conference report

FIBER OPTICS EMPHASIS ON SINGLE MODE

The third biennial Symposium on Optical Fiber Measurements, sponsored by NBS in cooperation with the IEEE Optical Waveguide Communications Committee and the Optical Society of America, drew some 300 attendees to Boulder Oct. 2-3 to hear 25 contributed papers, several invited papers, and to attend two workshops on the general subject of optical fiber measurements. Papers reflected the international interest in fiber optics, with speakers coming from seven countries outside the U.S.

At the first symposium in 1980, the topic of major concern was attenuation in multimode fibers. Two years later at the 1982 meeting, the emphasis turned to bandwidth in multimode fibers with special interest in the prediction of bandwidth for concatenated fibers. At the most recent meeting, the attention was on single-mode fibers with less interest in multimode. This progression of topics follows the industrial trend, which started with multimode fibers and then shifted to single-mode in more recent years.

At the 1984 meeting, the main single-mode fiber concern was with the measurement of chromatic dispersion. In fact, a whole session was devoted to this topic. The remainder of this brief meeting report will summarize the single-mode topics and mention a few specific contributions.

Agreement Lacking

For single-mode fibers there is a need to determine the cutoff wavelength of the second-order mode and the mode field diameter of the fundamental mode. Both of these parameters are under study by standards groups and at present there is no international agreement on how mode field diameter should be measured or specified.

C. A. Millar of British Telecom Research Laboratories reported on a near-field method which gives both the shape of the mode field radial intensity distribution and the refractive index profile. R. Caponi et al. of CSELT, Italy, presented a novel approach to the determination of mode field diameter using an "optical computing" technique whereby a specially prepared mask is inserted in an optical system and mode field diameter is obtained by taking three single data points. Three papers were concerned with cutoff wavelength measurements. The results were interesting because conflicting curvature dependencies were reported. It appears more work needs to be done on how cutoff wavelength depends on fiber-bend curvature. N. K. Cheung and P. Kaiser of Bell Communications Research discussed cutoff wavelength values with respect to the system's operational wavelength. Those investigations measured modal noise, which can occur if operation is too close to the cutoff wavelength. They conclude that effective cutoff wavelength can be slightly greater (1.35 μm) than the system wavelength (1.30 μm).

Chromatic Dispersion

Chromatic dispersion in single-mode fibers was the subject of seven papers. A knowledge of chromatic dispersion allows one to determine the wavelength of zero dispersion and pulse broadening due to source linewidth. The earliest and most common method for determining chromatic dispersion utilizes a high-power Nd:YAG laser to produce Raman scattering in a single-mode fiber, thereby producing a tunable wavelength source of 150-ps-wide pulses.

R. A. Modavis and W. F. Love of the Corning Glass Works reported on a technique using five pulsed laser diodes and curve fitting to yield chromatic dispersion. K. Tatekura et al. of KDD, Japan, described a similar technique but instead measured the phase shift of cw light from sine-wave modulated laser diodes. Chromatic dispersion can also be determined on fiber lengths less than 1 m using an interferometric technique with a tungsten lamp and monochromator. M. J. Saunders and W. B. Gardner of AT&T Bell Laboratories reported using this technique to determine minimum dispersion wavelength and group delay per unit length. L. Oksanen and S. J. Halme of Helsinki University of Technology described numerical methods to extract group delays from interferometric data.

The Technical Digest for the Symposium on Optical Fiber Measurements, 1984, containing three- to four-page summaries of the papers, is available as NBS Special Publication 683 from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 ($5.00)

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conference report

PROMISES OF LARGE-SCALE COMPUTATION

A conference on the Forefronts of Large-Scale Computational Problems (FF84), held at the National Bureau of Standards in Gaithersburg, MD, was organized on the hypothesis that large-scale computation will play an increasingly important role in science and industry, and that the spectrum of applications of large-scale computation will grow rapidly. Sponsorship was obtained through a consortium of industrial, academic, and government organizations, and the conference steering committee was chaired by Dr. David Wehrly of IBM.

Attending the June 25-27 conference were more than 400 engineers, scientists and others interested in current applications, new approaches and future trends in large-scale computation. A distinctive feature of the audience was the mix of researchers from academe and industry, hardware manufacturers, computer laboratory directors, and managers of R&D. Emerging computational methods and requirements which are held in common by a wide range of research activities were also featured prominently in FF84. The breadth of applications of speakers from industrial laboratories provided persuasive evidence that large-scale computation is being realized as a powerful, economic approach to seemingly intractable problems.

The application areas covered in the program, organized by B. L. Buzbee of Los Alamos National Laboratory and H. J. Raveche of the National Bureau of Standards, include medical imaging, materials science, pharmacology, biotechnology, physics, chemical synthesis, structural analysis, economics, fluid mechanics and movies.

Recent advances obtained from large-scale computation in such diverse topics as voltage characteristics in semiconductor devices, bone reconstruction in surgery, action of drug molecules at receptor sites, interaction of DNA with water, global economic modeling, and testing laws of nuclear physics were illustrated. The presentations revealed that exciting breakthroughs are possible in these areas if sufficient computing capability is forthcoming. Providing this new capability will require sizeable advances in state-of-the-art computing technology.

The FF84 Steering Committee, which has representation from industry, academe, and national laboratories, operates on the conviction that interdisciplinary interactions are essential to progress in the field of large-scale computation. The Steering Committee believes that Forefronts Conferences should be repeated. The purpose of the conferences is to provide a forum for researchers from academe and industry, students, computer vendors, lawmakers and R&D managers to discuss emerging applications, interdisciplinary problems, and future requirements in computing technologies.

This report will begin with a brief review of some of the new and emerging applications of high-speed computations as presented at FF84. It will then discuss specific needs for computing technology that are common to all users of high-speed computation.

'Third Scientific Revolution'

In his keynote address, Dr. Roland W. Schmitt, Senior Vice President of Corporate Research and Development at the General Electric Company and Chairman of the National Science Board, referred to the full emergence of large-scale computation as the "third scientific revolution." Dr. Schmitt also remarked that graphics is essential to gain insight from large-scale computations. He claimed that the combination of high-speed graphics and large-scale computation results in a third way of doing science that will stand alongside the well-established methods of laboratory experimentation and theoretical analysis.

For Dr. Schmitt, effective large-scale computing in an R&D environment not only is a matter of fast computers with large memories but also requires the correct design of the entire computing environment to enable a variety of people to do their work efficiently. The environment includes algorithm development, graphics, individual work stations, micros, minis, mainframes, array processors, and so on. As for improvements, he called for advances in communicating huge data sets to large-scale computers quickly and reliably, and advances in program development tools.

While Dr. Schmitt is generally dubious about government intervention in the commercial development of products, he feels that large-scale computer technology is an exception primarily because the Federal government is one of the principal users of this technology. In addition to Federal assistance for distributing state-of-the-art technology to universities, Dr. Schmitt indicated that the receiving universities should have the responsibility for devising campus-wide networks for their particular computing environment.

Changes for Synthetic Chemistry

Speakers in chemistry included Dr. David Pensak of DuPont and Dr. Enrico Clementi of IBM. Dr. Pensak remarked that, apart from some new reactions and instrumentation, the practice of synthetic chemistry has not changed substantially for more than a century. He added, however, that the introduction of large-scale computational techniques is changing the way synthetic chemistry is being done even though no molecule of any commercial importance has ever been designed on a computer. The combination of high-speed computation and high-speed color graphics provides the chemist with three-dimensional views of molecular geometry and it allows chemists to change geometry readily through, for example, the addition or deletion of functional groups.

Dr. Pensak furnished numerous examples of research areas in the chemical industry where large-scale computation offers substantial promise. These applications include the modeling of: chemical plant processing, requiring the solution of hundreds of simultaneous differential equations; drug molecules on receptor sites, requiring 3-dimensional finite element models; substance-specific membranes to separate alcohol from water or purify synthesis gas obtained from coal, requiring processors 1000 times faster than current technology; cellular kinetics and the metabolism of bacteria, requiring the solution of 15,000 differential equations; chemical reactions on the surface of catalysts; the efficacy of anti-tumor agents; and the toxicity of herbicides and pesticides. He pointed out that advances in such applications require not only advances in processing speed but graphics as well.

Dr. Clementi told the audience that, through research over the last 40 years, quantum chemists have learned how to calculate accurately some properties of molecules with as many as 30 electrons and, with more approximate techniques, the properties of molecules with as many as 400 electrons can be calculated. As an example, he showed results from his computations on the modeling of liquid water. When correlations between many different water molecules were included, the agreement with thermodynamic and x-ray experiments approached experimental uncertainties. Such complex calculations, however, approach the limit of current computing capability.

Computer-based imagery is being applied to an increasing number of problems.

Dr. Clementi provided further examples in the modeling of DNA in water and he reported on the discovery of an unusual arrangement of ions around DNA through these large-scale computations. He explained that the breakthroughs which could shed information on the transmission of genetic information require computing speeds that exceed substantially those now available. To approach these speeds, he is experimenting with a configuration involving as many as 10 FPS-164 array processors attached to three host computers, which are an IBM-4381 and two IBM-4341's. Since each processor is capable of 12 megaflops, he expects peak performance of 120 megaflops with a storage memory of 90 megabytes. Dr. Clementi announced plans for adding to each processor a vector-type feature called 164-MAX. Each MAX-board provides an additional 22 megaflops, and, since he is adding two boards for each of the 10 processors, he projects a maximum speed of 560 megaflops.

Medical Imaging

Speakers in this area were Dr. Gabor T. Herman of the University of Pennsylvania, Dr. Norman J. Pressman of Johns Hopkins Hospital, and Dr. Steven Johnson of the University of Utah. Dr. Herman discussed some fascinating applications of computer tomography, the result of combining high-speed computation with graphics.

For example consider surgery that involves removal or reconstruction of bone, or say the repair of a damaged organ such as the heart. In some cases, the success of the surgery rests on understanding the pre- and post-operative structure of the bone or organ. Surgeons can obtain a three-dimensional model of bones or organs through the use of computer tomography and study these for determining the best way to perform the surgery. Computer-based imagery is being applied to an increasing number of problems, according to Dr. Herman. He cited examples of current research on the three-dimensional visualization of tumors and organs in living patients. With reference to having this imaging technology available to a broad spectrum of patients, Dr. Herman emphasized that the cost of the service is a crucial factor.

Dr. Pressman spoke of the use of special purpose scanning transmission optical microscopes to obtain morphological and biochemical information on cells and tissues. He explained that the computational problems require high processing rates, high bandwidth and the capability of processing large data sets. The computational complexity arises in part from the fact that images need to be collected from all areas on the surface of the slide which is in the microscope's field, and this area can be as large as several square centimeters.

Dr. Johnson presented recent results on ultrasonic imagery which is aimed at obtaining both morphology and material properties. The latter can provide important clues about diseases. Dr Johnson explained that the problem of obtaining this information from ultrasonic imagery involves the solution of complex, nonlinear differential equations. He reported on recent progress involving the use of convolutions and stated that, in order to do three-dimensional imaging, speeds of more than 100 megaflops are required.

Modeling the Non-Linear

Dr. James Gunton of Temple University noted that high-speed computations have been successfully applied to studies of transport properties in semiconductors, devices modeling, and crystal growth. All of these are highly non-linear phenomena, and consequently, modeling them requires large-scale computation. As an example Dr. Gunton discussed the modeling of voltage signals across semiconductor materials. Such studies could be vital in improving the performance of very large scale integrated components used in computers—an example of computers being used to build better computers.

For example, consider charge transport under conditions where the magnitude of the electric field could go beyond the region of linear response analysis and hence the validity of Ohm's law can be in doubt. Through the development of powerful Monte Carlo methods, progress has been made in modeling such quantities as the mean energy and drift velocity of electrons in semiconductors which are essential for understanding the speed of solid state devices.

Dr. Gunton also reviewed results on the modeling of electronic transport in silicon and in aluminum-gallium-arsenide devices, and he showed that the agreement with laboratory measurements is promising. Further examples of the impact of large-scale computations in materials science included crystal growth and catalysis. The former entails heat transport in a moving interface, and the latter involve modeling of reacting molecules near metallic surfaces. The complexity of such simulations requires higher computing speeds than those available in current supercomputers or special purpose processors.

Applications in Structural Analysis

Speakers in this area were Dr. John A. Swanson of Swanson Analysis Systems and Carl Henrich of the MacNeal-Schwendler Corporation. These speakers emphasized the tremendous increase in human productivity that accompanies the combination of high-speed computation with high-speed color graphics. Also, their organizations are representative of the third-party software industry wherein companies must offer and maintain their products on a variety of systems while achieving cost-effective performance. It was made clear that portability does not necessarily mean loss in performance. Both organizations are already implementing their products on parallel processors and, currently, do not foresee any insurmountable obstacles. Results were presented on the use of finite element modeling for such varied topics as turbine blades and architectural structures.

The desirability of doing these calculations on dedicated computers with attached array processors versus supercomputers was reviewed. Dr. Swanson speculated that, with multi-ported memory, multiprocessor systems of the future could obtain a 40-fold improvement with many processors, with almost linear improvement for up to eight processors. He forecast that a desk-top-size computer with CRAY-1S capabilities and high-resolution graphics will be commercially available in about four years.

Computer-Generated Movies

Mr. Gary Demos of Digital Productions showed clips from the science fantasy movie, "The Last Starfighter." Digital Productions has developed Digital Science Simulation (SM), which is computer-generated moving imagery that simulates 3-dimensional objects and events realistically. This company has developed technology in computer-generated graphics whereby they can achieve resolution in the range of 4000 by 6000 lines per image. As a consequence, it is difficult in most cases to distinguish between the computer-generated images and actual color photographs. Mr. Demos indicated that computations are done on their CRAY-XMP.

The cost effectiveness of this technology now equals that of alternative techniques for movie production. The quality and cost effectiveness of graphics shown by Mr. Demos are simply not available to scientists and engineers who typically use large-scale computation, but clearly that technology would be of tremendous benefit to them. With respect to the arts, one suspects that Mr. Demos and friends still have some tricks up their sleeves that await the availability of equipment significantly faster than any available today. Future developments include the technology for the forthcoming major motion picture "2010."

Role in Economics Research

Speakers from this area were Dr. Lawrence R. Klein and Dr. Albert Ando, both of the University of Pennsylvania; Dr. Fred Norman of University of Texas; and Dr. Daniel F. X. O'Reilly of Data Resources Incorporated. State-of-the-art economic modeling is used primarily to investigate consequences of changes in economic policy or external events, to test economic theory, and to train students. Economists would like to enhance the capability to specify objectives and be able to explore policy alternatives for achieving them.

Dr. Klein, who is the 1980 Nobel laureate in economics, explained that the role of computers has been instrumental in the way economics and economic research has developed in the last few decades and that this role can only become more important in the future. He discussed a recent experience with international teleconferencing between participants in Europe and the United States. In the course of the conference, a world economic model of more than 10,000 equations was executed in response to a particular aspect of the discussion and the results were "brought up on the screen" and discussed. Unfortunately, approximately one half-hour was required to execute the model. Conferencing would be greatly improved if this time could be cut to about 5 minutes.

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Current research on macroeconomic modeling being done by Drs. Klein, Ando and Norman was reviewed. This work involves computations containing international data bases, time periods as long as 25 years, and as many as 13,000 equations. While inherent uncertainties in macroeconomic models lead to unavoidable limitations in their accuracy, advances in large-scale computing capabilities are necessary to improve existing models and the turnaround time for obtaining a balanced view of the global economy.

Dr. Ando and Dr. Norman amplified Dr. Klein's presentation and noted that a typical econometric model of a country or a group of countries can be characterized as a stochastic nonlinear system of several hundred or thousands of equations. Such models often involve some non-concavity in the system; and therefore, the computational problems involved in merely analyzing the dynamic properties of the system are formidable. The process of search for approximate optimal control strategies for policy authorities, especially when more than one active authority is involved, introduces game theoretic aspects. This is simply beyond the computing resources now available to economists, both in terms of funding and in power of the equipment.

Dr. O'Reilly mentioned that many of the economic models being used are somewhat coupled and that, while each model may entail 10,000 or fewer equations, the correlated aggregate would involve more than 100,000 equations. Such work could, for example, lead to improvements in the forecasting of monthly unemployment by taking into account weekly unemployment insurance claims. Since there are no adequate computational tools, the problem of correlations can only be handled by having modelers meet to estimate the effects of changing parameters. Dr. O'Reilly anticipates requirements in speed and memory in ranges of tens of megaflops and terabytes respectively.

Applications in Physics

Dr. Kenneth G. Wilson of Cornell University, the recipient of the 1982 Nobel Prize in physics, stated that physicists typically have two responsibilities: one is in their specialty area, such as solid state or elementary particle physics, and the other is in maintaining the basic laws of nature. Dr. Wilson's activities in the former area deal with quantum chromodynamics which is capable of predicting such fundamental quantities as the masses of the proton and neutron. The problem of verifying this theory is a computational challenge inasmuch as it entails four dimensions. The approach is to put the problem on a grid or lattice. The state-of-the-art is a 16^4 lattice and Dr. Wilson suggested that at least a 32^4 lattice is necessary. Since there are inherent fluctuations due to the quantum nature of the problem, statistics must be done on these fluctuations and this involves at least 1000 passes through the lattice, but 10^6 passes are likely to be required. The motivation for this work is that quantum chromodynamics shows promise of providing a new theory and an improved understanding of nuclear physics.

Beyond high energy physics, Dr. Wilson is working on the use of large-scale computation to verify basic laws of nature as they apply to many different subjects. In collaboration with Dr. Robert Swenson of Carnegie-Mellon University, he is studying the inherent mismatch encountered in characteristic features of a broad-class of natural phenomena. Consider, for example, the problem of incorporating atmospheric turbulence in global weather forecasts.

Meteorologists find that the basic hydrodynamic equations for global forecasting, which are solved on the most powerful computers available, require a grid with point spacings of about 50 miles. On the other hand, similar computations for describing a turbulent atmosphere require grid spacings of less than a millionth of a mile. How is this wide mismatch in fundamental length scales resolved? The answer given by Dr. Wilson is to develop the basic laws which are correct at each stage of the process of building increasingly larger grids, and to find the connection between the variables on different grid sizes. This follows the renormalization group approach pioneered by Dr. Wilson. The postulate is that the method leads to an equation which involves all the important grid point spacings, and that this equation captures the essence of the problem.

Dr. Wilson pointed out that many of the conference participants have similar computational problems, irrespective of whether they are chemists, engineers, physicists or image processors. This, Dr. Wilson believes, suggests some objectives for the next generation of hardware. One of these is expandability in basic architecture by factors of 10^3 and ideally by factors of 10^6. Dr. Wilson sees parallelism as a means of providing the desired expandability through a configuration of thousands or perhaps millions of processing elements, each having speeds of at least 20 megaflops. Other guidelines include expandability in data communication, as also mentioned by Dr. Schmitt in his keynote address on large-scale computation in the industrial environment.

Dr. Wilson gave his view of the disadvantages of Fortran, and described a new effort at Cornell called the Gibbs program. The goal of this effort is to provide a modular exposition of programs in a language for researchers to communicate with computers.

Computational Fluid Dynamics

Dr. John E. Bussoletti of the Boeing Company spoke on large-scale calculations used in the design and testing of airplanes, and Dr. Bengt Fornberg of Exxon gave a review of large-scale computers as an introduction to his work on fluid dynamics.

Dr. Bussoletti referred to the powerful computational methods developed for aircraft design and simulation. He cautioned, however, that simulations do not replace wind tunnel and flight tests but instead complement them. Several examples were presented where computations have led to considerable insight and financial savings. Computations played a key role in modifying the design of the 757 cockpit so that it could accommodate the instrument panel of the Boeing 767. In determining the feasibility of 747's to transport a fifth engine from one point to another, simulations revealed that the mounting kit for the extra engine had to be modified in order to avoid a large shock.

While today's supercomputers are capable of processing models for cruise conditions in transonic flow, they are inadequate for many important applications, such as the study of horizontal stabilizers and details of wing structures. Dr. Bussoletti called for bigger and faster machines not only for these types of calculations, but also for the development of improved models. He urged a close relationship between algorithm research and computer architecture.

Dr. Fornberg reported on massive computations for the flow of fluid around a cylinder which involve two space-variables, two velocity-variables, and complex boundary conditions. He said that the power of state-of-the-art technology has led to the discovery of new structure in the flow problem, and that this is stimulating research involving laboratory studies and theoretical analysis.

Dr. Fornberg explained that desired computational requirements in fluid dynamics vary. For the more complex problems, such as chemical reactions in flowing fluids, he projects computational and memory requirements in the range of gigaflops and gigabytes. He speculated that the history of this dynamic technology indicates that sustained rates in the gigaflop range will be available in the 1990's, for example, as some say ETA's GF-10 will achieve.

Public Policy Implications

The speakers in the area of public policy included two members of the U.S. House of Representatives: Rep. George E. Brown Jr. (D. Ca.) and Rep. Rod Chandler (R. Wa.), both of whom are members of the committee on Science and Technology. Dr. James Kane, the Deputy Director of the Office of Energy Research at DOE, and Jo Billy Wyatt, the Chancellor of Vanderbilt University, also spoke.

Rep. Chandler mentioned the importance of educating Congress on what he described as one of America's best kept secrets—large-scale computation and its impact on America's future. He discussed the initiatives of the Republican Task Force on High Technology, of which he is a member, and Task Force recommendations that are designed to promote technology, provide incentives for a vigorous R&D effort in America, and direct resources to universities for equipment modernization. It was explained that the House Science and Technology Committee held two hearings on large-scale computation last year and that these were instrumental in allocating increased support to NSF, NASA, and NBS. Rep. Chandler explained how the R&D joint venture bill, recently passed by the House, should provide some incentives for consortia such as Bobby Ray Inman's Microelectronics Computer and Technology Corporation, MCC.

Dr. Kane recalled how a dynamic partnership between America's computing industry and its national laboratories has been a key factor in building American leadership in computing technology. The responsibilities of DOE in areas of applied and basic research and in new issues, such as climate modeling and the nuclear winter problem, provide opportunities for DOE to continue its strong role in the area of scientific and engineering computations. Dr. Kane said that he has been made aware of the importance of American researchers having greater access to large-scale computing technology and he reviewed various initiatives in the DOE National Laboratories which are designed to provide more access.

Congress is just beginning to understand the connection between large-scale computation and innovation and productivity.

Chancellor Wyatt commented that the current activities in government and universities in the area of computer usage is reminiscent of initiatives taken by the NSF in the 1960's to establish university computational centers. He emphasized the continued importance of basic research in America and stressed the importance of America's ability to transfer technology from the research laboratory to commercialization. Chancellor Wyatt expressed the opinion that the linkages between the Federal government, private sector, and universities are as good as they ever have been for promoting high technology initiatives such as large-scale computations.

Rep. Brown explained that Congress understands the vital importance of computing technology to the continued development of science and engineering, but that it is just beginning to understand the connection between large-scale computations and innovation and productivity. He cited the growing recognition in Congress that, given the existing market, commercial computer manufacturers in the United States have neither the resources nor the motivation to singlehandedly undertake the advancement of high-speed computing technology. Rep. Brown acknowledged that a coordinated effort to maintain America' leadership in computing technology is vital not only for America's scientific strength, but also for its economic competitiveness in world markets. He pointed out that much needs to be done between industry, universities, and the Federal government, and he urged the audience to take a more active role and to view themselves as a transmission belt to opinion makers who have impact on Congress.

Common Technology Needs

Dr. James C. Browne of the University of Texas informed the audience that the next generation of hardware will be more difficult to use, if users expect to exploit the full power of the new technology. He urged more research on algorithms, software, and higher-level languages, and he emphasized the importance of training the current generation of students in these pressing topics.

Dr. Sidney Fernbach of Control Data Corporation corroborated Dr. Browne's remarks. He explained the further need for more research on software that allows one to do symbolic computation. He speculated that the difficulties encountered in the commercialization of large-scale computing technology may go beyond price and extend to the friendliness and versatility of software. Dr. Fernbach agreed that the users of present generation hardware must learn a great deal in order to tap its potential. Another problem is that peripheral equipment is often not designed to match the needs of the host computer.

As evidenced throughout the conference, the cost of computing must include the cost of people not doing science because of either having to wait on slow computers or having to spend time outwitting and coaxing slow computers. The issue is not only economic; it also raises questions about the optimal use of creative resources. This point is widely recognized among traditional users of large-scale computation and has been addressed by combining high-speed interactive graphics with high-speed general purpose computing.

As is evident from the preceding discussion, scientists in these emerging applications have arrived at the same solution. Implicit in this solution is the need for high-speed data communications and large data management facilities. Virtually every application of high-speed computation addressed at the conference showed the promise of major breakthroughs through the availability of more powerful computers, but advances in that area must be accompanied by advances in these other two areas in order to maintain a balanced system.

Equally important are mutual needs in software; for example, efficiency in software, including operating systems, is a clear concern. Improved software for networking and database management is needed. Last, but not least, greater emphasis must be placed on ease of use and quality of documentation.

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