that can predict the behavior of new or improved systems. The models will facilitate rapid evaluation and improvement of new approaches in the science of HENP data management. Dedicated testbeds will be created so that the more adventurous new ideas can be explored. The potential benefits of this HENP-motivated data-management science for other data-intensive sciences and for industry will be vigorously pursued.

We will be able to deal with the number of collisions in HENP experiments by factors of tens or hundreds. The need to make dangerous guesses about which collisions are worth recording will be reduced. The precision of physics measurements will increase and the sensitivity to the unexpected will be vastly improved.