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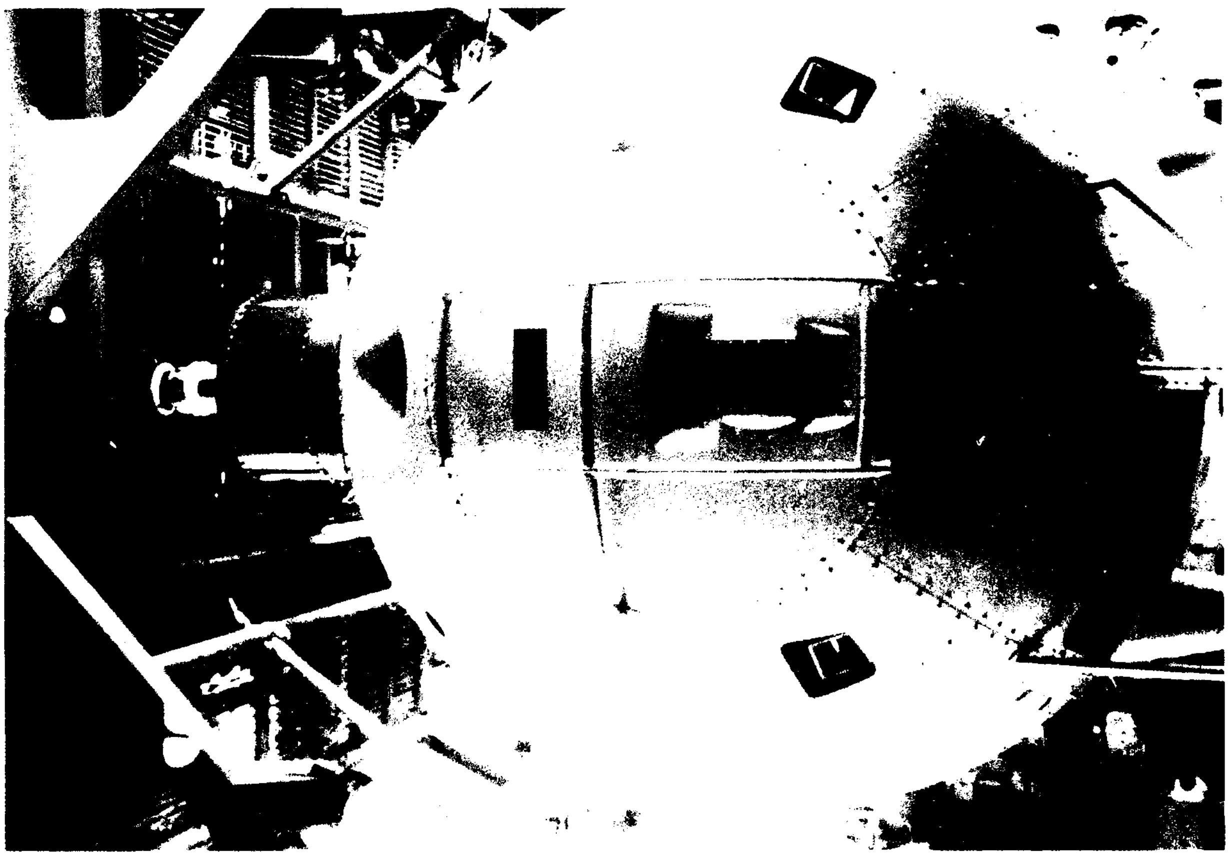

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONRASIA, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large. It is available free of charge to approved members of the DOD scientific community. Send written request describing DOD affiliation to: Director, Office of Naval Research, Asian Office, Unit 45002, APO AP 96337.

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Cover: A front view of a deep submergence rescue vessel (DSRV) owned by the Japan Maritime Self-Defense Force. See the article about the role of the DSRV in submarine rescue operations on page 125.

SIBRIEFs

Scientific Information Briefs

THE INTERNATIONAL SYMPOSIUM ON SHARED MEMORY MULTIPROCESSING (ISSMM)

Introduction

The International Symposium on Shared Memory Multiprocessing (ISSMM) was held in Tokyo on 2-4 April 1991. ISSMM was sponsored by the Information Processing Society of Japan (IPSJ), with Professor Tadashi Masuda from the University of Tokyo serving as general chairman and Dr. Norihisa Suzuki serving as program chairman.

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Both Japan and U.S. industry and academia were represented on the program committee. The proceedings were published by the Information Processing Society of Japan, and a version of them is expected to be published by MIT Press, with Dr. Suzuki serving as the editor. The current plan is to have the second instance of the conference in northern California in late 1992.

The conference included presentations of 23 refereed papers. Of the papers, 5 were from Japan and the remaining 18 were from abroad. The attendance was approximately 130, consisting of about 100 Japanese and 30 foreigners.

There was also a panel on the feasibility of large-scale shared memory multiprocessors. Thacker (DEC SRC) started off by making four observations:

(1) Single instruction/multiple data (SIMD) machines work well for large, regular problems.

(2) Multiple instruction/multiple data (MIMD) machines work well for less regular problems.

(3) Shared memory machines work well when they don't share and don't synchronize.

(4) Programming large, shared MIMD machines is much harder than programming SIMD machines.

Koike (NEC) commented that the history of processor design indicates that shared memory machines consisting of thousands of processors are not feasible in the near term. In addition, he recommended that we focus carefully on specific application domains and on the kind of parallelism they require to get the most from existing (and near-future) parallel machines. (Note that this is consistent with the discussion of the Cenju system, described below, in which a special-purpose machine was built that after-the-fact was viewed to be more general-purpose than intended.)

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Baskett (Silicon Graphics) argued that for many problems, computational complexity is greater than read/write complexity, and so large problem sizes need relatively less bandwidth than small problem sizes. He concluded that building large-scale machines is feasible if we intend to run large problem sizes on them.

Gifford (Massachusetts Institute of Technology) said that such machines are feasible, but that machines with 1,000+ processors cannot have balanced memory access and, therefore, we need some kind of remote procedure call or message-passing protocol. For this reason the term "multiprocessor" must be changed to "multicomputer." For programming ease, he stated that it was critical to name entities that are both local (in shared name spaces) and remote (in nonshared name spaces) uniformly; the performance consequences of this are acceptable, he suggested, if you don't in fact share very much in practice. The reason is that, in order to get machines on the order of 100 or more processors, we will have to manage nonuniform access times. Overall, Gifford saw the merging of two research streams: (1) the flow uniform access time machines (like TOP-1) to nonuniform access time machines (like Dash and Alewife) and (2) the flow of multicomputers (like hypercubes) to high-performance multicomputers (like J-Machine). The central issue in this merging is the programming model.

Y. Muraoka (Waseda University) said to look towards machines with hundreds of thousands of processors, based on wafer-scale technology. He observed that we should not forget Amdahl's Law when considering the relationship between increasing problem size and the increasing number of processors. He finished by stating that parallelizing compilers aren't working well enough, and that the need for distributed memory and programming paradigms is clear. He also pointed out that if a hypercube were to have more than 10^6 processors, we would need at least 1,000 wires per processor. Speedups achieved with current software paradigms are far less than the relative hardware speedups.

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Goodman (University of Wisconsin) concluded the panel by observing that shared memory machines are easy to program but hard to build, while nonshared memory machines are easy to build and hard to program. He believes that the trend is to merge the two by building nonshared memory machines with hardware primitives that support cache-coherent shared memory. He believes the challenge is to exploit the shared memory programming paradigms, perhaps extended in some ways, to nonshared memory algorithms and synchronization approaches. He felt that the communications problem is not bandwidth but latency, and that shared memory multiprocessors (SMMP) must minimize misses (need HUGE caches; must avoid sharing data that are private; must use appropriate algorithms) and accommodate latency (need to pay special attention to processor architecture; must have an efficient pre-fetch, efficient synchronization, and nonblocking reads and writes). Wong (Japan Research and Development Corp.) said that we don't have a suitable large problem to run on a huge SMMP. Now we build special-purpose machines to solve special problems. Halstead (DEC) pointed out that we need cleaner communications protocols. An attendee from IBM Japan asked, "Why do we need large-scale multiprocessors anyway?" Goodman answered, "Because big machines make innovations for small machines."

Discussion of Some Papers

"Cenju: A Multiprocessor System with a Distributed Shared Memory Scheme for Modular Circuit Simulation," T. Nakata, N. Tanabe, N. Kajihara, S. Matsushita, H. Onozuka, Y. Asano, and N. Koike (NEC). Cenju is an experimental multiprocessor system with a distributed shared memory scheme developed mainly for circuit simulation. The system is composed of 64 processing elements (PEs), which are divided into 8 clusters. In each cluster, 8 PEs are connected by a cluster bus. The cluster buses are in turn connected by a multistage network to form the whole system. Each PE consists of MC68020 (20 MHz), MC68882 (20 MHz), 4 MB of RAM, and a floating point processor, WTL1167 (20 MHz). In this system, a distributed shared memory scheme in which each PE contains a part of the whole global memory is adopted. The simulation algorithm used is hierarchical modular simulation in which the circuit to be simulated is divided into subcircuits connected by an interconnection network. For the 64-processor system, a speedup of 14.7 and 15.8 was attained for two DRAM circuits. Furthermore, by parallelizing the serial bottleneck, a speedup of 25.8 could be realized. In this article, the simulation algorithm and the architecture of the system are described, along with some preliminary evaluation of the memory scheme. The picture of the system showed three cabinets, each cabinet having four bays, the bottom bay of which is used for power. The interconnections were done with many ribbon-cables. [Kahaner comments that Cenju was reported on as a machine for transient analysis of circuits, for which it was originally built [I.S. Duff and D.K. Kahaner, "Two Japanese Approaches to Circuit Simulation," *Scientific Information Bulletin* 16(1), 21-26 (1991)]. Recently though, NEC researchers have been studying other applications and reported on a magnetohydrodynamic computation at the annual parallel processing meeting in May 1991.]

"MUSTARD: A Multiprocessor Unix for Embedded Real-Time Systems," S. Hiroya, T. Momoi, and K. Nihei (NEC). MUSTARD is a portable multiprocessor Unix for microprocessor embedded real-time systems. This Unix is a two-layered operating system consisting of a real-time kernel and a Unix kernel. It is operated on a tightly coupled multiprocessor without a dedicated kernel processor. In addition, to simplify the structure of the fault-tolerant system, MUSTARD supports the addition/separation of a processor during system operation. This paper presents the features, implementation, some performance measurements, hardware construction to evaluate MUSTARD, and user programming tools for MUSTARD. This machine is commercially available in

Japan now. It currently uses eight NEC V70 32-bit processors. It also makes use of "redundant" CPUs and has a 16-ms CPU switch time.

"Throughput and Fairness Analysis of Prioritized Multiprocessor Bus Arbitration Protocols," M. Ishigaki (Nomura Research), H. Takagi (IBM TRL), Y. Takahashi, and T. Hasegawa (Kyoto). Performance characteristics of bus arbitration protocols for multiprocessor computer systems are studied by queuing theoretic approach as an alternative to the previous method based on generalized Petri nets. Bus utilization of each processor is calculated numerically for a fixed priority, a cyclic priority, a batching priority, and a modified Futurebus protocol. Plotting utilizations against the rate of service requests reveals the fairness characteristics of these protocols. For instance, in the modified Futurebus protocol with statistically identical processors, the bus utilization is evenly divided to all processors at both light and heavy load conditions, while it is allotted unevenly in accordance with their priority order at medium load conditions.

"Design and Evaluation of Snoop-Cache-Based Multiprocessor, TOP-1," S. Shimizu, N. Oba, A. Moriwaki, and T. Nakada (IBM TRL). TOP-1 is a snoop-cache-based multiprocessor workstation that was developed to evaluate multiprocessor architecture design choices as well as to conduct research on operating systems, compilers, and applications for multiprocessor workstations. It is a 10-way multiprocessor using the Intel 80386 and Weitek 1167 and is currently running with a multiprocessor version of AIX, which was also developed at IBM's Tokyo Research Laboratory. The research interest was focused on the design of an effective snoop cache system and quantitative evaluation of its performance. One of the unique aspects of TOP-1's design is that the cache supports four different original snoop protocols, which may coexist in the system. To evaluate the actual performance, a hardware statistics monitor, which gathers statistical data on the hardware, was implemented. This paper focuses mainly on a description of the TOP-1 memory system design with regard to the cache protocols and its evaluation by means of the hardware statistics monitor mentioned above. Besides its cache design, the TOP-1 memory system has three other unique architectural features: a high-speed bus-locking mechanism, two-way interleaved 64-bit buses supported by two snoop cache controllers per processor, and an effective arbitration mechanism to allow a prioritized quasi-round-robin service with distributed control. These features are also described in detail. [Kahaner comments that several researchers at IBM's TRL told him that there were no plans for commercialization, and the project is very much for experimentation and education.]

"The Kyushu University Reconfigurable Parallel Processor--Cache Architecture and Cache Coherence Schemes," S. Mori, K. Murakami, E. Iwata, A. Fukuda, and S. Tomita (Kyushu). The Kyushu University Reconfigurable Parallel Processor system is an MIMD-type multiprocessor that consists of 128 PEs interconnected by a full (128x128) crossbar network. The system employs reconfigurable memory architecture, a kind of local/remote memory architecture, and encompasses a shared memory TCMP (tightly coupled multiprocessor) and a message-passing LCMP (loosely coupled multiprocessor). When the system is configured as a shared memory TCMP, memory contentions will be obstacles to the performance. To relieve the effects, the system provides each PE with a private unified cache. Each PE may have the cached copy of shared data in its cache whether it accesses to local or remote memory and, therefore, the multicache consistency, or inter-cache coherence, problem arises. The cache is a virtual-address direct-mapped cache to meet the requirements for the hit time and size. The virtual-address cache implementation causes the other consistency problem, the synonym problem, called the intra-cache coherence problem. This paper presents four cache coherence schemes for resolving these cache coherence problems: (1) cacheability marking scheme, (2) fast selective invalidation scheme, (3) distributed limited-directory scheme, and (4) dual-directory cache scheme. Cache coherence protocols and their trade-offs among several aspects are also discussed. [Kahaner comments that the Kyushu work was described in the electronic report parallel.904 (6 Nov 1990). He commented that given the resources available at Kyushu, a project like this might be best thought of as a mechanism for experience building and training. Another paper on this was also presented at the annual parallel processing meeting in May 1991. One of the project's principal investigators, S. Tomita, has recently moved to Kyoto University.]--*David Notkin, University of Washington; John Cowles, Convex Computer Corp.; and David K. Kahaner, ONRASIA*

* * * * *

ADVANCES IN CERAMIC POWDER PROCESSING SCIENCE

Production of high quality powders of the right shape and size and processing of these powders to form defect-free ceramic bodies are important to the development of advanced ceramics for high tech components with high reliability. These are, therefore, research areas of high priority in the field of ceramics. To review the progress in the area of powder synthesis and processing, a series of conferences called the

International Conferences on Ceramic Powder Processing Science was initiated 8 years ago. At the fourth in the series, which was held in Nagoya on 13-15 March 1991, each of the integral stages of powder processing and their interrelationships were discussed. During the course of the conference it was decided that the scope of the conference should be enlarged from ceramic powder processing science to ceramic processing science.

Agglomerates and inclusions are the sources of defects in the final ceramic body. To minimize them it is necessary to understand long range repulsive interparticle potentials in slurries with a low particle fraction. Dr. Fred F. Lange of the University of California, Santa Barbara, in his opening speech, discussed the influence of interparticle potentials on the rheology of the slurry and particle packing. The experimental results described by him confirmed his conclusions that highly dispersed slurries, produced with highly repulsive, long range electrostatic potentials, can be converted into weakly flocced slurries by the addition of salt. These weakly flocced or coagulated slurries can, when consolidated by pressure filtration or centrifugation, give the highest particle packing without mass segregation. Lange explained that a coagulative system was more desirable than a flocced slurry because in a coagulative system particles attract each other but do not touch. He also showed experimental results that indicated that the consolidated bodies prepared from coagulated slurries relax strain easily, while those from flocced slurries do not and are prone to cracking.

Another way of achieving defect-free ceramic bodies is to control the nucleation and growth of particles from the precursor solutions. Prof. Gary Messing of Penn State University reviewed the principles involved in the tailoring of precursor systems to control nucleation and phase development. He described results of his work on mullite and alumina. In the case of mullite, he obtained very fine grained structure by seeding the precursor solution (TEOS plus aluminum nitrate sol) with seed crystals of gamma aluminum hydroxide. Hybrid seeds consisting of gamma aluminum hydroxide and silica gave even better results. The temperature at which these gels were dried and sintered was also found to be an important factor.

A novel process to prepare fine ceramic powders that are monodispersed, with high purity and homogeneous composition in each particle and good sinterability, was reported by Prof. S. Matsumoto of Sakai Chemical Industrial Co. A variety of compounds including TiO_2, $BaTiO_3$, $MnZnFe_2O_4$, and γ-Fe_2O_3 have been prepared. The process essentially involves the interaction of precursor compounds in aqueous solution under hydrothermal conditions. For example, $BaTiO_3$ (perovskite structure) can be prepared by the interaction of titanium hydroxide gel with $Ba(OH)_2$. By controlling the pH, temperature, and pressure, the particle size can be controlled within narrow limits. Matsumoto described the preparation of $MnFe_2O_4$ and acicular γ-Fe_2O_3 and how the addition of certain impurities modified the crystal morphology of these compounds. The acicular γ-Fe_2O_3 was obtained by the interaction of ferric chloride and sodium hydroxide solution at 160 °C in the presence of an organophosphoric acid salt as an additive. These powders are used in tapes for recording and other devices.

Additives are very important as modifiers of particle size and morphology. Prof A. Takahashi of Mie University discussed the molecular mechanisms of polymeric interactions of mixing with solvents, bridging particles, and steric stabilization with features of adsorption of polymers and adsorbed polymer conformation.

Prof. Ilhan Aksay of the University of Seattle, Washington gave an excellent talk on the shape forming of ceramics from colloidal slurries. He classified processing of slurries into two categories: (1) shape forming while the fluid medium is partially drained, e.g., colloidal filtration, and (2) shape forming without any fluid drainage, e.g., injection molding or extrusion. He expounded that because of the different mode of particle-particle interaction in the two techniques, colloidal slurry filtration is not suitable for injection molding. He also described how ultrafine inorganic particles are formed in biosystems. When the particle size is <0.1 micron, high density dispersions cannot be achieved because of clustering. To overcome this, it is necessary to use gel systems. In nature surfactants with bilayers (and not a polyelectrolyte) are involved. Under these conditions it is possible to form strings of nanosized particles that can be very densely packed.

Coating of particles with a phase that could become viscous at elevated temperatures, such as alumina particles coated with silica, can produce excellent consolidated dense bodies. Prof. M.D. Sachs of the University of Florida reported that sialon prepared from powders of silicon nitride and aluminum oxide coated with silica gave a much better product than that obtained from uncoated powders. Dr. H.K. Schmidt of the University of Saarland reviewed the synthesis of powders using sol gel processes. Preparation of thin layer electroceramics such as titanates, zirconates, niobates, and cuprates using chemical precursors was described by Prof. D.A. Payne of the University of Illinois. He gave examples of the evolution of structure from clusters, cage structures, oligomers, network formation, gels, and amorphous and crystallized layers of these compounds. Niel Claussen of the Technical University of Hamburg showed that an isostatically pressed, attrition milled aluminum oxide/ aluminum powder mixture with siliceous additives, heated first between 800 and 1,100 °C followed by heating at 1,100 to 1,250 °C and then sintering at 1,250 to 1,500 °C, produces an excellent mullite ceramic. In the first heating step, aluminum is oxidized to aluminum oxide in the form of nanosized particles of alpha alumina. In the second heating step, silicon or silicon carbide is converted into cristobolite. In the third step, a reaction between alumina and cristobolite takes place, giving a dense mullite ceramic. The addition of zirconia and a humid air atmosphere enhanced the reaction velocity according to Dr. Claussen.

Dr. H. Wada of the Government Industrial Research Institute, Shikoku described a method for the preparation of aluminum borate ($9Al_2O_3.2B_2O_3$) whiskers by the interaction of aluminum sulphate and boric acid in a flux of potassium sulphate. Optimum yield was obtained at 1,100 °C. A number of studies reported preparation of electronic ceramics by the spray pyrolysis technique.

Although no breakthroughs were reported at this conference, a number of invited papers described considerable advances in understanding the nucleation and growth of particles, the structure of clusters, and the influence of surfactants on these clusters and the final consolidation. Aksay's observations on the mimicking of nature in producing higher density, nanosized particle packing were quite interesting. Also, the technique of producing high density, high quality mullite and aluminum oxide by sequential heating of an isostatically pressed mixture of aluminum oxide/aluminum metal powders with and without siliceous additive, respectively, appears to be a new approach to making high quality ceramics and ceramic matrix composites.--*Iqbal Ahmad, AROFE*

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NIPT FEASIBILITY STUDY AND WORKSHOPS

Recently, the Ministry of International Trade and Industry (MITI) announced that a feasibility study for the New Information Processing Technologies (NIPT) program, informally called the 6th generation project, has begun and described its plans for how international cooperation is to be managed. Apparently MITI is going to coordinate all NIPT activities through one governmental agency in the United States and one in the European Community (EC). The NIPT program is now being run by

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(Hirosawa works in the same office that has recently been involved in U.S./ Japan chip discussions.)

The feasibility study will last for about 1 year. It follows a preliminary study that was reported on in a previous issue of the *Scientific Information Bulletin* [D.K. Kahaner, "New Information Processing Technologies Symposium (Sixth Generation Project)," 16(2), 45-52 (1991)]. If the feasibility study is positive the 10-year program will begin April 1992.

The NIPT program is now seen as being in eight definite projects. My own guesses as to the hardware/software components of each are in brackets. This begins to formalize the way research funds will be spent. Also item (3) is now clearly specified as a neural computer. (This had not been decided by the NIPT Symposium in March.) While I don't know this for sure, I would assume that the technical leads on each part will not rotate, i.e., that they will stay with the program all the way through.

(1) Research on theoretical foundations of flexible information processing. [Theory]

(2) Dataflow ultra-parallel computer based on concurrent object-oriented model. [Hardware of a special kind, as well as low level (systems) software]

(3) Million neuron parallel processor. [Hardware]

(4) Adaptive massively parallel machine. [Hardware, software, but I don't really know what this means]

(5) Flexible information processing model based on modularized neural networks. [Neural network models (theory), maybe some hardware]

(6) Research on flexible understanding and flexible inference mechanism. [Theory, maybe with some software experiments]

(7) Optical neuro-computers--Theoretical modeling, device, and system technologies. [Hardware]

(8) Parallel digital optical computer architecture and algorithms. [Hardware for architecture, theory and software for algorithms]

Each project will be conducted by a consortium, consisting of companies and universities. The feasibility study will examine the following issues as well as others.

- Each project's feasibility (objectives, time-tables, consortium members, task sharing, budget, etc.).

- Organization of the NIPT Institute, which will be set up in Japan and will be the core body for the NIPT program.
- Research and development (R&D) infrastructure in Japan for NIPT, such as computer networks, etc.

MITI will set up a feasibility study committee as the executive body of the feasibility study beginning in July 1991. Observers are welcome as representatives of the U.S./EC.

MITI intends to hold workshops organized around each of the eight projects. These will run from September 1991 through March 1992. Participation in these workshops is limited to U.S./EC companies or universities if they have the intention of participating in the consortium at the R&D stage (although there is no commitment), and they are requested to inform MITI of their interest by the end of July. (Government officials will be allowed to participate as observers.) Workshop participants are obliged to make a report jointly on the feasibility of each R&D project.

International cooperation, which is an important part of NIPT, will proceed in one of two ways, facilitated by an Advanced Information Technology Forum established between MITI and the U.S. Government and between MITI and the EC Commission.

(a) The NIPT program will provide funding to the international consortia consisting of Japanese companies and or universities and U.S./EC companies and or universities.

(b) For R&D projects other than those in (a) that are conducted by the Japanese consortium, cooperation through exchange of R&D results and exchange of researchers will occur.

(c) In addition, the feasibility of joint funding to the international consortia by the U.S./EC and NIPT program will be considered as a medium-to-long-term possibility.

Assuming that the actual NIPT program begins, the MITI/NIPT Institute will accept R&D proposals from the consortia in FY92, a selection committee within the institute will examine the proposals and decide which to fund, and funding will begin in FY92 (1 April 1992). Funding is expected to be in terms, with an evaluation at the end of each term determining if the project will be allowed to continue.

Ownership of patent rights will be shared equally between the Japanese Government and the inventor (or his/her company). Patent rights belonging to the Japanese Government can be licensed to the inventor free of charge or at a lower rate.--*David K. Kahaner, ONRASIA*

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UNIVERSITY OF TOKYO DEPARTMENTAL REALIGNMENT IN MECHANICAL ENGINEERING

Background

The University of Tokyo (Todai) is Japan's most prestigious university. Its graduates go into the best government and university positions, including most of the new hires into Todai's own faculty. The buildings are quite old, solid reinforced concrete, and hard to modernize. Budgets are tight. Almost all the students are self-supporting, including graduate students. Tuition is high but apparently not nearly as high as at private U.S. universities.

The typical course of study is 4 years for a bachelor's degree, 2 more for a master's degree, and 3 more for a Ph.D. The undergraduate curriculum is almost all classroom courses while graduate study is mostly laboratory work and thesis, with only a few classes. This is important to understand in view of the subject of this report, which concerns curriculum reform. Information in this report was obtained from the author's personal visit to Prof. H. Inoue and from materials provided by Inoue.

New Departments

Mechanical engineering (ME) used to be split into three subdepartments called Mechanical Engineering, Production Engineering, and Marine Engineering. The latter came into being about 20 to 30 years ago as Japan became a prime shipbuilding country. Since Japan no longer leads in shipbuilding, this department has been totally eliminated in the new structure. When it existed, it dealt primarily with engines and other ship machinery, not with ship structure or other traditional naval architecture.

Three years ago the ME Department decided that it was losing students or would soon, with the defectors going into more modern technologies based on computers and information sciences. The response was to "restructure" and modernize the curriculum, adapting to recent progress in mechanical engineering technology in general and enhancing computer-intensive ME in particular.

The pressure to restructure came not only from trends visible in student registrations but also in general from the rush of technological change in society and industry. Japan identified information-intensive products as strategically important as early as 1970 with the launching of the PIPS (Pattern Information Processing Systems) national project and has pursued this area intensely since. Obviously mechatronic* products will proliferate and engineers will be needed to design them.

A departmental report in Japanese lists financial contributions from many companies. This is an indication of industry interest/pressure.

As can be well imagined, this restructuring was "painful," with several chairs being eliminated. Some faculty apparently left, others changed specialties (!), and several new hires are on the way or being sought. The prime source for new hires is the department's own graduates as well as those from other Todai departments, but several are being sought from the outside.

The restructuring began 3 years ago and the Ministry of Education took until this January to give final approval. Todai is a national university subject to the Ministry's governance. I do not know if there is an equivalent of ABET other than the Ministry, but I doubt it. All the debate, curriculum creation, and course design occurred during this time, according to Prof. Inoue, head of the new Mechano-Informatics Department, so the big fights are over and the new structure is fully in effect.

Department and Curricular Structure

The new department structure recognizes "traditional deep" ME, broad ME, and mechano-informatics (new ME):

Dept of Mechanical Engineering (Deep ME)

1. Strength of Materials and Structure
2. Fluid Dynamics
3. Thermodynamics
4. Mechanical Vibration and Mechanics
5. Material Physics and Tribology
6. Energy Conversion, Combustion Physics
7. Heat and Mass Transfer
8. Mechanical Science, Measurement Instrumentation

Dept of Mechanical and Industrial Engineering (Broad ME)

1. Production Systems, Manufacturing Systems
2. Machine Creation and Manufacturing
3. Systems Engineering, Security Engineering
4. Design Engineering
5. Human Systems Engineering
6. Industrial Systems, Transportation Systems
7. Humanware Systems Engineering

Dept of Mechano-Informatics (New ME)

1. Electronics and Computer in Machinery (digital systems, microcomputer, interface, micro-machine)
2. Mechanism and Control (mechatronics, control theory, mechanics and mechanisms)
3. Pattern Information Processing (sensors, signal processing, image processing, visualization)
4. Software Engineering (algorithm design, programming languages, operating system)
5. Computational Mechanical Engineering (computational mechanics, simulation, finite element method analysis, computer-aided engineering)
6. Bio-Mechanical Engineering (biomechanics, neuro engineering, cognitive engineering)
7. Information Systems Engineering (robotics, artificial intelligence, information systems)

Broad ME includes industrial engineering and production engineering. Both design and computing appear in all three subdivisions. Students majoring in any one of these three take courses from the various chairs, with 50% recommended from the home department and 25% each from the other two. There are no required subjects. I do not presently know what the requirements are for what we call "humanities" subjects. This way of setting up the curriculum may have been adopted in order to reduce conflict between the advocates of the new curriculum and those of the old who usually ask in such debates what mechanical engineering really is. The new structure actually moots this question in a very realistic way, acknowledging the fact that the old curricular and disciplinary boundaries have long since been destroyed by external events and it is necessary to build new ones. The three new subdepartments complement each others' research and education and respond to the challenge to form the "new discipline of mechanical engineering."

According to Prof. Inoue, the purpose of the Department of Mechano-Informatics is to enhance the research and education of computer-intensive mechanical engineering. Primary research fields include:

* "Mechatronic" means combining mechanical and electronic or other technologies. A CD player is an excellent example.

- creation of intelligent machinery such as robotics and mechatronics

- computer-intensive design and analysis of mechanical systems

- introducing new functions or approaches into machinery such as bionic functions, neuro science, and micro-machines

- advanced human-machine interface, virtual reality, cognitive engineering, etc.

On subsequent visits I hope to delve deeper into such questions as the relation between university training and company training and whether the university thinks any one student can really learn all the things that are offered. What should a competent design engineer know in a world of mechatronics? Since there are no required subjects, only "strongly recommended" ones, the department has not taken a rigid stand on these points.

I raised the question of the place of algorithms in this curriculum. It may seem odd to relate algorithms to mechanical design, but Inoue agreed immediately that this is an essential ingredient. Many complex products are algorithm-driven by their embedded microprocessors. Many have complex user interfaces and multiple internal states, both mechanical and electronic. Thus a sense of algorithms is essential for a comprehensive design approach.

A related question is why algorithm-aware students don't go into computer science (CS). The simple answer is that there is no CS department in Todai's engineering school! There is a CS department in the School of Science, however. I did not learn much about what it teaches. The electrical engineering (EE) department in the School of Engineering deals mostly with power and information systems, including signal processing and vision. Most U.S. universities have CS departments or CS divisions of EE departments. At Todai such competition does not exist, leaving a clear path to ME for such students who also have a mechanical bent.

Discussion

Many universities in the United States have trouble changing their curricula radically, in spite of obvious reasons to do so. At the Massachusetts Institute of Technology (MIT) I saw leading professors introduce new material at the graduate level and prove it out before trickling it down to the undergraduate curriculum. This can take many years and lacks a department-wide strategic approach. It also lacks a methodology for removing outdated material, leading to crowding in the undergraduate syllabus. At Todai the graduate curriculum has so few classes that this method may not be available. The MIT ME Department is currently engaged in a long-term redesign of its curriculum.

The methodology at Todai is not totally clear to me, except that the pressure came from within the department, apparently, and not from the dean. The methodology for selecting elements of the new curriculum is also not clear, except that the chairs focus on areas that are related to their research. This creates expertise but does not guarantee that generic material will be taught or that the students will obtain a balanced education. I will try to find out during subsequent visits if industry reviews or advice was involved, or whether departments have visiting committees as do U.S. universities.

What is clear is that the change was quite radical and has defined "mechanical engineering" in a way that would be almost unrecognizable at many schools in the United States.--*Daniel E. Whitney, ONRASIA*

* * * * *

PROPOSAL FOR JOINT RESEARCH PROJECT ON RETRIEVAL OF JAPANESE DATABASES

The Database Promotion Center (DPC), Japan is planning a 2-year research project with interested foreign partners in order to develop a system for retrieval of Japanese database information by use of English (or other non-Japanese) language queries [see also D.K. Kahaner, "Japanese Database Activities," *Scientific Information Bulletin* 16(1), 65-68 (1991)].

As of 1990, there were over 650 original databases created and available in Japan. Eighty-eight percent are described using Japanese (kanji). This makes them essentially inaccessible to non-Japanese speakers and adds to the sense that Japanese information is closed to Westerners. Providing databases in English within Japan is expensive and the market within Japan is seen as small. The eventual solution to this is to employ intelligent machine translation, and this is an active research area. There are also some commercialized systems, but their performance has thus far been limited.

DPC would like to improve this situation in the short run by allowing non-Japanese speakers to query Japanese databases in English or other languages. The plan is for a 2-year project, 1991-93, which will:

- Define the specifications for a retrieval system.

- Develop a prototype system and make it available to overseas users (the system is planned to run on a workstation or a PC).

- Release a report on the project.

Foreign organizations are encouraged to participate by

- Accepting Japanese researchers within the participating organization.
- Attending committee meetings (international transportation to be provided by DPC).
- Using and evaluating the prototype system for about 3 months.

Readers should note that this proposal relates to the query language. It does NOT imply that response from the English queries will be in English and thus does not appear to me to provide much additional access. However, the Japanese research assistant in my office felt it would help somewhat in that one level of translation would be eliminated. This is a very small step forward, but perhaps it can be achieved within 2 years.

For further information, contact either Mr. Keisuke Okuzumi or Mr. Hiroyuki Endo at DPC:

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--David K. Kahaner, ONRASIA

* * * * *

SECOND NTT SCIENCE FORUM

Nippon Telegraph and Telephone Corporation (NTT) is the "Ma Bell" of Japan and is the major player in Japan's telecommunications industry. Until April 1985 it was a public (government) corporation solely responsible for the industry. However, like AT&T earlier, it was privatized in 1985, allowing competitors to enter the field. Nevertheless, it remains the largest of the companies which operate Japan's telecommunications network, the large size of which is evidenced by the fact that, with the exception of the United States, Japan has more telephones than any other nation in the world.

As part of its effort to raise and enhance its image as a leader in science and technology, NTT in 1990 initiated a science forum program in which distinguished scientists in a particular field are invited to present lectures and discuss their work. The second of these forums was held on 10 April 1991 and its theme was "Marine Biotechnology -- Ocean as a Source of Life." Two speakers from the United States, Professor Andrew A. Benson of the Scripps Institution of Oceanography and Professor Harlyn O. Halvorson of the Woods Hole Oceanographic Institute, were the invited lecturers. The formal lectures were followed by a panel discussion with Benson and Halvorson, who were joined by Professor Shigetoh Miyachi, Executive Managing Director of the Marine Biotechnology Institute (MBI), and Professor Isao Karube of Tokyo University. The moderator was Mr. Akio Etori, the Executive Director and Editor of Mita Press. Before the discussions began, Professors Miyachi and Karube gave brief presentations of their work.

Professors Benson and Halvorson each reviewed past work in the field of marine biotechnology and discussed contributions that can be expected. Benson reviewed the field in terms of marine products, health, and environment. Among the topics he discussed were the Manzanar Project to develop mariculture in the Red Sea, regulation of calcium by calcitonin from salmon, and the ability of some marine organisms to detoxify arsenic by synthesis of nontoxic arsenic compounds. The work at Woods Hole was the subject of Halvorson's presentation and included a discussion of novel resistance mechanisms to infectious diseases displayed by some marine organisms and the novel processes employed by certain marine bacteria (archaebacteria) to withstand extreme environments.

Professor Miyachi described MBI, which was established last year in two locations, Shizuoka and Kamaishi. The institute is financed by government (Ministry of International Trade and Industry) and industry. Currently 24 companies provide funds and two-thirds of the researchers. Biodegradation of oil, bio-antifouling agents, and CO_2 extraction with marine algae are some of their projects. Professor Karube discussed studies related to the problem of global warming; among them were solar bioreactor experiments in Okinawa and CO_2 removal with coral.

Although the lectures presented "big picture" overviews rather than detailed discussions of specific research programs, the forum provided a good medium for people working in the field to get together.*--Sachio Yamamoto, ONRASIA*

* * * * *

TRON (THE REAL TIME OPERATING SYSTEM NUCLEUS)

TRON is a large and long term project to develop a computer operating system (OS) along with a global man-machine interface that can work with many other computer operating systems. Its main focus is to provide an environment for a very large number of small distributed computers to cooperate in real time. The project is supported entirely by industry, mostly Japanese. Western academic computer scientists should make themselves much more knowledgeable about the details.

by David K. Kahaner

SUMMARY

TRON (The Real Time Operating System Nucleus) is a complex and controversial subject, especially in the United States. It is an ambitious project which is attempting to develop an operating system (OS) specification that will be coupled to a global man-machine interface that can work with other, different computer operating systems, such as those of IBM, SUN, APPLE, and DEC. Its main focus is to provide an environment for a very large number of small distributed computers to cooperate in real time. The project is supported entirely by industry, mostly Japanese, but a few Western. The originator and principal investigator of the project is

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Professor Sakamura created the TRON concept in 1984 and has been working energetically to promote industry's acceptance of it since then. It could have an important impact, when completed and if accepted, in many areas of information technology, such as advanced numerical controls, robotics, task interfaced plant operations, and simultaneous intertask communications as well as in many consumer applications. Sakamura claims that all the funding for the project has come from industrial sources through the TRON Association. Membership now numbers almost 150 and includes essentially all major Japanese electronics companies, as well as construction companies, software houses, etc. (A complete list is given in the Appendix.) There are also a few U.S.-Japan subsidiaries such as IBM Japan and Apple Japan and a very small number of U.S. companies such as Tandem Computer and Motorola.

A great deal has been written about TRON. The April 1987 issue of *IEEE Micro* was entirely devoted to this topic, and Sakamura received an IEEE award for best paper of the year because of his work. TRON was also the subject of a short chapter written by Professor Michael Harrison in a JTEC report, "Advanced Computing in Japan," October 1990. Both these references also contain citations to many other research papers. TRON has been directly involved in basic trade friction between the United States and Japan, and this has obscured some of its major technical aspects. For example, more than 50% of Harrison's report was concerned with trade concerns. Even so, in the West, TRON is not well known, and details about the project are much better known in the industrial community than in the basic research community. The purpose of this report is not to repeat material that has already been covered in other sources or to deal with contentious trade problems in any way, but rather to point out to research scientists that there are TRON concepts that have wide implication in many other aspects of computing science.

Why is TRON important? It is not necessary to master the details of the various TRON architecture specifications to grasp its potential significance. Sakamura is visualizing a world even more computerized than today's. In such a world one's everyday life will be influenced by computers that adapt the local environment; provide basic functions for communication, transportation, and control; as well as interact between other heterogeneous computer environments. What are the key characteristics associated with such a computerized world? Clearly, these include distributed processing, toleration of faults, rapid response (real time) to multimedia inputs and outputs (voice, image, text, and others), a very human and friendly interface, and adaptation to a constantly changing universe in which the network of computers will be undergoing constant reconfiguration as nodes are added, removed, or replaced by different systems. These are some of the same issues confronting researchers in scientific parallel and distributed computing. (Of course, there is a difference between the needs of high performance distributed numerical computation and real time distributed computation, but this difference is primarily related to task switching speed rather than fundamental organization.) But one major difference between TRON and other distributed computing models is that TRON is driven by large numbers of small sensor-sensitive computers, the kind that are most likely to make their appearance in inexpensive consumer devices, light pens, touch screens, television, etc. The important part of this is that in Japan consumer electronics is fueling the computer industry rather than the other way around. Consumer product specialists such as Panasonic, Sony, Seiko, Ricoh, Kyocera, Oki, etc. are deeply involved in computer developments. When we realize that in the United States one of the most successful parallel computers, Intel's iPSC (hypercube), got its first boost by being able to make use of large numbers of inexpensive, off-the-shelf processors that were used in PCs, it is possible to imagine how the transfer from consumer technology to computer technology occurs here.

One very good (and well known) example is the TRON House. This is an extremely modern residence of almost 400 m^2 situated in the center of Roppongi, one of the most expensive sections of residential Tokyo. The general appearance of TRON House is similar to what one would find in the pages of *Architectural Digest*--modern, open, functional. The building connects about 1,000 computers that are all linked together to perform a dazzling variety of automated functions controlling lighting, heating, cooling, domestic hot water use, ironing, cleaning, personal hygiene equipment, entertainment, ticketing, etc. Currently, a family is actually living in the house at the same time that experiments are being conducted using the computers. (For example, what happens if some of the systems break down?) Plans are to open the residence in April 1991 to public inspection. The project is supported by 19 Japanese companies including NTT, Nippon Homes, Mitsubishi Electric, Toto, and Yamaha. The construction industry is Japan's largest, and since 1987 new-housing starts have been averaging about 1.7 million per year. The average Japanese new house is about 136 m^2 (about 1,400 ft^2). You can buy a two-floor, California style house of that size that sits cheek by jowl against its neighbor and is about a 1-hour train ride from Tokyo for about $700,000. Thus TRON House represents a substantial investment.

Sakamura plans to extend the concept to a TRON office building and even to a TRON city with "billions" of cooperating computers. The construction companies see in TRON a future of intelligent buildings, intelligent communities, and intelligent cities, in which nonobtrusive computers will control various functions in environmental control, security, communication, health, amenity, recreation, and transportation systems. The construction of a pilot intelligent building is to start in 1991. In addition, there is a 10-year project to build a computer city incorporating TRON concepts. Land has already been set aside in Chiba Prefecture and this project is being carried forward by over 40 corporations. Certainly, the research necessary to make such a distributed computing project work must have some relevance to other distributed/cooperative computing projects.

The one Sakamura laboratory that I visited was a feast of gadgets and experiments. There seemed to be no end of equipment, and high-end workstations were packed almost wall to wall. (His laboratory space occupies virtually an entire floor in the University of Tokyo's Faculty of Science building, although I was told that he is also moving into another larger facility in a different part of the city.) Sakamura has designed an ergonomic keyboard for a TRON-based Gmicro workstation that he demonstrated to me. It was hooked up to a standard Sony video camera and the operator could open a window that displayed the camera's output, which could be processed in real time. The workstation is definitely multimedia capable. There are also wireless electronic pencils (functioning like a mouse) and wireless erasers. He is designing "intelligent" glasses that will sense distance from the screen and adjust text image size accordingly. A video center also lets Sakamura and his students experiment with interaction to and from CDs.

The TRON project is now so large that it has branched; BTRON, ITRON, CTRON architectures are associated with business, industry (robotics), and communication, respectively. For example, the target application classes for CTRON systems include switching and communication, information processing, and workstation applications as central file servers in wide area networks or as hosts in large databases. The CTRON specification defines mechanisms to meet the special needs of hard real time constraints, high reliability and high performance. Each of the subprojects has ambitions goals. For example, BTRON workstations use a 16-bit character code to allow them to support many different languages. The BTRON specification make it likely that the system will have real time response capability even if equipped with advanced man-machine interfaces. The design also incorporates psychological techniques such as requiring users to confirm that they want to process sequences that will take a long time and the updating of only those portions of the display requiring user attention. BTRON defines a common data format for graphical data, and the BTRON OS has utilities for editing and displaying such data as well as hypertext functions and the ability to link documents in network fashion.

There are a number of committees and special interest groups. For example, the automotive committee is studying ways to use TRON in navigation and safety. There is a TRON computer education research group, consumer electronics research group, intelligent house research group, physically handicapped needs group, etc. The seventh annual TRON Project Symposium was held (in English) in December 1990, coincidentally with the TRON Show where products are displayed and demonstrated. Each symposium proceedings is published by Springer-Verlag (*TRON Project 1990*, Ken Sakamura, editor, ISBN 0-387-70066-8, Springer-Verlag, New York).

Sakamura has repeatedly emphasized that he is involved in basic research and wants an open system in which creative ideas are shared. For example, in the latest symposium, he gave a paper on programmable interface design for highly functional distributed systems. The idea here is that cooperation among elements in a large distributed system is only possible if some standard interfaces are provided on all the communication paths in the network. Such interfaces need to be defined between application programs, data formats, network protocol, printer control codes, human/machine interfaces, etc. But if the standard is fixed this will tend to stifle incorporation of new computer tech-nology. Alternatively, if the standard is updated via dated versions, then version inconsistency will soon be a problem. Sakamura proposes to deal with this in the following way. A system with which communication is made can be programmed, and interface specifications can be changed whenever needed. When communication takes place between systems, first the interface specifications on both sides are compared and, if necessary, the side requiring higher level specifications sends a program to the other side, establishing the necessary communications. For example, consider a system in which an ITRON-controlled air conditioner is operated by a BTRON computer. If the air conditioner sends to the BTRON machine a dialog window program for its control, interaction with people can then be left up to the BTRON machine, while the ITRON side need only receive instructions that have been determined based on a standard interface.

TRON specifications are published and available for everyone to examine. Members of the TRON Association have access to some additional information, but special provisions are in place to provide academic researchers with full details. Given the involvement of Japanese industry in the TRON project, it is not surprising that much of the research is being done at corporate laboratories, but it is somewhat disappointing that there has been so little involvement from the West, and essentially none from the academic community. At the 1990 TRON Symposium a few Western scientists did give papers, but with the lonely exception of Professor James Mooney from West Virginia University, their affiliations were entirely industrial. And while Mooney does make recommendations and assessments about CTRON, his paper is mostly concerned with general issues of software portability rather than about detailed TRON research. On the other hand, papers were presented by researchers from NTT, Toshiba, Hitachi, Matsushita, University of Tokyo, NEC, Mitsubishi, Oki, Fujitsu, and others in Japan. Topics ranged from the very general such as Sakamura's above to detailed implementations on Unix, PCs, and other systems, floating point, graphics, etc. Sakamura admits that there may have been some misunderstanding related to trade problems and that he personally does not know too many Western computer scientists. He explained that while many Japanese scientists like to study Western papers to then generalize and extend them, his approach has been to try and develop his ideas entirely independently. The fact that his support is only from industry may also have diluted interest from the basic research community in the West. However, now some Western companies have expressed their interest by joining the TRON Association. The latest is Tandem Computers, who is hoping to expand its knowledge of how to make large computer systems more fault tolerant. (A TRON-specification extended bus, TOXBUS, has been developed specifically to improve the performance of VME or Multibus for tightly coupled high performance systems, as well as fault tolerant systems.)

TRON has standard functions such as interrupt, exception handling, and memory control functions, in addition to such basic capabilities as input/output, file management, and debugging. U.S. operating systems with some similarity to TRON are RMX-86, MTOS-68K, and VRTX/68000. Users can write in C, C++, Fortran, Pascal, and Forth as well as TRON-specific language

(TULS). (Green Hills Software in the United States provides compilers for TRON architectures.)

About half a dozen TRON-based microprocessors are already commercially available, as are a number of ITRON products (see Tables 1 and 2).

One characteristic of TRON CPUs is the use of a large linear (nonsegmented) address space. The early design was for a 32-bit CPU with expandability to 64-bit addressing. TRON-based microprocessors include the 32-bit MN10400 by Matsushita, or a 32-bit Gmicro 300 from the combined efforts of Fujitsu, Hitachi, and Mitsubishi that I saw demonstrated. (The MN10400 has run floating point double precision calculations at 8.3 MWIPS at 20 MHz.) Oki Electric has developed a 0.8 μm CMOS 32-bit TRON-based micro (O32) containing 700,000 transistors, which will perform at 10 MIPS at 33 MHz.

The TRON Association also announced the development of CHIP64 (a 64-bit microprocessor). Hitachi has an IBM-PC bus board that allows its integrated system debugging tool (ISDT) to run. ISDT is part of Hitachi's European-based TRON project. Toshiba has an Intel 386-based operating system based on CTRON specifications. In the United States, Interactive Systems Corp. has ported UNIX System V Release 3 to a Gmicro/200. This company has many years of experience in porting various versions of Unix to Intel, Motorola, and RISC processors, and the development team found that the Gmicro/200 had some advantages that made hardware-dependent portions of the port relatively easy to implement (especially memory management and software generation system). Gmicro has a floating point unit (FPU). One interesting feature is that elementary functions are computed using the iterative "cordic" algorithm [C.W. Schelin, *American Math Monthly* 90(5), 317-25 (May 1983)]. Hewlett-Packard adapted a similar scheme for its pocket calculators.

It has also been claimed that the Japanese industrial involvement is as much for fear of being left behind as from any direct interest in the project. Part of their reluctance stems from the historical Japanese approach to building custom software from scratch, rather than using standardized components. My own observation is that research activity is active although industrial commitments might be a bit tentative. As an example, here is a quote from the Mitsubishi Research Institute,

Table 1. TRON-Based Microprocessors

Microprocessor	Number of Instructions	MMU	Cache	Number of Transistors (x 10,000)	Process (CMOS) (μm)	Packaging
TX1 (Toshiba)	93	X	X	45	1.0	155 PGA
Gmicro/100 (Mitsubishi)	92	X	256 inst	34	1.0	155 PGA 152 OFP
Gmicro/200 (Hitachi)	22[a]	O	1 Kb inst 128 stack	73	1.0	135 PGA
Gmicro/300 (Fujitsu)	102[b] 22[a] 11[c]	O	2 Kb inst 2 Kb data	90	1.0	179 PGA
MN10400 (Matsushita)	93	X	1 Kb inst	40	1.2	144 PGA
032 (Oki)	103	O	1 Kb inst 1 Kb data	70	0.8	208 PGA

[a]Coprocessor.
[b]Basic.
[c]Decimal.

Table 2. ITRON Products

Specification	OS	CPU	OS Vendor
mu-ITRON	MR7700	MELPS 7700 series	Mitsubishi
	MR3200	M32	Mitsubishi
	HI8-3X	H8/300 series	Hitachi
	HI8	H8/500 series (64 KB mem)	Hitachi
	HI8-EX	H8/500 series (1 MB mem)	Hitachi
	REALOS/7	F2MC-8 series	Fujitsu
	TR90	TLCS90 series	Toshiba
ITRON1	RX116	V20/30	NEC
	HI68K	68000	Hitachi
	HI16	H16	Hitachi
	REALOS/286	80286 (protected mode)	Fujitsu
	MR32	32032	Mitsubishi
ITRON2	HI32	H32	Hitachi
	REALOS/F32	F32	Fujitsu
	IX101	TX1	Toshiba
	MR3210	M32	Mitsubishi
ITRON/FILE	HI68KA	68000 file mgmt for HI68K	Hitachi
	HI16A	H16 file mgmt for HI16	Hitachi
	HI32A	H32 file mgmt for HI32	Hitachi
	MR3200F	M32 file mgmt for MR3200	Mitsubishi
	MR3210	M32 file mgmt for MR3210	Mitsubishi

We ... are conducting research into methods, based on the object-oriented approach, of defining application requirements, carrying out software design, and generating program code automatically. The object-oriented approach is especially geared to event-driven applications in real-time control fields so our immediate goal is to build prototype systems applying ITRON specifications.

Matsushita has been most active in the adaptation of TRON into its product lines and has produced an educational system geared for the school market under the sponsorship of the Center for Educational Computing (CEC), an organization affiliated with the Ministry of International Trade and Industry (MITI) and the Ministry of Education and Culture. The potential adoption of TRON standards for school computers was one of the trade-related concerns.

Some U.S. researchers do not think much of TRON, saying it is nothing but a warmed-up version of the Motorola 68000 to make it a real time OS and extendable to 64-bit chip applications, in other words, not innovative technology. And some of the U.S. vendors may feel that their real-time operating system kernels are superior to what could be done using ITRON. Sakamura feels that his viewpoint is rather different. TRON chips do not use RISC architecture. Sakamura believes that when floating point is required RISC speed drops off rapidly. Further, he feels that to get the most performance and cost benefit it will be necessary to use specialized chips (ASIC), commenting that using a RISC chip for video is not as effective as using a special ASIC, and that it would cost far too much to use a RISC chip in a game computer or in what should be an inexpensive consumer product. He claims that a TRON specification chip has functions that make it more suitable as an ASIC controller. Further, there is a family approach to TRON, something that RISC chips don't have (using the same architecture from 16 to 64 bits is not the RISC model). The TRON project is concerned about an architecture that is suited to systems with extremely large numbers of intelligent objects networked together, and compatibility is clearly necessary.

A reasonable question is the relationship between TRON and other Japanese computer projects, such as the proposed New Information Processing Technology (NIPT) [see my articles "New Information Processing Technology Workshop," *Scientific*

Information Bulletin 16(2), 31-43 (1991); "New Information Processing Technologies Symposium (Sixth Generation Project)," 45-52]. One major difference is that the funding for the latter is via the Japanese Government; TRON is industrially financed. While TRON is looking toward futuristic uses of computers, it is using silicon technology for chip design. Further, TRON has no provisions for new reasoning models and concentrates more on the interface, communication, and collaboration issues. TRON is focused on uses of computers in very direct applications, while NIPT envisions much more complicated information processing requiring new models of what it means to think and compute. TRON is being propelled by scientists who imagine a city where many computers cooperate; NIPT is viewing a world where computers and people are synergistic.

SUGGESTIONS

In the West many people are worried about TRON, because they fear that if Japanese electronic giants such as Sony, NEC, Fujitsu, Mitsubishi, and Matsushita someday adopt the TRON specification in their product standards, then these could eventually become the world-wide industry standard because of Japanese strength in the electronics and computer markets. Consequently, Western companies would then be forced to adopt TRON specifications in order to be competitive. There is another view, however. As all TRON specifications are published in English, there is nothing to stop Western manufacturers from implementing a TRON operating system and marketing it to the Japanese. *Computer Design* (1 February 1991) points out that TRON is only a specification, not real code. The fact that it can be implemented on many different levels appears to offer an opportunity for enterprising U.S. software companies. They go on to remark that "if the U.S. is so far ahead in software technology, it should be possible to create BTRON-based high-performance operating systems that would be strong competitors in the Japanese market."

My own view is that we should concentrate on the scientific content of this project. There is no doubt that promotional literature about TRON is often vague and sometimes fails to differentiate between the future that will come anyway and the future that will come using TRON. Several of the Japanese academic computer science researchers I spoke to were also politely tentative about TRON. They state that computer science research spans a broad range from highly theoretical to nuts-and-bolts extremely practical, and that TRON concentrates on quite practical applications. Nevertheless, there are many excellent ideas coming from the TRON community. Fueled by the Japanese ability in chip and other hardware design and manufacture, members of this group have been aggressive and successful in building experimental systems. Western scientists are not going to be able to assess these unless they are more active participants in the project. Western standards organizations as well as research scientists should start paying serious attention to TRON specifications now, realizing that sooner than we anticipate one of the Japanese giant electric firms may adopt TRON specifications. One way to begin would be to have serious U.S. attendance at the 1991 TRON Symposium, which will be held on 26-27 November 1991 in Tokyo. For more details contact Sakamura.

ADDITIONAL COMMENTS

After a draft of this report was distributed, several readers sent comments and amplifications to what I wrote. The two most substantial were from Prof. J.D. Mooney (West Virginia University), who was cited above for his participation in the last TRON symposium, and Prof. J. Hootman (University of North Dakota), who was editor-in-chief of *IEEE Micro* at the time that the TRON articles were published in that journal (1987). Their comments are quoted below.

Hootman

It strikes me as if the TRON concept is an ideal one for AI [artificial intelligence), neural nets, etc. If one is to really model the brain, etc., it will require a multitude of sensors and the interaction of many different types of systems--an ideal type of situation for the TRON. I am really surprised that no group has started to look at that. It would be interesting to study this and just see what kind of information was generated.

In order to really convey the place and importance of TRON, I think that it is necessary to make a table and compare TRON with something like Unix or other operating systems and give the good and the bad points of both.

I think that we in the U.S. tend to look at ourselves and concentrate on the good stuff we do. We don't spend time looking at others to see what they are doing. I bet Ken S. looked around and just made the considered decision to do something different. The other impressive part of Ken's operation is the support that he has from the government and industry [only industry as far as I can tell-DKK]. This says that the IBMs of the world are going to have to do some serious looking at TRON and other operating systems.

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Mooney

I would like to follow up and comment on some of the points made by the Kahaner report on the TRON project. Dr. Kahaner cited me (with some justification) as a "lonely exception" to the lack of participation by western researchers, especially academics, in the TRON project. He also observed that the project is controversial, and the follow-up comments certainly illustrated this: They all suggested that TRON was uninteresting and should not be taken seriously, although none of the posters had significant first-hand knowledge about the project.

I will speak as one who does have some first-hand knowledge. Dr. Sakamura first contacted me in 1985 because of my work on the IEEE "MOSI" standard (an operating system interface standard for small computer systems). I have participated in discussions about TRON since that time, and I have been an active participant in the CTRON subproject of TRON since 1988. For the record, I do receive research funds in connection with this project. I was an invited speaker at two TRON symposia in Tokyo, and a TRON researcher spent a year working with me at West Virginia University.

I am not an apologist for TRON or for the Japanese, but I am often amazed by the "uninformed" negative reactions to this project. A discussion which I initiated about TRON on USENET 2 years ago led to a wide range of criticisms, many based on inaccurate knowledge (and a few on outright anti-Japanese bias). I later summarized this discussion in the TRON special issue of *Microprocessors and Microsystems* (October 1989). There was no interest in establishing a TRON newsgroup to continue the discussion.

I would like to propose a more balanced view. The TRON projects are not a panacea, but with all respect to Professor Tanenbaum, it is foolish and shortsighted to call TRON "dead as a doornail."

First of all, it is important to remember that the TRON "project" is actually a large collection of subprojects motivated by a common vision. That vision is one of open, global networking, supporting everything from worldwide communication to local networks of "intelligent objects" in the home. It is fair to be skeptical or opposed to parts of this vision; Americans, especially, do not want to live in an environment where computers seem to have the upper hand. The total TRON vision may never come to pass, or may be far in the future. But the TRON subprojects do not depend on the vision and are not waiting for it. Some of them are already technically complete and are quietly finding their way into commercial products.

The TRON goals depend fundamentally on open participation. TRON subprojects are aimed at developing "standards," not products. Many commercial interests are participating, and each standard is intended to enable products of many vendors, although reasonably differentiated, to work together. Western companies with no present involvement in TRON may find advantage in offering products compatible with these standards.

TRON is, of course, of Japanese origin; in the U.S. view it will forever be "not-invented-here." There are obvious cultural and language barriers to foreign participation. But participants from any country have always been welcome, and specifications for the TRON subprojects, although still under development, are being openly published. A few TRON presentations and workshops have been held outside Japan, and the TRON Association is willing to help organize such events wherever there is sufficient interest. The text of Dr. Kahaner's report suggests that only a handful of Western companies have joined the TRON Association, but a detailed scan of the list he provides shows a lot of familiar names [thanks for the correction--DKK]. These companies may not all be actively participating in development, but they will not ignore potentially significant markets.

The TRON standards are not developed in a vacuum. They do not conflict with existing international standards, and they interface to these standards where appropriate (e.g., the OSI model, the Ada Language). TRON representatives participate in international standards activities, and the various TRON specifications are likely to be proposed for ISO/IEC JTC-1 standardization when completed.

TRON is funded purely by an industrial consortium; it receives no government support (is there a surer recipe for success?). TRON is also not a trade barrier; nothing in its nature suggests that it could be anything but a trade facilitator. In May 1989 the U.S. Government "proposed" TRON for possible inclusion on a list of sanctioned products. There was a clear misunderstanding of the nature of the TRON project. Part of the concern centered on the rumor that MITI would mandate use of TRON-based products in schools, creating a supposed obstacle to U.S. suppliers. This did not happen, although the U.S. Government certainly mandates widespread use of many American standards. This misunderstanding was soon resolved, and TRON was never listed, but the bad press continues.

The TRON project was conceived from the start to include five principal subprojects. It is not correct to say that the project has "branched" due to growth. It is also misleading to confuse the name TRON with a particular subproject or to form opinions or draw conclusions about the TRON project as a whole based on views about only one subproject.

Four of these subprojects have been well developed to date: ITRON, BTRON, CTRON, and the TRON CPU (or CHIP). Each of these has already led to both detailed specifications and products. ITRON, BTRON, and CTRON are each families of operating system interface specifications. The TRON CPU is a family of microprocessor architecture specifications. The fifth subproject, MTRON (for Macro TRON), is aimed at developing an intelligent distributed control for a complete network. It is in a much earlier stage of development.

These specifications were designed to work together; the TRON CPU is envisioned as the usual processor for ITRON-based embedded systems and for BTRON-based workstations. However, they surely do not depend on one another. In practice, most ITRON and BTRON products to date have used other processors (Intel, Motorola, etc.), while TRON CPU systems often run other types of OSs, including UNIX.

The TRON CPU has received the most criticism. I will not try to defend this architecture, but even if it is not admired it will soon be found in many Japanese products. Moreover, the OS specifications are being used without the CPU. ITRON is the basis for embedded systems in applications such as robotics, mobile communication, and consumer products--not to mention the TRON House, which does exist and apparently works. BTRON workstations to date have been specialized for Japanese input, which may limit their usefulness in the West. However, I have seen (in 1988) BTRON systems that include effective multilingual processing, high-level data management, multimedia output and "input," and (a special concern of Dr. Sakamura's) integrated support for disabled users. This could be effective competition for some existing workstations.

CTRON is in a special class, designed for larger environments and optimized especially for communications and information processing applications. It is likely to find application in telephone and communication systems, in Japan and elsewhere.

The TRON projects are not only feasible, they are developed and maturing. Annual international conferences have been held since 1987, with presentations in both Japanese and English and simultaneous translation. Papers in the first conference focused on TRON concepts and development of the specifications. In 1988 and 1989 increasing numbers of implementation reports were presented. The 1990 conference was concerned with topics such as performance, reliability, and validation. The CTRON committee has begun a series of formal portability experiments involving CTRON products of a number of companies to validate the ease of porting software in CTRON environments. This project was launched with a symposium on software portability in September 1990. My paper in the 1990 TRON Symposium Proceedings, to which the Kahaner report refers, emphasizes portability because it was originally presented at the portability symposium. A slightly revised version was then reprinted in the later proceedings.

In summary, I strongly agree with the conclusion drawn by Dr. Kahaner in his very objective report, that TRON is indeed a force to be reckoned with. You may like or hate the project, but each TRON specification deserves to be evaluated on its own technical merits. Many companies are doing this, and some are adopting TRON elements. Like it or not, these elements are already appearing in Japanese products and systems, and understanding them will be important for international commerce.

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David K. Kahaner joined the staff of the Office of Naval Research Far East as a specialist in scientific computing in November 1989. He obtained his Ph.D. in applied mathematics from Stevens Institute of Technology in 1968. From 1978 until 1989 Dr. Kahaner was a group leader in the Center for Computing and Applied Mathematics at the National Institute of Standards and Technology, formerly the National Bureau of Standards. He was responsible for scientific software development on both large and small computers. From 1968 until 1979 he was in the Computing Division at Los Alamos National Laboratory. Dr. Kahaner is the author of two books and more than 50 research papers. He also edits a column on scientific applications of computers for the Society of Industrial and Applied Mathematics. His major research interests are in the development of algorithms and associated software. His programs for solution of differential equations, evaluation of integrals, random numbers, and others are used worldwide in many scientific computing laboratories. Dr. Kahaner's electronic mail address is: kahaner@xroads.cc.u-tokyo.ac.jp.

Appendix

TRON ASSOCIATION MEMBERS AS OF 30 MARCH 1990

Aisin Seiki Co., Ltd.
Alps Electric Co., Ltd.
Amano Corp.
AMD Japan Ltd.
AMP (Japan), Ltd.
Ampere Inc.
Ando Electric Co., Ltd.
Anritsu Corp.
Apple Computer Japan, Inc.
Asahi Kasei Microsystems Co., Ltd.
Ascii Corp.
AT&T Japan, Ltd.
Aval Data Corp.
Brother Industries, Ltd.
Canon Inc.
Casio Computer Co., Ltd.
Central Information Center Co., Ltd.
Chubu Electric Power Co., Inc.
Computer Presence Corp.
CSK Corp.
Custom Technology Corp.
Digital Electronics Corp.
Digital Equipment Corp. Japan
Elco International K.K.
Electronics & Telecommunications Research Inst
Fanuc Ltd.
Ford Motor Co.
Fuji Electric Co., Ltd.
Fuji Facom Corp.
Fuji Software Inc.
Fuji Xerox Co., Ltd.
Fujitsu Ltd.
Fujitsu Network Engineering Ltd.
Garde Inc.
Goldstar Software, Inc.
Green Hills Software Inc.
Hazama Corp.
Hirose Electric Co., Ltd.
Hitachi, Ltd.
Hitachi Microcomputer Engineering, Ltd.
Hitachi Software Engineering Co., Ltd.
Hokkaido Information & Communication Co., Ltd.
Hoshiden Electronics Co., Ltd.
IBM Japan, Ltd.
Ikegami Tsushinki Co., Ltd.
Ines Corp.
Intec Inc.
Intel Japan K.K.
Iwasaki Electronics Co., Ltd.
Japan Air Lines Co., Ltd.
Japan Aviation Electronics Industry, Ltd.
Japan Direx Corp.
Japan Radio Co., Ltd.
Kawai Musical Instruments Mfg. Co., Ltd.
Keizo Ltd.
Kohgaku-Sha Publishing Co., Ltd.
Kohwa Joho Giken Inc.
Kokusai Denshin Denwa Co., Ltd.
Kokusai Electric Co., Ltd.
Kozu Systems Design Corp.
KSD Corp.
Kyocera Corp.
Logic Systems International, Inc.
Matsushita Communication Industrial Co., Ltd.
Matsushita Electric Industrial Co., Ltd.
Matsushita Electric Works, Ltd.
Matsushita Electronics Corp.
Meidensha Corp.
Microboards, Inc.
Micronics Co., Ltd.
Microtec Research, Inc.
Minolta Camera Co., Ltd.
Misawa Homes Inst of Research and Development Co., Ltd.
Mita Industrial Co., Ltd.
Mitsubishi Electric Corp.
Mitsubishi Electric Semiconductor Software Corp.
Mitsubishi Research Inst, Inc.
Mitsui Real Estate Development Co., Ltd.
Morson Japan
Motorola Inc.
NEC Corp.
Nihon Unisys, Ltd.
Nippon Columbia Co., Ltd.
Nippon-Data General Corp.
Nippon Homes Corp.
Nippon Koei Co., Ltd.
Nippon System Kaihatsu Co., Ltd.
Nippon Telegraph and Telephone Corp.
Nippondenso Co., Ltd.
Nissan Motor Co., Ltd.
Nissin Electric Co., Ltd.
Northern Telecom Japan Inc.
NTT Data Communications Systems Corp.
NTT Software Corp.
NUK Corp.
Oki Electric Cable Co., Ltd.
Oki Electric Co., Ltd.
Oki Electric Industry Co., Ltd.
Olivetti Systems Technology Co.
OMC, Inc.
Omron Corp.
Omron Tateisi Software Co.
Pasco Corp.
Personal Media Corp.
PFU Ltd.
Plus Corp.
Printing Machine Trading Co., Ltd.
R&D Computer Co., Ltd.
Ricoh Co., Ltd.
Roland Corp.
RSA Network Corp.
Sanyo Electric Co., Ltd.
Seiko Epson Corp.
Seiko Instruments Inc.
Seikosha Co., Ltd.
Sharp Corp.
Shimizu Corp.
Shinko Electric Co., Ltd.
Siemens AG
Software Consultant Corp.
Software Products and Systems Corp.
Software Research Associates, Inc.
Sony Corp.
Sumitomo Electric Industries, Ltd.
Sun Wave Industrial Co., Ltd.
System Algo Co., Ltd.
System V. Co.
Texas Instruments Japan Ltd.
Tokico Ltd.
Tokyo Computer Service Co., Ltd.
Tokyo Electric Power Co., Inc.
Tosei Systems Co., Ltd.
Toshiba Corp.
Toto Ltd.
Toyota Motor Corp.
Uchida Yoko Co., Ltd.
Uemura Giken Co., Ltd.
Victor Co. of Japan, Ltd.
Wacom Co., Ltd.
Wind River Systems, K.K.
Yamaha Corp.
Yamaichi Electric Mfg. Co., Ltd.
Yamatake-Honeywell Co., Ltd.
Yasukawa Electric Mfg. Co., Ltd.
Yazaki Corp.
Yokogawa Electric Corp.
Yokogawa-Hewlett-Packard, Ltd.

JAPAN'S ALPHA PROJECT

The Alpha Project is a coordinated effort by Japanese industry (NEC, Fujitsu, Matsushita, Hitachi, NKK, Kobe, Toshiba, etc.) to develop a modern three-dimensional computer program for computational fluid dynamics. This report describes the background of the project and its current status. We also assess its future potential.

by David K. Kahaner

INTRODUCTION

In 1988 several Japanese companies came together to form the Association for Large Scale Fluid Dynamics Code. One of their research activities has been investigation of new software for fluid dynamics, administratively called the Alpha-Flow Project. Initially the association was composed of 15 companies that together provided about $10 million. About 15% was also loaned to the association by the Japan Key Technology Center, which is set up by the Ministry of International Trade and Industry (MITI) and funded by interest on income from the stock of NTT. (Such non-profit foundations are part of Japan's "third sector" and play an important role in supporting science.) In addition, there were about 30 additional companies who have paid lesser amounts.

The motivation behind the project is that mathematical modeling of fluid flow by computer, computational fluid dynamics (CFD), is a crucial part of large scale engineering simulation for nuclear reactors, aircraft design, wind flow around large structures, etc. Japanese industry makes heavy use of programs that perform simulation, and their utilization is bound to increase. For example, it is estimated that between 1% and 2% of Japanese construction industry sales revenue goes for research and development (R&D); the figure in the United States is less than 0.05%, less than 1/20th as much. There is anecdotal evidence that the Japanese are using computational modeling for more long range projects than corresponding U.S. companies. U.S. firms tend to use simulation packages for immediate projects. One Western scientist told me that after the project is over, companies that he was familiar with often forget how to use the package and, in some cases, even forget that they have it.

Most CFD programs are either proprietary and only provided as "executables" by commercial vendors or private such as those used at the Department of Energy laboratories, such as Livermore or Los Alamos. Japanese use of Western simulation programs varies from using them as black boxes, without detailed knowledge of the "inside" of these packages, to significant enhancements that have been made to some programs that were made available to them from national laboratories.

CFD poses very severe difficulties in terms of the mathematical model and the details of its implementation. Programs that solve "real" problems usually contain tens of thousands of lines of (mostly) Fortran, written over many years by a heterogeneous collection of physicists, engineers, and computer scientists. Maintenance and documentation of these programs are often spotty; they are the typical "dusty decks." Recently, there has been some effort to modernize CFD programs, but it is rare that a completely new package is developed from first principles.

A large modeling problem can consume endless hours of supercomputer time and generate enormous quantities of printed and graphical output. Using these programs can be tricky. The underlying model incorporates various assumptions and approximations; designers and users are always hoping to "add more physics," refine the numerical mesh, improve the numerical methods, etc. It is often difficult to validate a program and scientifically risky to use one without a great deal of expertise and/or consulting assistance. Thus a good program represents a very significant economic asset to its owners.

Charge-back costs to users are high in order to recoup the substantial development expenses and to support ongoing research. Just as importantly, end user companies are often naturally nervous about being dependent on software that their engineers do not entirely understand. Most companies would rather have their engineers understand the working of computer programs that provide answers they need to rely on. Further, to get the most out of such complicated programs, and to avoid being misled by incorrect and incomplete answers, it is essential that users have some understanding of how these programs work. It seems perfectly reasonable that Japanese industry should want to develop their own in-house expertise.

ALPHA PROJECT

Three key people who have been instrumental in starting the Alpha Project are:

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These three have known each other for many years (Mizuta and Akiyama since high school); the common denominator is their association with nuclear technology. Before Mizuta moved to NASDA he spent a number of years at PNC, a government funded organization looking into fast breeder reactors and the nuclear fuel cycle. Now he is responsible for planning issues related to computing. Akiyama is primarily interested in thermal hydraulics but is also chairman of the committee that advises MITI about the nuclear industry. He also wrote a clear overview of the Alpha Project in the *Proceedings of the International Conference on Supercomputing in Nuclear Applications* (March 1989, pages A2:60-65). Takahashi specializes in large scale computing of nuclear models.

The association gets input from end users, academic researchers, as well as its members. Basic research, mostly in industrial laboratories or at universities, helps to decide the fundamental mathematical, physical, and numerical techniques. Akiyama told me that there are 50 to 100 people associated with the project in various ways.

A contract software company [Fuji Research Institute Corp. (FRIC)] does the program implementations. Currently, there are between 30 and 40 programmers and computer analysts working on the project at FRIC.

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is the technical leader of the FRIC group and coordinated a recent visit of mine to their institute.

A biannual meeting gives researchers an opportunity to show their latest results and for the Alpha Project developers to present their progress. A Proceedings is issued in Japanese, although at the March 1990 meeting Dr. Eric Hollnagel (Computer Resources International, Denmark) gave a very general discussion of the potential usefulness of artificial intelligence (AI) and human computer interaction when coupled with the power of a supercomputer.

According to Mizuta, a key aspect of the project is that Japanese scientists want access to the insides of complicated CFD programs in order to verify and understand exactly what they are doing. My own experience in other general mathematical software is that this is not always necessary in really well designed programs as long as the physical and mathematical models have been carefully worked out. The apparent need here probably reflects both the string and thumbtack construction of some CFD programs and the fact that the models are usually not entirely satisfactory. Mizuta claims that this phase of the Alpha Project has focused on the physical model to be solved and the numerical techniques to be utilized. The project has been developing single-phase, three-dimensional solvers, using finite differences only, for a variety of physical situations. Finite elements are not being considered at this time as they are thought to be too slow. Approximately 100,000 to 150,000 lines of Fortran have been written to support the solver part of Alpha, organized as follows.

Solver for incompressible flows (A module for Cartesian and cylindrical coordinates and one for boundary fitted coordinates. There is also a module for free surfaces.)
- Solver for heat transfer in solids
- Solver for mass transfer (where trace amounts of material are mixed with the fluid)

Solver for incompressible flows with multiple free boundaries
Solver for chemically reacting flows (low velocity reaction flow)
Solver for compressible flows (for high velocity viscous flow)

The 15 companies that support the association will be permitted to have copies of all the source programs; other members will get "executables" only.

However, during the development phases, participating researchers will have access to some parts of the source programs, presumably for them to study and test. It is expected that each company will modify the programs either for its own needs or to optimize sections for particular hardware.

This phase of the project is focusing on the scientific and engineering aspects in the design of a CFD package, i.e., the model. This is natural given the background of the research team and the engineering expertise of the supporting companies. However, there are other issues that are also very important such as the following.

- Modularity and portability.
- Hardware independence and optimization for different computers.
- Maintenance framework for large (huge) source programs.
- Documentation.
- User interface.
- Incorporation of expert systems and AI for advice on problem setup, interpretation, and management of results.
- Adaption of the programs to advanced computer architectures, such as parallel computers.

Mizuta claims that they want to tackle these issues and lists them as among their most important goals. Nevertheless, he admits that they haven't done much in any of these directions and that the concept of using expert systems, etc., is easier in principle than in practice. Some items in the list above will be easier to accomplish than others. For example, we already know how to design numerical software with interchangeable parts and to plan for a high degree of portability. It is more difficult to also get highly optimized software, especially over a wide spectrum of machine architectures. Adding intelligence to numerical programs is a new, major research area and there is significant work at Purdue, Rutgers, and other places. In the West, especially in the national laboratories, petrochemical companies, and other places where CFD programs are in heavy use, there are major efforts to study the implications of new machines, such as parallel and distributed computers. The Alpha Project has not looked into this aspect.

I was surprised to learn that Mizuta, and presumably the other Alpha-Flow Project scientists, was not well connected into the community of Western researchers who have been actively studying most of these topics, e.g., participation in the Expert Systems in Numerical Computation Conference that is held each year at Purdue. On the other hand, papers in the recent Alpha-Flow Symposium concerning the man-machine interface are full of references to current research in the West. At the moment there is also almost no participation from scientists in the West, although Mizuta and others are known in the Western CFD community and have recently returned from a trip to several U.S. laboratories. When I asked about this, Mizuta explained that at the beginning the Japanese didn't feel that they had anything to contribute and wanted to bring their own expertise up to a credible level first.

After Mizuta said that the emphasis was on the solvers, I was amazed to learn during my visit to Fuji that the user interface has not been neglected; almost 300,000 lines of C have been written in the man-machine section. These include

- Control module
- Module for input generation
- Module for interactive post-processing
- AI module (expert system)
- Module for data management

I was shown a few brief demonstrations of the system, which looked quite powerful as well as flexible, but had no opportunity to study any parts in detail. The design philosophy is to write the Fortran in the form of portable and modular machine independent subroutines and the man-machine interface in similarly portable and modular form. The latter would be expected to run under X-Windows on a Unix workstation and the Fortran on a remote (super) computer. Between these parts would be a "gateway" module that would contain all the machine specific details of the implementation. There is a complicated flow of data between modules, but this is standardized by use of a standard file format and a conversion description standard, which appear to be well thought out.

Mizuta and Akiyama have stated that they want international cooperation on the project. Akiyama wrote that "we solicit cooperation from all quarters." I asked what form this might take, as the only people who are entitled to copies of the source programs are the supporting industries. Initially, there was some ambiguity about this. Mizuta thought that Western scientists might want to participate in order to be able to compare their programs against Alpha's, but that certainly would not be enough to appeal to me. When I asked Akiyama the same question he admitted that he really meant cooperation from additional Japanese companies who may want to contribute financially. As far as other researchers are concerned, he thought that some neutral information could be shared with them, but that this would have to be discussed with the steering committee, as was my request to visit FRIC in order to see a demonstration. Subsequently, though, Mizuta explained that he expected to be able to offer Western researchers (academic, not commercial) copies of source modules. This would be a perfectly fair exchange to obtain cooperation and I hope that this is in fact what will happen. In fact, I hope to convince Mizuta to demonstrate Alpha during this year's Supercomputing 91 meeting, in Albuquerque, New Mexico.

I was told several times that this is not really a government project. In fact, one of Alpha's accomplishments has been to bring together distinct Japanese companies to build the software foundation that they can each particularize. Industrial partners get source programs and can then make modifications to suit their own needs. The Alpha group has no responsibility to maintain these modified programs.

At the current stage of the project, a good deal of program structure has been developed, combining computational modules with an intelligent front end through the gateway. According to the project schedule, most of the documentation work is being done this year. All the documentation that I saw was in Japanese, which would definitely be an impediment to Western cooperation, but is probably essential to effective use of the software here.

It was emphasized to me that the two goals are (1) developing vectorizable programs and (2) making the problem setup easy to use. Using the absolutely best algorithm, or at least fine tuning it, was not considered so important. The project participants are hard at work verifying the models by running them on about 20 major test problems, most of which are completed. These included such things as boundary fitted coordinates. The "boundary fitted coordinate" technique (sometimes referred to as "body" instead of "boundary") is quite similar to low order finite element methods. Both methods use nonrectangular meshes. I was shown several slides of flow patterns from Alpha side by side with those from other computations or experiments and the agreement looked excellent. I remarked to Akiyama that these pictures didn't give any information about how successful the project was at achieving either (1) or (2) above, but the demonstrations were persuasive with respect to the second. For example, in dealing with incompressible flow the AI module has about 100 rules. There is also an online manual.

My opinion is that we should not judge Alpha only by what it has produced thus far. Although it may have made major strides in educating and bringing together Japanese scientists, from a global research perspective its accomplishments seem modest. A great deal of their development has duplicated, i.e., either copied or adapted, existing published work. For example, the "multiple free boundary" work is based on SOLA-VOF, developed in the United States.

A recent visit to the vendor displays at Supercomputing Japan '91 shows many Western engineering analysis software packages with very graphically oriented interfaces. Alpha has only been in existence about 3 years, 75% of its funding schedule. Considering that it started with a clean sheet, this is not much time when compared to the efforts that have occurred developing CFD packages elsewhere. Hence, it is unlikely that the Alpha-Flow Project is yet competitive with the best CFD packages either from the United States or from Europe.

However, Mizuta is very clear that the code name Alpha represents the first letter of the alphabet, and that he firmly intends to see Beta, Gamma, even Omega. He claims that he has strong support from Japanese industry and that many new companies want "in." Further, there is interest in using the framework to develop software for molecular computations and new materials design. Akiyama is less interested in such grand goals. He admitted to me that the Beta Project will probably focus only on two-phase flow, which is of less general interest (few of the Japanese auto companies are likely to participate), and hence will need only about half its current funding ($5 million). The Gamma Project will probably involve Monte Carlo or stochastic methods development. For his own research, Akiyama is more interested in building a very advanced simulator (using a massively parallel computer and sophisticated software) for major nuclear accidents that he hopes will never occur.

The educational aspect of this project should not be ignored. Mizuta emphasized that one goal was to involve universities--the idea being the establishment of knowledge centers that will continue to produce people (students) with knowledge of computational fluid dynamics. About a half dozen university groups have been funded under the Alpha Project.

There has been a trend in the United States (possibly elsewhere) to use commercial/private software without understanding how the software functions or what assumptions and approximations are made in the software. This is a very bad trend; perhaps the Alpha Project is partly a reaction to this situation. The Alpha Project seems to indicate that the Japanese are taking a long range view by trying to increase the number of engineers and scientists who are familiar with large scale numerical simulation techniques. This approach will eventually put them in a much better position to exploit computational modeling for a wide range of applications. It would be useful if more U.S. companies thought the same way.

A final note. I asked if there was interest from the Japanese aircraft industry, as CFD is such an important aspect of aircraft design. Akiyama said no, mostly because in Japan that industry is concentrated in a few companies such as Mitsubishi Heavy Industries that already have extensive software of their own and see no need to support research outside their own organization.

SUGGESTION

Scientists outside Japan need to view the project as a first step and as an educational tool. At the same time Alpha's steering committee needs to clarify the question of access to information. Perhaps Western input could be helpful in forming these ideas.

COMPUTING IN HIGH ENERGY PHYSICS '91

The international Computing in High Energy Physics meeting, held 11-15 March in Tsukuba Science City, Japan, is summarized.

by David K. Kahaner

INTRODUCTION

High energy physicists are engaged in "big ticket" physics. These are the people whose experiments require the large accelerators at CERN, Fermi National Accelerator Laboratory (FNAL), National Laboratory for High Energy Physics in Japan (KEK), the Super Collider at Texas (SSC), etc. The experiments generate massive amounts of data. Experiments can generate 100 MB/s of data, a terabyte a day, and a pentabyte a year. Acquiring, moving, and storing these data need high speed, high bandwidth networks, libraries of tapes and other external storage devices, as well as automated retrieval systems.

Processing the data is required first in real time during the experiments and then as postprocessing afterwards for analysis. For both of these requirements, the computing needs have always outstripped the capabilities of whatever was the current fastest supercomputer. Related theoretical analysis, such as lattice gauge theory, which does not depend on the experimental data, also requires tremendous computing resources, which will barely be satisfied by teraflop computers. In fact, special purpose computers are being built specifically for some of these analyses.

Each year high energy physicists from around the world who are interested in computing come together for their annual meeting [Computing in High Energy Physics (CHEP)]. This year it was held in Tsukuba Science City, about 1 hour outside Tokyo, from 11-15 March 1991. This was truly an international meeting, as the following summary of the participants shows:

Country	No.
Brazil	2
Canada	1
China	5
Denmark	1
France	12
Germany	12
Israel	2
Italy	17
Japan	118
Malaysia	1
Spain	1
Switzerland	29
U.K.	4
U.S.	35
U.S.S.R.	32
Total	272

There were 30 plenary talks and 84 presentations in the parallel and poster sessions. There was also a small exhibition by vendors. Because several other meetings were being held during the same week, I was only able to attend the first day and a half of this conference. The purpose of this summary is to provide my general impressions of the work as far as I was able to assess it. Many thanks to Professor Yoshio Oyanagi (University of Tokyo) and Mr. Sverre Jarp (CERN), who participated in all of CHEP '91, read this report, and made important suggestions. A Proceedings is not yet available but will be published this summer by

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GENERAL IMPRESSIONS

(1) High energy physics computing demands are at least as great as those in some better known fields, such as fluid dynamics, molecular modeling, etc.

(2) The scientists working in high energy physics are already using large, interconnected, state-of-the-art hardware for their experiments. Thus the use of complicated computer networks and collections of distributed computers for data processing and analysis does not put them off. Rather, they have been doing distributed and parallel computing for years using "farms" of minicomputers, typically Vax computers. Vax computers are so ingrained into the culture that performance is measured in VUPs (Vax units of performance). Postprocessing of data is also done on whatever is the largest machine available (in Japan these are typically FACOM or Hitachi mainframes). A good deal of the "tracking" computations can be vectorized but not much else. However, there is a definite movement toward RISC workstations and parallel computers. In fact, the computing environment

surrounding some of these experiments may be more sophisticated (although often homegrown) than in laboratories that are famous for supercomputing. Also, at the software level these laboratories are already dealing with some extremely large (often multi-millions of lines) source programs. Few software tools are being used, and most of those are either homegrown or vendor supplied utilities. Thomas Nash (FNAL, nash@fnal.fnal.gov) emphasized the need for research in software engineering to aid in software management.

(3) The high energy physics (HEP) community has more or less spurned mainframes and related centralized services. HEP code has never been cost-justified on expensive supercomputers or mainframes because the programs (1) are often small and (2) rarely vectorize, hence, the interest for cheaper systems (Unix and RISC) that offer the promise of the huge computer quantities that the community needs. At the same time they realize that supercomputer companies can offer some services that cannot be duplicated elsewhere.

David O. Williams from CERN (davidw@cernvm.cern.ch) discussed the relationships between mainframes and workstations as seen by his constituency. With respect to the question "Is the role of the mainframe terminated?" he made the following conclusions.

- General purpose mainframes as we know them in HEP are at the start of their run-down phase. This phase will take about 5 years in HEP and longer in the general marketplace.

- The services provided by these mainframes are essential and over time will be provided by more specialized systems. He urged mainframe builders to realign prices towards the workstation server market; emphasize integration; push the mainframe's input/output (I/O) advantage relative to workstations; perform research related to quickly accessing vast quantities of data on a worldwide basis; and emphasize dependability, service, ease of use, and other things that will have a big payoff for scientists. [Robert Grossman from the University of Illinois (grossman@uicbert.eecs.uic.edu) echoed a part of this by pointing out that performance of database systems will have to be dramatically improved. For example, the "distance" between two physical events in a 10^{15} item database can be very great. Thus the first query will always be expensive, but research needs to be done on methods to speed up subsequent queries.]

Williams' advice for workstation builders is to maintain aggressive pricing, emphasize integration, push I/O capacity, and develop good peripherals and multiprocessors.

I believe that most of the audience agreed with these points.

(4) Specialized computers for simulation, in particular quantum chromodynamics (QCD), have been built or are under development in the United States, Japan, Italy, and perhaps other countries. These QCD machines include one at Columbia University, Italy's APE, Tsukuba University's QCDPAX, IBM Yorktown Heights' GF11, and FNAL's ACP-MAPS. The Japanese QCDPAX project began in the late 1970s and is now running with 480 nodes and a peak speed of about 14 GF (GFLOPS) [see D.K. Kahaner, "The PAX computer and QCDPAX: History, status, and evaluation," *Scientific Information Bulletin* 15(2), 57-65 (1990)], beginning its fifth generation. The Columbia machine has almost as long a history and has a similar performance. Table 1 (presented by Iwasaki at the meeting) gives some details of existing parallel computer projects dedicated to lattice gauge theory.

Several new machines are in the pipeline. A teraflop machine for QCD has been proposed to the U.S. Department of Energy by a collaboration of scientists from (mostly) U.S. universities and national laboratories. New machines are under development at FNAL and other places. The Japanese Ministry of Education, Science, and Culture (Monbusho) has just approved funding of the next generation PAX (about $10M from 1992-1996). All of these are estimating performance in the range of several hundred gigaflops within the next few years. The network topology of QCD machines has been getting more sophisticated, too, moving from one-dimensional (1D) (16 CPU), two-dimensional (2D) (16x16), three-dimensional (3D) (16x16x8), to four-dimensional (4D) (16x16x8x8). There are still plenty of problems, though, as neither the topology nor control structure [single instruction/multiple data (SIMD), multiple instruction/multiple data (MIMD), ?] is really settled. In addition, reliability (MTBF) as well as pin and cabling issues have to be addressed. Nevertheless, at the leading edge, some of these scientists are already talking about performance beyond one teraflop.

Table 1. Existing Parallel Computer Projects Dedicated to Lattice Gauge Theory

Computer/ Location	No. CPUs	Archi- tecture	CPU	FPU	Memory		1 CPU Performance (MF)	Network	Host	Peak (GF)	Status[a]
					SRAM	DRAM (MB)					
Columbia Univ.	256	MIMD	80286	80287; Weitek 3364x2	2 MB	8	64	2D NNM[b]	Vax 11/780	16	1
GF11/IBM	566	SIMD	--	Weitek 1032x2, 1033x2	64 KB	2	20	Memphis switch	IBM 3090	11	2
ACP-MAPS/ FNAL	256	MIMD	Weitek XL8032 chip set	Weitek XL8032 chip set	2 MB	10	20	X-bar & hyper^3	Micro Vax	5	2
APE/Rome	16	SIMD	--	Weitek 1032x4, 1033x4	--	16	64	Linear array	Micro Vax	1	1
QCDPAX/ Tsukuba	480	MIMD	68020	LSI Logic L64133	2 MB	4	32	2D NNM	Sun 3/260	15	1
APE100[c]/ Rome	2048	SIMD	MAD (custom)			4	50	3D NNM		100	3

[a] Status: (1) Running; physical results reported.
(2) Nearly working.
(3) Well underway.

[b] NNM = nearest neighbor mesh.

[c] For additional details concerning APE100, contact M. Malek (mmalek@onreur-gw.navy.mil), who is writing about high performance computing in ONR's London office.

(5) The community is very international, with visits to each other's laboratories and joint projects being very common. For example, Katsuya Amako (KEK, Japan) pointed out that in each of the Tristan experiments (Venus, Topaz, Amy), physicists from almost 17 institutes are participating. Frankly, this is one of the most well mixed international research communities that I have seen. Consequently, there is a great deal of data sharing and savvy about advanced computing and networking. There is not much going on within their world that is not rapidly known by all the active participants. On the other hand, there does not seem to be nearly as much communication between this group and others doing high performance computing. I see several reasons for this, including an intuitive sense by the physicists that they have the best expertise needed to treat their problems (because their computing needs are so special purpose), and an almost exclusive dependence on VMS software until recently--thus an isolation from the Unix world. High energy physicists are moving heavily and rapidly from minicomputers to workstations, and a "wind of Unix" was definitely blowing through the conference. The growth of Unix is already bringing people closer together, and I am very optimistic that all parties can learn from each other. In particular, it seems to me that as computing becomes more distributed, the experiences of the physics community, who have actually been doing this for some time, can be beneficial in more general situations. Similarly, the physicists can learn from computer scientists and algorithm developers, who have broader views. Incidentally, Japanese contributions in this area are bound to increase rapidly; when Unix is the accepted standard, then the best hardware will be easily adopted worldwide.

(6) For the future, the participants see data storage, CPU power, and software as three crisis issues. Networking between remote scientists and the experiment, or among scientists, was seen as something that needed to be beefed up but not emphasized as at a crisis stage. In Japan, future high energy physics projects are viewed as large international collaborations, and there is a strong feeling that a more unified worldwide HEP computing environment is needed.

(7) Parallel computing is moving mo-e into the mainstream of Japanese science. Two Japanese parallel computers that I reported on within the past year (QCDPAX and AP1000) were used to perform real work presented at this meeting. In addition, some applications of transputers were also shown. I am predicting that we will see this trend continue as Japanese-built parallel machines are installed in other "friendly" outside user installations.

JAPAN'S FIFTH GENERATION COMPUTER PROJECT

*Japan's Fifth Generation Computer Project (FGCP) is summarized.**

by David K. Kahaner

INTRODUCTION

Beginning in 1982, Japan embarked on a 10-year program called the Fifth Generation Computer Project (FGCP), funded at over ¥40B from Government sources. The goals of the Ministry of International Trade and Industry (MITI) directed project are to focus on large-scale parallel processing for nonnumerical computation, in particular on logic programming. The project has generated a great deal of excitement in the West, partially because of the implications for Japan of its success and partially because of questions about its scientific feasibility. The program is managed and most of the research is performed at the Institute for New Generation Computer Technology (ICOT):

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(Many ICOT staff have electronic mail access, such as Dr. Koichi Furukawa, Research Center Deputy Director, FURUKAWA@ICOT.OR.JP.)

BACKGROUND

In 1979, MITI assigned the Electrotechnical Laboratory (ETL) in Tsukuba the task of defining a project to develop a computer system for the 1990s. MITI accepted the early reports on the project, presented its plan for the project at an international conference in October 1981 and, in April 1982, initiated a 10-year Fifth Generation Computer Systems (FGCS) project establishing the Institute for New Generation Computer Technology (ICOT).

ICOT is a consortium of Japanese companies--including associate members IBM Japan, DEC Japan, and UNISYS Japan--and MITI institutes with a Central Research Laboratory. The number of staff at the laboratory has ranged from 50 initially to about 90 now; they stay in ICOT for 2 to 4 years and then rotate back to their companies' research institutes. Fewer than a dozen people have been with ICOT from its beginning. ICOT research and development (R&D) is funded by MITI. Annual funding for the project has risen from less than ¥3B to nearly ¥7B. This figure includes salaries of the 90 staff members but does not include management and administration services--provided by NTT--and building rental fees; these are paid for by donations from industry that annually total about ¥500M.

ICOT's main activities consist of developing a hardware and software prototype system, conducting joint research at overseas research centers, and studying new information processing technologies and new generation computer applications. According to Dr. Kazuhiro Fuchi, ICOT Managing Director, ICOT's goal has been to develop an easier-to-use, non-Von Neumann computer system with parallel processing ability and an ability to make inferences when executing a program. The key words, he said, were "parallel" and "inference." To accomplish this, ICOT has been developing hardware and software for each of three subsystems--knowledge base, problem solving and inference, and human-machine interaction. Programming is done "in house" as is computer design; hardware manufacture is contracted out.

Contrast with Earlier Computers

According to Takashi Kurozumi, Deputy Director of ICOT's Research Center, the title "Fifth Generation" was used to differentiate the project from the earlier generations of computers that had been classified according to their constituent hardware elements developed to increase storage: vacuum tubes, transistors, integrated circuits, and LSI and VLSI chips. These kinds of computers are characterized by addressable memory or stored program schemes, sequential processing, and numerical calculation.

Shunichi Uchida, the Manager of ICOT's Research Department,

* This article is based on a summary of the FGCP prepared by the Office of Science and Technology Affairs at the U.S. Embassy in Tokyo.

described the development of such Von Neumann computer systems as follows: First the hardware is designed, then the software, then the applications are devised. He said the development of the ICOT computer would follow a different path: First concept, then language/software, then hardware, then applications based on parallel knowledge processing ICOT's computer was to be based on a new framework, a framework that would allow the computer to do processing that depends on circumstances, more in the style of human thought, rather than having to follow predefined procedures. Uchida said the power of the ICOT computer is measured in logical inferences per second (LIPS) rather than in instructions per second (IPS).

At the Beginning

According to documents published in the early 1980s, the project goal was very ambitious. It was to develop a knowledge information processing system (KIPS)--something like an expert system--with an intelligent conversation function and an inferential function employing a knowledge base. The prototype computer would acquire, accumulate, and use various types of knowledge; it would infer information from what previously was not known explicitly; it would make conjectures based on incomplete knowledge; it would use natural written and spoken language, graphics, and other types of image input data; and it would effectively translate between languages at a semantic level. The prototype computer would use a new programming language based on new principles thereby enabling people with no expert knowledge to write programs with ease At the 1988 FGCS Conference, Kurozumi reconfirmed most of these goals. He did not include the language translation goal nor the goal of using spoken language in communication with the computer.

To succeed, the project needed to make major technological innovations to enable the fifth generation computer to support very large knowledge bases, allow very fast associative retrievals, and to perform logical inference operations as fast as other computers perform arithmetic operations. The project also needed to utilize parallelism in program structure and hardware to achieve high speed and to develop a machine-user interface allowing significant use of natural speech and images. ICOT was not to be an artificial intelligence (AI) project, but ICOT researchers hoped to combine their own research with that being done in artificial intelligence and in architecture and software technology. Fuchi and Uchida, who have been with ICOT since 1982, said that the project has not included VLSI and device techniques nor has it included neural networks.

One of the FGCS's significant characteristics was the decision to use the European programming language Prolog as the machine language of the logic processor. Prolog is an "if...then" language, or a predicate logic language, not designed for numerical calculations. It is useful for situations and ambiguous activities where the procedures that the computer is to perform cannot be clearly stated in the program at the outset, where the way to proceed is not explicitly specified. That was done, Fuchi said, because the project was to develop technology to carry out high-level symbolic operations, not numerical calculations. One American computer expert, evaluating Prolog, said it represents knowledge elegantly but often opaquely and arcanely. He stated further that Prolog solves automatically the problems it sees, without the user being involved. This is not universally considered a plus, he noted, because knowledge engineers typically do not want to abdicate step-by-step control to a process that conducts massive searches automatically.

RESULTS

Because this was Japan's first attempt at parallel computing, ICOT began by developing sequential inference machines. Development continued throughout the project, culminating in the completion this year of the PSI III machine having 1.2M LIPS of power. (ICOT officials consider 10M to 15M LIPS to be equivalent to 400 MIPs.) From this base, multiple processor sequential inference machines were built, as were components for a parallel inference machine. The 1992 hardware goal is a 1,000-processor parallel inference machine (PIM) having 300K to 600K LIPS power. A 32-processor parallel inference machine has been built, and the larger machine will have 31 additional 32-processor elements. Table 1 summarizes the various models of parallel inference machines that have been built as prototypes. (PIM/p is the latest.)

In 1989, the Japanese brought ICOT's sequential inference machine PSI II to the United States. It generated interest and resulted in a visit to Japan in February 1990 from Argonne National Laboratory of scientists to discuss cooperative activities. In September 1990, ICOT hosted a bilateral workshop on parallel knowledge systems and logic programming; more than a dozen participants came from the United States side alone. Argonne has been doing logic programming and genetic information processing research, and the laboratory now has two of ICOT's PSI II machines (power: 330K LIPS), which are being evaluated. In June 1991 Argonne will host a workshop sponsored by the National Science Foundation (NSF) on parallel theorem proving. National Institutes of Health officials are actively considering using ICOT's machine for biological work. The Lawrence Berkeley Laboratory has network access to ICOT, and ICOT is building its own 64-Kbit line in Japan to increase domestic access to its computers. (Currently, for example, Tokyo University cannot access ICOT's computers.)

ICOT officials have wanted to provide programmers with a parallel system for which they can write programs as easily as they can write programs for Von Neumann computers. Project researchers, therefore, have developed several parallel programming languages for the computers they have developed. ICOT's longest logic language program, KL-1, is 100,000 lines and growing. This, Uchida said, was the world's longest program written for parallel processors and was equivalent to more than 300,000 lines of a Von Neumann language program. In addition, ICOT has developed the world's only full-scale logic language operating systems, SIMPOS, for its sequential machines, and PIMOS for its parallel ones. Finally, the latest versions of the ICOT machines also have some Unix capability.

Various application programs have been written on PIM, including VLSI (logic design, routing, logic simulation), playing the board game Go, genetic information processing, legal reasoning, parallel constraint solving, parallel theorem proving, and parallel parsing.

ICOT programs can work on other parallel computers, said Uchida, albeit much slower than on ICOT computers, in part because other parallel computers were designed to accommodate Von Neumann programming for numerical computation. The front end processor of such a computer is designed to find parts of such linear programs that can be worked in parallel, to send those parts out to the various processors, and then to reintegrate those parts back into the program. ICOT'S nonnumerical programs do not run efficiently on such machines. On the other hand, Fuchi noted, since Cray (and other parallel) computers were designed (for numerical computation and thus) to accept languages such as Fortran, there is much more demand for them today than there is for ICOT's nonnumerical computers, which cannot use Fortran or other sequential programming languages.

Table 1. Various Models of the Parallel Inference Machine (PIM)

Model of PIM	Machine Instructions	Target Cycle Time (ns)	LSI Devices	Process Technology (Line Width) (μm)	Machine Configuration	No. of PEs
PIM/p	RISC+macro	50	standard cell	~1	multicluster connections in hyper^3 (8 PEs linked to shared memory)	512
PIM/c	horizontal micro	50	gate array	0.8	multicluster in X-bar (8 PEs+CC linked to shared memory)	256
PIM/m	horizontal micro	50-60	cell base	0.8	2-dimensional mesh	256
PIM/i	RISC	100	standard cell	1.2	shared memory through parallel cache	8PEx2
PIM/K	RISC	100	custom	1.2	two level parallel cache	16PEx2

There have been three conferences held in connection with the project--in 1981, 1984, and 1988. ICOT will sponsor the project's final conference in the Tokyo Prince Hotel on 1-5 June 1992, where final results will be presented. ICOT publishes a quarterly journal which is distributed to over 1,100 locations, 600 of these in 36 foreign countries. ICOT also receives long-term researchers from the United States, the United Kingdom, and France and short-term researchers from those and a variety of other countries. Dr. Mark E. Stickel, SRI International, currently is being supported at ICOT through an NSF award. Dozens of personnel sequence inference machines have been commercialized by the companies party to ICOT.

SUMMARY

The Fifth Generation Computer Project ends on 31 March 1992. During 1-5 June 1992, ICOT will host its fourth and final conference where the project's final results will be presented. The project has met most of its goals, albeit on a small scale. Parallel programming languages have been developed that are no more difficult to use than current sequential languages. ICOT computers do make inferences, but from small knowledge bases. The computers do not use spoken languages in their operation, nor do they translate between languages. Neither is the speed of the ICOT computers as fast as that of numerical computers.

The future looks hopeful, though, for the ICOT computers. ICOT and U.S. researchers have identified several applications for the computers that may be realized during the 1990s. These include VLSI computer-aided design (CAD) applications, theoretical math systems, a variety of expert decision systems, legal reasoning and grammar/syntax programs, genetic sequencing and other applications in biology, and Go-playing programs--similar to current chess-playing programs. Also, MITI may continue supporting one or more parts of the project past next year; the Ministry's decision may come as early as this fall. According to Fuchi, the most successful part of the project is the hardware model based on the PIMOS operating system. Fuchi thought that the world's computer industry is "not yet mature enough to capitalize on the research coming out of ICOT," that ICOT was "too far out in front" of the rest of the computer industry. He said he will suggest to MITI that it will be the Government's responsibility to nurture the ICOT computer until industry is ready for it.

WHAT DOES THE FUTURE HOLD?

ICOT's future also might be spelled NIPT. MITI is now deciding whether to launch a subsequent computer initiative, the New Information Processing Technology (NIPT) project. If feasibility study results turn out positive, the new program will begin in April 1992.

The NIPT project differs in several respects from ICOT:

1. NIPT is, from the beginning, an international project; MITI officials have been actively seeking international input into the design of the NIPT program. ICOT has been a domestically planned MITI project but an open one, whose information has been shared with the rest of the world.

2. NIPT is building on the advances made during the 1980s by ICOT and others in computers and associated technology, although at the moment MITI officials do not see NIPT as directly incorporating any ICOT technology. NIPT probably will concentrate on massively parallel systems that will be optically connected. It will benefit from advances made in VLSI and VLSI technology. Advocates hope they can use future advances in biology, physiology, psychology, and neurology to develop neural networks for the NIPT computer.

3. NIPT's initial focus is principally on hardware; ICOT's principal initial focus was more on software.

4. NIPT computers will be able to crunch numbers; ICOT's cannot.

5. The NIPT project will not be conducted in a single institute, such as ICOT, and it will have many R&D objectives.

NIPT will be funded initially at a lower level than ICOT currently is. MITI officials have indicated that NIPT will be funded at $30M per year, after the feasibility study. This is about 60% of current ICOT funding. There is much more interest in NIPT worldwide, especially within industry and government, than there has been in ICOT, which has generated almost all of its interest in academia. Nonetheless, ICOT has been a respectable program; its researchers have made major developments in inference languages and consideration is being given to tie-ups with vector supercomputers, such as at the Pittsburgh Supercomputer Center in the United

States. Its latest machines are becoming more Unix-capable. If the Government of Japan continues to support the program after 1992, if an increasing number of applications can be found for ICOT's computers, and if users can be convinced that there is money to be made by these nonnumeric applications, ICOT R&D may continue in parallel with NIPT. How appropriate.

For more information on NIPT, see my *Scientific Information Bulletin* articles, "New Information Processing Technology Workshop" [16(2), 31-43 (1991)] and "New Information Processing Technologies Symposium (Sixth Generation Project)" [16(2), 45-52 (1991)].

THE CYCLIC PIPELINED COMPUTER AND ERATO

A brief description of ERATO (Exploratory Research for Advanced Technology) and one of its projects, QMFL (quantum magneto flux logic), with particular emphasis on the cyclic pipelined computer (CPC), is given. CPC is a shared pipelined memory, single processor, multiple instruction stream architecture, originally designed to be compatible with Josephson junction devices. This ERATO project ends this year.

by David K. Kahaner and Paul Spee

ERATO

The Exploratory Research for Advanced Technology (ERATO) projects were started in 1981 by the Research Development Corporation of Japan (JRDC). JRDC is set up by Japanese law under the administration of the Science and Technology Agency (STA), which is a ministerial agency reporting directly to the Prime Minister's office (see Kahaner's E-mail report japgovt.udt, 30 July 1990). ERATO's objective is to conduct interesting basic research. Essentially it is an experiment in the management of research and development (R&D) in which mostly young researchers from industry, government, and universities gather and conduct multidisciplinary research on high risk projects. A great deal has already been written about ERATO (see, for example, Ref 1 and 2). In this article we want to focus on one particular program; nevertheless, for completeness, we present a thumbnail sketch of the general program.

There are about a dozen ERATO projects at any time; the total budget is around $30M, so the support levels for the projects vary around $2M to $5M per year. The staff also varies, but may be as large as about 20 researchers during the most active phase of a project.

One of the most unusual things about ERATO is that all the projects are of fixed duration, 5 years. Although the program does not allow for extensions, promising activities might be continued by other organizations. To emphasize the temporary nature, each project rents whatever office and laboratory space it needs at a university, corporation, or research institute.

ERATO focuses on young researchers; the average age is just slightly more than 31. They are given good facilities and good salaries. A JRDC study showed that starting salaries exceed those of 75% of U.S. Ph.D. chemists in industry, and that salaries of ERATO researchers with three or more years of experience exceed those of 90% of U.S. Ph.D. chemists in industry.

A key ingredient of each ERATO project is its director. The perfect person is charismatic, with a dynamic personality, eminent in his field, who is capable of attracting and inspiring his coworkers. Once found, the director is more or less free to recruit and organize the team as he sees fit. In fact, the projects are informally referred to by the director's name, i.e., "the Goto Project," etc.

Eiichi Goto, who directs the QMFL project, typifies this profile. Goto, who retired from the University of Tokyo in April 1991 and is now at the University of Kanagawa, invented the Parametron about 30 years ago. He is an extremely extroverted person and still bristles with new ideas. In fact, one of the younger scientists complained to me that Goto has so many ideas that it was difficult to keep up with his thinking. The proceedings of the latest project symposium (the Eighth RIKEN Symposium on Josephson Electronics, 15 March 1991) list Goto as a coauthor on all but one of the papers, including one on a new type of refrigerator.

About half of the ERATO researchers are seconded from industry; a few are from universities or national laboratories. The remainder are hired as individuals. Most of these are Japanese but about 10% are foreign. The seconding system preserves the researcher's seniority and benefits because ERATO reimburses the company for the researcher. The non-Japanese researchers give the projects a definite international flavor. Several of them speak little or no Japanese, and papers in the proceedings of the symposium mentioned above are almost entirely in English, although most of this was done as a preparation for presentations in the United States in August.

Patents for ERATO projects are jointly owned by the inventors and

JRDC. Researchers share legal expenses for patents they own with JRDC, but they may also assign ownership of the patent to JRDC. Company researchers may assign patent ownership to their company. Until 1988 there were 415 patent applications filed in Japan and 82 outside Japan. Up to 1988 the 338 ERATO researchers had written almost 1,400 papers, and of these more than one-third were published or presented outside of Japan.

Each year there is an ERATO symposium held in Tokyo. In each of four afternoon sessions, researchers from four different projects present the progress in their respective programs. Individual projects can also have symposia, although these are more informal.

A foreign researcher has, in principle, a 1-year contract, which may be renewed. In fact, the ERATO budget explicitly allows for foreign researchers to stay for the full length of a project, 5 years, and through 1989 27 researchers have participated, but only a few have remained the full 5 years. (Perhaps there is some concern among these young non-Japanese researchers about the incremental benefit of staying all 5 years. Employment opportunities exist within Japanese corporations, but upward mobility is questionable.) A few foreign companies have also sent researchers, including Allelix (Canada), Celltech (U.K.), Intel (U.S.), and 3M (U.S.). Some formal recruiting occurs, but most of the foreign researchers apply because of word-of-mouth recruiting. In 1989 there were five researchers from the United States. Foreign researchers receive the same base salary as Japanese, but they also receive moving expenses, a housing allowance, and some provision for Japanese language training. Researchers must locate their own housing; there are no special housing facilities because the ERATO projects are widely dispersed.

QUANTUM MAGNETIC FLUX PROJECT (GOTO-QMFL PROJECT)

This project began in 1986 and is directed by Professor E. Goto, recently retired as Professor on Information Science at Tokyo University. Goto is famous for his patenting in the 1950s of the Parametron, which uses resonating circuits in which current phase is used to store information. In fact, the first Japanese computers were based on the Parametron, e.g., the Hitachi HIPAC-xxx (P = Parametron). However, Hitachi eventually changed to transistor technology (the Hitachi HITAC-xxx).

In 1983 Goto proposed a Parametron-like element using Josephson junctions. The binary states of the element are the two locations of magnetic flux. This idea is a natural step in Josephson technology in which devices use a single quantum of flux. In 1982 IBM's Josephson program was abandoned; several Japanese companies have continued their research and have been reporting steady progress (see, for example, the comments about Hitachi in Kahaner's E-mail report parallel.903, 6 Nov 1990).

The current Goto-QMFL project is divided into three groups:

- Fundamental Property
- Magnetic Shielding
- Computer Architecture

The first group within the project is working on a new Josephson device called QFP (Ref 3 and 4), in which the unit of information in not represented by voltage but by magnetic flux. The second group is researching a helium liquefying process and magnetic shielding. The third group is researching a new type of architecture called the cyclic pipelined computer (CPC) (Ref 5). Furthermore, software for this highly pipelined parallel computer is being developed. The three groups illustrate the temporary nature of ERATO projects. When I first went to visit the Computer Architecture Group, it was housed in an ordinary office building in central Tokyo. Last fall the group moved to the Hitachi Central Research Laboratory in suburban Tokyo. The Fundamental Property Group is also at Hitachi and the Magnetic Shielding Group is at ULVAC.

The overall project's aims are (1) to demonstrate that QFP devices can operate in the range of 10 GHz, (2) to demonstrate the capability of removing magnetic flux from superconductors, and (3) to develop a computer architecture suitable for a QFP computer.

The Fundamental Properties Group has six to seven persons, and the Magnetic Shielding and Architecture Groups each have about four people, excluding secretaries. A discussion of the Fundamental Property and Magnetic Shielding Groups, which are essentially associated with building Josephson devices, was given in a recent Japan Technology Evaluation Program (JTECH) report (Ref 6). The Architecture Group was not in that author's (Rowell) area of expertise and was only mentioned in his report. His summary with respect to the Josephson technology is that the project is "plowing new ground (or old ground with new devices), and it will be most interesting to see the magnitude of its impact in 10 years' time." A second JTECH study in 1989, "High Temperature Superconductivity in Japan," also has a short summary of the Goto project written by M. Dresselhaus, again only focusing on the Josephson aspects and concluding that "this technology benefits from very high speeds and extremely small power consumption and is being examined for a variety of digital applications including next generation computers." The potential for high performance using Josephson devices comes from this combination of very high clock speeds (tens of GHz) and low power (10^{-9} W/gate). Another advantage of the QFP device is the flux transfer characteristics, and it has just been reported that a prototype of three-dimensional integration was proven by stacking two chips together and by observing signal transfer between these chips (Ref 7). The hope, of course, is to replace the silicon with Josephson devices to build a three-dimensional package that is a computer in a 1-cm cube.

The Computer Architecture Group investigates new architectures to take advantage of specific features of Josephson devices. The main difference between Josephson devices and conventional devices is that Josephson devices act as a latch. Because there is no delay caused by the latches between the pipeline stages in a pipelined computer, the processor may be deeply pipelined. In pipelining, multiple instructions in a computer are overlapped in execution. Each instruction is broken into parts, called stages. Pipelining is a key implementation technique used to make today's fast CPUs. Figure 1 shows a simple (and ideal) example of pipelining. In the figure five instructions execute in sequence. The stage of the instruction denoted with x's represents the actual execution (EX), as opposed to instruction fetch (IF), decode, etc.

In a super-pipelined computer, each stage is divided into smaller pipeline segments, as in Figure 2, which is also idealized.

Pipelining and super-pipelining permit higher potential performance. The main impediments to achieving this are:

(1) The extra overhead associated with a large number of segments. Circuitry, called latches, is needed between the segments.

(2) A situation that prevents the next instruction in the instruction stream from executing during its clock cycle. This could be a hardware resource conflict, a data conflict when an instruction depends on the results of an unfinished instruction, or a control problem when the program counter is changed because of a branch instruction (Ref 8).

(3) The memory system. Hennessy and Patterson (Ref 9) claim that the "biggest impact of pipelining on the machine resources is in the memory system." Highly pipelined processors require a much higher memory bandwidth than nonpipelined processors because instructions and data are fetched from and stored to memory at a much higher rate.

Concerning (1), as mentioned above, one of the distinct characteristics of Josephson logic is that each basic logic device acts as its own latch and, in principle, this permits a very large number of segments with little overhead.

Concerning (2), the CPC has two main characteristics: pipelined memory and a fixed number of instruction streams, which share the functional units and main memory. In a CPC, a fixed number of instruction streams share common hardware. Only the hardware, which can be considered part of the context of the particular instruction stream, is duplicated. This hardware includes the program counter, processor status, registers, etc. By alternating the instruction streams in a cyclic manner, distinct virtual processors are created. In effect, the CPC implements a multiple instruction multiple data (MIMD) computer. Figure 3 illustrates this idea with three distinct instruction streams in a pipelined computer. An analogous figure could be given for a super-pipelined CPC.

```
I1.   |-IF--|-ID--|-OF--|-EX--|-WB--|
I2.         |-----|-----|-----|XXXXX|-----|
I3.               |-----|-----|-----|XXXXX|-----|
I4.                     |-----|-----|-----|XXXXX|-----|
I5.                           |-----|-----|-----|XXXXX|-----|
I6.                                 |-----|-----|-----|XXXXX|
```

Figure 1. Simple example of pipelining.

```
I1.   |-----|-----|-----|XXXXX|-----|
I2.    |-----|-----|-----|XXXXX|-----|
I3.     |-----|-----|-----|XXXXX|-----|
I4.      |-----|-----|-----|XXXXX|-----|
I5.       |-----|-----|-----|XXXXX|-----|
I6.        |-----|-----|-----|XXXXX|-----|
I7.         |-----|-----|-----|XXXXX|-----|
I8.          |-----|-----|-----|XXXXX|-----|
I9.           |-----|-----|-----|XXXXX|-----|
```

Figure 2. Each stage in a super-pipelined computer is divided into smaller pipeline segments.

Concerning (3), if the performance of the CPU can be increased by pipelining, then why not increase the performance, that is, the access rate of the memory, by pipelining as well? If a memory access can be divided into successive independent operations, for example, decode column, decode row, access cell, output data, such operations could be executed in parallel, thus pipelining memory. In Josephson computers, the main memory is to be built with the same Josephson logic devices as those used in the processor. For such a computer, both the processor and the main memory would be naturally pipelined with the same pipeline pitch.

Memory is often a bottleneck in many high performance computer systems. By increasing the machine-level parallelism, the number of memory accesses (instruction fetch, operand fetch, operand store) increases, making further demands on the design of efficient memory systems. High performance computers often use techniques such as n-way low-order interleaving (distribute n memory modules over the lower bits) and n-bank memory, where the high order bits specify the bank and the low order bits are offsets into the bank. Low-order interleaving is especially efficient for array and vector processors where memory is often addressed sequentially (access to vector), while n-bank memory is used in a shared memory multiprocessor where processors and memory modules are connected through an interconnection network.

The pipelined memory of the CPC has the advantage that it does not suffer from performance degradation caused by memory access conflicts. Neither does the CPC require an interconnection network, which may suffer either from path conflicts or memory access conflicts (Ref 10).

Current high performance computers require cache memory that can keep up with the memory access rate. When the processor requests data that are not in the cache, a cache miss occurs and the data must be fetched from memory. For super-pipelined and superscalar computers, a cache miss can easily cause an overhead of a factor of 10. (In a superscalar machine, the hardware can issue a small number, two to four, independent instructions in a single clock cycle.) In the CPC, the pipeline pitch of the main memory is the same as the pipeline pitch of the processor. CPC does not currently implement a cache, but the group is still researching this question.

On the other hand, one disadvantage of a CPC is that the random memory access pattern of different instruction streams decreases locality of memory reference, but this is not a problem if a cache is not used. The Architecture Group feels that a CPC can be very well suited for random memory access patterns such as neural network simulations.

CPC STATUS AND PROSPECTS

The work of the Computer Architecture Group has been overshadowed by the attention drawn to the hardware. The Architecture Group has been designing a computer architecture that is specifically suited for implementation on a machine with Josephson devices that are used both for the main processor as well as for the memory. The inherent rapid switching capability of Josephson devices means that it might be profitable to rethink some fundamental assumptions about the relationship of memory to processing. To most effectively implement their ideas, it is necessary to have Josephson technology in place, but all other aspects of the research are essentially independent of it. In other words, using basic assumptions about this technology, the group can design and simulate using silicon integrated circuits (ICs). Furthermore, the group feels that it would be reasonable to use CPC even without Josephson technology.

```
                Instruction stream A
A1.  |-----|-----|-----|XXXXX|-----|
A2.        |-----|-----|-----|XXXXX|-----|
A3.              |-----|-----|-----|XXXXX|-----|

                Instruction stream B
B1.  |-----|-----|-----|XXXXX|-----|
B2.        |-----|-----|-----|XXXXX|-----|
B3.              |-----|-----|-----|XXXXX|-----|

                Instruction stream C
C1.  |-----|-----|-----|XXXXX|-----|
C2.        |-----|-----|-----|XXXXX|-----|
C3.              |-----|-----|-----|XXXXX|-----|
```

Figure 3. Three distinct instruction streams in a pipelined computer alternated in a cyclic manner.

But in a fully Josephson computer, the CPC approach claims to be able to increase clock speeds to 10 GHz, with resulting increases of processing speed. For example, for a Josephson CPC, matrix multiplication is predicted to execute at 20 GFLOP peak on a processor equipped with one floating point adder and one floating point multiplier when two matrix operands can be fetched from memory in parallel. Fast Fourier Transform (FFT) performance depends on the number of arithmetic units and the number of instruction operands that can be fetched in parallel, but a peak performance of 50 GFLOP is predicted if five operands can be fetched in parallel and if there are three floating point adders and two floating point multipliers.

Several versions of CPC have been designed and at least one has been built, FLATS2 (Ref 11), using silicon (ICs) rather than Josephson junction technology. FLATS2 is a CPC with two virtual processors that share 10 pipeline stages. Machine cycle time is 65 ns, which is equivalent to memory cycle time. The transfer rate of memory is 117 MB/s for instructions and data. FLATS2 consists of 26 logic boards, each of which contains between 200 and 400 IC chips, connected by a backplane board and by front flat cables, mounted on an air-cooled rack chassis (57 x 62 x 37 cm), which is then packed into a cubic box along with power supplies.

FLATS2 is running. In addition to the operating system (Ref 12), a Fortran language based on Jordan's Force with parallel constructs is available. The Architecture Group has run simulations on various matrix computations based on DGEFA and DGESL from LINPACK, conjugate gradient, FFTs, and Livermore loops. The results are interesting, but it is still too early to tell if this technique can really be applied without Josephson devices. Further, there are some scientists who feel that traditional methods will be equally efficient.

But what is important about this research is that it presents an almost orthogonal view of how to design very high performance computers. Almost without exception today, researchers feel that highly parallel is the future, that is, large numbers of processors each with their own memory. The CPC approach uses shared pipelined memory, single processor, with multiple instruction streams. Of course, to be most practical, it may have to await Josephson technology. Nevertheless, as a research activity it has demonstrated several extremely innovative approaches and should be followed closely. Furthermore, there is a chance that new ECL devices could be built that have the ability to function as their own latches, an important characteristic of Josephson devices. Goto told me that he had recently devised such new devices and that Hitachi was sufficiently excited about their potential to involve several others on their research staff in a more thorough study of their costs and benefits. Finally, it was reported late last year that members of the Goto project had successfully fabricated a new chip, 2.5 mm square, on which four QFP devices were set. When cooled in a liquid-helium environment (-269 °C), all of the single devices had a clock frequency of 16 GHz, corresponding to a measured switching speed of 15 ps. Linewidth of the manufactured device is 5 microns, but when 0.5 micron VLSI technology is applied it is believed that the speed can be increased by about a factor of 10.

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PARALLEL PROCESSING RESEARCH IN JAPAN

Parallel processing research (mostly associated with the dataflow model) and database research in Japan, based on visits to various laboratories and attendance at the IEEE Data Engineering Conference in Kobe (10-12 April 1991), are summarized.

by Rishiyur Nikhil and David K. Kahaner

INTRODUCTION

Prof. Rishiyur Nikhil

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spent 2 weeks in Japan (April 1991) visiting five research laboratories and attending the IEEE Data Engineering Conference in Kobe. What follows are Nikhil's observations along with Kahaner's comments, when relevant.

PARALLEL PROCESSING

Electrotechnical Laboratory

The projects at the Electrotechnical Laboratory (ETL), the Institute for New Generation Computer Technology (ICOT), and Prof. H. Terada's laboratory at Osaka University are primarily focused on parallel processing architectures and languages and are the closest to Nikhil's own research work. Nikhil continues to be very highly impressed with the machine-building capabilities of his Japanese colleagues, but he thinks that with the exception of the ICOT researchers, many of them are still very weak in software. Nikhil comments that it is quite breathtaking to see how quickly new research machines are designed and built, and by such small teams--and he wishes we could do as well in the United States. However, once built, their machines do not seem to be evaluated thoroughly--good languages, compilers, and run-time systems are not developed and (consequently, perhaps) very few applications are written. The new designs, therefore, do not benefit from any deep lessons learned from previous designs. Also, another consequence of the "hardware-centric" nature of the machine builders is that certain functions are built into hardware that one would expect ought to be done in software (such as resource allocation decisions and load monitoring in the ETL machines).

According to Nikhil, ETL's EM-4 and proposed EM-5 are the most exciting machines in Japan (and the world). The reason is this: as first elucidated in Reference 1, a large, general purpose parallel machine must be able to perform multithreading efficiently at a fine granularity, because this is the only way to deal effectively with the long internode latencies of large, parallel machines. The von Neumann processors are very bad at this, and dataflow architectures have always excelled at this. However, previous dataflow architectures (including MIT's TTDA and Monsoon and ETL's previous Sigma-1) were weak in single-thread performance and control over scheduling, two areas that are the forte of von Neumann processors. Recently, new architectures have been proposed to obtain the best of both worlds: the *T architecture at MIT and the EM-4 and EM-5 in Japan. Nikhil believes that these machines are the first truly viable parallel multiple instruction/multiple data (MIMD) machines.

EM-4 (Ref 2 and 3) is a medium sized machine (80 nodes) but does not have any floating point arithmetic. However, the chief problem is the lack of any good programming language or compiler. It is currently programmed in DFC ("dataflow C"), a very simple subset of C with single assignment semantics. Perhaps this situation will change in the future; the ETL researchers said that they have just hired a compiler expert, but they still do not expect a good programming environment for some years. Nikhil has doubts about their choice of C as the programming language for the EM-4 and EM-5.

According to Kahaner, dataflow research at ETL has a long history, including the Sigma-1, EM-4, and the proposed EM-5. The EM-4 was designed to have 1,024 processors. A prototype with 80 processors is running and he was told that if the budget is maintained then the full system will be built. See his article in the *Scientific Information Bulletin* ["Electrotechnical Laboratory Dataflow Project," 15(4), 55-60 (1990)] and his electronically distributed report "parallel.904" of 6 November 1990.

Kahaner's interpretations of the ETL research direction are that their evolving designs are moving away from a pure dataflow model. At the same time interest in numerical applications, which was ambivalent, seems to have increased. Nikhil agrees that the ETL group is now more explicit about this but feels that they were always interested in general purpose computing, including scientific applications. Perhaps in the atmosphere of the 1980s, when there was so much emphasis in Japan on knowledge processing, they may have emphasized symbolic aspects, but in technical discussions they usually compared their machines to vector and other supercomputers and never to "symbolic supercomputers" such as Lisp machines or ICOT's machines. In other words, they may have always considered machines from Cray, NEC, and Fujitsu and the Connection Machine to be their real competition. It is interesting to note that the Connection Machine was also initially portrayed as a supercomputer for artificial intelligence (AI); the reality today is that it is mostly used for scientific supercomputing.

Sigma-1 was pure dataflow, similar to MIT's Tagged Token Dataflow Architecture. The EM-4 is based on what the ETL group called a strongly connected arc model. Their description of that follows (Ref 4).

> In a dataflow graph, arcs are categorized into two types: normal arcs and strongly connected arcs. A dataflow subgraph whose nodes are connected by strongly connected arcs is called a strongly connected block (SCB). There are two firing rules. One is that a node on a dataflow graph is firable when all the input arcs have their own tokens (a normal data-driven rule). The other is that after each SCB fires, all the processing elements (PE) which will execute a node in the block should execute nodes in the block exclusively. ... In the EM-4, each SCB is executed in a single PE and tokens do not flow but are stored in a local register file. This property enables fast-register execution of a dataflow graph, realizes an advanced-control pipeline, and offers flexible resource management facilities.

The designers also wrote in 1989:

> The dataflow concept can be applied not only to numerical computations involved in scientific and technological applications but also to symbolic manipulations involved in knowledge information processing. The application field of the EM-4 is now focused on the latter.

EM-4 was not originally designed to have floating point support, but Kahaner was told that this was also a budgetary issue.

For the EM-5, its objectives are as follows (Ref 4).

> ... to develop a feasible parallel supercomputer including more than 16,384 processors for general use, e.g., for numerical computation, symbolic computation, and large scale simulations. The target performance is more than 1.3 TFLOPS, i.e., 1.3×10^{12} FLOPS (double precision) and 655 GIPS. Unlike the EM-4, the EM-5 is not a dataflow machine in any sense. It exploits side-effects and it treats location-oriented computation [see note below]. In addition the EM-5 is a 64-bit machine while the EM-4 is a 32-bit machine.

The EM-5 will be based on a "layered activation model," a further generalization of the strongly connected arc mode of the EM-4.

The machine will be highly pipelined, with a 25-ns clock and 25-ns pipeline pitch. This is half the pitch of the EM-4, largely because of the use of RISC technology. Each of the up to 16,384 processors (called EMC-G) is 64-bit, RISC, with global addressing and no embedded network switch. Similarly, the floating point unit will not be within the processor chip but separate, like a coprocessor, because of limitations of pins and space on the chip. At the present time the designers have not decided on the topology of the interconnection network. Peak performance of the floating point unit will be 80 MFLOPS with a maximum transfer rate of 335 MB/s. The EMC-G will be built in a CMOS standard-cell chip with 391 pins and 100K gates, using 1.0 micron rules. This processor will have its logical design completed in 1991, and the gate design of the EMC-G will be completed in 1992. A full 16,384 node system will be designed in 1993 and a prototype is planned to be operational by March 1994.

With regard to languages, new work will emphasize DFC-II as Nikhil explained. This will have sequential description and parallel execution and is not a pure functional language. DFC-II can break a single assignment rule and programs can contain global variables. The group is also planning to implement several other languages, such as Id and Fortran. Finally, some object-oriented model is also being considered.

In Japan at least, the ETL research group is considered to have some of the best (most creative, energetic, visionary, etc.) staff among all the nonuniversity research laboratories. Readers may be interested to know that Dr. Shuichi Sakai of ETL (the chief designer of EM-4) is now visiting the dataflow group at MIT for 1 year, as of 1 April 1991. He will be assisting the group in the design of the new *T machine, which Nikhil mentions above (Ref 5). *T is based on Nikhil's previous work on the P-RISC architecture (Ref 6) and is a synthesis of dataflow and von Neumann architectures (Nikhil says that one should think of it as a step beyond EM-4-like machines). The group plans to build this machine in collaboration with Motorola, in a 3-year project that will follow the current MIT-Motorola project to build the Monsoon dataflow machine.

Concerning the remarks that the EM-5 will NOT be a dataflow machine, Kahaner passed them on to Nikhil, who was also quite surprised. Nikhil comments that the EM-5 is not fundamentally different from the EM-4. In both those machines, as well as in MIT's P-RISC and *T, the execution model is a HYBRID of dataflow and von Neumann models. In MIT's terminology, a program is a dataflow graph where each node is a "thread." ETL's equivalent of MIT's "thread" is the SCB, or strongly connected block.

Dataflow execution is used to trigger and schedule threads, just as in previous dataflow machines. In MIT's *T, this scheduling happens in the Start Coprocessor; in ETL's machines, it happens in the FMU (fetch and matching unit).

Within a thread, instructions are scheduled using a conventional program counter, as in von Neumann machines. In MIT's *T, this happens in the Data Coprocessor; in ETL's machines, it happens in the EXU (execution unit).

In both the EM-4 and EM-5 the processor is organized as an IBU (input buffer unit), followed by an FMU, followed by an EXU. The overall execution strategy is the same in both machines.

The EM-5 and EM-4 differ in smaller details: EM-5 has newer chip technology, a separate memory for packet buffers, a finer pitch pipeline, a direct instruction pointer in packets, a floating point unit, a 64-bit arch, etc., but the fundamental organization is the same.

Nikhil also asked Sakai about the statements in Reference 4. Sakai claims that what he meant was "... the EM-5 is not a dataflow machine in SOME sense" and faults his poor command of English for this error. With respect to the second sentence, "It exploits side-effects and it treats location-oriented computation," Nikhil is not sure what the authors meant by this. He explains that dataflow architectures have never prohibited side-effects or enforced single-assignment semantics. It is only dataflow languages that take this position on side-effects. Dataflow architectures merely provided support for this, while not enforcing it. Dataflow architectures are equally appropriate for other languages, such as Fortran or C.

Institute for New Generation Computer Technology

After visiting ICOT, Nikhil remarks that he got a sense of complementary strengths relative to ETL. ICOT researchers seemed to be very sophisticated with respect to parallel languages, compilers, and runtime systems; the parallel machines, on the other hand, were not that exciting.

Nikhil does not think that anyone can claim any longer that the KL1 language used extensively at ICOT is a logic programming language (ICOT researchers themselves are quite frank about this). The main remaining vestige of logic programming (albeit a very important one) is the "logic variable," which is used for asynchronous communication. Logic variables in KL1 are very similar (perhaps identical) to "I-structure variables" in Id, the programming language developed at MIT over the last 6 years.

Regardless of whether we label KL1 as a logic programming language or not, it is certainly a very interesting and expressive language and is perhaps the largest and most heavily used parallel symbolic processing language in existence anywhere. Because of the sheer volume of applications that people are writing in KL1 and running on ICOT's parallel machines (Nikhil saw five demos from a very impressive suite of demos), ICOT researchers are certainly as experienced and sophisticated as anyone in the world about parallel implementations of symbolic processing: compilation, resource allocation, scheduling, garbage collection, etc.

ICOT's machines are not as exciting as ETL's. The original PSIs (130 KLIPS) were heavily horizontally microcoded sequential machines, and one must wonder whether they will not go the way of Lisp machines, i.e., made obsolete by improving compiling technology on modern RISC machines. PSIs were not originally conceived of as nodes of a parallel machine. Thus, ICOT's two multi-PSIs, which are networks of PSIs (two-dimensional grid topology), are just short term prototypes for experimentation. ICOT researchers want to put one of the two multi-PSIs on the Internet for open access, but they are having trouble convincing the Ministry of International Trade and Industry (MITI) to allow this.

ICOT's real parallel targets are the PIM machines, the first of which (a PIM/p) had just been delivered to ICOT during Nikhil's visit (it was not yet up and running). ICOT's machines are built by various industrial partners, of course with heavy participation in the design by ICOT researchers. There are five different PIM architectures (different node architectures, different network architectures) with five different industrial partners. This is surprising because it will lead to serious portability problems for the software. On the positive side, they will gain a lot of experience on a variety of architectures, and on portability, and can learn from the best of each! Based on Nikhil's limited knowledge of PIM architectures, he feels that they do not seem to be as exciting as ETL's EM-4 and EM-5 machines.

The NEC C&C Systems Research Laboratory has also been involved with ICOT in the Fifth Generation project. NEC's CHI machine (300 KLIPS), a single user microcoded machine for logic programming, predates and outperformed ICOT's PSI machine. However, like the PSI machine and Lisp machines, Nikhil expects that this type of machine will become obsolete as compiling technology on RISC machines improves. NEC has also started work on an implementation of ICOT's A'UM programming language.

Kahaner notes that additional technical details of ICOT research are given in the article "Japan's Fifth Generation Computer Project" on page 31 of this issue. A number of Japanese researchers have remarked that one of the most important aspects of the ICOT project is that it gives many young Japanese researchers the opportunity to meet informally (outside their individual corporate or university environment) and assists in the networking that is so prevalent in Japanese science.

Osaka University

Nikhil notes that Prof. Terada's dataflow laboratory at Osaka University is remarkable in the degree to which they collaborate with industry.

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Terada's group is one of the notable exceptions to Nikhil's prior image of research at Japanese universities: starved of funds from the education ministry and generally not very exciting. Terada has close collaborations with Mitsubishi, Sharp, Matsushita, and Sanyo. They developed a TTL dataflow machine Q-p in 1983-86 (2-4 MOPS); they now have Q-pv, a multichip VLSI version (20 MFLOPS), and they are planning to integrate this further in Q-v1, a single-chip version (50 MFLOPS). A unique aspect of their technology approach is that they have an asynchronous, self-timed design; they have consciously avoided clock-synchronous circuits.

The architecture of all these machines is a ring, similar to the Manchester dataflow machine. Like the ETL project, this project again seems weak in software, with the result that no significant applications are written, which in turn means that the hardware design is difficult to evaluate. Prof. Nishikawa, a member of the group, is leading a project to develop AESOP, a program development environment for these dataflow machines.

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It appears that he is aiming for some kind of a visual programming style, where one draws dataflow graphs on a screen and chooses a mapping of these graphs onto the physical rings of the dataflow machine. Nikhil has not been very impressed with the visual programming languages that he has seen to date: they are too complicated and inflexible.

SEVENTH IEEE CONFERENCE ON DATA ENGINEERING

The conference has become very large, with at least three parallel sessions at all times and over 700 pages in the proceedings, so it was impossible for anyone to get a complete overview.

The dominant topic was object-oriented databases (OODBs). There were papers on:

- notions of consistency
- declarative (or associative access) query languages
- storage and indexing
- models of views
- models of time
- user interfaces

Unfortunately, it is disappointing that there is still very little work on developing a simple and clear semantics for OODBs. Whereas the relational model had a single, simple model that was agreed upon by a large community of researchers, today each OODB seems to come with its own unique model, often described imprecisely or with arcane formalism. Consequently, there is very little basis available for objective comparisons of OODBs with each other or with relational DBs.

There were several papers on parallel implementations, including:

- parallel transitive closure and join algorithms

- scheduling on shared-memory and shared-nothing machines
- data distribution strategies
- dataflow implementation

Most parallel implementations are on stock parallel hardware. Parallel database machines per se seem to have fallen out of vogue--only one such machine was described (FDS-R2 at the University of Tokyo; Kitsuregawa et al.). Kahaner notes that Prof. M. Kitsuregawa, from the University of Tokyo Institute of Industrial Science, has published several papers on SDC, the "Super Database Computer" (e.g., Ref 7). He also notes that the National Science Foundation (NSF), in cooperation with other agencies, has funded the Japanese Technology Evaluation Center (JTEC) at Loyola College in Maryland to assess the status and trends of Japanese research and development in selected technologies. In March 1991, a JTEC team headed by Prof. Gio Wiederhold (Stanford University, gio@earth.stanford.edu) visited Japan to evaluate Japanese database technology, and the team presented a workshop on their preliminary results on 30 April 1991 at NSF. A comprehensive report is currently in preparation.

Genomic databases generated a lot of excitement--the panel on this topic drew a huge audience. Genomic databases will contain huge volumes of data with unique requirements: inaccurate information, incomplete information, retrieval using approximate matching, and sophisticated inference. Many people seem to view genomic databases as the new frontier and driving force in DB research, a beautiful application with lots of exciting research problems (and lots of funding?) for the DB community.

Deductive databases (the marriage of logic programming languages and databases) seem to be generating less interest than they were some years ago. There were a few papers on query optimization.

The remaining papers reported steady, if unspectacular, progress on a variety of topics:

- distributed database management systems (DBMSs) (optimization, voting protocols)
- concurrency control (in high contention DBs, parallel DBs)
- indexing and query languages for temporal databases (time attributes, versions)
- indexing and query languages for spatial databases (e.g., geographic maps)
- incomplete information (formal models, approximate answers to queries)
- heterogeneous databases (transaction protocols, serializability)
- efficient post-failure restart algorithms
- simultaneous optimization for multiple queries

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6. R.S. Nikhil and Arvind, "Can dataflow subsume von Neumann computing?" *Proc 16th Intl Symp on Computer Architecture*, Jerusalem, Israel, 29-31 May 1989, pp 262-272.

7. S. Hirano, M. Harada, M. Nakamura, Y. Aiba, K. Suzuki, M. Kitsuregawa, M. Takagi, and W. Yang, "Multiple processing module control on SDC, the Super Database Computer," in *Proc Japan Soc Parallel Proc*, Kobe, Japan, 14-16 May 1991, pp 53-60.

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JOINT SYMPOSIUM ON PARALLEL PROCESSING '91

An overview is given of the Joint Symposium on Parallel Processing '91, held in Kobe, Japan, from 14-16 May 1991. A few abstracts that warranted comment are also included.

by David K. Kahaner

INTRODUCTION

The Joint Symposium of Parallel Processing is an annual research conference associated with parallel processing. Approximately 250 people attended this year's conference, which was held on an artificial island in the Kobe harbor. (Kobe is an important port city near Osaka.) There were 59 half-hour papers in three parallel sessions, one panel discussion on the future of parallel processing, and two invited lectures, by C. Polychronopoulos (Illinois) and D. Gannon (Indiana). The cross section of topics was as follows:

Topic	Papers
Architecture	25
Applications	10
Systems	9
Neurocomputing	4
Fundamentals	6
Operating systems	3
Invited papers	2

Except for the lectures by the two invited speakers, all the presentations were in Japanese. A few papers are printed in English in the bound Proceedings. The organizers told me that they made extra efforts to encourage papers with more software and application content, but that the resulting mix was still heavily weighted toward hardware.

SUMMARY

I concentrated on the applications papers and discovered that there were only a very few surprises; perhaps being here a year and a half helps. One surprise was the paper on Super Data Base Computer being developed by

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especially since I was part of a Japanese Technology Evaluation Center (JTEC) team here in March to study Japanese activities in the database area. Another surprise was the paper on the next generation of the Electrotechnical Laboratory (ETL) parallel computer (EM-5), in which it was stated emphatically that this would not be a dataflow machine in any sense. I reported on this in another article (R. Nikhil and D.K. Kahaner, "Parallel Processing Research in Japan," on page 43), where Dr. Sakai, one of the designers, explained that this comment was an error in the English translation.

While I have reported on Japanese parallel computing in the past, it is worth repeating that there are a number of highly capable parallel machines [multiple instruction/multiple data (MIMD)] that are being used here for real science applications. There are also some single instruction/multiple data (SIMD) machines, typically associated with even more specialized applications such as image, text, or speech processing. Most Japanese parallel computers are in the hands of very friendly users, or in prototype form. They have from 64 to about 1,000 processors and have peak performance of several tens of gigaflops (perhaps more when fully configured). However, thus far I have not seen any general purpose parallel computers in the sense of CM, Hypercube, etc. An exception to this is the PIE (Parallel Inference Engine) computers being developed by the Institute for New Generation Computer Technology (ICOT), but these have not been used for numerical computation. Instead parallel computers in Japan have been developed by Japanese companies with very specific applications in mind. Some examples follow. It seems to me that these companies are being very conservative about marketing parallel computers. Senior administrators in two different organizations told me that they were not sure about the market size for highly parallel machines. They felt that it was necessary to have an active research effort but would be tentative about going further. In my opinion parallel computers from NEC and Fujitsu could easily be commercialized. At the same time these two companies are very aggressively pursuing the traditional supercomputer market. In fact, while I was at this meeting, NEC announced that its one-processor SX-3/14 had taken first place in Dongarra's LINPACK benchmarks with 314 MFLOPS for n=100 and 4.2 GFLOPS for n=1000, mostly through tuning and enhancements in the Fortran system. The list of examples of parallel computing given below is definitely not exhaustive but simply meant to suggest the level of activity. There is one Connection Machine in Japan, at the ATR laboratory between Kyoto and Osaka. Researchers there have been using it for speech processing related research.

EXAMPLES OF PARALLEL COMPUTING

Industry

Hitachi. Hitachi is developing the 64-node H2P and the parallel programming language Paragram. An Hitachi researcher gave a talk describing various comparisons between Multigrid, Jacobi, Red-Black SOR, ADI, PCG-ICCG, and Gaussian elimination for solving the partial differential equation (PDE) "div(-k gradU)=Q" on a rectangle. Hitachi also has a general purpose neurocomputer with a peak performance of 2.3 GCUPS, the world's fastest. Practical applications like stock prediction are expected in 2 to 3 years.

Fujitsu. A 1,024 processing element (PE) version of the AP1000 will be available in 1991. At this meeting, Fujitsu researchers described using the AP1000 to perform molecular dynamics on the 64-node AP1000 using an adaptation of AMBER (Assisted Model Building with Energy Refinement), developed by A. Kollman at the University of California at San Francisco. Speedup with 64 processors was about 55 (86%), and they predict that with 128 processors it will be about 80%. The AP1000 is the most "general purpose" of the Japanese parallel computers. An AP1000 is installed at the Australian National University in Canberra, where I will be visiting in July, so I hope to have additional details at that time. Fujitsu also described its work on the nonnumeric parallel processor MAPLE-RP (routing processor) for laying out integrated circuit (IC) designs. In one benchmark (384x256 grid) known as the "Burnstein switch box problem," the 4,096 PE MAPLE-RP ran 300 times faster than a Sun4/1. Fujitsu is responsible for the parallel inference machine of the fifth generation project. This year Fujitsu will complete a neural computer to rival Hitachi's.

NEC. NEC has been steadily preparing for super parallel machines, including trials for in-house semiconductor design via the 64-processor Cenju [see I.S. Duff and D.K. Kahaner, "Two Japanese Approaches to Circuit Simulation," *Scientific Information Bulletin* 16(1), 21-26 (1991)]. At this meeting NEC presented a nice application of Cenju for a completely different application, plasma simulation in magneto hydrodynamics (MHD). The major issue here is solving the specially block structured linear equations that arise after the discretization. For this problem a speedup of about 40 with 64 PEs was reported. The authors also suggest that a version of Cenju with 512 processors is somewhere in the development stage. A NEC keyboarded neurocomputer is being sold for PC applications.

Matsushita. Matsushita is developing ADENA with Kyoto University. At this meeting the Fortran compiler and the preprocessor for the special purpose language ADETRAN were described. Matsushita also has worked on OHM256, with 25 GFLOPS peak performance, and may combine four of them to reach 100 GFLOPS. Matsushita is also marketing a sweeper assembled with application of neurotechnology.

Anritsu. Anritsu is working on the commercial version of Tsukuba University's PAX. At this meeting one talk was given analyzing the number of computations for a parallel implementation of Gaussian elimination on PAX. In another article ("Computing in High Energy Physics '91," page 27) I reported that support for a new version of PAX has been approved by the Ministry of Education. A very early version of PAX was also marketed by Mitsubishi. Prof Y. Oyanagi, one of the principal investigators from Tsukuba, has just moved to Tokyo University.

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Toshiba. Toshiba is developing the 512-PE Prodigy.

NTT. NTT is involved in research in using the 256-PE SIMD computer LISCAR for Japanese full text retrieval. Also NTT engages in research in applications of neurocomputers to voice recognition and automatic translation systems. NTT has also developed a 4-Kbit content addressable memory (CAM), which is being used by Waseda University, ETL, as well as NTT itself as part of a string-search chip.

Universities

The universities are busy, too. Several of the parallel computing projects that are now supported in companies began as university projects, including PAX and ADENA. Kyushu University's reconfigurable parallel computer is still moving forward, although the main investigator, Prof. S. Tomita, has just transferred to Kyoto University.

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Kyushu also reported on several other projects, including a parallel rendering machine for high speed ray-tracing, a streaming FIFO processor, and a hyperscalar architecture. (This department supports an extremely large variety of projects.) Waseda University has two interesting independent projects directed by Prof. Muraoka (the Harray system and its Fortran compiler) and Prof. Kasahara (Oscar system). Keio University described the experimental system ATTEMPT 10 (A Typical Testing Environment of Multi-Processing Systems) for evaluation of the communication performance of multiprocessors, and this should be followed by those in the performance evaluation area. Keio's Prof. Boku presented a paper on DISTRAN (Distributed System Translator), a language for discretizing partial differential equations via explicit differencing, first into Prolog and then other languages so that they can be run on parallel machines. Finally, the government laboratories ETL and ICOT are very active, with ICOT especially presenting five papers on diverse topics (see "Parallel Processing Research in Japan," mentioned earlier).

Because there are (as yet) no general purpose parallel computers from Japan, universities here are far behind in the kind of algorithmic work that is common in Western universities. There are also very few Western commercial general purpose parallel computers at Japanese universities. There is an iPSC/2 in the Information Science Department at the University of Tokyo, Alliants at the University of Tsukuba and Hiroshima, one or two BBN machines at other universities, and perhaps a few other machines scattered about, but these are the exceptions, and they are not common. (There may be more at industrial research laboratories.) Reliable machines like these are very useful for experimentation without having to worry too much about the system staying up. Naturally, those headaches reduce the time and resources available for development of algorithms, system software, and tools, and ultimately the time available for solving real problems. There is a great deal of tool building on Unix workstations, however, and much of that is directly related to parallel processing. On the other hand, there is much more system building (hardware) here than in the West, and this is reflected in the mix of accepted papers for this conference.

SELECTED ABSTRACTS

- "Implementation and Evaluation of Coherency Protocol for Virtual Shared Memory in the Network-Connected Parallel Computer," Hironori Nakajo, Newton K. Miura, Yukio Kaneda (Department of Systems Engineering, Faculty of Engineering, Kobe University); Koichi Wada (Institute of Information Science and Electronics, University of Tsukuba)

Parallel logic simulation is treated as parallel event simulation. In parallel event simulation, the time keeping is important. There are two time keeping algorithms, the conservative method and the virtual time method. As the conservative method may introduce a deadlock, the means to avoid the deadlock is important. The virtual time method, although deadlock never takes place, needs a rollback operation when a time discrepancy occurs. The authors have implemented a parallel logic simulation program based on the virtual time method on their parallel computer Multi-PSI, which has 64 PSI computers interconnected with an orthogonal bus. The performance observed by experiment is 60 kilo events per second and the speed-up ratio obtained is more than 40 by using 64 processors.

[A comment made by Prof. Yasuura of Kyoto University, however, pointed out that even a single workstation can attain as high as 100 kilo events per second.]

- "A Parallel Router based on a Concurrent Object-oriented Model," Hiroshi Date, Yoshihisa Ohtake, Kazuo Taki (Institute for New Generation Computer Technology), E-mail: date@icot.or.jp

The design of LSI routing is well known as a process that requires massive computational power. So speed-up using parallel processing leads to a shortening in the LSI design period. This paper presents a new parallel router based on a concurrent object-oriented model. The objects corresponding to line segments find the path between terminals by exchanging messages with each other. This method has high parallelisms. The searching algorithm of our model is based on a look-ahead line search algorithm. We implemented this algorithm using the KL1 language on Multi-PSI. We have been verifying our router using real LSI data, and the initial results are described.

[Comment. This paper presents a parallel routing algorithm based on a look-ahead line search algorithm and the result of speed-up obtained by running the program on their parallel computer Multi-PSI. The algorithm is based on the object-oriented model in the sense that each net is considered an object that exchanges messages to avoid intersection. Although the obtained speed-up was favorable, the routing rate was not.]

COMPUTING AND RELATED SCIENTIFIC ACTIVITIES IN SINGAPORE

Science and technology in Singapore, especially related to computing, is reviewed.

by David K. Kahaner

SUMMARY

I visited Singapore for 4 days during April 1991. This was among the most impressive places I have seen, and certainly the most surprising. Part of the material in this report is the result of my own observations; other parts were the results of discussions with Singaporean scientists or extracted from technical reports they provided me. There is a little redundancy and overlap, and I feel that this helps to paint a picture of remarkable purpose and energy. I am astonished that there are so many different projects, all being undertaken with a great deal of vigor by researchers who read, write, and speak in English. The Government has clearly committed its resources to pushing advanced technology in a way that is tightly tied to industry and the development of precompetitive products. This is especially true for information technology and it appears that every nook and cranny of Government has been told to hunt for ways to computerize. Given the size of the country it would be unrealistic to expect very long term or unfocused research projects such as those that occur within some large Japanese laboratories. The projects appear to be highly focused and credible, appropriate for an industrializing country. The scientists I met are good and the more senior ones seem well aware of the major research projects that are occurring outside their country. There is a tremendous amount of communication and coordination between departments and this helps to multiply their efforts, as does the physical proximity of the research facilities.

I think that any of the laboratories or university departments I saw would be an excellent place for a collaborative visit, sabbatical, or joint research project. Nevertheless, Singapore is a small country, far from some better known centers of scientific excellence (flying time to Tokyo is 7 hours). Their scientists will have to be aggressive to be sure that they remain well plugged into the international research community, and also tough minded enough to be willing to pare down redundant or marginal projects in order to avoid being spread too thinly.

SINGAPORE OVERVIEW AND GOVERNMENT ROLE IN SCIENCE AND TECHNOLOGY

Singapore is an island nation, lying only 1° north of the equator, between the Malaysian peninsula to its north and Indonesia to the south. Singapore has been a trading center since the time of Marco Polo and has been associated with Malaysia and Indonesia. It was a British Crown Colony since 1819, became part of the Malayan Union in 1946, and became fully independent of Britain and Malaysia in 1965. Nevertheless, it still has many British traditions including the use of English as its official language. Its 2.6 million people are a mix of original Malays, Indians, Chinese, and others, occupying an island of about 600 km^2. Three-quarters of the population is of Chinese descent. Government studies indicate that Singapore can comfortably house about 4 million, and land fill can increase the land mass of the island by about 15%.

Until recently population growth was decreasing, with a growth rate as low as 1.4 in 1986 (number of children a women gives birth to during her lifetime). This same trend has been seen in Japan, where the 1990 growth rate was 1.53. The rate in Singapore is now higher than it was, but still not high enough, and the Government is trying to encourage couples to have larger families, as well as encouraging in-migration by qualified skilled workers. It is estimated that a country needs a growth rate of 2.08 to keep its population intact.

Since 1960, Singapore's economy has grown by nearly 9% a year, save for a dip in 1985-86. It is one of the financial, industrial, and communications centers or Asia, has the world's busiest port, and has recently benefitted from industrial and financial movement out of Hong Kong. Over 600 international companies have facilities in Singapore, including AT&T, Compaq, Dupont, Motorola, IBM, Mobil, Ashton-Tate, Sony, Philips & Siemens, Exxon, Beecham, Okamoto, Aerospatiale, GM, Nippon Miniature Bearing, and Alfa Laval. Over 100,000 Singaporeans work for more than 200 U.S. corporations, most of them fabricating and assembling electronic components for export to the United States. Singapore's largest private employer is General Electric.

Several industrial products from Singapore are world class, including some computer peripherals (largest producer of small format Winchester disk drives), refrigerator compressors, specialized pharmaceuticals, as well as technology related to petroleum refining and shipbuilding.

Since 1980, Singapore's workforce has had the highest rating of any country's in an international scoring system combining worker productivity, legal framework, worker attitudes, and technical skills. Switzerland was number two this year, Japan was third, and the United States was eighth. Singapore's Changi International Airport was recently voted the world's best. Singaporeans have a fairly high standard of living. While not as well-to-do as Japan, from what I saw Singapore looks like a modern, industrial country, rather than a poor, third world one. Eighty-four percent of the population own the homes they live in (65% for the U.S., 62% in Japan), although obviously homes in Japan and Singapore are much smaller than those in the United States.

Singapore runs smoothly; it is modern, safe, and with flowers everywhere, fragrant and lush. During my visit (April) the weather was ideal although it might get hot in the summer. Its multiracial population is vibrant, making for interesting contrasts. Singapore is relatively expensive. Recently, Japanese tourism has decreased because Japanese tourists, who are great shoppers, have felt that bargains are not as conspicuous there as in the past.

The Government of Singapore exercises a great deal of control and coordination, much more so than in the United States or other Western countries. For example, a recent planning document shows a master land use plan for the entire country (admittedly Singapore is small). A positive aspect of this that I observed is the large amount of communication and joint planning that goes on among the country's scientific organizations. Occasionally this causes conflicts when value systems clash. For example, the *Wall Street Journal* is not sold because of disagreements between its editorial staff and the Singaporean Government, although I have been told that this issue has now been resolved. Overall, Singapore is considered an excellent place to do business; Westerners feel comfortable and welcomed, and essentially all needed services appear to be readily available.

Singapore has very strong government support for science-based and research-oriented industry. Government research and development (R&D) policy focuses on areas that are very high-tech but will have a payoff in jobs and products. Support includes direct support via grants and science and technology (S&T) centers and indirect support through exceptionally generous corporate tax incentives. These vary from company tax exemptions, double deduction of R&D expenses, 100% government matching grants to 30% locally owned companies developing new processes, full depreciation in 1 year for R&D equipment, etc. There is also a good deal of emphasis on training highly skilled workers, another form of indirect industrial support.

Government R&D expenditures are on the order of 1% of the country's gross national product (GNP). Areas that have been identified specifically for emphasis are:

- biotechnology/biology
- microelectronics
- robotics & artificial intelligence
- information technology
- laser and electro-optic technology
- communications technology

The Government aims to increase the percentage of engineers in the workforce from its current level of 1.1% to 2.3% by the year 2000, at which time there will be 34,000 engineers in country. (An earlier program to increase the number of Information Technology (IT) professionals from about 850 in 1980 to 10,000 by 1990 has been successful.) Scientists are to be trained at the two major universities, National University of Singapore (NUS) (with about 7,000 in the science, engineering, and medical schools), and Nanyang Technological University (NTU) (2,000 to 3,000 enrolled). Additional training occurs at three polytechnics and various training centers and technical institutes. The Government has recently established the National Computer Board and the Information Technology Institute (ITI) to perform R&D as well as to train specialists. There are also three new centers of excellence, the Institute of Systems Science (ISS) and Institute of Molecular & Cell Biology at NUS and the Grumman International CAD/CAM (computer-aided design/computer-aided manufacturing) Center at NTU. Many of these are located near the Singapore Science Park, where I spent most of the time during my visit. The Science Park is the result of planning by the Singapore Science Council (now replaced by the National Science and Technology Board) and the Jurong Town Corporation. It contains about 80 S&T organizations, both private and public, and is immediately adjacent to NUS. (Some of these are described in more detail below). Because Singapore is small, even those organizations not in the Science Park are close to it. During my visit I saw no significant traffic jams, and the road system looks very well maintained.

The list below shows the structure of the Government of Singapore and the departments that have scientific activities; other departments are omitted. The National Computer Board, National Science and Technology Board, Singapore Institute of Standards & Industrial Research, National University of Singapore, Information Technology

Institute, Institute for System Science, and the Advanced Computation Center at the Singapore Technology Corporation are discussed in detail.

Prime Minister & Cabinet (Ministries)

Environment

- Public Health Div
- Environmental Engineering Div

National Development

- Housing & Development Board
- Primary Production Dept
- Public Works Dept

Health

- Dept of Scientific Services
- Dept of Pathology
- Hospitals

Finance

- National Computer Board (& ITI)

Trade & Industry

- Economic Development Board
- Jurong Town Corp.
- National Science &Tech Board
- Singapore Institute of Standards & Industrial Research

Education

- National Univ of Singapore (& ISS)
- Nanyang Technological University
- Polytechnics Science Center

Communications

- Meteorological Services Singapore
- Port of Singapore Authority
- Telecoms

Defense

- Defense Science Organization

The Government of Singapore provided me with a great deal of information about S&T organizations. Some names that I expected did not appear, such as the large subsidiaries of GE, Advanced Logic Research, etc. Further, among those that are listed, the level of science appears to vary from almost 100% to essentially zero. Nevertheless, for a country of its size, it is amazing that such a large amount of coordinated S&T information is available.

NATIONAL SCIENCE AND TECHNOLOGY BOARD (NSTB)

This organization was formed to address the need for a coordination of Singapore's R&D efforts and to be proactive in R&D promotion. The board, established only in January 1991, is directly under a ministerial S&T committee that is chaired by the Minister of Trade and Industry. NSTB replaces the Science Council of Singapore. Its primary functions are to

- promote R&D
- coordinate establishing of research institutes and S&T facilities
- assess and develop R&D manpower
- undertake joint S&T programs with international organizations
- promote public awareness of S&T

The research institutes are its most visible product. Table 1 lists these and their staffing projections. Senior staff at the institutes are occasionally seconded. For example, the Microelectronics Institute is headed by Dr. Bill Chen, who is on secondment from AT&T Bell Labs.

NSTB also provides funding to stimulate industrial R&D. At the end of 1990 this was as follows:

Engineering & Physical Science	
Completed projects	32 (S$22.37M)
Projects in progress	18 (S$15.19M)
Biological & Medical Science	
Completed projects	21 (S$9.34M)
Projects in progress	26 (S$14.91M)

NSTB also decides on which areas to focus (a tech master plan). These areas are:

- Biotechnology
- Medical Sciences
- Food and Agrotechnology
- Microelectronics
- Electronic Systems
- Information Technology
- Manufacturing Technology
- Materials Technology
- Energy, Water, Environment, and Resources

NSTB assists in the planning and tenants selection of the Singapore Science Park. The park's current profile is as follows:

Tenants/What	No.
Government Agencies	6
Information Tech	33
Computer Hardware/Microelect.	13
Biomedical/Biotechnology	8
Chemicals/Petrochemicals	7
Materials Tech/Engineering	5
Others	6

Tenants/Who	No.
Government Agencies	6
Local Companies	13
Joint Venture	
Local Majority	8
50/50 Local/Foreign	1
Foreign Majority	9
Foreign Companies	41
	78

Table 1. Staffing Projection for NSTB Research Institutes

Name	Purpose	FY91	FY92	FY93	FY94	FY95
GINTIC Inst of Computer Integrated Mfg (CIM), Grumman International-NTU CAD/CAM Res Center	Develop local expertise in CIM via cooperative R&D, consulting, & training ($S11.8M FY90)	96	112	127	142	--
Information Tech (IT) Inst	Applied R&D arm of National Computer Board; to become national IT powerhouse, get international recognition ($S9.7M FY90)	110	115	120	130	140
Inst of Systems Science	To carry out world class research and to provide expertise and leadership to Singapore in IT ($S8.1M FY90)	125	150	175	200	200
Inst of Molecular & Cell Bio	To be internationally competitive center; research and postgrad training ($S14.2M FY90)	161	177	215	233	235
Inst of Manufacturing Tech	Promote advanced manufacturing technology by industry-driven research; provide postgrad programs ($S8.7M FY91)	23	54	65	77	89
Inst of Microelectronics	To become national research center, train industry-oriented researchers, and engage in tech transfer ($S19.2M FY91)	16	31	53	53	77

NSTB plans a computer network centered at the Science Park to connect the local R&D community, the universities, and government agencies, providing Email, file transfer, databases (DB), etc., as well as international connectivity. (There is already BITNET access to many of the computing organizations, and the National University of Singapore network has access to INTERNET.) The board has also proposed a National Supercomputer Research Center, modelled after the National Science Foundation (NSF) Supercomputer Centers in the United States. Presumably, if this plan goes forward, it will subsume the Advanced Computation Center, now under the Singapore Technology Corporation (see below).

NSTB has an even more elaborate plan to develop a science habitat as a national project. The idea would be to develop a quality living environment along with employment opportunities that will retain local talent and attract foreign experts. The universities and Science Park would be the focal points.

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NATIONAL COMPUTER BOARD (NCB)

NCB was established in 1981 under the Finance Ministry (staff of 700, with 10 Ph.D. degrees). It is the focus for information technology (IT) in Singapore and has the explicit mission to "drive" Singapore into the information age by developing an export-oriented IT industry and to exploit IT to improve productivity. Its primary method is to implement a National IT Plan, a strategy that cuts across all government agencies with seven prongs:

- Manpower. Upgraded skills, research professionals, postgraduate training, etc. Universities and institutes have primary role.
- Culture. Educational programs at all levels from schools to offices and factories, programs on TV, etc., to raise consciousness. Ministry of Education has primary role.
- Information/Communication Infostructure. Telecommunications for voice, data, text, and images, etc. Singapore Telecom (the telephone company) has primary role.
- Applications. Business, database, storage. Public sector has primary role and civil service computerization program is an important part.
- Creative Entrepreneurial Climate. Information Technology Institute, universities, telecoms, etc. have primary role.
- IT Industry. Hardware manufacturing, computer services, telecommunication services. Private sector has primary role.
- Coordination/Collaboration. National Computer Board has primary role.

There is a national computerization program, now moving into its second decade. Singapore ranks seventh in terms of computers per capita and was ranked number 1 in 1990 among 34 newly industrializing economies and OECD countries in the extent to which IT was effectively used. Various interesting computer networks have been implemented such as TradeNet, for export/import documentation, which links 18 government agencies and almost 2,000 companies and is claimed to process about 80% of import/export declarations electronically, virtually all within a few minutes. A related project is to set up a few data centers to act as nodes in a distributed environment where data is shared by the entire civil service with different application specific front end systems in the ministries and departments. Two specific examples of data sharing are the Land Data Hub (combines conventional DB and geographic information system and provides a repository of land-related data items) maintained by the Ministry of Law and the Establishment (business) Data Hub under the Ministry of Trade and Industry. On-line data services, such as "On Government Services," "Community & Arts," and "Business Link," are available to the general public as well. The entire enterprise goes under the slogan, "one stop, non stop government." (Not a bad idea.) NCB also helped to organize an IT show in December 1990 that registered more than 125,000 people. This was held jointly with the Supercomputing Conference mentioned below.

NCB has a substantial number of programs devoted to pushing IT in industry, but I did not have any opportunity to discuss these in detail. However, one interesting new project is the Japan Singapore AI Center. This is a training and development center to train a core group of 450 artificial intelligence (AI) specialists. Japan will provide 6 AI experts to advise, coordinate, and instruct. Singapore provides local instructors, administrative support, facilities, etc. There are four programs: a 3-day program for senior managers, a 2-week program for professionals in building expert systems, and a 6-month program for trainees to develop expert system prototypes. The initial focus will be expert systems, and the center is to be closely associated with commercial market potential. A related Singapore-Japan project is to develop an intelligent computer-aided instruction (CAI) system which is hoped will provide spin-off technology in the CAI field.

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INFORMATION TECHNOLOGY INSTITUTE (ITI)

The research arm of NCB is the Information Technology Institute (ITI), also housed in Science Park in another beautiful, airy, modern building. ITI has 75 professionals and 50 engineers from industrial partners (one-third with M.S. or Ph.D. degrees). If the Institute of System Science and the National University (both described below) emphasize long-term research, then ITI focuses on the shorter term, with an even stronger emphasis on industrial collaboration and support of local industrial R&D driven by market needs. ITI appears to have excellent facilities, and there seemed to be an ample supply of workstations. ITI was the first place I visited in Singapore. The staff I met were mostly young, and I worried about who was directing the show. To a large extent this concern was relieved as I met the more senior managers and learned more about the organizational structure. ITI has an ITI Board (composed of experts from academia and industry) that reviews the direction and makes recommendations. There is also has an International Advisory Panel, which comprises Les Belady from MCC, Mike Stonebreaker from UCLA, and Charles Rich from MIT. In addition, various consultants such as Joseph Hardin from the National Center for Supercomputer Applications (NCSA) and Jeffery Macmann from Stardent are engaged for technical consultation. There also seems to be excellent communication between ITI, the university (NUS), and the Institute for Systems Science and the National Computer Board (NCB).

ITI is divided into a Systems Engineering Laboratory, a Knowledge Systems Laboratory, and a Computer & Communication Laboratory. In all cases they produce "products" that are precommercial. Some I heard about later at NUS or ISS because of their collaborative research. Several of the projects are innovative; their commercial value varies from global to regional. A brief description of the projects that I learned about follows.

- Port of Singapore Ship Planning System. Set up on a network of Unix workstations, this is an interactive knowledge based system, using object-oriented principles, hierarchical planning, and heuristic search, built to help scheduling of container ship movements in this huge port. It was implemented in Common Lisp with Flavors and Objective-C, uses INGRES DBMS, and is linked to a mainframe ADABAS DBMS. Presently, planning for loading and unloading of about 80% of the container ships at the terminal is done with this system, which is claimed to have reduced planning time from 8 to 4 hours. The Ship Planning System won an award from the American Association for Artificial Intelligence in 1989. There is also a project to develop an expert system to automate the planning and allocation of ground services at Singapore's international airport.

- The Scientific Visualization Library seeks to provide a reusable library of visualization techniques that will reduce application development time on different platforms and also give a standard look and feel to applications developed at ITI, such as computational fluid dynamics (CFD) (see galaxy simulator below) and financial data visualization projects. ITI believes that these have potential commercial values and is exploring partnership with vendors and industrial organizations. However, Western supercomputing centers have many years of experience producing visualization applications, and it remains to be seen how competitive these products will be.

- Galaxy simulator. The galaxy simulator is a joint project with the Physics Department at NUS. It uses Newtonian mechanics and a particle mesh algorithm. Stars are treated as infinitely long rods with fixed mass. The rods are parallel to each other and initially distributed so that their cross sections collectively form a circular disk. Motion occurs in such a way that centrifugal and gravitational forces balance. At every time step a Poisson equation needs to be solved [via fast Fourier transform (FFT)], and this is iterated until the motion stabilizes. The basic computation is done on the NEC SX-1A and then images are post-processed on an Iris workstation. This project is apparently mostly a ramp-up to visualization software for three-dimensional (3D) fluid dynamics and the development of a user library of scientific visualization routines. However, a videotape illustrating galaxy evolution is on permanent exhibit at the Singapore Science Center.

- POSE is a CASE tool supporting the planning, analysis, and design phases of the software development life cycle. It is now being marketed by ITI's industrial partner, CSAR (Computer Systems Adviser Research), and it has more than 2,000 installed bases worldwide. It was recognized by Datamation as one of the top 10 CASE products and voted best CASE tool by *DBMS Magazine*.

- ITI is also working on several fax and communications related projects such as the ISDN PC Card. This is a PC plug-in card that transforms a PC compatible into an ISDN terminal. It provides a high data bandwidth for PC applications communication. The card handles all communication related tasks and frees the PC to handle application related tasks.

- Multimedia Document Environment (MDE) is a network-based electronic document management system that gives users the ability to electronically compose, index, retrieve, archive, route, track, and collaborate on multimedia documents (documents comprising text, image, graphics, voice, video, etc).
- Visual Programming Environment (VPE) is a CASE tool for rapid prototyping, aiming to provide a quick and intuitive way for users to define both the user interface and database processes of their application. Simulation is supported to allow the user to test the application and source code can also be generated to help produce the final stand-alone application.

ITI staff attend international meetings. In fact, ITI had a booth at Supercomputing Japan '90, where I first learned about them.

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NATIONAL UNIVERSITY OF SINGAPORE

The National University of Singapore (NUS) has 13,000 undergraduates, 1,600 graduates, 1,250 faculty members, and 2,400 staff members. My hosts were from the Faculty of Science and the Department of Mathematics, including

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and

Prof. Chong Chi Tat
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I did not know any of the faculty in either the Computer Science (CS) or Math Departments, but their list of research reports has a heavy concentration in discrete optimization (path and assignment algorithms), multivariate spline approximation, a small amount of numerical analysis, and some interesting image analysis. Time did not permit me to speak with anyone in the Faculty of Engineering.

Propitiously, during the time I was in Singapore, there was a lively discussion among the Science Faculty about a new degree program in computational science, focusing on numerical computation and graphics visualization to study problems in math, physics, chemistry, or biology. What makes this program very interesting is that it will be offered at the undergraduate level, beginning in the fall of 1991. The plan is as follows:

Year I

Computational Science Course
- Basic computer concepts
- Pascal and assembler
- Computer graphics I
- Data structures
- Numerical methods I

Mathematics Course
Subject Course (math, physics, etc.)

Year II

Computational Science Course
- Computer organization and architecture
- Fortran and C
- Computer graphics II
- Algorithms
- Numerical methods II

Mathematics Course
Subject Course (math, physics, etc.)

Year III

Computational Science Course
- Parallel computing
- Simulation, visualization, modelling

Mathematics Course or Physics Course
Optional Course in Ordinary & Partial Differential Equations

Year IV (Honors)

Project
Computational Math or
(statistics, OR, dynamical systems, theory of computation, etc.)
Computational Physics
(condensed matter, molecular dynamics, fluid dynamics, image/signal processing, neural nets, optics, holography, high energy physics, etc.)

The faculty freely admitted to me that the program was still evolving. Nevertheless, this is a very ambitious project, the emphasis on scientific computation (as opposed to computer science) is exciting, and I suspect that the graduates will be in high demand by industry.

INSTITUTE OF SYSTEMS SCIENCE (ISS)

The Institute of Systems Science has a staff of 100 (26 with Ph.D. degrees) and 52 students. ISS's mission is devoted to training and research for information and systems technology, with emphasis on technology transfer to industry. An autonomous body of the National University of Singapore, ISS represents long-term science research, but not so long term that definite industrial benefit cannot be imagined or that industrial partners will not be interested in doing joint R&D. Nevertheless, its goal is to produce world class research. In terms of training, ISS offers about two dozen courses, in areas such as technology management, systems development, database development, office systems, knowledge systems, etc. (Systems analysis and knowledge engineering courses are offered at the postgraduate level.) ISS offers consultation services, an industry affiliates program, current issues seminars, residency, etc. A long-term partnership with IBM brings in scientists from IBM's R&D laboratories to assist. Specific areas mentioned that are of particular interest are as follows:

- Hypermedia
  - Development Environment
  - Application Knowledge Bases
  - Video and 3D Graphics
  - Optical Disk Storage
- Multimedia User Interfaces (live motion video, interactive 3D graphics, images, menus, icons, and other coexisting objects).
- Image Archival System and Data Compression
- Multimedia Object-Oriented Database System. There are several projects oriented around hypermedia, related to information structuring and generalizing links, converting printed material into hypertext with little human intervention, development of an interpretive object-oriented language, development of tools to create hypermedia knowledge bases and creating specific knowledge bases for users, applications emphasizing motion of 3D solid objects, nearest neighbor searching algorithms and natural language queries for images, a user interface management system allowing rapid prototyping, etc. In the object-oriented database management system (OODBMS) area, research into how to exploit the semantics of the OO model (such as superclass-subclass, composite-component relationships) for query optimization, concurrency control, etc. and development of a language, query optimizer, view, storage, transaction, and interface manager.
- Modelling and Simulation of High Speed Local Area Networks (LANs) in Multimedia Communications. This project will study traffic characteristics and performance requirements of multimedia communications and then build performance models, algorithms, and analytical techniques to predict performance of high speed networks such as FDDI.
- Neural Nets. This is essentially theoretical research focusing on pattern processing and reasoning via neural nets.
- Connectionist Expert System Shells. This is a project to merge neural network ideas and rule-based expert systems.
- Fuzzy Pattern Recognition. This is part of an automation project in the Port of Singapore to study computerized systems to automatically recognize cargo container number (see also ITI above).
- Computer-Aided Translation. This research is associated with helping IBM develop a machine system to translate computer manuals from English to Chinese.
- Text Abstraction. This is a 5-year project into natural language processing that will look at two distinct techniques: (1) text analysis and reduction into canonical form and (2) summaries via statistical and morphological analysis, with specific application for the Ministry of Defense.
- Rapid Prototyping and Production of Distributed Software. This project will develop primitives, language extensions (to C++), and runtime support environments. Runtime features consist of support for recoverable objects, synthesis of higher level recovery from recovery objects, etc. Key emphasis will be on heterogeneity and reliability in distributed applications.
- Scientific Visualization on Shared Memory Multiprocessors. A toolkit and graphics user interface (X-Windows) will be developed. Techniques are claimed to reduce response time compared to other systems. This is being developed in collaboration with ITI (see galaxy simulation project above).

At ISS, my hosts were

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ISS is in a spectacular building set on a hill, but it is already being enlarged and looking much like a modern Western research facility. Large numbers of color and black-and-white Unix workstations and related equipment were set up throughout the building. I noticed RS/6000s, RT/PCs, PS/2s, Macs, Apollos, TI Explorer, and of course many Suns. They all seemed to be in active use. I was told that there is both a Token-Ring and Ethernet. While I only had time for a short visit, ISS gave me a very good feeling. As mentioned above, a close relationship with IBM brings senior scientists from different IBM research facilities, and many have solid research records and years of contacts and experience. A booklet sent to me (printed in 1990) lists almost 100 accepted papers, about one-third in international journals, since 1989. A substantial number of the ISS scientists have Ph.D. degrees from well known universities, not only in the United States (Minnesota, Illinois, University of California-Irvine, MIT, RPI, Wisconsin, Texas, Rutgers, etc.) but from the United Kingdom, Australia, China, Scotland, Canada, Spain, and others. There is an International Review Board, set up to advise on the R&D program and recruitment of staff. It currently consists of

- Prof. H. Kobayashi, Dean, School of Engineering and Applied Science, Princeton
- Prof. C. Ramamoorthy, Dept of Electrical Engineering & Computer Science, UC Berkeley
- Prof. L. Pau, Technical Director, DEC European Technology Center, France
- Dr. T. Agerwala, Director, Future Systems Technology, IBM U.S.A.
- Dr. N. Suzuki, Director, Tokyo Research Laboratory, IBM Japan
- Dr. C. Ellis, Technical Director, Micro Electronics & Computer Technology, U.S.A.

ISS also has had a good selection of visiting experts, including H. Simon (CMU), S. Grossberg (Boston Univ), A. Lippman (MIT), A. Lazar (Columbia), P. Johnson (Minnesota), G. Wiederhold (Stanford), M. Stonebraker (Berkeley), and C. Rich (MIT).

Several international conferences have been hosted by ISS, including the 10th Very Large DB Conference, the IEEE Language for Automation Conference, the 1990 Computer Graphics International Conference, and others.

Because ISS is on the campus of NUS, senior staff and students interact freely. Although ISS has no formal responsibilities with respect to ITI, there is ample communication. As far as I can tell, the essential differences between these organizations have to do with the time-line on the research and the level of development. ISS appears to be focused more on the longer term, but even so there is a definite sense of application in their interests, and all their projects list "deliverables."

SINGAPORE INSTITUTE OF STANDARDS AND INDUSTRIAL RESEARCH (SISIR)

The Singapore Institute of Standards and Industrial Research (SISIR) has 100 professionals (about 2 dozen with Ph.D. degrees) and a staff of 250 who work in standards and quality assurance, materials technology, design, food technology, and product evaluation. SISIR generates income by industrial R&D, consulting, testing, analysis, certification, etc. to corporate and government clients. In FY89/90 there were over 3,000 clients generating about $11M in revenue, or about $50K per staff member. SISIR is committed to operating on a self-financing basis beginning in 1990/91, and there are significant efforts in marketing, business, and corporate planning. Primary activities are as follows. I have also listed some of the projects that looked interesting to me.

Materials Technology

- Polymer (joint work with French CEMOTA, rubber research)
- Metals and Advanced Materials (microelectronics failure testing with GEP Hirst Research Center-U.K., residual stress in metal components and silicon wafers, magnetic properties of metal components, corrosion in stainless steel tanks)
- Chemical Technology (solvent reclamation system, chlorofluorocarbon (CFC) alternatives)
- Surface and Particle Technology (microcontaminants and failure diagnosis of Winchester disk drives)

Product and Process Technology

- Food Technology
- Mechanical Technology
- Design and Development
- Electronics Technology

Electronics and Computer Applications

- Intelligent Systems (computer-assisted management tool)
- Vision and Imaging (frame processing system, scanning electron microscope image collection/processing system, integrated circuit (IC) mark inspection system, IC package visual inspection system, grey scale machine vision system)
- Electronic Communications
- Sensors and Instruments

Technology Transfer

- Tech Diagnosis, Training, Information (more than 20K loans of material)

Standards and Quality

- Good Manufacturing Practice Certificate
- Quality Systems
- Agency Inspection
- Singapore Lab Accreditation Scheme
- Measurement Standards

Marketing and Business
Corporate Planning

SINGAPORE TECHNOLOGY CORPORATION

Singapore Technology Corporation is a government-related organization that comprises companies such as Singapore Aerospace, Singapore Automotive Engineering, and Singapore Shipbuilding. The (more than 50) companies together have a staff strength of about 9,000, with about 1,500 engineers, system analysts, and other specialists.

One of the most interesting aspects of this organization is that it runs an Advanced Computation Center to support its own users as well as outside contract and research activities. The focal points of the center are an IBM 3090-200E with two vector processors and an NEC SX-1A, along with various other mainframes, Vax 8800, terminals, workstations, and network. The center was set up with the support of the Ministry of Education and the Economic Development Board to be a catalyst for R&D as well as a resource. The center is also tightly coupled with the National University, as attested by the address of my host.

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As this is the only supercomputer center in the region, it is also hoped that it will be used by others from outside Singapore. There is a sophisticated set of application software available, mostly of the engineering analysis type, and the center's newsletter (*SuperTimes*) describes applications in aircraft design, coastal water modelling, microwave scattering, weather prediction, as well as general engineering. *SuperTimes* is a glossy, multicolor product that is professionally done. Of course, the center is trying to encourage new users. During 11-12 December 1990, Singapore's universities, the National Computer Board, and the Computer Society organized an international conference on Supercomputing for Strategic Advantage. A very impressive list of invited speakers included Hockney, Navon, Kuwahara, Hardin, Bell, Bailey, and others from the United States, Japan, Australia, the United Kingdom, Indonesia, etc.

In conversations with center staff we discussed some of their problems. As I saw it, their major difficulty is that the SX-1A supports NEC's proprietary operating system. This means that it is more difficult to get applications software. NEC is helpful, but only modest resources are being devoted to this. Further, except for "mission critical" needs, potential users are very reluctant to spend a great deal of their time learning another system that is not going to benefit them in the long run. One user expressed tremendous satisfaction after obtaining excellent speedup by moving a program from a Vax to the SX-1, but commented that it was a painful and time-consuming process. We all agreed that the task of converting users and applications would go much more quickly in a Unix environment, because users see it as the wave of the future. In addition, the SX-1A has poor support for any language except Fortran, and many scientists are already developing applications in C, Pascal, Prolog, etc. on Unix workstations. We all agreed that the center should try to move toward Unix as quickly as possible.

During my visit I saw no activities related to parallel processing, nor is there any mention of this in the materials provided to me, except for an allusion to shared memory in the galaxy simulator. This was a little surprising, given the amount of computer-related research, even in the supercomputing field, but perhaps it reflects a realization that the current commercial potential for this in Singapore is quite low. I expect that this will change as the National Supercomputing Research Centre comes up to steam and NUS's scientific computing program begins to turn out graduates.

OTHER SCIENCE AND TECHNOLOGY ORGANIZATIONS IN SINGAPORE (INCOMPLETE)

- Telecoms. A staff of 12,000 is responsible for telephone and postal services. All 26 exchanges in Singapore are served with about 8K km of optical cable. Various research activities focus on ISDN, electronic mail, etc.
- Singapore Science Center. Nonformal science educational institution, with various galleries, large planetarium, etc.
- Nanyang Technological University. 5,000 students, 300 faculty.
- Institute of Molecular and Cell Biology. 200 scientists, 150 with Ph.D. degrees.
- Ministry of Health. 13,000 staff including 1,000 doctors, 5,500 nurses, 100 scientific and engineering staff; research at medical clinical research center.
- Economic Development Board. In addition to the usual things they also run the German-Singapore Institute, French-Singapore Institute, Japan-Singapore Institute, and several training centers.
- Singapore Trade Development Board. Maintains 20 overseas centers and provides data via five online database services.
- Pacific Biomedical. Producer of heart valves (more than 100K sold last year).
- Primary Production Department. 1,000 staff related to agriculture, veterinary, fisheries, and rural development.
- Jurong Town Corporation. 210,000 workers, responsible for development of Singapore's industrial infrastructure, such as land sites, cargo handling facilities at main port, electrical railway system, etc.
- Primary Industries Enterprise. 550 staff (biologists, chemists, microbiologists, nutritionists, vets, etc.) engaged in agro food activities.
- Singapore Engineering Consultancy Services. 100 professional staff engaged in engineering, planning for Port of Singapore.
- Singapore Electronic & Engineering. Subsidiary of Singapore Aircraft Industries provides electronic engineering services, 600 staff of which almost 500 are technical, professional engineers, software specialists.
- Indeco Engineers. Integrated engineering services, emphasizing large building projects such as China World Trade Center, Beijing, 610 staff.
- Microprocessor Applications Center. 19 staff, 15 engineers working on machine vision & noncontact measurement, precision motion control, factory communication, Vax VME controllers, scanning electron microscopy equipment, etc.
- National University Hospital. 1,400 staff plus 500 staff from NUS in 712 bed teaching/research hospital.
- Automation Applications Center. 30 staff focusing on factory automation and robotics.
- Computer Systems Advisors Group. 400 staff have computerized over 1,000 installations in Asia/Pacific.
- Fraser & Neave. Founded in 1883, 3,000 staff, business in soft drinks, beer, etc., some research in food technology.
- Lam Soon Oil & Soap Manufacturing. 1,500 staff in Singapore, 6,000 world wide, works in food technology areas, especially fats and oils.
- Singatronics. Contract manufacturer of electronic products, 900 staff. Owns Healthcheck in the U.S.
- Yeo Hiap Seng. 3,500 staff, producing processed foods and drinks, now involved in high-tech prawn farming.

JAPANESE ADVANCES IN FUZZY THEORY AND APPLICATIONS

Fuzzy theory is currently well respected and supported in Japan and, as a result, Japan is far ahead not only in the theory itself but in its practical utilization. Fuzzy control is currently the most successful application area of fuzzy theory in Japan. This article describes fuzzy theory, provides an historical overview, and then discusses the current research in the area in Japan.

by George J. Klir

INTRODUCTION

The term *fuzzy theory* is used in this paper to encompass a family of mathematical theories whose aim is to quantify uncertainty of several distinct types. Two main branches in this family are *fuzzy set theory* (and the associated *fuzzy logic*) and *fuzzy measure tneory.*

Fuzzy Set Theory

Fuzzy set theory is an outgrowth of classical set theory. Contrary to the classical concept of a set, or *crisp set*, the boundary of a *fuzzy set* is not precise. That is, the change from nonmembership to membership in a fuzzy set is gradual rather than abrupt. This gradual change is expressed by a *membership grade function*, μ_A, whose most fundamental form is

$$\mu_A : X \rightarrow [0,1],$$

where X denotes a crisp universal set under consideration and A is a label of the fuzzy set. The value $\mu_A(x)$ expresses the *grade of membership* of element x of X in the fuzzy set A or, in other words, the *degree of compatibility* of x with the concept represented by the fuzzy set. A fuzzy set A is called *normal* when $\mu_A(x) = 1$ for at least one element of X.

For every $\alpha \in [0,1]$, a fuzzy set yields a crisp set

$$A_\alpha = \{x \in \Omega \,|\, \mu_A(x) \geq \alpha\},$$

which is called an *α-cut* of A. Since $\alpha_1 \geq \alpha_2$ implies $A_{\alpha 1} \subset A_{\alpha 2}$, the set of all distinct α-cuts of any fuzzy set A forms a nested sequence of crisp sets.

Every fuzzy set is uniquely represented by its sequence of α-cuts via the formula

$$\mu_A(x) = \sup_{\alpha \in \rho_A} \alpha \mu_{A_\alpha}(x),$$

where μ_{A_α} denotes the membership (characteristic) function of A_α and ρ_A signifies the subset of [0,1] induced by μ_A (consisting of values a for which $\mu_A(x) = \alpha$ for some x in X). This representation provides us with an important criterion for generalizing properties of crisp sets into their fuzzy counterparts: when a fuzzy set A satisfies a property that is claimed to be a generalization of a property established for crisp sets, this property should be preserved (in the crisp sense) in all α-cuts of A. For example, all α-cuts of a convex fuzzy set should be convex sets. Cardinality of a fuzzy set should yield for each α the cardinality of its α-cut. Each α-cut of a properly defined fuzzy equivalence relation should also be an equivalence relation in the classical sense, similarly for compatibility relations, ordering relations, etc. Every property of a fuzzy set that is preserved in all its α-cuts is called a *cutworthy property*. A fuzzy set that is normal and convex is viewed as a *fuzzy number*. An arithmetic of fuzzy numbers, which is a generalization of the well-established interval-valued arithmetic (Ref 1), is now well developed (Ref 2).

Several fuzzy sets can be combined by one of three types of aggregating operations: intersection operations, union operations, and averaging operations. Operations of each of these types are not unique. The whole scope of operators of each type is conveniently captured by a class of functions distinguished from one another by distinct values of a parameter that are taken from a specific range of values (Ref 3). The choice of a particular operation is determined by the purpose for which it is used.

The most important and common intersection and union operations on fuzzy sets are, respectively, the minimum and maximum operations:

$$\mu_{A \cap B}(x) = \min[l_A(x), l_B(x)]$$

$$\mu_{A \cup B}(x) = \max[l_A(x), l_B(x)]$$

These are the only operations that are idempotent and cutworthy.

For some applications, it is useful to modify the concept of a membership grade function in various ways. An important modification is to allow a function of the more general form

$$\mu_A : X \to L$$

where L is a lattice. Fuzzy sets defined by a function of this form are called *L-fuzzy sets*. Lattice L may, for example, consist of a class of closed intervals in [0,1] or a class of fuzzy numbers defined in [0,1].

Fuzzy Logic

In general, fuzzy logic may be viewed either as a branch of fuzzy set theory or as a generalization of the various n-valued logics. Regardless how it is viewed, fuzzy logic has much greater expressive power than the classical two-valued logic. This is crucial when knowledge is represented in natural language, in which most concepts are vague and any attempt to replace them with precise concepts is often superficial and wanting.

Fuzzy sets and fuzzy propositions are closely connected. The membership grades $\mu_A(x)$ for x in X, by which a fuzzy set A is defined, may be interpreted as the truth values of the proposition "x is a member of set A." Conversely, the truth value for all x in X of any proposition "x is P," where P is a *fuzzy predicate* (such as *tall, young, narrow, expensive*, etc.), may be interpreted as membership grades $\mu_p(x)$ by which the fuzzy set characterized by the property P is defined on X.

In addition to fuzzy predicates, fuzzy logic also allows the use of the following:

(1) *Fuzzy quantifiers*, such as *many, few, almost all, often, usually*, etc., which are characterized by appropriate fuzzy numbers. Some fuzzy quantifiers, such as *frequently, unlikely, very likely*, etc., may be viewed as *fuzzy probabilities*. Being fuzzy numbers, fuzzy quantifiers can be dealt with by rules of fuzzy arithmetic.

(2) *Fuzzy truth values*, such as *true, very true, mostly false, quite true*, etc., each represented by a fuzzy subset of the unit interval [0,1].

(3) *Linguistic hedges*, such as *very, extremely, somewhat*, etc., which are viewed as operators that act on fuzzy predicates. For example, if a membership function μ_{old} may be taken as a reasonable representation of the predicate "x is very old," then μ^2_{old} may be taken as a reasonable representation of the predicate "x is very old."

These elements of fuzzy logic allow us to deal with virtually any proposition expressed in natural language. For example, the proposition, "It is very unlikely that the price of gold will significantly increase in the near future," which is beyond the scope of classical first-order predicate logic, is perfectly manageable by fuzzy logic. The meanings of propositions like this can be determined, for example, by a method known as *test-score semantics* (Ref 4).

An important concept in fuzzy logic is the concept of a *linguistic variable*: a variable whose values are words or sentences in natural language (Ref 5). In general, any relation between two linguistic variables can be expressed in terms of fuzzy if-then rules. Such rules, when properly elicited from experts, form the knowledge base of fuzzy controllers or, more generally, fuzzy expert systems.

Once the meanings of relevant propositions are determined, fuzzy logic provides us with *approximate reasoning* in linguistic terms. The approximate reasoning may involve deductive inferences as well as ampliative (interpolative) inferences. An example of a deductive inference is the following syllogism:

Old coins are usually rare collectibles.
Rare collectibles are expensive.
Old coins are usually expensive.

An example of an ampliative inference (an inference based upon incomplete information) is the following: given two linguistic variables, x and y, and knowing that "y is small when x is very large" and "y is large when x is small," what is the value of y when x is medium?

Fuzzy Measure Theory

Fuzzy measure theory is an outgrowth of classical measure theory (Ref 6,7). It is obtained by replacing the additivity axiom satisfied by classical measures with the weaker axiom of monotonicity (with respect to set inclusion) and continuity or, at least, semi-continuity. Formally, a *fuzzy measure* is a function

$$g : P(X) \to [0,1]$$

such that

1. $g(\phi) = 0$ (*boundary condition*)

2. If $A \subseteq B$, then $g(A) \leq g(B)$ (monotonicity)

3. For any increasing sequence $A_1 \subseteq A_2 \subseteq A_3 \subseteq \ldots$ or any decreasing sequence $A_1 \supseteq A_2 \supseteq A_3 \supseteq \ldots$,

$$\lim_{i \to \infty} g(A_i) = g(\lim_{i \to \infty} A_i) \text{ (continuity)}$$

In this definition, P(X) denotes the power set of a universal set X. In general, the domain of function g may be an appropriate subset of P(X).

When function g satisfies the third property only for one of the two sequences, the measure is called *semi-continuous*. If, in addition to the three properties, $g(X) = 1$, function g represents a generalization of probability measures.

The general notion of a fuzzy measure encompasses a number of special classes of measures. Some of the best known and best utilized are plausibility, belief, possibility, and necessity measures and, of course, the classical probability measures.

Plausibility and belief measures, Pl and Bel, are defined by the formulas

$$Pl(A) = \sum_{B \cap A \neq \phi} m(B),$$

$$Bel(A) = \sum_{B \subseteq A} m(B),$$

where m is a function

$$m : P(X) \rightarrow [0,1]$$

such that

$$m(\emptyset) = 0 \text{ and } \sum_{A \subseteq X} m(A) = 1$$

Plausibility and belief measures are connected by the equation

$$Pl(A) = 1 - Bel(\bar{A})$$

where $\bar{A}$ denotes the complement of set A.

Plausibility measures are subadditive and semi-continuous; belief measures are superadditive and upper-continuous. Together, they form a theory that is referred to as the *Dempster-Shafer theory of evidence* (Ref 8). Subsets A for which $m(A) \neq \emptyset$ are called *focal elements*. The set of all focal elements associated with a particular function m is called a *body of evidence*.

The role of the basic assignment m in the Dempster-Shafer theory is similar to the role of the probability distribution function in probability theory, but it is defined on P(X) rather than on X.

When all focal elements are singletons, the plausibility and belief measures become equal, and we obtain a *probability measure*. When all focal elements are nested (ordered by set inclusion), we obtain special plausibility measures, which are called *possibility measures*, and the corresponding special belief measures, which are called *necessity measures*.

A possibility measure, Pos, is conveniently (and uniquely) determined by a *possibility distribution function*

$$r : X \rightarrow [0,1]$$

via the formula

$$Pos(A) = \sup_{x \in A} r(x)$$

for all $A \in P(X)$. The corresponding necessity measure, Nec, is then determined for all $A \in P(X)$ by the formula

$$Nec(A) = 1 - Pos(\bar{A})$$

A theory that deals with nested bodies of evidence in terms of possibility and necessity measures is usually called *possibility theory* (Ref 9). This theory can be formulated not only in terms of nested bodies of evidence but also in terms of fuzzy sets (Ref 4). Given a normal fuzzy set A with membership function μ_A, a possibility distribution function, r_A, associated with A is defined as numerically equal to μ_A, i.e.,

$$r_A(x) = \mu_A(x)$$

for all $x \in X$. In this interpretation of possibility theory, focal elements correspond to distinct α-cuts A_α of the fuzzy set A. This follows from the property that $A_\alpha \subseteq A_\beta$ when $\alpha > \beta$.

It is already well established that the Dempster-Shafer theory can be fuzzified (Ref 10). In its fuzzified form, focal elements are fuzzy sets rather than crisp sets.

AN HISTORICAL OVERVIEW

Fuzzy theory emerged in the second half of this century by challenging basic assumptions of three classical theories: the assumption of sharp boundaries in classical set theory; the assumption of classical (Aristotelian) logic that each proposition must either be true or false; and the assumption of additivity in classical measure theory and, in particular, probability theory. The first challenge came from fuzzy set theory founded by Zadeh in 1965 (Ref 11), even though some key ideas of the theory were envisioned by Black in 1937 (Ref 12). The second challenge came from fuzzy logic, which emerged as an outgrowth of fuzzy set theory (Ref 3) as well as a generalization of the Lukasiewicz infinite-valued logic defined on the unit interval (Ref 13). The third challenge came from fuzzy measure theory founded by Sugeno in 1974 (Ref 14), even though the basic ideas of fuzzy measures, monotonicity and continuity, were already present in Choquet capacities introduced in 1953 (Ref 15).

In its initial stage, fuzzy theory encountered a lot of skepticism and, on some occasions, open hostility (Ref 16). In spite of the opposition, the development of fuzzy theory became quite strong in the 1970s. New important concepts were introduced such as fuzzy numbers, fuzzy topology, and various kinds of fuzzy relations. An extension principle was introduced in 1975 (Ref 5) by which other concepts and theories of classical mathematics can readily be fuzzified. Operators for aggregating fuzzy sets were investigated in a comprehensive way, fuzzy sets of more general types were introduced, a theory of dynamic fuzzy systems was developed, and various categories of fuzzy sets and relations were formulated in category-theoretic terms. All these advances influenced the development of fuzzy logic. For example, fuzzy arithmetics is crucial for dealing with fuzzy quantifiers; fuzzy operations of complementation, union, and intersection can readily be mapped into the corresponding logic operations of negation, disjunction, and conjunction; and fuzzy relation equations play an important role in implementing fuzzy rules of inference.

Fuzzy measure theory was also significantly advanced in the 1970s. In particular, several theories that generalize or complement probability theory were introduced during this decade. They include probability theory of fuzzy events (Ref 17), random set theory (Ref 18), theory of Sugeno λ-measures (Ref 14), Dempster-Shafer theory of evidence (Ref 8), and possibility theory (Ref 9).

Some ideas of prospective applications of fuzzy theory also emerged in the 1970s, for example, fuzzy control (Ref 19), fuzzy decision making (Ref 20), and fuzzy pattern recognition (Ref 21). These ideas were still "halve-baked" and of interest almost exclusively to the academic community only. Industries, business, and government showed little interest in this new area. In spite of this general lack of interest, fuzzy theory continued to advance rapidly, as documented by the need for a specialized journal, *Fuzzy Sets and Systems*, which was established in 1978. Applications of the theory, however, were hopelessly behind the theory itself.

The situation gradually changed in the 1980s, primarily due to four factors: (1) the theory became sufficiently mature; (2) several organizations promoting the theory and applications emerged (e.g., North American Fuzzy Information Processing Society (NAFIPS) in 1981, International Fuzzy Systems Association (IFSA) in 1984, Japan Society for Fuzzy Theory and Systems (SOFT) in 1989); (3) the theory became recognized as a respectable academic subject by a growing number of academic programs, where courses covering various aspects of the theory and applications were initiated which, in turn, contributed to the publication of the first textbooks in this area; and, above all, (4) some applications of fuzzy theory became sufficiently appealing to attract the attention of industries and other nonacademic constituencies.

The increasing interest in fuzzy theory and applications during the 1980s was most pronounced in Japan, a country that is now the undisputable leader in this area. The United States, unfortunately, is not only far behind Japan (especially in applications) but also behind China, the Soviet Union, and a host of other countries.

Research in fuzzy theory in Japan started early. Although it was initially pursued only by a small group of researchers, these were renowned scholars who managed to obtain a stronger support for the research than was possible in other countries. It is important to notice that these scholars paid considerably more attention to applications of fuzzy theory than their colleagues in other countries.

A genealogical tree of Japanese researchers and a list of early papers by Japanese (1968-1971) in the area of fuzzy theory were prepared by Zadeh (Ref 16). The following is a chronological list of more recent major events regarding the development of fuzzy theory and applications in Japan:

1985 Japanese Chapter of IFSA was founded; it organized the first of annual meetings called Japan Fuzzy Symposia.

1987 Hitachi successfully implemented fuzzy control of the subway system in Sendai City in northern Japan.

1987 The Second IFSA Congress was held in Tokyo.

1988 The Japan Science and Technology Agency began to study "Expected Fields for Fuzzy Engineering."

1988 The IFSA Workshop on Applications of Fuzzy Systems was held in Iizuka.

1989 SOFT was established and started to publish its own quarterly journal; in February 1991, the society had over 1,700 members, 60% of whom were engineers from more than 100 companies.

1989 The Biomedical Fuzzy System Association was founded at Kawasaki Medical University in Kurashiki.

1989 The Laboratory for International Fuzzy Engineering Research (LIFE) was initiated with a budget of approximately $40 million for 6 years. The support comes from the Ministry of International Trade and Industry (MITI) and a consortium of 48 companies. The laboratory has a staff of 25 researchers.

1989 The Japan Science and Technology Agency initiated a National Project on Fuzzy Systems and Their Applications to Human and Natural Problems with a budget of approximately $4 million for 5 years.

1990 The Fuzzy Logic Systems Institute was established as a private research foundation supported initially by 14 companies.

1990 The International Conference on Fuzzy Logic and Neural Networks was held in Iizuka, resulting in a publication of 1,236 pages of Proceedings and Tutorials.

1991 The Center for Promotion of Fuzzy Engineering was established at the Tokyo Institute of Technology.

1991 The First International Congress of Biomedical Fuzzy Systems was held in Tokyo.

1991 The International Fuzzy Engineering Symposium is scheduled in Yokohama.

CURRENT RESEARCH ON FUZZY THEORY AND APPLICATIONS IN JAPAN

It is well known that research on fuzzy theory and applications has been given high priority in Japan for the last few years by the government as well as most industries. The motivation to support research in this area quite generously is likely an outcome of some highly successful industrial applications of fuzzy control in Japan in the late 1980s. The first significant application of fuzzy control was the automatic drive fuzzy control system for subway trains in Sendai City. Although it took 7 years to complete this project, the final product was extremely successful. It is generally praised as superior to other comparable systems based on classical control. The fuzzy controller achieves not only a higher precision in stopping at any designated point (to within 7 cm) but makes each stopping more comfortable by lowering the frequency and speed adjustments. In addition, it saves about 10% of energy.

Many other industrial projects that employ fuzzy control have been completed in Japan since the opening of the subway system in Sendai City in 1987. A complete list would be too long. The following are just a few representative examples to illustrate the great utility of fuzzy control:

- chlorine controller for water purification plants
- elevator control systems
- traffic control systems
- control of bulldozers
- air conditioning systems
- control systems for cement kilns
- control of washing machines, vacuum cleaners, video cameras, refrigerators, etc.

Most of these products are well publicized. Extensive lists of products that employ fuzzy control can be found, for example, in special issues of the Japanese magazines *Trigger* (July 1989) and *Quark* (March 1991). Less information is available about current research in the area of fuzzy theory, which is perhaps less conclusive at this time but involves greater long term implications. The following is an overview of current activities at several key organizations involved in research on fuzzy theory and applications. The information is based on personal visits to these institutions in February 1991.

Laboratory for International Fuzzy Engineering Research (LIFE)

LIFE seems to be currently one of two principal centers devoted fully to research on fuzzy theory and applications. The other center is the Fuzzy Logic Institute in Iizuka, Fukuoka.

LIFE was founded on 28 March 1989 to vitalize the basic study of fuzzy theory, to research its efficient utilization by strengthening ties between industrial and academic circles, and to promote international technological exchange. LIFE is located in Yokohama and headed by Dr. Toshiro Terano, Professor at Hosei University, who is one of the earliest and most important contributors to fuzzy theory in Japan.

Since its very beginning, the principal aim of LIFE has been to study comprehensively the many issues associated with *human friendliness* of machines. It was early realized that there are two principal requirements every user-friendly machine must satisfy: it must be sufficiently intelligent and its communication with the user must be smooth. It is believed that fuzzy theory is capable of contributing significantly to achieving these requirements.

After an initial stage, during which the focus was on formulating specific research projects compatible with the overall aim, LIFE settled on nine projects, which are now organized under three research groups. The three groups are: Decision Support Group, Intelligent Robot Group, and Fuzzy Computing Group.

Projects under *Decision Support Group* are oriented to the investigation of intelligent support systems for dealing with various problems involving large-scale systems models. In the first project, the aim is to investigate fuzzy expert systems that can deal not only with all types of numerical or statistical data but also with various types of news data expressed in natural language. As a concrete theme, it was chosen to develop a prototype of a foreign exchange support system by which macroscopic predictions of exchange rates can be made on the basis of market participants and economic situation. The second project is aimed at the development of intelligent support systems for human plant operators. A power plant was chosen as a specific testing ground for the project. The third project is oriented to the study of anticipating control systems based upon fuzzy dynamic models.

The *Intelligent Robot Group* consists of three projects whose aim is to develop a robot that combines sophisticated visual perception capability with the capability of understanding natural language. The ultimate goal is to design a home robot. Such a robot must be much more adaptable to changes in environment than common industrial robots and must also be able to understand the intentions of its owner. The first project is concerned with the issues involved in natural language understanding, such as the ambiguity and vagueness inherent in natural language, the dependence of meaning on context, the intention of the language producer, and the ability to apply the experience to present situations. This is clearly an extremely challenging project, in which fuzzy logic plays an essential role. The aim of the second project is to develop high level visual perception capabilities. The research is centered on the knowledge-based model description of objects and appropriate reasoning methods to deal with the model and actual image data. The third project is concerned with the overall capability of robots to make intelligent decisions and the required control skills to resemble the behavior of human beings. The primary foci are on sensor fusion, global path planning, and decision making for autonomous motion.

The orientation of projects under the *Fuzzy Computing Group* is the investigation of various aspects of computer systems from the standpoint of fuzzy theory. The first project focuses on fuzzy neural networks. The aim is to combine advantages of fuzzy logic and neural network technology. This idea, which was originated by Bart Kosko in the United States (Ref 22), is now far more rapidly being developed in Japan (not only at LIFE) than in the United States. The goal of the second project is to develop a fuzzy expert shell called LIFE FESHELL for building fuzzy expert systems associated with the other projects, such as the foreign exchange support system or the image understanding system. The third project focuses on the development of a computer specifically designed for fuzzy information processing. The project will result in specifications for the entire architecture of the computer and the necessary hardware and software technology to implement the architecture. Research on software involves the design of a language in which fuzzy sets and operators on fuzzy sets can be easily implemented, aiming at a software development support system capable of flexible fuzzy information processing. Research on hardware involves the development of a high-speed fuzzy set operation chip as well as the study of how parallel processing can be best utilized in the fuzzy computer.

Fuzzy Logic Systems Institute (FLSI)

FLSI, located in Iizuka (southwest Japan), was established 1 year after LIFE, on 15 March 1990, with the following aim: "to offset the disadvantages of existing deterministic methods of information processing by conducting experimental research into fuzzy information processing and neuroscience and to promote the wider use of fuzzy information processing and neuroscience." The institute is headed by Dr. Takeshi Yamakawa, Professor of Kyushu Institute of Technology, who is well known for his pioneering work on hardware technology implementing fuzzy inference rules for fuzzy controllers.

Since FLSI was less than 1 year old when I visited it, its program was not as well defined and final as the program of LIFE. Nevertheless, the following areas seem to form the primary orientation of the institute:

1. Research and development of *high-speed hardware to support fuzzy logic*. This is a natural outgrowth of previous work of Professor Yamakawa. In his publications (e.g., Ref 23-26), an electronic circuit is described where the speed is 10 MFIPS (mega fuzzy inferences per second). The ultimate goal is to use the hardware developed at FLSI for designing and building a fuzzy computer (in cooperation with LIFE), which will be capable of using rules of fuzzy logic at very high speed. This part of the computer is usually referred to in Japan as the sixth generation computer.

2. Research on *fuzzy neural networks*, which involves relevant theory, hardware development, and various applications. Currently, the main focus seems to be on hardware development of an artificial fuzzy neuron, a neuron in which the weights of synaptic junctions are represented by fuzzy numbers rather than ordinary numbers. Although research on fuzzy neural networks is currently very active in Japan and not restricted to FLSI, the latter plays undoubtedly a leadership role in this area. This was exemplified by its principal sponsorship of the first International Conference on Fuzzy Logic and Neural Networks (22-24 July 1990), which happened to be a very successful event (Ref 27). Among the applications of fuzzy neural networks that are currently researched at FLSI is pattern recognition of handwritten characters. A combination of designability of neural networks with their usual learning capabilities is explored. At this time, a hardware system for handwritten character recognition was implemented by one layer of fuzzy neurons, with each neuron designed for recognizing one particular character, whose speed is 10 μs per character recognition.

3. Research on *fuzzy control systems*. Emphasis is on systems in which the needed inference rules are implemented in hardware, which itself is also studied and developed at the institute. A good example of the effectiveness of fuzzy control, associated with FLSI, is a fuzzy controller designed to stabilize an inverted pendulum. The performance is excellent even under severe noise such as the movement of mice placed in a container on top of the pendulum or pouring water into the container. It is amazing that only seven fuzzy inference rules are needed to achieve such a high performance.

4. FLSI is also increasingly getting involved in research of various aspects of *biomedical fuzzy systems*, as documented by its major role in organizing, jointly with the Biomedical Fuzzy Systems Association, the First International Congress of Biomedical Fuzzy Systems in Tokyo (13-15 February 1991).

The congress, which was preceded by 2-day tutorials (organized also by FLSI) on fuzzy theory for medical doctors, showed that fuzzy theory can offer a great deal to the medical profession and that the medical professionals are beginning to recognize this potential. Topics that were particularly well covered at the congress include fuzzy expert systems in the various area of medicine, the role of fuzzy neural networks in the organization of medical knowledge, and the role of fuzzy control in medicine. My expectation is that the importance of biomedical fuzzy systems will grow rapidly in Japan within the next few years and FLSI will undoubtedly play a major role in this development.

Tokyo Institute of Technology

The center of research on fuzzy theory and applications at the Tokyo Institute of Technology (TIT) is referred to as the *Sugeno Laboratory*. Associated with the Department of Systems Science in Yokohama, the laboratory is headed by Professor Michio Sugeno, who is well known for his pioneering work on fuzzy measures, fuzzy integral, and fuzzy control. The current research at the laboratory involves the following areas:

1. *Fuzzy measure theory and fuzzy integral.* Professor Sugeno originated the concepts of a fuzzy measure and fuzzy integral in his dissertation at TIT in 1974. He and his group have been active in this area over the years. Current work focuses on investigating the concept of fuzzy t-integral, which subsumes three types of fuzzy integrals as special cases, Choquet integral, Sugeno integral, and Weber integral.

2. The Sugeno Laboratory has been a leader in the area of fuzzy control (Ref 19). It currently focuses on two projects in this area: the design and construction of a microprocessor-based fuzzy controller for general purposes, and the design of a fuzzy controller for an unmanned helicopter. The latter project, which is supported by the Ministry of Transportation, is particularly challenging. A helicopter is a highly unstable object, especially under rapidly varying wind conditions. To model its behavior adequately, 15 input variables and 4 output variables, which are strongly interrelated, must be considered. Attempts to design a classical model-based controller for this purpose have not been successful thus far. Fuzzy control, on the other hand, seems to work quite well, at least on the basis of simulation experiments. I saw results on video of some simulation experiments under various wind conditions and for various remote control oral instructions (fly straight, turn left, hover, land, etc.). The performance was very impressive. Experiments with a real helicopter are scheduled for March 1992. Compared in these experiments will be fuzzy control and conventional control, the latter being developed independently at another laboratory. This will be an important test which, I suspect, will demonstrate the superiority of fuzzy control in this and similar applications, which are characterized by high instabilities, nonlinearities, and time-varying conditions. The helicopter flight control project is a 2-year project, which was initiated in April 1990. It consists, in fact, of these subprojects: (1) to develop a remote control of a helicopter by oral instructions, (2) to develop a control for automatic autorotation entry and landing in case of engine failure, and (3) to develop a full control of a helicopter for sea rescue operations based on control instructions from a mothership and information from a satellite about the position of the helicopter.

3. The Sugeno Laboratory is also involved in researching some problems associated with the development of a *fuzzy computer*. This research, which is performed in cooperation with LIFE, consists of two projects:

   (a) *Linguistic modelling of images* using fuzzy case-based reasoning. The aim of this project is to develop fuzzy logic technology for high-level image understanding similar to that of humans.

   (b) *Analysis of natural language* in the context of the prospective fuzzy computer. The principal aim is to develop methods for linguistic modelling and simulation based upon both numerical and linguistic data.

Hosei University

One of the most active academic groups in the area of fuzzy theory and applications in Japan is housed at the Department of Measurement and Control of Hosei University in Tokyo. This is a result of the long-term leadership of Professor Toshiro Terano (currently the director of LIFE) and more recent leadership of Dr. Kaoro Hirota. The group is primarily involved in three areas:

1. Numerous applications of *fuzzy control* have been investigated, for example, the tracing of a randomly moving object, control of a yo-yo, semiautomatic control of a bulldozer, control of a helicopter, control of a double inverted pendulum and, more recently, even a triple inverted pendulum. Based on this extensive experience with a variety of applications of fuzzy control, the group came to the conclusion that fuzzy control is very cost effective, robust, and easily implementable even in dealing with processes that involve nonlinearities, instabilities, and varying conditions. In addition to the work on applications of fuzzy control, the group is also involved in theoretical research regarding the problem of how to analyze stability of fuzzy control systems (for example, how to identify fuzzy control rules that affect stability). Although fuzzy control has been very successful in practice, its theory is still in its infancy. It is generally recognized that appropriate stability analysis for fuzzy control systems is currently the most needed component of the emerging theory.

2. *Fuzzy pattern recognition and image processing.* One problem in this category, which was investigated in the late 1980s, was recognizing crops by fuzzy logic. Results obtained by working on this particular problem are now being utilized in other fields. In the area of image processing, the focus is on linguistic description of scenes. Such a description can capture not only characteristics of objects on the scene and their relationships but also the season (winter, summer, etc.), time (early morning, noon, etc.), and other characteristics like these. Since 1989, the group has also investigated the combination of neural networks and fuzzy techniques for dealing with the problem of image reconstruction. Research on two-dimensional image reconstruction based on this approach was apparently completed at the time of my visit (February 1991); currently, they are working on three-dimensional image reconstruction.

3. The group is particularly strong in *applications of fuzzy logic to robotics.* In fact, most of the work on fuzzy control, pattern recognition, and image processing within the group has been motivated by its utility in robotics. The goal is not to develop a universal, human friendly robot (in the sense of the robotics project at LIFE) but rather to implement special, highly complicated (and, in some instances, unusual) skills of humans by robots. The following are some of these implementations (all based upon fuzzy logic) that have recently been completed: a robot playing two-dimensional ping-pong; a robot capable of throwing arrows to a target in the same way as humans do; Japanese flower arrangement by a robot equipped with knowledge of a human expert (encoded in eight fuzzy inference rules); inspection and evaluation of carnation seedlings in a plant factory with the aim of deciding for each seedling whether it is sufficiently healthy for planting or should be discarded (the results agree very well with judgments made by skilled inspectors from whom the knowledge was elicited and encoded in appropriate fuzzy inference rules involving shapes, colors, and other characteristics of the inspected seedlings); and Chinese calligraphy by a robot (painting Chinese characters by a brush, which in Japan and China is considered as an art). The problem of learning by robots based on fuzzy models has also been investigated. In analogy to Bayes' theorem of conditioning in probabilistic models, fuzzy integral and conditional fuzzy measures play a similar role in the context of fuzzy models.

In addition to the described research, the group also developed a computer-aided instruction system to teach engineers in various industries fundamentals of fuzzy theory and its existing and potential applications. In 1 year, almost a thousand copies of the system were purchased by various companies. This indicates, again, the strength of the current interest in fuzzy theory in Japan.

Research in Osaka

Until 1971, Osaka had been the only place in Japan (according to known publications) where research on fuzzy set theory took place. Both of the major universities in Osaka were involved at this early stage, Osaka University and the University of Osaka Prefecture. Since Osaka is an industrial city with a long tradition in strong cooperation between universities and industries, it is not surprising that some industries in Osaka have been influenced for more than two decades by research on fuzzy theory at the local universities.

The strong cooperation between universities and industries was clearly exhibited during my visit to Osaka. Prior to my visit, my only acquaintances in Osaka were at the universities. Instead of arranging a meeting at one of the universities, they proposed, quite thoughtfully, to have a joint meeting at the Central Research Laboratories of the Matsushita Electric Industrial Company (MEIC).

MEIC is a comprehensive electronics manufacturer. The primary task of its research laboratories, particularly its Intelligence Sciences Laboratory, is to develop products that are human friendly. MEIC is one of the founding members of LIFE.

The Intelligence Sciences Laboratory, senior researchers of which I met during my visit, is currently involved in research pertaining to the following areas:

- speech synthesis and recognition
- text, graphic, and image recognition
- three-dimensional image processing
- fuzzy data processing
- multistage reasoning and judgment
- fuzzy data and neural networks
- hypermedia
- information structuring and classification
- multimedia conversion and integration

Fuzzy theory is involved in virtually all of these areas.

MEIC has already developed and currently manufactures a number of consumer products that use fuzzy control. They include washing machines, refrigerators, air conditioning systems, vacuum cleaners, kerosene heaters, microwave ovens, hot and cold water mixing units, and video cameras. The fuzzy control automatic washing machine, for example, senses the quantity of work load, the fabric type, the intensity and type of dirt, and both the room and water temperature. Based on these sensory data, it adjusts the wash, rinse, and spin cycle times automatically on the basis of six fuzzy inference rules that adequately capture knowledge of an experienced operator.

A fascinating new product of MEIC is a video camera that not only adjusts zoom and flash automatically but has also an image stabilizer that significantly reduces the movements of the image caused usually by shaking hands of the user. The image stabilizer compares pictures taken at two sufficiently close time instants and, using appropriate fuzzy inference rules, makes a judgment of whether any recognized change in the pictures is due to a moving object in the scene or due to a movement of the camera itself. This judgment is then employed for choosing an appropriate corrective action. The performance of the fuzzy stabilizer is outstanding.

As any other institution I visited in Japan, MEIC is also heavily involved in research combining fuzzy theory and neural networks. Their principal interest in fuzzy neural networks is to employ them for determining appropriate membership grade functions (by learning from input-output data) for new products.

CONCLUDING REMARKS

There is no doubt that fuzzy theory is currently well respected and supported in Japan. In the United States, on the contrary, it is still regarded largely with suspicion or even hostility. As a result, Japan is far ahead not only in the theory itself but, above all, in its practical utilization.

Fuzzy control is currently the most successful application area of fuzzy theory in Japan, but successes in other areas, such as image processing, pattern recognition, and robotics, are by no means negligible. Fuzzy theory seems intimately connected with the notion of user friendliness of machines and with the development of the sixth generation of computers.

Why are fuzzy theory and its applications so successful in Japan? A combination of three factors may give a reasonable, even though somewhat speculative, answer. The first factor seems to be the Japanese culture, which is known to be much more receptive to vagueness and other types of uncertainty than the various Western cultures. The second factor is likely the early and rather strong support given to fuzzy theory by some influential and highly respected Japanese scholars. In the United States, on the contrary, some highly influential scholars were quite hostile toward fuzzy theory during the early stages of its development. The third factor seems to be the Japanese talent for applications. Once the pragmatic value of fuzzy theory was established by its successful applications, it was easier to obtain support, and that, in turn, helped to further advance the theory itself and, at the same time, explore new applications.

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OMRON'S FUZZY TECHNOLOGY BUSINESS PROMOTION CENTER

This article provides an overview of Omron Corporation and its fuzzy-related activities, a table of fuzzy-related patent applications in Japan, and a look into the special edition on "fuzzy" of the Japanese popular science magazine Quark.

by Thomas Hagemann

INTRODUCTION

On 5 March 1991 I visited the Central Research and Development (R&D) Laboratory of Omron Corporation in Kyoto to speak with members of the fuzzy project team. My hosts were

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This article provides an overview of Omron Corp. and its fuzzy-related activities, a table of fuzzy-related patent applications in Japan, and a look into the special edition on "fuzzy" of the Japanese popular science magazine *Quark*. For different aspects of fuzzy in Japan, see *Scientific Information Bulletin* articles by D.K. Kahaner et al. ["Fuzzy Logic," 16(1), 41-47 (1991)], T. Hagemann ["Second Fuzzy Logic Systems Institute Hardware Practice Seminar," in "Scientific Information Briefs," 16(2), 2-3 (1991)], and G.J. Klir ["Japanese Advances in Fuzzy Theory and Applications," see page 65].

COMPANY OVERVIEW

Omron Corp., founded as Tateisi Electric Manufacturing Company in May 1933 by Kazuma Tateishi, has major business divisions for factory automation systems, control components, automotive electronic components, traffic control systems, electronic fund transfer systems, health and medical equipment, and office automation systems. The number of employees is about 14,000 including all subsidiaries, 10.000 of them in Japan. Other Omron Corp. statistics (excluding subsidiaries), found in the spring 1991 edition of a Japanese handbook listing 2,577 companies, published by Toyokeizai-Shinposha, are:

Paid-in capital	¥38.5B
Sales	¥350.7B
Profit	¥27.1B
Investment	¥11.4B
Major shareholders	Mitsubishi, Sumitomo, Taiyo-Kobe-Mitsui Banks
Employees	6,957
Average age	33.4 years
Average salary	¥296.4K

The banks hold between 2.0% and 4.7% of the company's shares (5% being the legal upper limit of shareholding by financial institutions according to paragraph 11 of the Anti-Monopoly Law); chairman Takao Tateishi of the founder's family holds another 1.8%.

The Central R&D Laboratory with its 800 employees is one of Omron's research facilities covering a wide range of technologies. Others are the Communication Systems Laboratory and the Systems Laboratory (R&D in computer systems) in Tokyo, the Life Science Laboratory in Kyoto (R&D in medical and health care systems), and the Tsukuba R&D Laboratory. Omron has developed within and parallel to the SIGMA project of the Ministry of International Trade and Industry (MITI) a Unix workstation called LUNA.

FUZZY AT OMRON

Although located in the Central R&D Laboratory, the Fuzzy Technology Business Promotion Center is not part of that but is directly under the management of the company president. It has one marketing and one R&D section; gives support to fuzzy researchers in various business divisions (there are more than 200 fuzzy researchers in Omron altogether) by developing hardware and software tools; and does fuzzy R&D on its own, focusing mainly on development, since basic research of fuzzy theory is said to be done mostly at universities. For the researchers, who receive 3 months of training when entering the company, there are regular weekly in-house seminars, sometimes with lecturers from universities. At present, one researcher has been sent to Osaka University to attend the 2-year Master's course. In general, as in all other Japanese companies, researchers often go to the factory, to the sales department, and to customers to bring back new ideas for their own work.

Omron's major fuzzy products are used in factory and plant automation and automotive control. The video I was shown presented, among others, a temperature controller in a chemical plant; a vending machine selecting cans by color; a camera following moving objects; and a conveyor belt, the speed of which was controlled such that boxes, coming randomly along the belt, passed a fixed check point in constant time intervals.

The scope of fuzzy products ranges from digital fuzzy chips, a hybrid controller (combining fuzzy and proportional-integral-differential (PID) control), expansion boards for NEC-PCs and IBM-PC/AT compatibles (to be presented in April at Hannover Fair, Germany), various controllers and control boards, and a fuzzy human body sensor for detecting living objects in rooms to software for simulation and study on NEC-PCs and the LUNA workstation and a fuzzy expert system for machine diagnosis. One of Omron's fuzzy devices, the FZ-1000, is built into the prototype heavy water reactor "Fugen," where it controls the water temperature in a tank. Under normal and stable conditions the temperature is controlled by a PID device, but when the reactor starts firing or is shut down, PID control is less suitable for the huge amount of information to be handled during these phases; therefore, control is switched to fuzzy control under the monitoring of a human operator. It is claimed that this still limited system is only used in noncritical places. The Fugen reactor is operated in Fukui prefecture, central Japan, by the Power Reactor and Nuclear Fuel Development Corporation (PNC), an R&D organization supervised by the Science and Technology Agency (STA).

A digital fuzzy chip was put on the market in October 1990 for use in automobiles and home electronics, and 100.000 of these chips are expected to be sold in the first year. In 1990, only 0.5% of Omron's sales (see above) came from fuzzy products, but the sales plan for 1994 is ¥100B. This means that Omron expects a lot from fuzzy technology in the future, and with respect to its importance and potential, it is compared with microprocessor technology a couple of years ago. Nevertheless, it is thought that fuzzy technology cannot replace traditional methods everywhere, although it is often easier and cheaper to implement. For example, fuzzy control seems to be superior when precision of up to 1% is sufficient, but hybrid fuzzy/PID control is necessary for higher precision. Similarly, PID control is better for tasks like keeping temperature on a constant level, whereas fuzzy control is better for reaching this level because overshooting rarely occurs.

HISTORY OF OMRON'S FUZZY COMMITMENT

Whenever you visit a Japanese company and get an introduction to its activities, you first will be presented the company philosophy and its vision for the future. The past might also be mentioned, but the focus lies on the future. Whether vision and philosophy are derived from the company's products and business strategies, or vice versa, is not as important as to have a philosophy at all, which is easy to understand for the management, the employees, and the customers, like the philosophy of a big Japanese cosmetics company, "For Beautiful Human Life." Omron's philosophy fits perfectly into the company profile: "To the machine the work of machines, to man the thrill of further creation." Omron has always been in search of technologies to help free man from burdensome work, to make more human friendly machines, and to let machines act more according to human needs, not the other way around. Fuzzy technology was recognized early as a possible candidate of such a technology. For Omron, fuzzy is a paradigm to introduce human subjectivity into objective science and a method to model and use human knowledge and senses as they are without complicating abstraction.

Back in 1966, Omron built an analog computer called DECIVAC for decision making based on probabilistic methods that could handle (in modern terminology) crisp membership functions and weighted inference rules; at that time, Omron was not aware of the very young fuzzy theory. With some pride I was told that this computer was even exported to West Germany.

In 1983, when the first fuzzy technology appeared in Japan (control of a drinking water treatment plant by Fuji Electric and the famous subway control by Hitachi), Takeshi Yamakawa of Kumamoto University visited Omron's Tokyo office in search of financial support for his fuzzy integrated circuit (IC), a hand-made sample of which he had completed in October 1983. Omron saw the potential of this new technology, and in October 1984, Yamakawa came to Omron's head office in Kyoto for a lecture, which was also attended by Kazuma Tateishi, the founder of Omron. Tateishi showed a deep interest in this new technology, and in that year, Omron started R&D on fuzzy expert systems. In 1986, a medical diagnosis expert system and, under the guidance of Yamakawa, fuzzy hardware were developed.

The "fuzzy boom" in Japan began in 1987. Omron built a fuzzy controller and a "fuzzy computer" [a fuzzy arithmetic logic unit (ALU)]. In 1988, this was marketed as the FZ-1000, and a special task force, the "F-Project" team, was established within Omron. A prototype fuzzy chip designed by Yamakawa was manufactured (now the FZ-5000), and the hybrid (F+PID) temperature controller E5AF was developed. Omron took part in establishing the Laboratory of International Fuzzy Engineering Research (LIFE), participated on STA's Fuzzy Committee, and received a grant of Y600M from the Japan Research and Development Corp. (another STA organization) for a 3-year project to develop a fuzzy microprocessor.

In 1989, 10 new fuzzy products were announced by Omron, and 60 fuzzy demonstrations appeared at the Omron Festival, an idea contest held regularly within Omron. Prof. Zadeh became a senior advisor of Omron, and the F-Project team was transformed into the Fuzzy Technology Business Promotion Center, while the team leader was dispatched for 2 years as head of one of LIFE's three research laboratories in Yokohama.

In 1990, a fuzzy human body sensor, a fuzzy expert system for machine diagnosis (together with the machinery manufacturer Komatsu), a digital fuzzy chip, a new tuning method for fuzzy control, and a fuzzy inference unit were developed, but this listing is not complete.

In April 1991, Omron appeared at the Hannover Industrial Fair in Germany to start its fuzzy control overseas.

FUZZY PATENTS

Omron Corp. has filed applications for several hundred patents related to fuzzy technology, although presently only 171 of them have been made public officially (patents are made public 18 months after application), and none are registered yet (this process can take more than 5 years). Table 1, which lists fuzzy-related patents made public in Japan between 1987 and 1990, gives an impression of the current situation.

FUZZY EDITION OF THE SCIENCE MAGAZINE *Quark*, MARCH 1991

Quark calls itself a "visual science magazine, revealing science for pleasant life," and has a circulation of 120,000 copies per month. The 20-page special feature, titled "Becoming Definitely Strong at Fuzzy," rides heavily on the Japanese media's present "fuzzy fad," epitomized in the first of its four parts: a dialogue on "Who is fuzzy's 'mother of invention'?" Such dialogues or round-table talks are a necessary part of any special feature on any theme in any Japanese magazine, where specialists and so-called commentators (hyoronka) talk freely about anything considered relevant, leaving conclusions to the reader. This dialogue was between Prof. Takeshi Yamakawa, the father of the dedicated fuzzy chips, and Kazuhiko Kimura, a "best-selling trend watcher" and columnist of several magazines and TV programs. They talked about the reason for the high acceptance of fuzzy theory in Japan and the post-fuzzy era. While Yamakawa tried to guarantee a certain level of quality during the dialogue, Kimura gave a glimpse into the shallowness of pop-science by arguing, for example, that automating daily necessities like cooking by fuzzy rules and devices would change mankind considerably: "man's secret reason for marriage has been to have his wife do the cooking and household work, and hence fuzzy makes marriage unnecessary (haha)".

The reason for the high acceptance of fuzzy in Japan was believed to be its "eastern" background: oriental vagueness versus occidental exactness. While eastern and western people would "think" in their brains similarly, the way of "expressing" their thoughts was different: westerners would just express themselves straightly and rationally, but easterners would also take into account the point of view and situation of their listeners, thus preferring often vague expressions. The father of fuzzy theory, Lotfi Zadeh, is an Iranian (like his wife, who was born in Japan and lived here until the age of 3) and used his eastern experience when he tried to solve control problems that were intractable by exact methods.

Part two of the special feature consisted of test reports of three fuzzy consumer products, a video camera by Matsushita (NV-SI, ¥165,000), a washing machine by Toshiba (AW-50VF2, ¥95,000), and a vacuum cleaner by Hitachi (CV-AX760D, ¥55,000), and a short description of 20 other home electronics products.

Part three described five examples of "automatic control of master skills": sake distillation (Gekkeikan), stock investment (Yamaichi Securities), teeth correction (Matsumoto Dental University), subway control (Sendai City), and prediction of "udon" noodle soup or "tofu" bean curd sales in relation to weather conditions (Japan Weather Association).

Part four was a question & answer section.

Q1: How can fuzzy theory express vagueness scientifically?

Q2: What are membership functions?

Q3: How are membership functions constructed?

Q4: Where does fuzzy inferencing differ from conventional?

Q5: Why is fuzzy control suddenly used in home electronics products?

Table 1. Fuzzy-Related Patents in Japan According to Applicant and Technical Content

Technical Content	Om	Hi	To	Mi	FF	Ma	Ni	Fe	Other	Total
Control Applications										
Furnace			1						3	4
Process		3	1							4
Elevator		3	7	3						13
Air conditioning		1		1		1	1			4
Robot			2	1					1	4
Tunnel drilling									1	1
Home electronics	2					3				5
Automotive	9	1	2	5			11		13	41
Grinding, treatment	2			1						3
Electric power		1	1	1						3
Measurement	1				15				2	18
Electric musical instruments									6	6
Others	9	1	9			1			1	21
Other Applications										
Recognition	7	1		1					1	10
Detection, verification	4	1							2	7
Diagnosis, supervision	2	1		1				1	2	7
Inference, prediction		9				1			1	11
Retrieval				1		1			2	4
Picture processing	2									2
Support, MMI[a]	1	3								4
Others	8					1			2	11
Method, Structure										
Fuzzy reasoning	11	5	4	5		2		6	7	40
Fuzzy control	5	4	6			1		3	9	28
Computer controller	12									12
Auto-tuning				8		2				10
Rules	7	1								8
Membership function	20			1					7	28
Fuzzy calculation	1		1	1					1	4
Defuzzification	3								1	4
Others	1					1				2
Total	107	35	34	30	15	14	12	10	62	319

[a]MMI = man-machine interface.

Note: Om=Omron, Hi=Hitachi, To=Toshiba, Mi=Mitsubishi Electric, FF=Fuji Film, Ma=Matsushita Electric, Ni=Nissan Auto, FE=Fuji Electric, Other=applicants with less than 10 patent applications.

Q6: Are special integrated circuits necessary for fuzzy control?

Q7: Can false conclusions occur at the end of a chain of vague inferencing?

Q8: What would a fuzzy computer look like?

Q9: What can happen when fuzzy control malfunctions?

Q10: Where do fuzzy computers differ from neuro computers?

While most questions were dealt with in the *Scientific Information Bulletin* articles mentioned earlier, the answer to Q6 lists four different kinds of fuzzy ICs presently in use:

(1) General purpose microprocessors, which are programmed for fuzzy inferencing (used also for fuzzy simulation). Advantage: easy program changes.

(2) Analog circuits like in Yamakawa's chip, where the values of membership functions are represented by electric current or voltage. Advantage: high speed.

(3) Digital circuits like Masaki Togai's (AT&T) chip, where values of membership functions are transformed into binary digits.

(4) Look-up tables, where all results of fuzzy inferences are stored beforehand and just retrieved according to input values (often used in home electronic products). Advantages: high speed and low cost.

The last part ended with a list of 10 books on fuzzy theory, authored by well known insiders (Mukaidono, Sugeno, Terano, Yamakawa), published by first-rank companies (Iwanami Shoten, Kodansha, Nikkan Kogyo Shinbunsha). The bestseller among them is *Recommending Ambiguous Engineering*, by T. Terano, December 1981, now in its 16th printing. Of the 80,000 printed, 75,530 have been sold.

CONCLUSION

Fuzzy technology is widely used in Japanese products, is believed to have an enormous future potential, is well known to the ordinary educated Japanese, and might be an example of a technology invented and successfully implemented in the East.

Thomas Hagemann is the Deputy Director of the Tokyo Bureau of the German National Research Center for Computer Science (GMD). He received his master's and Ph.D. degrees in mathematics from Ruhr-Universitat Bochum in 1980 and 1986, respectively. From April 1981 to March 1983, he did graduate study at Keio University, Department of Mathematics, Yokohama, in dynamical systems and differential equations. From 1986-88 Dr. Hagemann was a researcher at the Fraunhofer Society, Institute for Information and Dataprocessing in Karlsruhe, focusing on system engineering, software development environment, and object-oriented databases. From 1988-90 he was the Assistant to the Director at GMD Sankt Augustin, specializing in R&D planning and budgeting. At GMD Tokyo, Dr. Hagemann reports on Japanese R&D in computer science, especially software-related areas, and performs liaison office work for the German scientific community.

A GLIMPSE OF ELECTRONICS RESEARCH AND DEVELOPMENT IN JAPAN

A group of scientists and engineers representing the U.S. Navy visited several leading electronics science and technology industrial centers to identify areas of mutual interest, to gain a better understanding of the Japanese industrial technical culture, and to seek mechanisms for mutually beneficial collaborations. This visit allowed first hand observation of the quality and to some degree the depth of Japanese science and technology as it relates to electronics and optoelectronics. There can be no mistake that Japan will continue to play a dominant role in the development of electronic systems into the 21st century. It is clear that Japan is a major contributor and leader pushing back barriers along a broad front of electronics technologies. Expansion of the dialogue that has been opened with these companies by continued mutual visits and exchanges will not only be useful in hastening general scientific and technological developments but will also be most beneficial to the U.S. Navy.

by G.M. Borsuk

INTRODUCTION

A group of scientists and engineers representing the U.S. Navy made visits to several leading electronics science and technology industrial centers in Japan in the fall of 1990. These individuals were principally from the Naval Research Laboratory (NRL), but the group also had representatives from the Office of Naval Research (ONR), the Office of Naval Technology (ONT), and a U.S. academic institution. The members of the group and their respective affiliations are listed in Appendix A. The centers visited along with a list of the principal hosts are given in Appendix B.

The principal objectives for these visits were to identify areas of mutual interest, to gain a better understanding of the Japanese industrial technical culture, and to seek mechanisms for mutually beneficial collaborations. Success of these visits should be measured not only by a significant increase of the group's knowledge but also by the establishment over time of meaningful interactions between U.S. Navy scientists and engineers and their Japanese counterparts in research areas of common interest.

GENERAL OVERVIEW AND OBSERVATIONS

Our team was impressed with the extremely gracious and forthcoming discussions afforded to us by our Japanese hosts. They were justifiably proud of their forward-looking planning horizon that was supported by apparent and substantial investments in research and development (R&D). Facilities were well maintained and equipped. (Particularly impressive about the scope and quality of their scientific instrumentation was the machining and tool and die work.) All aspects of R&D appear to be growing at a high rate. Of particular note, there appeared to us to be some evidence of a new emphasis upon basic scientific research in contrast to the commonly held view that Japan would continue to depend upon others (the United States and Europe) for this commodity.

There seemed to be a consensus among our hosts that growth in the direct consumer electronics market is limited. Business and subsequent R&D focus as presented to us now is being placed upon business equipment and information services. Along with this was a strategy to increase job quality and skill level in Japan with lesser quality jobs involving mature manufacturing being done elsewhere. Although there appears to be a consensus on this business strategy, the companies visited seem to compete furiously to gain manufacturing advantage over each other.

Business strategies and activities by non-Japanese companies seem to have only a secondary influence upon the Japanese once a consensus is reached. In this context, the popular contemporary U.S. view of the Ministry of International Trade and Industry (MITI) as the lead in developing alliances is too simple a model. However, there is no doubt that the Japanese private sector approach to the management of R&D is different than that of the United States.

A fundamental theme of their work is "focused" research in the sense that it progresses through a set of stages which results ultimately in a manufacturable and manufactured product. Important in the Japanese way of doing R&D is the decomposition of broad areas of activity into manageable pieces (problems) that can be addressed in a focused manner with sufficient resources applied to its solution. This approach has the important feature that managers can grasp fully the significance and progress of work without reliance upon surrogate measures such as papers published, outside funding, or promised importance to a system.

Another crucial aspect of the route from applied research to manufactured product is the role played by the bench scientist or engineer in technology transfer. His job (we saw few female professionals) requires that he move with the project through the various stages of development right through to production. As a result, professional bench personnel in the R&D centers were significantly younger than one might expect to find in a comparable laboratory in the United States. The ratio of those holding advanced degrees from universities to those holding a bachelor's degree was significantly lower than in the United States. This does not appear to impact the quality of their research activity.

In addition to providing sufficient funds for a given focused research or technology objective of interest, they do not balk at doing nonglamorous evolutionary research if it is necessary for the eventual development of an advanced technology. There appears to be little concern between companies about redundancy of research objective for it often leads to beneficial differences in approach.

We were also told almost universally by our hosts that Japanese higher educational institutions are not capable of supplying the numbers of well trained scientists and engineers necessary to fill their expanding needs. Solutions, we were told, are to import such talent (up to 10% of total complement) from other countries or to establish and staff foreign facilities in situ. We saw evidence and heard of both approaches.

The primary agenda items for our visits consisted of microwave device and circuit technologies, optoelectronics, and supporting technologies. However, we were selectively exposed to advanced silicon microelectronics technologies. Themes which repeatedly appeared were electronic processing technologies including x-ray lithography technology, display technology, high frequency fiber optic communications and optoelectronic integrated circuit technologies, electronic materials research and development, and superconductivity research and development.

HIGHLIGHTS OF THE ORGANIZATIONS VISITED

Canon Research Laboratory at Atsugi

Canon ranks third for U.S. patent awards in the past 3 years with only Hitachi and Toshiba ahead. It was easy to see why after visiting Canon's facility. About 80% of its new products come from its research laboratories.

As an introduction, our hosts described the long term phases of Canon's R&D business strategy. They noted that in response to changing business opportunities in recent years, Canon has changed its corporate business approach from one of vertical integration of products to one of diversification of products. We were presented an overview of Canon's current business areas, which are cameras, business machines, and optical products, and of the structure of its laboratories. This was followed by a detailed description of Canon's work on the selective nucleation based epitaxial growth technique dubbed "Sentaxy." This method has been used to grow silicon islands upon silicon dioxide substrates for possible application to flat panel displays and to grow diamond thin film islands on silicon wafers as potential field emission elements.

Canon is also developing an x-ray lithography aligner/stepper for use with synchrotron light sources. It will be capable of cassette-to-cassette loading. It is a low pressure helium system with a resolution of 0.25 μm. The unit is to be ready for sale some time in 1993.

Canon has a strong interest in thin film transistors for flat panel displays, and the research in this area is focused upon silicon-on-insulator (SOI) technology.

We left Canon with the feeling that this company really knows how to move work from the research laboratory to the production line--a theme we would find elsewhere as well.

Fujitsu Laboratories at Atsugi

At this laboratory we were exposed to a wide variety of current research topics. An interesting aspect of Fujitsu's microelectronics research strategy is the "staggering" of insertion time of key technologies into systems. This was evidenced on a grand scale by Fujitsu's plans to replace silicon microelectronics in its next generation high end computer systems with a gallium arsenide based technology and to follow that generation of computer with a niobium based superconductor technology. (In this regard, Fujitsu has a clear goal to be the world leader in mainframe computer technology in the decade of the 90s). On a more limited scale, Fujitsu plans to insert improved high electron mobility transistors (HEMTs) in its direct satellite broadcast (DSB) receiver systems.

Fujitsu carries its research from basic device studies through circuits and into systems with a prototype system demonstration planned for each technology. Major technology thrusts in electronic devices are advanced materials research, advanced silicon VLSI development, HEMT integrated circuit (IC) and heterojunction device technologies, Josephson devices, optical integrated circuits, infrared (IR) sensors and solid state lasers, and flat panel display technology.

Highlights of Fujitsu's silicon research include work on 0.1-μm p-channel metal oxide semiconductor (PMOS) technology using SOI for 1-Gbit DRAMs and high speed heterojunction bipolar transistors with photoepitaxial grown base regions showing a transition frequency response of greater than 40 GHz. This latter device technology was implemented in a divide-by-six demonstration circuit that operated with an input clock of 12 GHz. A heterojunction bipolar transistor that used an SiC emitter was also described.

Fujitsu's optical compound semiconductor device work is extensive and is aimed at supplying components to a 10-Gbit fiber optic communications system. This fiber optic system, which is a national goal, will be a coherent lightwave system, so much of the Fujitsu work is aimed at reducing the "chirp" effect in narrow linewidth laser diodes. The chirp effect limits transmission distance due to increased dispersion in the fiber.

Fujitsu's optoelectronic integrated circuit (OEIC) detector approach is to integrate optical and electronic components together using a hybrid InP PIN (intrinsic layer photodiode) detector flip chip mounted on a semi-insulating GaAs substrate in which the amplifier circuit has been fabricated.

Fujitsu also has an extensive effort in HEMT device technology. At the research level, researchers are pursuing InP based HEMTs for both low noise and power device technologies at millimeter wave frequencies (to 100 GHz). At the development level they are pursuing a "super" HEMT device whose main feature is noise performance at microwave frequencies lower than the standard HEMT technology. Superior performance is achieved by introducing into the structure an interfacial InGaAs intrinsic layer between the heavily doped n+ AlGaAs region and the intrinsic GaAs layer. Typical performance of the super HEMT is a 0.4-dB noise figure at 30 GHz. This device is planned to be transitioned to production.

Fujitsu is also producing 3 million GaAs HEMT discrete devices per month on 3-inch wafers with molecular beam epitaxy (MBE) grown layers for use in direct satellite broadcast receivers. DSB is a large market in Japan. Over 20% of all households in Japan that have a television have a DSB receiver as well.

In summary, Fujitsu R&D programs are state of the art and well connected to the goals of the corporation.

NTT R&D Center at Atsugi

NTT is working on many, if not all, critical elements of the next generation, coherent fiber optic 10-Gbit/s communications system mentioned above as a national goal. The work briefed to us was on optoelectronic and related device and supporting technologies connected to this initiative.

For future lithographic needs of both optoelectronic and VLSI technologies, NTT is developing an x-ray compact synchrotron source named "Super ALIS." We were shown this machine. Some of its specifications and unique features were described. Of interest was its ability to sustain a beam current in excess of 100 mA at 0.8 GeV. NTT's mask technology approach uses tantalum as the pattern absorber on a silicon nitride membrane. The capability of the machine to perform fine line lithography was demonstrated by means of a description of a double feedback laser grating structure defined using Super ALIS. [This facility was also visited later in the fall of 1990 by a Navy sponsored team of U.S. experts. More details can be found on this subject in a summary report by K. Davis, "X-Ray Lithography in Japan," *Scientific Information Bulletin* 16(1), 79-81 (1991).]

Other topics described were Er doped fiber amplifiers operating at a wavelength of 1.5 μm with 90% electrical to optical efficiency, two channel PIN junction field effect transistor (JFET) photodiode OEICs with developmental effort concentrating upon reducing crosstalk between detector elements, InP epitaxial layers deposited upon silicon using superlattice InGaAsP and GaAs layers as buffer materials being developed for OEIC applications, a novel GaAs/GaAlAs ballistic collection heterojunction bipolar transistor having a large intrinsic layer with a measured cutoff frequency of 171 GHz, and a double self-aligned silicon bipolar process technology that minimizes base crowding effects. Our hosts also described to us future efforts on silicon heterojunction bipolar devices using wide bandgap emitters such as SiC.

In summary, in consonance with constraints of NTT activities in the private sector, work at this laboratory seems to respond to more general national goals than to specific product line objectives. A clear focus on satellite communications technology aimed at the world market place is also evident.

NEC Central R&D Laboratory at Kawasaki

This is one of two NEC R&D laboratories visited. Particularly impressive at this laboratory is its focus on understanding the materials problems necessary to achieve high performance electronic devices. Research projects on microelectronics, photonics, and advanced materials were described to us. In the area of microelectronics, NEC's approach to the 64-Mbit DRAM that features 0.4-μm trilayer resist lithography was described. An ultra high density three-dimensional silicon technology dubbed "CUBIC" that uses multilayers of silicon fabricated by means of recrystallization growth techniques was also described. High frequency silicon heterojunction bipolar transistors with 300-Å base widths made using MBE have achieved cutoff frequencies of 40 GHz without resorting to Si-Ge heterostructures.

As at other laboratories that are addressing optoelectronics, NEC's focus is on lasers and photodetector OEICs necessary for a 10-GBit/s coherent fiber optic communications system. NEC's laser approach is centered upon a 1.5-μm wavelength InGaAs quantum well double-feedback laser diode with low chirp. Our hosts also described a 10-channel coherent fiber optic system using optical frequency division multiplexing. Central to this approach is a distributed Bragg reflection (DBR) laser that can be tuned by a phase conjugation region between active regions of the diode.

NEC's optical detector work is centered upon back-illuminated InGaAs avalanche photodiodes, while future work is aimed at integrating such structures with a GaAs pre-amplifier on a monolithic OEIC. A photonic network switching device based on lithium niobate for fiber optic systems was also described. A 32-by-32 cross point switch was described while an 8-by-8 switch was demonstrated to us. This latter device has an optical insertion loss of less than 12 dB and requires about 85 volts to switch.

NEC is performing materials research in three areas: electronic ceramics, functional thin films, and oxide superconductors. Among these areas, our hosts described work on diamond and amorphous carbon films made using the hot filament and dc glow discharge techniques for use as heat sinks and x-ray mask materials and thallium based oxide superconductors made by laser ablation for use as passive conductors for electronic devices.

Hitachi Central Research Laboratory

The work described to us on this visit included heterojunction silicon device efforts; 256-Mbit DRAM development; and a general description of some optoelectronics developments, particularly work on a distributed feedback (DFB) laser with 5-Å linewidth and reduced chirp necessary for coherent fiber optic systems. A new Si-Ge HEMT, called a buried channel HEMT, was described which displayed mobilities comparable to analogous GaAs devices. Hitachi has a Class 0.1 Super Clean Room that is used for developing ultra high performance devices and circuits. The company is projecting 0.2-μm feature sizes for 256-Mbit DRAMs with a storage capacitance of 25 fF (femtofarad) and 1.5-volt supplies. Our hosts described how they used 0.3-μm e-beam lithography on only two circuit die of a 5-inch wafer to achieve a functioning 64-Mbit DRAM circuit.

Hitachi also placed a great deal of emphasis on multi-dielectric oxide/nitride/oxide (ONO) structures for nonvolatile silicon semiconductor memories. This approach is in contrast to the U.S. microelectronics industry, which is emphasizing floating gate technology. Hitachi believes ONO technology is the best approach to realizing a 256-Mbit "silicon disk" capability for lightweight and compact commercial computer products.

Toshiba Central Research Laboratory

The discussions at Toshiba centered principally upon two areas: advanced silicon VLSI technology and GaAs digital technology for use in fiber optic systems. A Toshiba approach for 256-Mbit DRAMs and beyond is a three-dimensional stacked surrounding gate transistor (SGT) structure with 0.4-μm feature sizes. This approach differs from the general community's approach, which involves a trench cell structure with 0.2-μm feature sizes. To support this work Toshiba has a very impressive ULSI Class 1 Clean Room designed for fabricating advanced silicon devices and circuits with gate lengths down to 0.1 μm.

In the area of GaAs digital technology, a strategy for implementing data control buses, multiplexers, and repeaters for a 10-Gbit/s fiber optic communications system was described. Heterojunction bipolar transistor (HBT) technology ICs are used for multiplexer data rate functions and repeater circuit functions above 5 Gbit/s. GaAs metal-semiconductor field effect transistor (MESFET) technology ICs are used for lower data rate applications. The MESFET IC technology described was of the Schottky diode field effect transistor logic (SDFL) and the direct coupled field effect transistor logic (DCFL) types fabricated upon 3-inch wafers. Excellent threshold uniformity across the wafer was described (less than 3% nonuniformity across the wafer for a threshold voltage of 0.30 volt). This allows high yield on ICs with gate counts as high as 3,700 gates per die.

Oki Research Laboratory

Oki was the only organization visited that reported a connection to the military market place. Oki has been developing and marketing underwater acoustic systems for submarine detection to both the Japanese navy as well as the U.S. Navy. Oki, except for printers and cellular telephones, is not well known in the United States. But it is a well known force in Japan where its consumer telecommunications products rank high on the list of competitive products in the market place. Among the technologies described were silicon gate array developments, GaAs microelectronics efforts, optical communications device efforts, rf device efforts, and supporting materials developments.

In the case of silicon technology, a great deal of emphasis has been placed upon the development of state-of-the-art gate arrays. A 0.8-μm feature size, 225K complimentary metal oxide semiconductor (CMOS) nonmerged logic gate array was described which was dubbed a "sea of gates." A merged logic BiCMOS gate array development was also described. Circuits fabricated from these processes are used in telecommunications products such as echo cancelers and cellular telephone systems.

GaAs microelectronic circuits were also described. A 0.5 μm feature size MESFET ion implant technology is used as Oki's mainline process for digital components. A 0.3-μm feature size technology is being developed to support high speed digital processing for the 10 Gbit/s fiber optic system. This technology will use a self-aligned gate with carbon implants in the source/drain regions and with a low doped drain profile. A divide-by-4 frequency divider circuit fabricated using a 0.2-micron feature size gate structure that operates with an input clock frequency of 36 GHz was described as representing the state of Oki's development. Oki is not now pursuing HEMT or HBT devices for digital circuit applications.

In the area of optoelectronic devices, a major thrust is in the development of distributed Bragg reflection (DBR) wavelength tunable laser diodes in support of the national 10-GHz/s coherent fiber optic communications system. Other developments briefly described were work on optical solitons and optical amplifiers (an Er doped fiber optic amplifier pumped at 1.48 microns by a solid state laser diode array), optical photodetectors, and an optical 4x4 matrix switching circuit fabricated both in lithium niobate and in GaInAlAs materials.

Oki has a significant effort in rf devices and monolithic microwave integrated circuits (MMICs) based upon III-V semiconductor materials systems in support of fiber optic and cellular telephone markets. A 0.5-micron ion implanted MESFET technology was described for low power cellular telephone applications. (The low power consumption and high efficiency offered by GaAs technologies are crucial for very compact personnel communicators because of battery limitations.) A 0.25-micron MBE MESFET technology was described for high linearity microamplifier applications and several 0.25-micron HEMT MMIC technologies were described for low noise rf applications at 12 GHz (which is the DSB downlink frequency).

All the GaAs parts which go into Oki's products are fabricated in its co-located production facility and represent an impressive list of rf components such as low noise pre-amplifiers, mixers, oscillators, and power amplifiers. Oki's production facility processes about 600 wafers per month with rf good yields in the 50% to 70% range and about 200K chips per month.

In the materials research area, Oki's work on GaAs on silicon was described. A novel hot carrier ballistic bipolar transistor device was mentioned. This novel device is intended to have a high temperature superconductor base with an InGaAs emitter structure. Also the development of porous piezoelectric ceramics for high sensitivity hydrophones was described briefly.

In summary, Oki is pursuing an impressive array of electronic and optoelectronic device technologies aimed at keeping the company competitive in the telecommunications market place.

Matsushita Research Laboratory at Osaka

This laboratory is nestled in a much larger Matsushita operation that includes a three-story building housing a museum. Inside the museum is a sizable display of impressive commercial audio-visual electronic products. (Matsushita products sell under the brand names of Panasonic and Technics in the United States.) Clearly a developing new product area of emphasis revolves around high definition television.

Our technology interaction centered principally upon silicon technology. Matsushita's work on nitrided oxides for application to flash electrically erasable programmable read only memory (EEPROM) was described. A particularly interesting experiment aimed at characterizing hot carrier degradation of oxides was also described. The very weak photon emission of hot carriers from the drain region of MOS devices is analyzed using spectroscopic microscopy. The spatial extent of the emission spectra is correlated with oxide reliability.

Sumitomo Research Laboratory at Osaka

Sumitomo Electric Industries is the largest supplier of III-V compound semiconductor substrates in the world. Sumitomo supplies 70% of the world's production. Of that percentage, 75% of this product goes to the production of LEDs. It is not surprising that our visit to Sumitomo's laboratories centered upon electronic materials research, development, and production. Somewhat unexpected was the description of significant exploratory device work being carried out at Sumitomo's Yokohama laboratory. This work includes GaAs IC development using MESFET and HEMT device technologies, InP based GaInAs PIN photodetector development for fiber optics, InP based AlInAs/GaInAs pseudomorphic HEMT development, and diamond MESFET transistor development. Research and development is being performed in an effort to grow semi-insulating undoped InP. Sumitomo's approach is to anneal InP boules grown without iron doping in a phosphorous ambient. Researchers have found that although the material appears to be semi-insulating at high temperatures, it is not at room temperature. New techniques for GaAs wafer cleaning are also being pursued.

Sumitomo has a large thin film diamond effort; the growth method is a microwave plasma assisted chemical vapor deposition (CVD) process. A diamond MESFET transistor was described. The device was of annular design. The active region consisted of a boron doped 900-Å diamond thin film grown on a diamond substrate. An intrinsic buffer layer of 450 Å was used as an interface between the aluminum Schottky gate and the active region. Ohmic source drain contacts were made using titanium. Diamond dome shaped diaphragms for audio speakers were also described as a commercial product. The use of a diamond diaphragm extends the linear frequency response of such speakers to above 80 kHz, resulting in distortionless response in the human audible range.

Of final note, Sumitomo showed us several empty manufacturing areas in which planned crystal growth expansion has been put on hold pending an increase in demand for substrates.

Sharp Central Research Laboratory at Nara

Sharp also has a museum similar to that of Matsushita which serves to set in context the transition of R&D to commercial products. As a historical note, we were informed that the Sharp Company's first product was the patented Eversharp mechanical pencil. From this beginning at the turn of the century, Sharp later expanded into the production of radios and from there followed a path that has led the company to become the consumer electronics products giant of today.

R&D activities include advanced materials, silicon VLSI, III-V device technologies for optoelectronics, and rf components. In the area of advanced materials, a CVD process for use in the fabrication of electroluminescent color displays was described. Homoepitaxial growth of ZnS on ZnS by vapor phase photo assisted MBE was also described. Silicon carbide growth on both alpha silicon carbide and silicon substrates was described. As is the case for Sharp's ZnS materials work, the major driver for this material system is light-emitting diodes (LEDs) that emit in the blue. Sharp has successfully demonstrated such devices using a beta thin film silicon carbide diode structure.

Some work on lithium-intercalated carbon materials as a cathode electrode for lithium secondary batteries was also described briefly. A 3-volt battery made with this material has been successfully recharged over 500 times.

The Sharp approach to achieving a 64-MBit silicon DRAM is the stacked capacitor cell structure with 0.3-micron design rules. This structure is said to offer a two-fold increase in capacitance over the more conventional trench structure. A cell size of 1.7 μm^2 is projected for the 64-Mbit circuit while a 0.8-μm^2 cell size with a capacitance of 30 fF is projected for the next generation 256-Mbit DRAM chip.

Sharp's main thrusts into GaAs device research are aimed at developing advanced components for DSB, cellular telephone systems, high definition TV (HDTV), and fiber optic systems. Advanced HEMT devices were described that had noise figures of less than 0.6 dB and a gain of greater than 11 dB at 12 GHz. A developmental GaAs MMIC dual gate mixer was also described. Laser diode development is concentrating on 1.33-μm wavelength sources for fiber optic systems.

In summary, Sharp is yet another Japanese company that knows how to develop and transfer technology from the laboratory into production.

NEC Fundamental Research Laboratory at Tsukuba

This impressive basic research laboratory is new and yet construction has already started on doubling its size. Major research areas being addressed at this facility are microscience, bioelectronics, computational science, molecular electronics, and optoelectronics. Research is partitioned into three laboratories: the Exploratory Research Laboratory, which is responsible for microscience, bio-electronics, computational science, and new organic materials; the Advanced Device Laboratory, which is responsible for superconductor LSI, quantum devices, heterostructure devices, and mesoscopic phenomena; and the Semiconductor Laboratory, which is responsible for processing science, defect physics in semiconductors, synchrotron radiation lithography, and materials characterization.

In the area of advanced devices, work on a GaAs/Ge heterojunction bipolar transistor was described. In this device structure, the base region is MBE deposited germanium doped by gallium. Computer simulations project about a 300-GHz Fmax for this device. Theoretical studies are being performed on mesoscopic systems. The high field transport of electrons in 100-Å AlGaAs surrounded GaAs quantum wires was described. A niobium/oxide/niobium superconductor junction technology was described that has been used to fabricate 4-KB RAM circuits. The memory cell is a vortex transitional nondestructive read out (VT NDRO) structure. Access times of 580 ps with a power dissipation of 3 to 7 mW have been achieved.

In the area of optoelectronics, work was described on a new class of optical devices. A vertical-to-surface transmission electrophotonic device (VSTEP) was demonstrated that has the property of optical self-routing. This device exhibits optical bistability. Work was also described on solid state diode microlasers and surface emitting lasers. The emphasis of this work is upon achieving lower current thresholds for lasing on-set. Present threshold currents are in the 10- to 16-mA range.

In the area of processing science, work is centered upon in-situ processing of III-V compound semiconductor materials. NEC's approach is to use a hybrid MBE processing system that includes, in addition to the growth chamber, an analytical chamber for EBE, a RIBE for etching, and a FIBE for deposition.

Other materials growth and processing research efforts include two techniques for atomic layer epitaxy. One system is a hybrid VPE reactor while a second system uses metal organic CVD (MOCVD). Using the latter system, materials for resonant tunneling and delta doped GaAs FETs have been produced.

Sidewall epitaxy of III-V compound semiconductors is also being investigated for the formation of three-dimensional structures. Using this growth procedure silicon dioxide islands are deposited upon a GaAs semi-insulating substrate. A thick GaAs layer is then formed over the wafer by VPE. Next 0.6-μm columns of GaAs are etched out over the silicon dioxide islands. A conformal deposition of layers of InGaP/GaAs/InGaP is then made, creating a quantum well in the GaAs region.

Other processing research includes work being carried out at the two NEC beam lines at the Photon Factory--the SOR operated by a Japanese consortium. One beam line is used for x-ray lithography experiments while the other is used for material characterization. Semiconductor interface characterization of silicon/silicon dioxide and III-V heterostructures based on high resolution transmission electron microscopy (HRTEM) and Fourier transform infrared (FTIR) spectroscopy was also briefly described. This laboratory also has an NEC SX-2 supercomputer (with an upgrade to an SX-3 planned for 1991). Computational physics is being carried out in several areas using this machine. One area is the study of impurities and defects in semiconductors. In this area the following studies are being performed: diffusion, aggregation, and thermal donors in silicon; deep level trap centers in AlGaAs; transition metal impurities in ZnS; and mono and divacancies in silicon. In another computational physics area, surface and interface studies of silicon materials are being carried out with emphasis on mechanisms of oxidation and interface reconstruction. Finally, in the area of new material systems, computational studies are being performed on high temperature superconductors.

In the Exploratory Research Laboratory, work is ongoing on growth of diamond films. Silicon wafers treated with a fine diamond powder form the nucleation sites for epitaxial growth by CVD of polycrystalline islands on the silicon surface.

A final area of research described was that of bio-electronics. Research is being pursued in two areas. The first is in bio-information science dealing with the modeling of human brain processing and mechanisms. This work centers upon visual recognition systems and specifically the "four color problem." The second area deals with attempts to understand elemental neural functions. Nemitodes, because of their well known neural structure, are being used for this work.

In summary, activity at this laboratory spans a broad swath of science and technology from basic to somewhat applied research. Both device and nondevice research seem to be nicely balanced. The facilities and staff are impressive.

Optoelectronics Technology Research Laboratory (OTRL) at Tsukuba

This private sector laboratory is the scaled down remainder of the MITI-sponsored optical measurements and control system initiative (1980-86). Thirteen companies contributed to this research consortium under the auspices of MITI and NTT to pursue basic research in support of optical telecommunications by founding the Optoelectronics Technology Research Corporation (OTRC) in 1986. The OTRC consists of the OTRL, which we visited, and 13 branch laboratories located at member companies.

Work at OTRL now centers upon III-V material growth and characterization. In particular, atomic layer epitaxy and the characterization of surfaces and interfaces on the atomic level with scanning tunneling microscopy (STM) and HRTEM techniques were described. Further, OTRL is looking at options for next generation nanoscale processing where epitaxy and patterning are carried out without breaking vacuum. Focused ion beam (FIB) and e beam etching techniques are alternatives being investigated with e-beam etching causing negligible damage to the device.

Of general interest was the description of the mechanisms for technology sharing and transfer amongst the member organizations. An observation made by the laboratory's director was that very large MITI-sponsored consortia may be a way of the past in Japan. Significant funding for these ventures has typically been made available from the proceeds of NTT stock owned by the Japanese Government. As the Government sells its interest in NTT stock, funds available are likewise decreasing. Also, the budgets for MITI-sponsored consortia apparently do not include the salaries of the participating professionals, which continue to be paid by their own company so that the size of the effort is somewhat obscured.

CONCLUSIONS

This visit of U.S. Navy scientists and engineers allowed first hand observation of the quality and to some degree the depth of Japanese science and technology as it relates to electronics and optoelectronics. There can be no mistake that Japan will continue to play a dominant role in the development of electronic systems into the 21st century. It is clear that Japan is a major contributor and leader pushing back barriers along a broad front of electronics technologies. The major themes of smaller geometry devices and improved and/or new electronic materials development coincide with thrusts of the U.S. Navy's electronics R&D efforts at the Naval Research Laboratory in materials and nanoelectronics research. Expansion of the dialogue that has been opened with these companies by continued mutual visits and exchanges will not only be useful in hastening general scientific and technological developments but will also be most beneficial to the U.S. Navy.

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Appendix A

U.S. NAVY TEAM

Dr. Gerald M. Borsuk, Superintendent
Electronics Science and Technology Division
Naval Research Laboratory
Washington, DC

Dr. Sidney Teitler, Associate Superintendent
Electronics Science and Technology Division
Naval Research Laboratory
Washington, DC

Dr. Denis Webb, Chief, Microwave Technology Branch
Electronics Science and Technology Division
Naval Research Laboratory
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Dr. Joseph M. Killiany, Chief, Solid State Device Branch
Electronics Science and Technology Division
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Dr. Neal D. Wilsey, Chief, Electronic Materials Branch
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Dr. Yon Soo Park, Program Director
Electronics Department, Applied Research Directorate
Office of Naval Research
Washington, DC

Mr. James Cauffman, Director
Support Technology Directorate
Office of Naval Technology
Washington, DC

Dr. Ingham A.G. Mack, Program Director for Electronic Devices
Support Technology Directorate
Office of Naval Technology
Washington, DC

Appendix B

JAPANESE LABORATORIES VISITED

Dr. Takeo Utsumi, Deputy Director
Canon Research Laboratory

Dr. Takahiko Misugi
Director
Fujitsu Laboratories, Ltd.

Dr. Tetsuhiko Ikegami
Deputy Director
Functional Device and Development Division at Atsugi
NTT

Dr. Fujio Saito
Vice President
Fundamental Research Laboratory
NEC

Dr. Koichi Yashimi
Assistant General Manager
Central Research Laboratory
NEC

Dr. Takao Miyazaki
Central Research Laboratory
Hitachi

Dr. Y. Takeishi
Director
ULSI Research Center
Toshiba

Dr. Katsuzo Kaminishi
General Manager
Research Laboratory
Oki

Dr. Takeo Kajiwara
Director
Semiconductor Research Center
Matsushita

Dr. Koji Tada
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Basic High-Technology Laboratories
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Dr. Nobou Hashizume
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Central Research Laboratories
Sharp

Dr. Izou Hayashi
Director
Optoelectronics Technology Research Laboratory

JAPANESE RESEARCH ON THE MECHANICAL PROPERTIES OF MATERIALS AT HIGH TEMPERATURES

This article describes some of the current research activities in Japan on the mechanical properties of materials at high temperatures. Visits were undertaken to major educational centers where work is currently in progress in the areas of high temperature creep and superplasticity.

by Terence G. Langdon

INTRODUCTION

A one-semester sabbatical leave from the University of Southern California (USC) provided me with the opportunity to spend 5 months in Japan. Although I had made several previous visits to Japan, and we receive many Japanese visitors at USC, this was my first opportunity to stay in Japan for an extended length of time. I took this opportunity to undertake several visits to universities and institutes in an attempt to examine the current status of research in the high temperature mechanical properties of materials.

I based my visit on Kyushu University in Fukuoka, and then I travelled around Japan in an essentially counterclockwise direction. This article follows the same itinerary. The centers I selected to visit cover the major Japanese research activities in the areas of high temperature creep and superplasticity.

KYUSHU UNIVERSITY

Kyushu University was established in 1911 as one of the seven Imperial universities of Japan. It became a national university in 1947, and presently it has about 12,600 students and 4,700 faculty. The university is located in Fukuoka, the largest city of the Kyushu district. The university consists of four different campuses, and two of these campuses contain very active materials programs. The Hakozaki campus is located in the eastern ward of the city and it contains the newly named Department of Materials Science and Engineering (formerly known as the Department of Metallurgy). This department includes both undergraduate and graduate programs and a serious attempt is now being made to expand the program to include nonmetallic materials. The new Chikushi campus is located several kilometers south of the city center and it contains the Department of Materials Science and Technology within the Interdisciplinary Graduate School of Engineering Sciences. This is a graduate department with students undertaking M.S. and Ph.D. degrees.

The work of Professor Hideo Yoshinaga is conducted at the Chikushi campus and he is ably assisted by Associate Professor Hideharu Nakashima. This research is comprehensive in outlook, covering both metals and ceramics and using both mechanical testing procedures and extensive high resolution transmission electron microscopy.

In metals, Yoshinaga established a strong reputation for his early work on the deformation mechanisms in pure aluminum, and this work has now been expanded to include the effects of solution and dispersion hardening. In a series of classic experiments on a dispersion-strengthened Al-1.5 vol % Be alloy, Yoshinaga has established the presence of a threshold stress having a value approximately equal to the Orowan stress. At even lower stresses, plastic deformation is very slow and probably arises from grain boundary sliding and diffusional creep. In situ high voltage electron microscopy has shown that the interaction between dislocations and the Be particles is of the attractive type and no dislocation line is visible at the particle/matrix interface. The latter observation implies that the dislocation stress field is almost fully relaxed at the interface. Parallel experiments on a series of Al-Mg-Mn alloys have revealed threshold stresses that are very close to the calculated Orowan stresses.

Yoshinaga's work in ceramics has concentrated primarily on interface studies with SiC and Si_3N_4 and deformation mechanisms in TiC. Nonstoichiometry has an important influence in TiC due to the presence of vacant carbon sites, and the research has shown that the yield drop decreases in magnitude as the value of the C/Ti ratio decreases. A detailed investigation of steady-state deformation in TiC gave an activation energy about 0.75 of the value for lattice self-diffusion of Ti in TiC and stress exponents of about 7 at temperatures of 1,745 to 2,125 K and about 5 at 2,270 K. The observations were interpreted in terms of a network growth model and a transition from growth by pipe diffusion along the dislocation cores at the lower temperatures to lattice self-diffusion of Ti at the higher temperatures.

UNIVERSITY OF OSAKA PREFECTURE

The University of Osaka Prefecture is located in Sakai City, immediately adjoining and to the south of Osaka City. The university is located on a pleasant and fairly spacious campus, and facilities include a new and very modern conference center. Associate Professor Kenji Higashi recently transferred to the Department of Mechanical Engineering from the Department of Metallurgical Engineering and he is now very active, in part with Professor Shinji Tanimura, in a large research program on high strain rate deformation. Higashi speaks excellent English as he worked for some time in Dr. Norman Ridley's superplasticity group at the University of Manchester, England.

Higashi is undoubtedly at the forefront of university research in Japan designed to develop superplastic alloys where the superplastic effect occurs at high strain rates. This is a major objective in many laboratories at the present time because superplasticity will then occur at rates which are comparable with normal, and economically feasible, commercial forming operations. Higashi has recently introduced the term "positive exponent strain-rate superplasticity" to denote the occurrence of superplasticity at strain rates greater than 10^{0} s^{-1}. Procedures under investigation in Higashi's laboratory include powder metallurgical processing with rapidly solidified powders (PM) and mechanical alloying (MA) techniques. In MA, milling is used to produce metals with a submicron homogeneity. Higashi's results in this area are quite remarkable, with elongations of up to 750% at a strain rate of 2 s^{-1} in a commercial IN 9021 alloy. Composites are also under investigation based primarily on a 2124 Al matrix with 20% Si_3N_4 in particle or whisker form. The work on composites is a joint research program with Dr. Mamoru Mabuchi of the Government Industrial Research Institute in Nagoya.

OSAKA UNIVERSITY

Osaka University is another of the former Imperial universities with a long history of outstanding research in the field of materials science. The Department of Materials Science and Engineering is located at the Suita campus, to the north of central Osaka. Professor Shigenori Hori is well known for his detailed experiments in superplasticity and, following his recent retirement, this work is now being continued by Assistant Professor Norio Furushiro and his graduate students. Furushiro has an excellent background in superplasticity and, having spent a year in my research group several years ago, he speaks excellent English. He is also the Secretary General for the International Conference on Superplasticity in Advanced Materials (ICSAM-91), to be held in Osaka in June 1991.

Furushiro has recently investigated the effect on superplasticity of varying the amount of Zr in the PM 7475 Al alloy. By testing alloys with 0 to 0.9 wt. % Zr, he has shown that good superplastic properties are achieved at reasonably high strain rates ($>10^{-1}$ s^{-1}) with alloys having 0.7 and 0.9 wt. % of zirconium. In a 7475 Al alloy with 0.9% Zr, Furushiro obtained a maximum elongation of 900% at a strain rate of 3.3×10^{-1} s^{-1}.

GOVERNMENT INDUSTRIAL RESEARCH INSTITUTE, NAGOYA

It was a great pleasure for me to visit the Government Industrial Research Institute (GIRI) in Nagoya. GIRI Nagoya has become famous in superplasticity circles because of the pioneering work of Dr. Fumihiro Wakai of the Ceramic Science Department in first reporting, and subsequently investigating in some detail, the occurrence of superplastic deformation in ceramics. On 5 July 1985, a news report appeared on the front page of *Asahi Shimbun*, the leading national newspaper of Japan, describing Wakai's success in achieving a tensile elongation of >100% in an yttria-stabilized tetragonal zirconia (Y-TZP). This first report of tensile superplasticity in a ceramic was followed later by reports of superplasticity in a ZrO_2/Al_2O_3 composite, hydroxyapatite (a biomaterial), and a covalent composite (Si_3N_4/SiC).

GIRI Nagoya is a national institute administered by the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry (MITI). It was established in Nagoya in 1952 and the experimental facilities are impressive. It is remarkably strong in the areas of ceramic processing and testing. The institute is open to guest researchers from overseas, and Wakai has had visiting scientists from Europe (but not, I believe, from the United States); Dr. Tanguy Rouxel from France was working in his group when I visited. International cooperation is encouraged at GIRI Nagoya, and Dr. Nobuyuki Azuma is the Chief for International Research and Development.

Wakai's group continues to lead the world in research activities in superplastic ceramics. However, progress may be held up slightly this fiscal year (1991/2) as Wakai is taking a 1-year leave of absence to perform administrative duties with MITI in Tokyo. Wakai's current research interests include the superplastic deformation of various ceramics and the role of intergranular liquid phases, and also other areas such as internal friction experiments and measurements of elastic properties. There are also several other related activities at GIRI Nagoya, including the superplasticity of Si_3O_4 whisker-reinforced aluminum alloys by Drs. Tsunemichi Imai and Mamoru Mabuchi of the Mechanical Engineering Division.

YOKOHAMA NATIONAL UNIVERSITY

Yokohama National University occupies a reasonably spacious campus in the port city of Yokohama. Professor Takao Endo is a member of the Department of Mechanical Engineering and Materials Science and he is well known for his research on high temperature deformation. He also speaks good English, having spent 6 months in my research group at USC.

Endo's recent work has been concentrated in the two areas of superplasticity and high temperature fatigue. In superplasticity, he has investigated the significance of dynamic recrystallization in the 7475 aluminum alloy. In high temperature fatigue, in experiments conducted with Associate Professor Hiroshi Fukutomi, his research has followed our earlier experiments at USC where we demonstrated an essentially one-to-one correlation in Al and Pb between the migration markings of grain boundaries and the number of cycles imposed on the samples. In experiments on aluminum at 700 K and with a frequency of 0.001 Hz, Endo has demonstrated that the occurrence of grain boundary sliding and migration takes place in an alternating manner. Whereas our earlier experiments at USC were conducted primarily in simple reverse bending fatigue, Endo has now extended the experimental procedure to include tests in tension-tension and tension-compression. Using these procedures, he has shown, in an elegant manner, that stepped surface markings are formed by a tension-tension stress but convex or concave markings are formed by a tension-compression stress. These observations demonstrate that grain boundary sliding occurs in opposite directions under tension and compression, and they are therefore consistent with the tentative model we presented a few years ago to explain the occurrence of cyclic boundary markings.

UNIVERSITY OF TOKYO

As the premier center of learning in Japan, the University of Tokyo needs little introduction in these pages. The university includes various associated centers and institutes scattered throughout Tokyo, but I visited the main campus in Bunkyo-ku.

The first metallurgical department in Japan was established at the University of Tokyo in 1877. In 1976, the metallurgical department was split into two parts: the Department of Metallurgy and the Department of Materials Science. Each department contains six divisions, which means in effect that there is a total of 12 possible professorships. To the outsider, the distinction between the two departments is not clear cut; however, the Department of Metallurgy tends to contain the chemical and processing aspects of metals whereas the Department of Materials Science covers essentially the solid state approach to both metals and nonmetals. The two departments have an impressive educational and research budget of about ¥350M (in fiscal year 1990), *excluding* salaries, overhead, and utilities.

I met with Professor Taketo Sakuma of the Department of Materials Science. Sakuma is responsible for ceramic materials and he has established a strong reputation for his careful experiments on microstructural evolution and superplasticity in oxide ceramics. His English is excellent as he worked for 1 year at the University of Cambridge, England. It is now known that the presence of thin grain boundary glassy phases is important in superplastic ceramics, and Sakuma has conducted critical experiments on tetragonal zirconia by adding small amounts of alumino-silicate glass, alumino-lithium-silicate glass, and beta-spodumene glass. Sakuma's research is fundamental in nature and is designed to elucidate the mechanism for the reduction in the superplastic deformation temperature due to the glass addition, but clearly the research has a considerable potential for practical applications in the area of ceramic forming processes.

TOKYO UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

Tokyo University of Agriculture and Technology is located on two separate campuses several kilometers to the west of the Shinjuku railway station in western Tokyo. I visited the campus of the Faculty of Engineering, located in Koganei City.

For many years, Professor Tadashi Hasegawa of the Department of Mechanical Engineering has maintained a good reputation for his significant experiments and insightful interpretations in the areas of deformation and fracture. Hasegawa speaks excellent English and has worked in both the United States (with Dr. U.F. Kocks at the Argonne National Laboratory) and in Germany (with Professor B. Ilschner at the University of Erlangen-Nürnberg). Although Hasegawa has essentially represented research in mechanical properties single-handedly in his department for many years, the situation will now change with the recent appointment of Dr. Tohru Takahashi as Assistant Professor; Takahashi is a former member of Professor Oikawa's group at Tohoku University.

Hasegawa's current research is concerned primarily with the deformation and fracture of mechanically alloyed aluminum alloys and the mechanisms of particle dispersion strengthening of Cu-1 vol % SiO_2 and Cu-1 vol % Al_2O_3. There are also related programs on high temperature crack tip deformation and crack growth in heat-resistant steels and the cutting processes and mechanisms of tool wear associated with ceramic-particle reinforced aluminum composites. Takahashi performed extensive research on the creep behavior of TiAl intermetallics during his time with Oikawa at Tohoku University, and there is a plan to continue this work at Tokyo University of Agriculture and Technology.

TOHOKU UNIVERSITY

Another former Imperial university, Tohoku University was founded in 1907 and is now one of the most distinguished universities in Japan. It is also famous for its very strong research activities in materials science. The university is located in the city of Sendai in the Tohoku district of northern Japan, and it is significant to note that Sendai is also the headquarters of the Japan Institute of Metals. The university has several campuses, of which the Katahira campus near the city center is the home of the Institute for Materials Research and the Aobayama campus on a hill to the west of the city is the home of the Faculty of Engineering.

I visited the Aobayama campus to speak with Professor Hiroshi Oikawa of the Department of Materials Science. Oikawa is in charge of the Structural Materials Group, and he is assisted in this task by Associate Professor Kouichi Maruyama. This research group is famous for its outstanding contribution to our knowledge of high temperature creep during the period when Professor Seiichi Karashima was in charge. Oikawa has continued in that direction since Karashima's retirement, looking especially at the creep deformation of h.c.p. (Mg-Al) and f.c.c. (Al-Mg) alloys and intermetallics (the Ti-Al system). Oikawa is also very well known in the United States because of his frequent presentations at U.S. and international conferences.

Maruyama and Oikawa have now made significant progress in examining and refining the so-called θ-projection method for the prediction of long-term creep curves. Based on a modified θ-projection concept that they have developed, they claim the successful prediction of long-term creep curves for CrMoV ferritic steels up to almost the point of rupture. They are now examining the physical basis for the constitutive equation used in the prediction. Clearly, this type of approach is important because structural components are often in service for more than 10^5 hours and this time scale far exceeds the practical limit for useful laboratory testing.

An additional member of the group, Dr. Tadao Watanabe, has established a worldwide reputation for his careful experimentation on grain boundary effects and especially his concept of "grain boundary design." Watanabe is well known in the West because of his frequent contributions at international meetings, and his English is perfect as a result of spending a period, many years ago, as a postdoctoral worker in the University College of Swansea, Wales. The concept of grain boundary design concerns controlling the grain boundary character distribution in order to control or even suppress the occurrence of intergranular fracture. This concept is indeed intriguing, and Watanabe has gone some way toward examining the potential for using this concept to control structure-dependent intergranular fracture and the related brittleness. There seems little doubt that grain boundary design will become an increasingly important concept in the future development of advanced structural materials.

TOYAMA UNIVERSITY

Toyama University was established in its present form in 1949 and is now located on a fairly new campus near the center of Toyama City. I visited Associate Professor Kenji Matsuki, who is working, in part with Professor Mitsugu Tokizawa, on the superplasticity of rapidly solidified aluminum-based alloys. This research is conducted within the Department of Mechanical Engineering for Production.

Matsuki's recent research has concentrated on the PM 7475 Al-0.7 wt. % Zr alloy. This material exhibits superplasticity at reasonably high strain rates, and Matsuki and his colleagues have performed very careful experiments in which they measured the changes in sub-boundary misorientations as a function of strain. Their experiments show that grain boundary sliding can occur on sub-boundaries with misorientations of only 5° to 15° (as demonstrated also in recent work by Dr. Terry McNelley at the Naval Postgraduate School in Monterey) but, since superplasticity was not observed at low strain rates, they speculate that a critical stress is required for sliding on the sub-boundaries with low misorientations. This suggestion leads to a markedly novel view of superplasticity in this alloy and clearly it requires a very critical examination.

CONCLUDING REMARKS

My travels through Japan demonstrated the breadth and vitality of materials science research in the areas of high temperature creep and superplasticity. Although some aspects of this work are well known in the West, such as Wakai's first demonstration of superplasticity in ceramics, there remain many centers of activity where important research is currently in progress. Close interactions with Japanese materials scientists, and especially regular visits to Japan, will do much to ensure that this work becomes publicized, and therefore effectively utilized, without the inevitable lengthy delays associated with scientific publications (and possibly translations into English also).

Finally, I must express my gratitude to Professors Hideo Yoshinaga and Minoru Nemoto and Associate Professor Zenji Horita for their exceptional hospitality during my stay at Kyushu University. Without their help and encouragement, it would have been difficult to travel so easily and to make such extensive arrangements.

Terence G. Langdon is Professor of Materials Science, Mechanical Engineering and Geological Sciences at the University of Southern California (USC) in Los Angeles. He received a B.Sc. degree in physics from the University of Bristol in 1961 and a Ph.D. degree in physical metallurgy from Imperial College, University of London, in 1965. Following appointments at UC Berkeley, the University of Cambridge, and the University of British Columbia, he joined USC in 1971 and was promoted to Professor in 1976. He served as Chairman of the Department of Materials Science in 1988-90. His current research interests are primarily in the areas of high temperature deformation and superplasticity, including both metals and ceramics. He was awarded a D.Sc. degree by the University of Bristol in 1980 for his research on the mechanical properties of materials.

THE FIFTH U.S.-JAPAN SEMINAR ON DIELECTRIC AND PIEZOELECTRIC CERAMICS

This article summarizes observations and opinions of many of the participants of the Fifth U.S.-Japan Seminar on Dielectric and Piezoelectric Ceramics as to the most significant developments within the topic areas of dielectric ceramics and applications, reliability of multilayer capacitors, materials processing, piezoelectric and electrostrictive ceramics and applications, actuators and motors, mechanical properties, and dielectric and ferroelectric thin films.

by S.W. Freiman, M.F. Kahn, W.A. Smith, and R.C. Pohanka

INTRODUCTION

Dielectric and piezoelectric materials are critical to a large number of electronic systems and devices. Extensive research and development (R&D) of such materials has been and continues to be carried out in both the United States and Japan. The U.S.-Japan Seminar Series on this topic was launched in 1982 to facilitate the exchange of information on these important topics. The format was developed to maximize opportunities for one-on-one exchanges between researchers in the two countries. Visits to key industries and universities have also been an integral part of the series.

The Fifth U.S.-Japan Seminar was held from 11-14 December 1990 in Kyoto, Japan. The major topic areas addressed in the seminar itself can be broken down as follows: dielectric ceramics and applications; reliability of multilayer capacitors (MLCs); materials processing; piezoelectric and electrostrictive ceramics and applications; actuators and motors; mechanical properties; and dielectric and ferroelectric thin films. This article summarizes observations and opinions of many of the participants (both U.S. and Japanese) as to the most significant developments within each of these topic areas. Also, many of the U.S. attendees visited Japanese industrial and university laboratories before and after the workshop; the insights gained from these visits are also reflected in this article.

DIELECTRIC CERAMICS AND APPLICATIONS

Research and development on dielectrics now appears to be primarily focused on the following three areas: (1) lead-based, primarily relaxor, dielectrics; (2) barium titanate (degradation of nickel electrodes and new processing procedures); and (3) novel materials.

Research on lead-based, relaxor dielectrics (e.g., lead magnesium niobate) shows progress in two areas: fundamental theory (primarily in the United States) and product development (primarily from Japan). Relaxor materials are important because of their high dielectric constants relative to barium titanate. Professor L.E. Cross (Pennsylvania State Univ.) presented work that described the fundamental physical picture of the ferroelectric processes in relaxor ceramics. This work showed that the dielectric properties of relaxors can be described in terms of the kinetics of the polarization fluctuations. The results showed evidence for a static freezing temperature, as in a magnetic spin glass, which agreed with the temperature at which a stable remanent polarization would be induced.

Extensive experimental work on relaxor ceramics is being carried out by Japanese investigators. For example, Dr. A. Ochi (NEC Corp., Kawasaki, Japan) demonstrated a relaxor in multilayer form (layer thicknesses approximately 10 μm) with a specific capacitance of 495 $\mu F/cm^3$, which was larger than that of currently used aluminum electrolytic capacitors which are six times its volume. This material was shown to be able to replace the larger capacitors in applications such as filtering in switching mode power supplies. Dr. O. Furukawa et al. (Toshiba Corp., Kawasaki, Japan) reported a new low loss (<0.1% at 100 kHz) composition (a strontium and/or titanium modification of lead zinc niobate) made by a solid state reaction for high voltage applications.

Work on barium titanate showed progress toward the development of processes that permit the use of base metal (lower cost) electrodes and new routes that would permit the use of copper electrodes. Dr. H. Chazono et al. (Taiyo Yuden Co., Gunma, Japan) reported progress on developing a process that permitted the use of low cost nickel electrodes for both inner and terminal electrodes. The material can be densified at 1,200 °C in a nitrogen-hydrogen atmosphere. MgO was added to control oxidation, and Li_2O-SiO_2-CaO glass was added to aid densification. The resulting multilayer dielectric capacitor meets X7R requirements and could result in a commercial product. Burn et al. (DuPont) reported significant progress in developing high frequency multilayer capacitors with copper electrodes. The material consisted of a mixture of magnesium titanate, calcium titanate, and barium aluminoborate flux, which was fired at approximately 1,000 °C.

New material approaches for dielectrics were presented by G. Love (Alcoa) and H. Igarashi et al. (National Defense Academy, Yokosuka, Japan). Love reported an analysis suggesting that SiC should receive careful consideration for advanced dielectric packaging materials due to its high strength, excellent thermal expansion, good thermal conductivity, and high dielectric constant (for power and ground decoupling). Igarashi reported on attempts to develop new multilayer dielectrics in which the chemistry was varied for each alternating layer. The work shows promise for reducing the temperature dependence of the dielectric constant. Clearly, such an approach gives an extra degree of freedom in tailoring properties.

RELIABILITY

The papers in this area were almost exclusively U.S. presentations by capacitor manufacturers and were phenomenological in nature, with little discussion of the underlying causes of the reliability problems. Work on reliability-test development seems to be increasing in the United States. Evidence of the use of process control as a means of ensuring reliability was observed in the production of PZT resonators at NGK Sparkplug, in which computer feedback of polarization data is used to modify properties in order to meet specifications.

Thermal stress failures of capacitors continue to be a problem, particularly with respect to wave soldering of surface-mount devices. However, there is no evidence to suggest that extensive research into the solution of this problem is going on in either the United States or Japan.

PROCESSING OF ELECTRONIC CERAMICS

Professor S. Hirano (Nagoya Univ., Nagoya, Japan) presented an excellent overview of the field of chemical processing. Chemical processing of electronic ceramics is an important research topic in both the United States and Japan. Hirano's paper illustrated the potential for this approach in the development of hybrid materials, preparation of very pure materials, processing of unique microstructures, and new routes to make ferroelectric materials in fibrous form. A significant development reported by Hirano was the production of grain-oriented, stoichiometric and Ti-doped $LiNbO_3$ for guided optics by a sol-gel technique. This approach could lead to a more economical method for producing advanced optical materials.

A significant development in the processing of dielectric powders was reported by Swanson et al. (DuPont). Their process was shown to create uniform, fine particles and to permit coating of the particles with metal oxides and glass. These new powders were shown to lead to increased densification and presumably improved device reliability.

A.S. Bhalla et al. (Pennsylvania State Univ.) and S.C. Choi et al. (Univ. of Tokyo, Tokyo, Japan), in collaboration with D. Payne (Univ. of Illinois), presented papers on making ferroelectric fibers ($Sr_xBa_{1-x}NB_2O_6$ and PZT, respectively). Such work could provide the basis for new optical and electronic composites.

PIEZOELECTRIC AND ELECTROSTRICTIVE CERAMICS

Papers by H. Takeuchi et al. and H. Masuzawa et al. (Hitachi Ltd., Tokyo, Japan) described innovative work on electrostrictive ceramics as well as an imaginative application in acoustics. Electrostrictive ceramics [$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$] were prepared as high strain actuators. Details of the synthesis were not presented, but the properties measured were indeed impressive. These materials distort quadratically with an applied electric field. The bias field converts the electrostrictor into a piezoelectric whose properties can be tuned from nonpiezoelectrically active at zero bias to an excellent electromechanical energy converter near biases of 5 kV/cm. The electrical measurements reveal dielectric constants in the 10,000 to 20,000 range. However, loss tangents up to 12% must be reduced to reach the values of conventional piezoelectrics. Electromechanical coupling approaches 80% of that achievable in PZT.

Masuzawa et al. applied the above materials in an imaginative way to fabricate an ultrasonic probe with dynamic aperture control. Plates of the electrostrictive ceramics were fabricated into a 1-3 composite structure by the usual dice-and-fill technique. Linear array transducers were patterned on the composite plate. By applying a bias field to the entire plate a wide aperture acoustic beam can be formed and focused far from the transducer. To focus closer to the transducer a smaller portion of the plate is made piezoelectrically active by applying a bias field. This work points towards a broader class of acoustic devices whose properties can be dynamically adjusted by the appropriate application of an electric bias field.

The work reported in this session also showed substantial progress in the development of other piezoelectric composites. B.A. Auld et al. (Stanford Univ.), H. Banno et al. (NTK Technical Ceramics, Nagoya, Japan). and W.A. Smith (Office of Naval Research) presented papers on modeling of composites. These models now allow for a complete understanding of the static electroelastic properties of such composites and provide new approaches to tailoring dynamic behavior through the amount, type, and distribution of constituents.

Another significant development was reported by K. Sakata et al. (Univ. of Tokyo, Tokyo, Japan), who showed that non-lead-containing materials [$(Bi_{0.5}Na_{0.5})TiO_3$] and lead titanate modifications of these materials had properties of interest for piezoelectric actuators. The materials were shown to be amenable to tape casting and had high strength as well as good electroelastic properties (e.g., k_{33} = 0.56, k_t = 0.51, E = 40). The absence of lead may be important if there is a need to meet OSHA requirements.

ACTUATORS AND MOTORS

There did not appear to be as much emphasis by the Japanese participants on actuators and motors as in previous years. However, Professor K. Uchino (Sophia Univ., Tokyo, Japan) continues to develop very interesting and innovative devices. Uchino has developed close working relationships with a number of Japanese companies, which enables him to get his ideas into production quite rapidly. He discussed two types of unimorph structures based on barium titanate and PZT. Uchino displayed a number of other piezoelectric actuator and motor applications that are already in production. He briefly discussed the development of "smart" actuators, which include position sensors. He is looking at the development of acoustic emission sensors for prediction of electrical and mechanical breakdown of actuators.

In a visit to NEC Corp., Dr. A. Ochi discussed the development of a multilayer, tape-cast, PZT actuator for use in a dot impact printer head. It was suggested that this actuator provided better reliability than an electromagnetic head. However, Ochi did state that there were still problems associated with electrostrictive materials in this application. Nonetheless, no mechanical failures of the device were observed even after 500 million pulses. Such work demonstrates that piezoelectric materials can be used reliably in actuators.

There were papers presented at the workshop by researchers from the University of Tokyo (Tokyo, Japan), Nippon Steel (Kawasaki, Japan), and Hitachi (Tokyo, Japan) that discussed the use of lead zinc niobate and lead magnesium niobate as actuator materials. Emphasis was placed on obtaining chemical compositions which lead to optimum electrostrictive properties. There was no evidence of problems with mechanical failure of such devices.

Both H. Shimizu and T. Yoshida (Tokin Corp., Miyagi, Japan) and J. Toyoda and K. Murano (Sony Corp., Tokyo, Japan) demonstrated piezoelectric motors at the workshop. There was obviously a great deal of thought that went into the design of these motors.

MECHANICAL PROPERTIES

It was clear from this seminar that the desire for a basic understanding of mechanical failure in brittle materials such as dielectrics and piezoelectrics has increased during the period over which these workshops have been held. There now is a greater interest on the part of both U.S. and Japanese scientists to describe the fracture mechanisms in addition to using already existing fracture models for engineering purposes.

Based upon discussions at the workshop as well as a visit to NGK Sparkplug, there appears to be a growing interest in both the United States and Japan in cyclic fatigue. NGK is developing a cyclic loading test system that they intend to market. S.W. Freiman (National Institute of Standards and Technology) reported cyclic fatigue data on PZT that suggest that quite complex failure mechanisms can come into play, which would not be necessarily predicted from static testing. Fatigue under cyclic loading will affect the conditions under which high power transducers and actuators can be operated.

Papers presented at this meeting by both U.S. and Japanese researchers indicate that there is still considerable uncertainty and controversy over the meaning of the term "internal stress" as it applies to piezoelectric materials. In general, this term refers to the microstresses produced by ferroelectric phase transitions. However, the correct measurement procedures are still being developed. This topic is important because these "internal stresses" will be the driving force for aging phenomena in dielectrics and piezoelectrics, as well as contributing to fracture. An excellent microstructure modeling study reported by Kurtz (Pennsylvania State Univ.) may help to elucidate some of these problems.

There were continuing discussions over the intrinsic resistance of relaxor materials such as lead magnesium niobate (PMN) to fracture. Direct measurements of the fracture toughness of PMN indicate that it is no weaker than other dielectrics, but there is still a reluctance of U.S. capacitor manufacturers to use it, despite its wide acceptance as a dielectric material in Japan. As an example of problems experienced with the use of relaxors, Ling (AT&T Bell Labs) reported that the dielectric breakdown strength of relaxor capacitors (K = 14,000 to 16,000) was smaller than that for barium titanate (K = 4,800 to 7,700). Based upon work reported at a previous U.S.-Japan seminar, smaller breakdown strengths suggest the presence of flaws, which would also lead to lower mechanical strengths.

Finally, the mechanical properties (e.g., adhesion, fracture toughness, residual stresses) of thin films will become an increasingly important research topic with the development of ferroelectric and electrooptic films. While there does not currently seem to be a large research effort in either Japan or the United States in this area, most of the participants believed that work in this area will increase significantly in the near future.

FERROELECTRIC THIN FILMS

J. Scott (Univ. of Colorado) reviewed the status and potential for thin film ferroelectric memories. He noted the problems in the compatibility of ferroelectric thin film processing with Si/GaAs devices and discussed the fact that fatigue of these materials with time can be a significant factor. The field, however, is growing rapidly; Scott suggested that by 1992 half of the EPROMS would consist of ferroelectric switches.

There were a number of interesting papers presented by both U.S. and Japanese researchers in this field. For example, the Japanese papers on ferroelectric thin films went beyond the usual sputtering and sol-gel growth methods to focus attention on innovative synthesis routes, e.g., a hydrothermal electrochemical technique and a photo-MOCVD (metalorganic chemical vapor deposition) approach.

Researchers from Murata Manufacturing Company and the Tokyo Institute of Technology collaborated to form high quality $SrTiO_3$ and $CaTiO_3$ films at temperatures in the range of 100 to 250 °C. During film growth, a thin titanium-metal layer is immersed in a $Sr(OH)_2$ or $Ca(OH)_2$ solution in a pressure vessel; an electrical current from a platinum electrode in the solution to the titanium layer converts the metal into the desired oxide. The very low growth temperatures are an important feature since they suggest a route for incorporating these films into semiconductor devices. Smooth, pinhole-free films with high resistivity (10^8 to 10^{10} ohm-cm), low dissipation (3% to 6%), and substantial dielectric constants (80 to 150) were produced. The titanate family contains a rich collection of properties that could be exploited in passive capacitors, switchable capacitors, and electrooptic applications.

A paper by M. Shimizu (Kyoto University, Kyoto, Japan) reported on films grown on both MgO and Si substrates in the temperature range 550 to 700 °C. Illumination from a Xe-Hg lamp enhanced the MOCVD deposition rate of pinhole-free films on silicon and reduced the growth temperature into the practical range for ferroelectric/semiconductor integration. Electrical characterization showed hysteresis loops, moderate loss tangents (3% to 19%), and appreciable dielectric constants (155 to 290). The precise role of the illumination has not been delineated, although photocatalysis and surface energy deposition are possible explanations for the growth enhancement achieved.

Other interesting developments were reported by researchers from RAMTRON, Pennsylvania State Univ., North Carolina State Univ., the Univ. of Arizona, Kyocera, and Matsushita.

OBSERVATIONS AND TRENDS

In this section we compare observations of the significant results of this meeting to those at the previous seminars in order to establish trends in the science and technology.

- The first and most obvious observation is the large increase in R&D involving ferroelectric thin films that has occurred in both the United States and Japan over just the past 2 to 3 years. The increase in the United States is primarily due to an interest in ferroelectric films for nonvolatile memory (computer) and sensing applications. In Japan, a wider range of uses is under consideration, including high permittivity DRAMS and piezoelectric applications. It is our perception that the United States and Japan are at approximately equal positions vis-a-vis both basic research as well as the development of devices based on ferroelectric films.

- One particularly significant development in the area of ferroelectric films is the work reported jointly by Murata and the Tokyo Institute of Technology on the innovative electrochemical/hydrothermal processing of double oxides. This work suggests low temperature routes for incorporating ferroelectric oxides into semiconducting devices.

- While the United States continues to lead in the understanding of the ferroelectric nature of relaxor materials, the development of relaxor ceramics for MLCs is now being carried out exclusively in Japan. The reluctance of U.S. manufacturers to market these devices seems to stem both from their inability to improve the reliability of the capacitors, which seem to have a greater susceptibility to thermal shock and dielectric breakdown, as well as concern over OSHA requirements on lead. The extensive R&D effort in Japan on lead-based, relaxor materials is one of the factors that contributes to their domination of the capacitor business.

- Companies in both the United States and Japan are continuing to develop capacitors made from non-lead-containing, titanate-based materials as well as exploring piezoelectric applications of these materials. Such ceramics are currently competitive with the lead-based materials and have the added benefit of possibly meeting projected OSHA requirements.

- The trend toward reducing the thickness of the dielectric layer in MLCs continues; minimum layer thicknesses now approach 5 to 7 μm. This work is divided fairly equally between the United States and Japan. Vapor processes are now being considered as a means of producing the thin dielectric layers.

- Piezoelectric composites, which were in their infancy at the first U.S.-Japan seminar, have progressed to the point where manufacturing is now being done. Applications include transducers for medical ultrasonics and hydrostatic sensors.

- Piezoelectric motors are being pursued in Japan for many applications. There is virtually no comparable work going on in the United States, although a number of U.S. companies are pursuing the development of piezoelectric/electrostrictive actuators.

- Less work on microwave materials was reported by both the United States and Japan than in previous years. It is not clear, however, whether this reflects less R&D or simply a different priority in the choice of topics for the meeting.

Stephen Freiman received a B.ChE. and an M.S. in metallurgy from the Georgia Institute of Technology and a Ph.D. in materials science and engineering from the University of Florida. Before joining the National Institute of Standards and Technology (NIST) (then the National Bureau of Standards) in 1978, Dr. Freiman worked at the IIT Research Institute and the Naval Research Laboratory. Dr. Freiman is currently Group Leader of the Electronic Materials Group in the Ceramics Division at NIST. He is a Fellow of the American Ceramic Society. For a number of years, Dr. Freiman's research interests have been focused on the mechanical reliability of electronic ceramics.

Manfred Kahn received a BSEE degree from the University of Wisconsin, a MSEE degree from Rensselaer Polytechnic Institute, and a Ph.D. in ceramic science from Pennsylvania State University. Dr. Kahn worked for 20 years at Sprague Electric Company and for 8 years at AVX Ceramics in the electronic ceramics area. For 1 year he taught electrical engineering. Since 1983 he has been in charge of the Electronic Section in the Ceramics Branch of the Material Science and Technology Division of the Naval Research Laboratory in Washington, DC. Dr. Kahn is a Fellow of the American Ceramic Society. His current research interests include composites made from electronic ceramics.

Wallace Arden Smith earned a B.A. in physics at Rutgers University in 1964 and completed his formal education in 1970 with a Ph.D. in physics from Princeton University. In 1987 Dr. Smith joined the Office of Naval Research, where he currently serves as a Scientific Officer with responsibilities spanning electronic and optical materials for acoustic transducers, electronics, electro-optics, radar absorbing, and electronic packaging, as well as high temperature superconducting ceramics; his personal research focuses on modeling of acoustic materials and devices. From 1975 to 1987, Dr. Smith was with Philips Laboratories, where he led research teams working on pyroelectric materials for infrared imaging devices and piezoelectric materials for medical ultrasonic and naval transducers, as well as related tasks in medical imaging. Dr. Smith held research and teaching appointments in the physics departments of New York University and The City University of New York from 1969 to 1975; his research then concentrated on laser physics and hydrodynamic instabilities.

Robert Pohanka received a B.S. and an M.S. degree from Michigan Technological University. He received a Ph.D. in solid state science from Pennsylvania State University in 1972. From 1972 until 1978, Dr. Pohanka was employed at the Naval Research Laboratory. He joined the Office of Naval Research in 197[illegible], where he is currently the Director of the Materials Division.

POLYMER 91, POLYMER MATERIALS: PREPARATION, CHARACTERIZATION, AND PROPERTIES

This article concerns POLYMER 91, an International Symposium on Polymers, held in Melbourne, Australia; highlights of general interest and of specific interest to workers in the field of polymers for technology are presented.

by Kenneth J. Wynne

INTRODUCTION

The 1991 Polymer Symposium "POLYMER 91," sponsored by the International Union of Pure and Applied Chemistry (IUPAC), is the second International Symposium on Polymers sponsored by the IUPAC in Australia, the other being POLYMER 85. POLYMER 91 was held from 10-14 February 1990 at Monash University, which is about 20 miles east of Melbourne. POLYMER 91 was also sponsored by the Australian Academy of Technological Sciences and Engineering and was organized by the Royal Australian Chemical Institute (RACI). Professor James O'Donnell, Department of Chemistry, University of Queensland, was chairman of the Organizing Committee for POLYMER 91.

A book of preprints of papers is available from the Polymer Division, RACI, through Professor O'Donnell's office. According to Professor O'Donnell's introduction in this volume, "POLYMER 91 is the largest conference on polymer science to be held in Australia. There are 200 papers, 100 posters, and 400 participants." There were 14 different countries represented in the invited lectures; of the participants, about 140 were from overseas. Unfortunately, a few of the overseas participants, including a half a dozen or so of the 48 invited lecturers, canceled out at the last moment due to concern about travel during the war in the Middle East. This problem was solved in some instances by additional lectures from invited speakers.

Because of the scope and interest in this meeting, there were three parallel sessions underway at any one time. This article presents selected highlights of general interest and of specific interest to workers in the field of polymers for technology.

IUPAC SEMINAR: FUTURE DIRECTIONS

Professor Walter Heitz, Phillipps University, Marburg, gave an overview of the progress in the field of polymer science. He noted the enormous growth in the field, world capacity having risen from 1.6 million tons in 1950 to 86 million tons in 1988. Commodity polymers such as polyethylene, polypropylene, polystyrene, and polyvinylchloride account for about 90% of this total. The remainder is made up of engineering plastics (e.g., polycarbonates) and high performance polymers [e.g., poly ether ether ketone (PEEK)]. Professor James Economy (University of Illinois) reviewed developments and trends in structural polymers, while Professor James Feast commented on trends in education in polymer science.

Considerable discussion ensued on the topic of polymer recycling. Various opinions were expressed concerning the efficacy of efforts in this direction. It was pointed out that polymeric materials use only about 8% of current consumption of oil. Some attendees argued whether there was really a net gain in conservation of energy for the recycling process, considering processing costs and transportation. Many argued for the concept on the grounds polymers should not be left out of the framework of conservation of resources, including metals, paper, glass, etc.

In the context of recycling, an interesting paper was given later in the symposium by Professor E.B. Nauman, Rensselaer Polytechnic Institute. This paper described a solvent-based process that relies on the same thermodynamic differences between polymers that lead to incompatibilities in multicomponent polymer melts. The process involves exposing polymer mixtures to solvent at successively higher temperatures. Remarkably, experiments on "virgin" polymer mixtures demonstrated *quantitative* separations using xylene as a solvent at the temperatures shown below:

Dissolution Temperature (°C)	Polymer Dissolved
25	Polystyrene
75	Low density polyethylene
105	High density polyethylene
120	Polypropylene
138	Polyvinylchloride
Not dissolved	Polyethylene terephthalate

This led to experiments using commercial grade xylene to separate common polymers that occur in "New Jersey curbside tailings," which sounds better than "real trash." The above polymers were separated readily using the same batch dissolution sequence. Solvent was recycled in the process by flashing from the dilute polymer solutions.

Total product cost including overhead, depreciation of equipment, and contingencies (but excluding profit) was estimated at $0.20 per pound. Virgin polymer prices are in the range of $0.40 to $0.70 per pound. This is a clever feasibility study, the results of which are encouraging to those concerned with resource management and environmental quality.

ELECTRONICALLY CONDUCTING POLYMERS

Opening Lecture

Professor James Feast, Durham University, gave the opening lecture in place of the scheduled speaker. He reviewed the status of the field including:

- Original work of Natta, 1958 (Nobel Prize in Chemistry), which led to the preparation of polyacetylene (PA) powder (air sensitive, not processable).
- Interfacial polymerization (Shirakawa, 1974), which produced PA films (stable for short exposure to air).
- Partial oxidation of PA (Shirakawa, MacDiarmid, and Heeger, 1976) to give highly conducting films.
- Preparation of "Durham PA" (1980) from a soluble, processable precursor.
- Current work on PA (collaborative Durham/Cambridge effort), which has documented strong χ^3 effects [value parallel to extension (chain) direction, 2.7×10^{-8} esu; perpendicular, order of magnitude less].
- Reactivity of PA utilized to lithographically pattern thin films.

Molecular Recognition

Professor P.R. Teasdale, Department of Chemistry, University of Wollongong, described his approach to molecular recognition with conducting polymers. This term, *molecular recognition*, has been adopted by scientists from a range of disciplines to describe a kind of complexation depending critically on shape-specific interactions that enhance the effect of usually weak long range forces. Antibody-antigen interactions are one kind of molecular recognition. Molecular recognition may be detected by a wide range of chemical and physical methods and is leading to applications in areas such as separations and detection. Key points of Professor Teasdale's presentation are:

- Overall goal of research: Induce molecular recognition in conducting polymers.
- Used electrochemically polymerized heterocycles (pyrrole, aniline, thiophene, and derivatives).
- Accomplishment: Electrochemically enhanced separation systems based on column and membrane technology used to separate molecules with marginal molecular differences (e.g., caffeine and theophylline).

Latex Stabilization

Professor Brian Vincent, School of Chemistry, University of Bristol, United Kingdom, described some important work on the synthesis and characterization of electrically conducting polymer latex particles. Professor Vincent has addressed the problem of unprocessable (brick dust) conducting polymers in a novel way. He has developed a number of "stabilized" systems in which a *dispersion* of conducting polymer is obtained by use of a custom-synthesized stabilizing copolymer. Thus, a polypyrrole latex is obtained using an aqueous solution of monomer (pyrrole), oxidant (ferric chloride), and a number of polymer stabilizers. With high molecular weight polyethylene oxide (PEO), 300- to 400-nm-size particles were obtained, while other particle sizes, morphologies, and compositions may be obtained with other polymers present. Interestingly, needle-shaped particles of a polyaniline latex are formed by the oxidative polymerization of aniline/water solutions in the presence of PEO. Conducting films (>1 S cm^{-1}) using standard film-forming latexes (e.g., polybutylacrylate) may be obtained using relatively low "loadings" of the polyaniline latex, as the percolation threshold for conductivity is shape sensitive.

Microelectrodes

Professor R. John, Department of Chemistry, University of Wollongong, gave an interesting presentation on electropolymerization at microelectrode centers. Microelectrodes of $<20 \mu$m in diameter were utilized, compared to conventional electrodes (5 to 10 mm diameter). Transport of reactants to and products from microelectrodes is much faster than at a conventional electrode. Thus, in contrast with standard electrodes, no growth of polymers occurred from dilute solutions of monomer at microelectrodes (although charge was consumed due to oxidation of monomer). It is envisaged that enhanced transport of products away from microelectrodes results in the transport of monomeric and oligomeric species away from the electrode before advanced chain lengths required for precipitation of polymer films are reached. At high monomer concentration, deposition occurs normally due to more rapid chain growth and concomitant deposition of solid polymer. Under such conditions, the enhanced mass transport properties at microelectrodes result in significantly greater rates of electropolymerization compared to conventional electrodes.

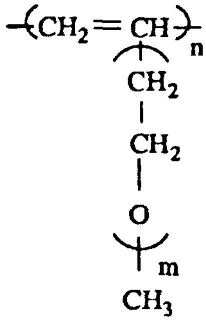
IONICALLY CONDUCTING POLYMERS

New Polyelectrolytes

Professor J.M.G. Cowie, Department of Chemistry, Heriot-Watt University, Edinburgh, Scotland, reviewed progress in the area of ion conduction in polymer electrolytes. Such polymer electrolytes are important to high-energy battery technology and typically consist of a polymer that contains coordinating atoms or groups and a salt. Professor Cowie reviewed the requirements to obtain useful ion conductivity levels ($>10^{-5}$ S cm^{-1}) in polymer electrolytes:

- Polymer host must be capable of dissolving and ionizing a range of salts (requires donor atoms, commonly, O, N, S).
- Polymer host must have a low glass transition temperature, as ion conduction takes place in the amorphous regions of the polymer and is assisted by polymer chain motion.
- Polymers with ($-CH_2CH_2X-$) provide an optimum environment for complexing cations due to the formation of five membered rings; this gives such polymers high binding capacity.

A prototype polymer electrolyte is polyethylene oxide/lithium chloride (PEO/LiCl), wherein the ratio of salt to polymer can be varied over a wide range. Professor Cowie described work on comb-branch polymers that contain linear backbones with regularly repeating side chains. Two classes of polymers were examined: **1**, which contains polyether side chains, and **2**, which contains cyclic ether units in the side chain (see Figure 1).



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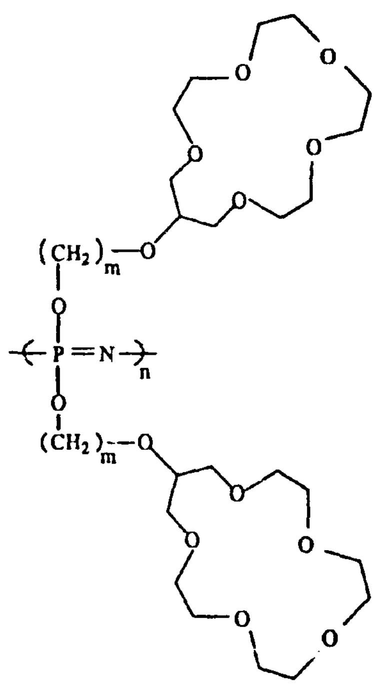

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Figure 1. Two classes of comb-branch polymers: **1** contains polyether side chains, and **2** contains cyclic ether units in the side chain.

The oligo(ethylene oxide) comb polymers **1** combined with salts such as $LiClO_4$ give polymer/salt compositions with conductivities of about 10^{-4} S cm^{-1}. Cyclic analogues can be prepared, and a series of comb-branch polymers with 16-crown-5 macrocycles was synthesized and attached to polyphosphazene chains (2). However, polymers **2** had glass transition temperatures higher than the linear analogues and concomitantly lower conductivities. It was concluded that polymers of structure **1** were generally better than those of type **2** for electrolyte applications.

Because of the branched structures of the comb polymers, one might expect better resistance against creep, which has been a problem in real polymer electrolyte-based battery systems. This aspect was not examined. Justifiable concern was expressed in the question session about the safety of preparation of perchlorate polymer/perchlorate salt electrolytes. Professor Cowie replied that relatively small amounts of materials were prepared for examination.

Molecular Motions via Nuclear Magnetic Resonance (NMR)

Professor H. Walter Spiess, Max-Planck Institute for Polymer Research, Mainz, gave an authoritative paper on the characterization of molecular order and dynamics in solid polymers and liquid crystalline polymers by two-dimensional (2D) solid state NMR spectroscopy. Two-dimensional NMR spectroscopy allows deep insight into the structure and dynamics in solid polymers.

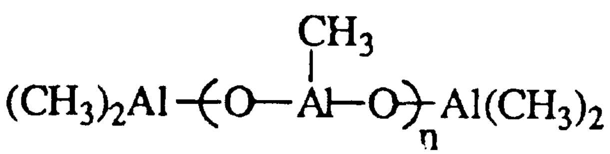
The power of 2D NMR in analyzing chain motions in the glassy state was revealed in a study of ^2H - 2D NMR of polyelectrolytes deuterated at selected methylene groups with different distances from the ionic centers. The glass transition of these polyelectrolytes is attributed to the melting of the ionic structure. The chain motion associated with this transition is the rotational motion of the methylene groups, which is described as angular fluctuations with an amplitude described by Gaussian distributions. The motions observed are similar to those reported recently by Professor Spiess for chain motion in polyamides. The 2D NMR show no evidence for trans-gauche isomerization, which has often been asserted to be the source of chain mobility.

Professor Spiess' paper reinforced the role of the powerful technique of 2D NMR spectroscopy in providing insight at the molecular level for chain motions associated with physical transitions and mechanical processes.

SYNTHESIS

New Catalysts

Important progress in the synthesis of new polymers was reported at this meeting. Professor W. Kaminsky of the University of Hamburg reported new catalysts formed by the combination of methylaluminoxane **3** and matallocenes **4** for the polymerization of olefins (see Figure 2).



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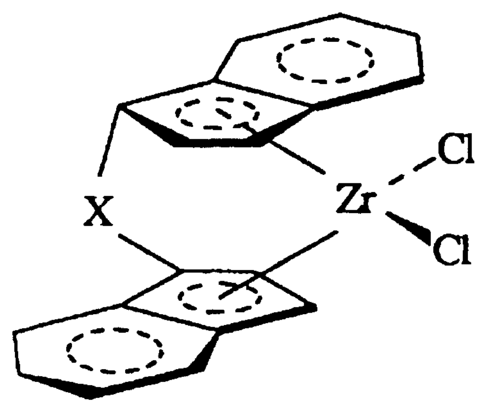

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Figure 2. New catalysts formed by the combination of methylaluminoxane **3** and matallocenes **4** for the polymerization of olefins.

This system is conceptually related to Zeigler-Natta systems, possessing an acceptor component (3) and coordinately unsaturated metal complex (4). In the metal complex "X," the group that bridges the indene groups is ethylene (**4a**) or dimethylsilyl (**4b**). This new co-catalyst system is important in providing a route to the polymerization of cyclic olefins like cyclobutene, or norbornene **without** any ring opening. The resulting polymers are highly crystalline and display the highest melting points ever observed for polyolefins (400 to 500 °C, *in vacuo*). Copolymerizations are readily catalyzed. A copolymer of ethylene and norbornene is amorphous and displays glass transition temperatures greater than 130 °C, suggesting use in optical discs or fiber optics.

RADIATION EFFECTS

The Polymer Materials Radiation Group from the University of Queensland made a strong showing at the symposium, with 18 presentations including lectures and poster papers. This group, which is in the Physical Chemistry Section of the Department of Chemistry, consists of Professors James H. O'Donnell, Graeme A. George, David J.T. Hill, and Peter J. Pomery. This group has developed sophisticated instrumental and chemical methods for determining the degradation mechanisms of polymers in hostile environments. These methods have also been applied to elucidating the mechanism of free radical polymerization and copolymerization. Closely coupled with these interests are efforts in composite materials and polymer surface analysis.

An example of the high quality research efforts underway at Queensland is the paper by Professors Hill, O'Donnell, and Pomery and their coworkers T. Carswell, R. Kellman, D. Londero, and C. Winzor. In this work, the kinetics of copolymerization reactions of methyl methacrylate (MMA) with other methacrylate and dimethacrylate monomers was studied to high conversion. Double bond concentration was estimated directly by near infrared spectroscopy, and the concentration of propagating radicals was determined by electron spin resonance spectroscopy. This work has allowed an accurate assessment of important rate constants for propagation and termination steps in the chain growth process for this commercially important polymerization reaction.

CONCLUDING REMARKS

As noted in the Introduction, this was a well-attended international meeting of broad scope. The Australian polymer science community used this meeting to good advantage to showcase a wide range of interesting research results. I was impressed with the growing programs in polymer chemistry at many Australian universities and the youth and vigor of the new faculty members. This infrastructure, which is increasingly producing well-trained polymer scientists, will help Australia in its efforts to develop an independent industrial base in polymeric materials. In the United States, industrial/academic partnerships in research are common and represent a growing element in the support picture for university research. This phenomenon has been driven by the shortage of adequately trained students and the high cost (risk) of basic research carried out in industry. According to the Australian faculty members with whom I spoke, this strong partnership is lacking in Australia due to the absence of a strong domestic industrial base. This meeting provided evidence that a good *beginning* to the solution of this problem is well underway, namely, a domestic source of students trained in polymer science who will *broaden the existing base* of native chemical industry and *provide the innovative advances for the initiation of new companies* of the future.

Kenneth J. Wynne, who received his Ph.D. from the University of Massachusetts in 1965, is Program Manager, Organic and Polymeric Materials, at the Office of Naval Research. Dr. Wynne's research interests include electronically conducting polymers, preceramic polymers, and polymer surface design and characterization. He is a member of the Polymer and Polymer Materials, Science and Engineering Divisions of the American Chemical Society. He is also a member of the Editorial Advisory Boards of the *Journal of Applied Polymer Science*, the *Journal of Inorganic and Organometallic Polymers*, and *Polymers for Advanced Technologies*.

U.S.-JAPAN SEMINAR ON INORGANIC AND ORGANOMETALLIC POLYMERS

A U.S.-Japan Seminar on Inorganic and Organometallic Polymers was held from 24-28 March 1991 in the Nagoya International Center, Nagoya, Japan. This article summarizes some of the presentations on topics which included high temperature polymers, polymers which may be thermally converted to ceramic materials, and polymers with unusual electronic and optical properties.

by Joseph H. Magill and Kenneth J. Wynne

INTRODUCTION

A U.S.-Japan Seminar on Inorganic and Organometallic Polymers was held from 24-28 March 1991 in the Nagoya International Center, Nagoya, Japan. This seminar was sponsored by the Japan Society for Promotion of Science and the National Science Foundation, U.S.A. The U.S. participants for this meeting were organized by Professor Kris Matyjaszewski of Carnegie Mellon University, Pittsburgh. On the Japanese side, Dr. Katsumichi Ono of the Chemical Research Institute of Non Aqueous Solutions, Tohoku University, Japan, was primarily responsible for the Japanese participants. This was the first joint meeting organized in Japan between U.S. and Japanese scientists on the topic *Inorganic and Organometallic Polymers*. The objective of the seminar was to provide exchange of information in this important field as well as to create "bridges" between active researchers now and into the future. Lectures from both sides and a poster session provided the participants with opportunities for questions and discussions. The lecture sessions were chaired jointly by participants from both countries to emphasize the cooperative nature of the meeting.

Navy interest in inorganic and organometallic polymers stems from potential applications as precursors to ultra-high temperature materials, as materials which facilitate microstructural fabrication, as electronics packaging materials, and as optical materials. This article is written with this perspective and presents highlights of the joint seminar, which covered the research in progress in many laboratories.

As a brief background, it is noted that initiation of the seminar came from Professors K. Murakami (then at Tohoku University) and Professor M. Kajiwara (Nagoya University) at the time of their visit to Denver for the First International Symposium on Inorganic and Organometallic Polymers in 1987. Opening remarks and welcome for the Nagoya seminar came from Professors Murakami (now at Teikyo University) and Matyjaszewski.

SILICON CONTAINING POLYMERS

Polysilanes **1** (Figure 1) and other silicon-containing polymers discussed below are of interest as photoresists, semiconducting polymers, precursors for silicon carbide materials, and as nonlinear optical materials. Professor Robert West (University of Wisconsin) highlighted the growth and development of polysilane chemistry since 1949. He pointed out research interest (through growth of papers published) and technological developments via the increasing numbers of patents in the field. Chemical and physical features of polysilane homo and copolymers (with variable side group dimensions) were discussed.

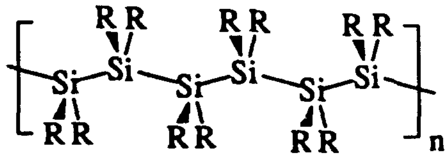

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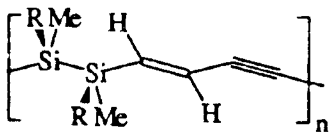
Figure 1. Polysilanes 1.

Columnar liquid crystalline behavior was found to be pervasive for this class of polymers. Ultraviolet-visible spectra were sharply dependent on temperature and pendant organic substituent ("R-group") on the polysilane backbone. This allows tailoring for optical applications.

Professor Mitsuo Ishikawa (Hiroshima University) presented his work on the synthesis and properties of polymers that have a regular, alternating arrangement of -Si-Si- and π-electron systems. Thus, the rhodium(I) catalyzed reaction of 1,2-diethynyl-1,2-dimethyldiphenylsilane in the presence of a catalytic amount of chlorotris(triphenylphosphine)-rhodium(I) gave polymer 2 (Figure 2) with the novel alternating -Si-Si- and butenyne units in the backbone. These interesting polymers were obtained with high molecular weights. Polymers 2 were photoactive in the ultraviolet (UV) region.



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R = Me, Et, Ph

Figure 2. Polymers 2

Professor Kris Matyjaszewski stressed the need and technological importance of synthesizing well characterized inorganic polymers. He illustrated an approach to such polymers through ring opening polymerization procedures to control conformation and molecular weight. His lecture was illustrated with several synthetic procedures involving (a) reductive coupling, (b) sonochemical, and (c) anionic polymerization methods. Recent results on the preparation and characterization of novel polysilanes 1 and polyphosphazenes were presented. The former work is briefly described below, while the latter is discussed in the section on polyphosphazenes.

As an example of Matyjaszewski's research, ring-opening polymerization of 1,2,3,4-tetramethyl-1,2,3,4-tetraphenyl-cyclotetrasilane initiated with carbanions and silyl anions provided polysilanes with molecular weights from 10,000 to 100,000 amu. This method provides the potential for ultramicrostructural control. Synthesis and characterization of random copolysilanes were covered. Model studies based on well-defined oligosilanes shed light on the mechanism of various polymerization reactions. Thermal, mechanical, and chemical degradation of polysilanes was addressed.

Dr. Nobio Matsumoto (NTT Basic Research Laboratories, Tokyo) introduced his talk with some background physics on semiconducting inorganic systems, which he discussed in terms of band theory in polysilanes and polygermanes. He went on to outline the synthesis of three kinds of Si/Ge hetero-copolymers by Wurtz-type coupling. In a three stage reaction series, he produced a new type of Si/Ge superlattice, confirmed by ^{29}Si nuclear magnetic resonance (NMR) and UV absorption spectra and by comparing the ordered Si/Ge sequenced polymer with other known random hetero-copolymers. If these results are further substantiated, this is the first example of a 1D superlattice of this kind.

Professor Kiyohito Okamura (College of Engineering, Osaka) described a radiation curing procedure for polycarbosilanes. This method controls oxygen content in the cross-linked polymer precursor. Through oxygen control in the curing-processing of polycarbosilane fibers, oxygen levels below the customary 10% were obtained in the resulting SiC fibers. Improved moduli were found with decreased oxygen content. A comprehensive study of oxygen-radiation-dose and annealing-morphology-property parameters was made. The higher quality SiC fibers were made only in small amounts, but the principle established is important for improvement of high temperature metal and ceramic matrix composites.

Dr. Fred Schilling (AT&T Bell Laboratories) described work on the solid state thermochromism and piezochromism in polysilanes. This research focused largely on the structural characterization of polysilanes (homo and random copolymers) as this relates to solid state electronic properties. It was determined that *trans* conformational arrangements of bonds along the Si backbone were associated with a lower energy absorption, although these absorptions cover a 40 nm range. However, some polymers wherein the *trans* structure has not been identified also show lower energy absorptions. Other factors, including bond lengths, valence angles, and side group arrangements, clearly play a role in determining properties, and further work is warranted. Dramatic changes in UV absorption were observed with pressures up 250 MPa and were related to thermochromic and piezochromic behavior. A large number of various experimental methods were employed in this extensive investigation.

Professor Katsumichi Ono (Tohoku University, Sendai) discussed the kinetics of β-SiC formation from the product of the reaction of ethylsilicate with a phenolic resin in the presence of toluene sulfonic acid. The kinetic behavior differed appreciably from that found for heterogeneous precursors with which the work was compared. It was concluded that the carbothermic reduction of SiO_2 in the range 1,500 to 1,800 °C was controlled by the diffusion of carbon through an amorphous matrix to the growing β-SiC surface. The nucleation process was simultaneous in the example of the homogeneous matrix.

Professor Yoshimoto Abe (Science University of Tokyo, Noda) gave a paper on the synthesis and properties of poly(titanosiloxanes) and polysilazanes as precursors for ceramics. The usual ammonolysis of methylchlorosilanes used for oligo and polysilazane Si_3N_4-precursors was replaced by a new method. The ammonolysis of $MeSi(NCO)_3$ gave polysilazanes characterized by analysis and spectroscopic techniques. Films and fibers are readily obtained from the polymer solution. Pyrolysis results in a high yield of ceramic material, the nature of which is under investigation. It is noteworthy that the isocyanate-based polymer fibers have decreased water sensitivity compared to those derived from halogenated precursors.

Professor Dietmar Seyferth (Massachusetts Institute of Technology) lectured on the reactions of preceramic polymers with transition metal complexes and transition metal powders. In his address he pointed out the need for processable materials of elemental composition that were either soluble or fusible to yield high ceramic residues. Much of the new chemistry described involved utilizing the reactivity of Si-H bonds in a preceramic polymer. Thus, Nicalon® polycarbosilane (PCS) normally gives about 60% ceramic yield. Through reaction with a small amount of $Ni(CO)_4$, an improved yield (90%) of ceramic product could be obtained. Furthermore, through reactions with organometallic reagents, the stoichiometry of the resultant ceramic could be controlled.

In a related approach, Si-H bonds in a preceramic polymer were used to introduce the bis(cyclopentadienyl)-titanium moiety. In an interesting twist, the Cp_2Ti-modified carbosilane (which upon pyrolysis would normally yield a ceramic with excess carbon) was intimately mixed with a desired metal. The resultant preceramic material, a metal-Cp_2Ti-carbosilane, gave metal carbide-silicon carbide ceramic "blends" with controlled composition. X-ray diffraction proved to be very useful for crystalline phase identification. This approach is important because it is known that such "blends" or alloys of different ceramic compositions can give improved properties (e.g., fracture toughness) compared to the pure components.

The research of Dr. Yoshio Hasegawa (Research Institute for Special Inorganic Materials, Ibaraki) introduced a new curing method for polycarbosilanes using CCl_4 vapor or unsaturated C_6H_{10} hydrocarbon vapor as a curing agent. The ceramic fibers produced from polymers cured (cross-linked) by this method have superior strength up to 1,500 °C, compared with the best Si-C-O fiber that was cured by electron beam irradiation in Ar atmosphere. The mechanism of the curing chemistry is under study at present.

Dr. R.D. Miller (IBM Almaden Research Laboratories, Almaden) discussed the photochemistry of substituted silane polymers. Insight was provided into the important processes of fluorescence quenching and accelerated photobleaching. The principles and requirements for short wavelength microlithography were introduced. The application goal of this work is to generate high resolution ($<0.5\,\mu m$) images with deep UV exposure.

New poly[(aryl)(alkyl)]silanes wherein the aryl group is substituted (e.g., *p*-t-butyl) have lithographic sensitivities improved by an order of magnitude compared to poly(phenyl methyl)silane. This is understood in terms of improved molecular weight reduction which accompanies spectral bleaching. There is an important connection between this work, which is aimed at *micro*-structures, and preceramic polymer work discussed above, which is generally aimed at *macro*-structures, viz., the polysilanes have a *dual role* in microlithographic processes. Part of their utility stems from their photolability in imagining. A remaining structure exists which is oxygen reactive ion etch (RIE) resistant. Under RIE conditions, SiO_2 is formed on the surface of the areas containing polysilane previously protected by the mask. The conversion to SiO_2 protects the underlying area, permitting the remaining area to be selectively etched away.

Professor Kazuyuki Kuroda (Waseda University, Tokyo) dealt with the preparation and reactivities of 1, 2, and 3D silicate polymers. Using natural products such as Kanemite ($NaHSi_2O_5 3H_2O$), intercalation was effected with alkyltrimethyl-ammonium cations to create a structure with alternating layers of silicate network and intercalated organoammonium cations. Magadite ($Na_2Si_{14}O_{29}nH_2O$) and Kenyaite ($Na_2Si_{20}O_{41}.nH_2O$) are now being investigated along similar lines to create larger layered spacings in the design of controlled layered materials.

Professor Yasuaki Nakaido (Gunma University, Kiryu) discussed preparation procedures for polysilazanes. He described co-ammonolysis of binary methylchlorosilane mixtures and the reaction of hexamethylcyclo-trisilazane with methyltrichloro-silane. The products are reactive and can be carefully heat treated to produce thermoplastic polysilazanes. Professor T. Taki (Tokushima University) provided solid state ^{29}Si NMR data that helped elucidate the structure of these highly branched polymers. Thermal stability was very good in cured polymer fibers produced via melt spinning. These fibers were converted to $10\,\mu m$ Si-N-C ceramic fibers, which had good mechanical properties (tensile strength 2.9 GPa).

Dr. Takemi Yamamura (Ube Industries, Ltd.) described the synthesis of Si-Ti-C-O (Tyranno®) ceramic fibers derived from melt spinning of a poly(*titano*-carbosilane) precursor. The ceramic fibers display high tensile strength and modulus as well as very high transverse flex strength. They possess good wettability and high thermal stability. An aluminum matrix "prepreg" film is available as well as Tyrannohex® composite, which is a SiC matrix/SiC fiber based material. The latter material is stable in an argon atmosphere to 1,800 °C and has 20 times better fracture toughness compared to monolithic ceramics. The Tyranno® based materials are being promoted for use in sporting goods such as tennis rackets, golf clubs, fishing rods, as well as high temperature applications such as ceramic engines.

Mr. Yoshio Yamashita (Oki Electric Industries) with Professor

M. Kajiwara (Nagoya University) discussed crysotile-derived polymers for microlithography. Crysotile is commercially available as a bilayered mineral. By a series of clever reactions, one of the layers may be selectively functionalized, ultimately with dimethylvinylchlorosilane and/or trimethlychlorosilane to give a soluble, organic functionalized silicate (OFC). When spun as a thin film, the OFC behaves as a n-type resist (due to radiation induced vinyl polymerization), which is developed with aqueous base. The OFC has a high sensitivity (2 $\mu C/cm^2$) and resolves 0.2 μm lines and spaces. The O_2-RIE resistance is 50 times higher than that of a novolac based photoresist. Using other chemistry a p-type resist was derived from the OFC. This work embodies novel chemistry with promising development potential.

Professor Bruce Novak (University of California, Berkeley) presented a lecture on "Inverse Organic-Inorganic Composite Materials." "Inverse" means that the compositions of matrix and reinforcement, which are usually organic and inorganic, respectively, are inverted. Thus, in an inverse composite the matrix is inorganic (derived from a sol-gel approach) and the reinforcement is an organic polymer. A number of innovative approaches were devised to address a variety of problems that arise in the synthesis, processing, and characterization of such materials. As an example of this work, the problem of generation of desired organic polymers in an aqueous medium was addressed. It is often desirable to generate such polymers catalytically, for example, by ring opening metathesis polymerization (ROMP). However, most ROMP catalysts are insoluble in water. Thus new chemistry was developed to create a water soluble ROMP catalyst. An example of one such palladium catalyst **3** is shown in Figure 3.

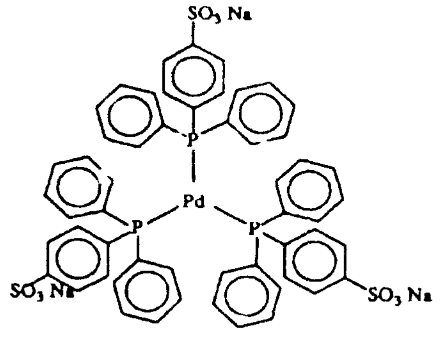

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Figure 3. Palladium catalyst **3**.

Other problems were also addressed in this presentation, including *in situ* generation of desired organic polymers, matrix shrinkage, matrix-organic polymer compatibility, production of homogeneous phases, and rapid processing.

POLYPHOSPHAZENES

In addition to the polysilane work described above, Professor K. Matyjaszewski presented a new approach to well-defined polyphosphazenes **4** (Figure 4) via anionic polymerization of N-silylphosphoranimines to produce linear, relatively high molecular weight poly[bis-(trifluoroethoxy)phosphazene] under mild conditions (below 100 °C). This route provides new possibilities to prepare polyphosphazenes with controlled molecular weight and terminal functionality.

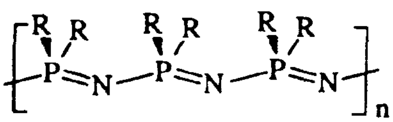

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Figure 4. Polyphosphazenes **4**.

Professor Harry Allcock (Penn State University) illustrated a broad range technological potential for polyphosphazenes, providing examples from his own research of their use as high performance elastomers and in battery applications. A new application of polyphosphazene hydrogels for encapsulation of mammalian cells was described. The objective was to control the release of hormones and to protect the host antibodies of cells. In addition, electroactive, photochromic, and nonlinear optical (NLO) active polyphosphazenes were discussed. Overall, the diverse properties that may be incorporated into polyphosphazenes are unique in terms of polymer chemistry, structures, and properties.

Professor Toro Masuko (Yamagata University) presented his results on the single crystal morphology and chain conformation of poly[bis(p-methylphenoxy)phosphazene]. Electron and X-ray diffraction investigations were combined to provide a structural representation of this molecule in the solid state. This was consistent with a 2-chain helical conformation with 16 monomer units per orthorhombic cell.

Professor Meisetsu Kajiwara (Nagoya University) described oxygen gas permeability in water and the mechanical properties of poly(organophosphazene) films. Compared to silicone and silicone-methylacrylate copolymers under wet test conditions, the poly(organophosphazenes) displayed superior behavior to current commercial contact lenses. Oxygen gas permeability was found to be almost tenfold higher than that measured for polysiloxanes. Dry as well as wet gas permeability studies were carried out on a variety of polyphosphazenes. These polymers may also be usefully employed in commercial applications where O_2 separation from air, for example, is needed.

Professor Joseph H. Magill (University of Pittsburgh) re-evaluated and extended the idea of smectic phase formation as a common theme involving crystallizable polyphosphazenes with oxyaryl or oxyalkyl side groups. Well characterized polymers were studied by advanced characterization techniques to provide a uniform picture of smectic phase formation (from a diffraction viewpoint). Interpretation of results was complicated when the side chains were relatively small and therefore mobile above and below the thermotropic transition temperature, T(1). In these cases, overlapping and convoluted diffraction spots obscure smectic morphology in diffraction. From all of the physical information taken in concert a single picture prevails. From practical and mechanical points of view, more evaluation is required of homo-polymers that have been melted or heated above T(1) where chain extension occurs and interchain or intercrystallite cohesion is greatly reduced so that friable materials result.

Professor Keichi Moriya (Gifu University) reported on a collaborative effort with Professor M. Kajiwara (Nagoya University) concerning the synthesis of polyphosphazenes with bi-phenoxy-based mesogens connected to the backbone without the usual spacer chain. The polymers formed mesomorphic states at elevated temperatures, and the phase transitions were investigated by polarizing microscopy and differential scanning calorimetry.

Professor Ichiro Murakami (Okayama University) presented work on the dielectric relaxation of poly(organophosphazenes). Many of the measurements made were novel. They were made at constant temperature over a wide frequency range of more than four decades. The complex dielectric modulus $E^* = E' + iE''$ was studied from below Tg through the T(1) transition and above it to provide transitional maps of dielectric behavior. The α-relaxation peaks are assigned to micro-Brownian motion of chain segments above Tg. β-peaks were attributed to side group rotation at temperatures less than Tg, corresponding to activation energies of ≤6.5 kcal/mole in the case of poly(bis-trifluoroethoxy)-phosphazene and ~8.7 to 12 kcal/mole for polymers with longer side groups. Broad β-peaks were interpreted as overlapping peaks corresponding to discrete side group motions that may be deconvoluted.

BORON CONTAINING POLYMERS

Professor Robert Paine (University of New Mexico) dealt with boron nitride (BN) formation and precursor synthesis and processing. A branched BN precursor polymer was prepared from hexamethyldisilazane and trichloroborazene trimer. The polymer could be processed from solution into fibers and films. Conversion to BN was effected by thermolysis at 900 to 1,200 °C. Aerogels and xerogels were obtained giving products with surface areas upwards of 600 m²/g. Other approaches outlined included the formation of spherical amorphous BN particles that can be converted into platelets upon sintering at 1,600 °C (3 h). Many variations in processing and synthesis and applications are yet to be explored in this promising area.

Professor Yoshihara Kimura (Kyoto Institute of Technology) discussed the formation of boron nitride ceramics in the form of fibers and coatings from borazine-derived polymers. An important synthetic breakthrough was effected in the synthesis of B,B,B-triaminoborazine. This was carried out through reaction of B,B,B-tri(diethylamino)borazine with ammonia at low temperature. Interestingly, B,B,B-triaminoborazine is a dimer in the solid state. The procedure creates borazine intermediates that are further processed at elevated temperatures as high as 1,800 °C in an inert atmosphere to produce white BN fibers of good quality, geometry, and high tensile strength and modulus. These are important results due to the ready availability of the starting materials, the facile processing, and good materials properties of the resulting ceramic materials.

OTHER POLYMERS

Dr. Kenneth J. Wynne (Office of Naval Research) described some phthalocyanine (Pc) containing polymers with improved properties. For example, <1% metal Pc incorporated in Kevlar® renders it inert to ultraviolet radiation. In addition, Kevlar® can be made conducting by incorporating partially oxidized Pcs. Other Pc containing polymers were described, including highly thermally stable Pc siloxanes and electronically conducting Pc compositions.

Professor James McGrath (Virginia Polytechnic and State University, Blacksburg) described synthetic routes to phosphorous containing thermoplastics and thermosetting materials that have composites applications. Providing a background to high performance homo and copolymers, he dealt with aryl-P-containing polymers from reactants of a similar chemical nature. High glass temperatures (~200 °C or more) were observed as well as good thermal stability as evidenced by low weight loss in thermogravimetric analysis measurements upwards of 500 °C. These materials proved to be quickly self-extinguishing after they were ignited in air.

SUMMARY

This seminar was marked by the presentation of considerable new results in the field of inorganic, inorganic/organic, and organometallic polymers. These results in basic and exploratory developmental research will no doubt lead to new materials for demanding applications in structural, electronic, optical, and biomedical materials of the future.

ACKNOWLEDGMENT

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Joseph H. Magill received his Ph.D. (1956) and D.Sc. (1990) degrees from Queens University, Belfast, Northern Ireland. He is a professor in the Departments of Materials Science and Engineering and Chemical and Petroleum Engineering and an adjunct professor in the Chemistry Department of the University of Pittsburgh. Dr. Magill's research interests include the physical properties of polymers and small molecules. He is a fellow of the American Institute of Physics and of the Royal Society of Chemistry, London, and is on the editorial advisory board of the *Journal of Polymer Science*.

THE JAPAN MARITIME SELF-DEFENSE FORCE UNDERSEA MEDICAL CENTER

The Japan Maritime Self-Defense Force Undersea Medical Center located in Kurihama is the sole military submarine, diving, and hyperbaric medical research facility in Japan. With the advanced deep diving simulator, the Undersea Medical Center has conducted manned saturation diving experiments to a depth of 370 meters. The present goal is for divers to safely work at depths reaching 450 meters.

by Neal A. Naito, Kenneth C. Earhart, and Cameron A. Gillespie

INTRODUCTION

Located approximately 50 miles south of Tokyo, the Japan Maritime Self-Defense Force (JMSDF) Undersea Medical Center (UMC) is only one of two government research institutions in Japan with state-of-the-art saturation diving simulation facilities. The other is the civilian-run Japan Marine Science and Technology Center situated nearby in Yokosuka. Founded initially in 1967 as the Undersea Medical Laboratory of the JMSDF Hospital Yokosuka, the name was changed to the Undersea Medical Center in 1977 when it became an independent organization under the control of the Chief, Maritime Staff Office. It was moved to the present site in Kurihama that same year.

The purpose of UMC is to support the JMSDF submarine and diving communities through research into solving the medical and human engineering problems associated with explosive ordnance disposal diving, saturation diving, and submarine rescue. Additional missions include training of saturation divers and diving medical officers, medical screening of submarine crews and divers, recompression treatment of injured divers, and deployment of diving medical officers in support of fleet operations.

Militarily, saturation diving is important as part of an overall submarine rescue capability with a deep submergence rescue vehicle assuming complete control of the role over depths of 300 meters. To accomplish these various taskings, UMC has gradually acquired equipment and constructed facilities that are some of the finest in the world. It has also sought to build a cadre of trained diving physiologists and career-oriented diving medical officers (DMO), which could lead to expansion of its research efforts in the future.

PERSONNEL

Table 1 is an organizational diagram of UMC. There are about 70 personnel employed at UMC. Each research division is composed of approximately five members. In the administration division, which may be headed by a civilian or military member, there are 10 to 12 people. The education and training division has 30 to 40 people. The commanding officer is a JMSDF medical officer, usually a rear admiral (RADM). He does not necessarily have a background in undersea medicine. His executive officer is a diving or submarine qualified line captain.

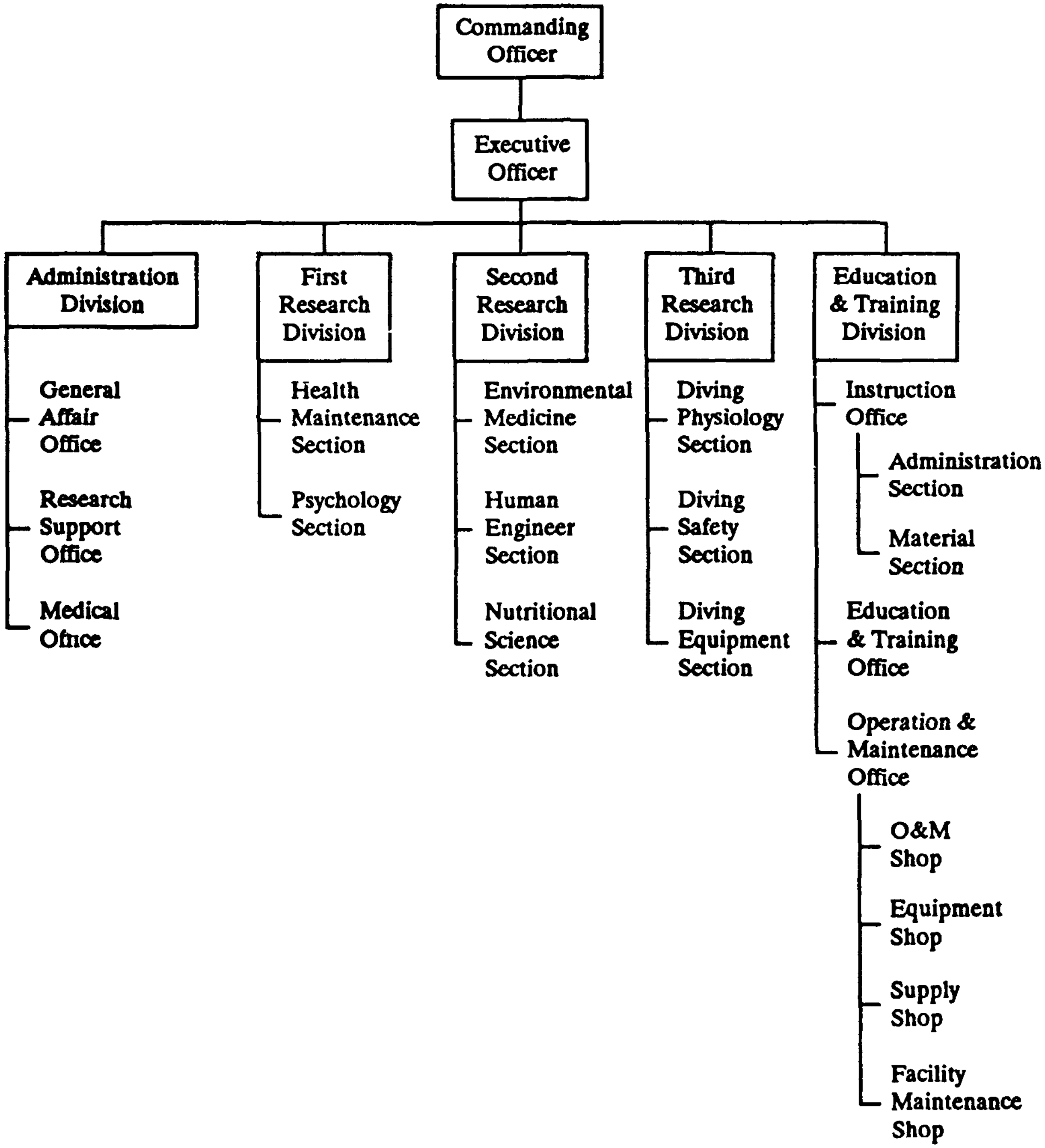
The present commanding officer of UMC, a DMO, is RADM Hiromichi Oiwa, who has an M.D. from Nihon University and a Ph.D. in hygiene from Tokyo Medical and Dental University. He was the developer of the mixed gas capable semi-closed circuit breathing apparatus that is still used by JMSDF explosive ordnance disposal (EOD) divers. He has numerous medical publications in the area of undersea medicine to his credit.

Although not currently assigned to UMC, two other DMOs should be mentioned since they will probably be commanding officers of UMC in the future. Commander (CDR) Tomosumi Ikeda is a gastroenterologist interested in using echocardiography to detect intracardiac bubbles formed during decompression and its correlation to the development of decompression sickness. He received his M.D. from Shinshu University and is currently pursuing his Ph.D. in diving physiology at Saitama Medical College. CDR Ikeda is also a graduate of the Royal Navy saturation diving school. Captain

(CAPT) Atsushi Itoh, M.D., Ph.D. in diving physiology from Hokkaido University and Tokyo Medical and Dental University, respectively, is an internist who has done research on the various physiological effects of saturation diving in humans. Both are invited to UMC to provide additional medical expertise when UMC conducts a saturation dive.

At this time, there are three DMOs at UMC, Lieutenant (LT) Michiya Sato, LT Shoichiro Shimizu, and LT Yutaka Tadano. All are graduates of the National Defense Medical College (NDMC). UMC trains approximately four DMOs each year. It also sends another two physicians to the United States to attend the diving medicine course at the Naval Dive and Salvage Training Center in Panama City, Florida.

Table 1. Organizational Structure of the Undersea Medical Center



To increase the research capability of UMC, two physicians who will have just received their Ph.D. degrees will join the staff soon. Lieutenant Commander (LCDR) Nariyoshi Shinomiya, Ph.D. in bacteriology from NDMC, and LCDR Masao Seno, Ph.D. in physiology also from NDMC, will arrive this fall. There are four civilian investigators at UMC, two with B.S. degrees, one with an M.S. degree, and one with a Ph.D. degree

Mr. Kuniaki Okonogi, who is doing postgraduate studies in physiology under a work study program at Kyorin University School of Medicine, is the senior civilian researcher. Dr. Akio Hashimoto, who received his doctorate in physiology at the University of Wisconsin-Madison, is bilingual in English and Japanese. He is the type of researcher most valuable to UMC, able to serve as either an exchange scientist or as a host for visiting scientists from English-speaking countries. The other civilian scientists are Mr. Kazuhiko Nakabayashi, with a B.S. in biology from Toho University, and Mr. Koji Ozawa, with an M.S. in psychology from Waseda University.

The executive officer of UMC is CAPT Hiroshi Yamanaka, a graduate of the National Defense Academy and a trained deep sea diver. The head of the first and third research divisions is a pharmacist, CDR Masao Tamaki. The head of the second research division is a psychologist, LCDR Hiroshi Nishiwaki.

FACILITIES

UMC is composed of six main buildings and several smaller ones housing administrative offices, a medical clinic, research laboratories, hyperbaric chambers, and maintenance and support work spaces. The centerpiece of UMC is the deep diving simulator (DDS), completed in 1985. Modeled after the DDS at the U.S. Navy Experimental Dive Unit in Panama City, Florida, it has a maximum depth of 750 meters seawater unmanned and 450 meters seawater manned. Mixed gas capable, it is set up like an operational shipboard system with two deck decompression chambers (DDC) connected by a center lock, a personnel transfer capsule (PTC), and a large wet pot.

The two DDCs can accommodate up to six divers each comfortably on dives lasting up to several months (Figure 1). From the main control center, the DDCs are fully environmentally monitored for temperature, pressure, humidity, oxygen, and carbon dioxide. Observation of the divers is provided by closed circuit television (CCTV) cameras. There are connections for physiological monitoring of the divers inside the DDC including vital signs, electrocardiogram, electroencephalogram, pulmonary function testing, and echocardiography.

Figure 1. Deck decompression chamber.

Transfer of divers from the DDC to the wet pot is via the PTC. Access into the PTC is gained through the center lock. The PTC is a completely outfitted operational saturation diving bell. It can hold two divers and a tender (Figure 2). Divers lock out of the PTC and into the wet pot simulating an actual excursion dive at depth. With a volume of 32 m³, the wet pot is large enough to allow for a high degree of underwater activity. The wet pot, a horizontal cylinder with a massive finger pin closure door, is filled with freshwater and can be heated or chilled (Figure 3).

The entire DDS is housed in a mammoth warehouse type structure. The support facilities are almost as large, especially the gas storage area. All the helium-oxygen is purchased premixed from outside sources and shipped to UMC. Although the helium is imported and consequently very expensive, UMC does not possess a helium gas recovery system. Housed one floor below the simulator is the vast machinery spaces filled with pumps, blowers, tanks, and electrical panels needed to maintain the complex life support and pressure systems.

In addition to the DDS, UMC has several other recompression chambers. For the treatment of diving injuries, UMC possesses a walk-in recompression chamber that can hold two litter patients. It is outfitted with CCTV and O_2 monitoring but not a CO_2 scrubber or a heater-chiller unit.

UMC also still maintains and uses a smaller saturation diving system that was installed prior to the DDS. It consists of a single recompression chamber where the divers live that is attached via a hatch to a small wet pot. The wet pot has an upper and lower level with divers getting on a stage and being lowered into the water-filled bottom compartment for simulated excursion dives.

Two animal recompression chambers are available for research as well. The chambers have a maximum pressure of 50 ATA and 6 ATA, respectively, and are mixed gas capable. Animals up to the size of a rat can be put into the chambers.

To aid in the study of the health effects of the submarine environment on crewmembers, a simulator was built at UMC in 1976 that is capable of accommodating up to six people. The inside temperature, pressure, humidity, CO_2, O_2, noise level, and lighting can be varied to investigate whether changes in such parameters can have a medical impact on submarine personnel. Not used very much at present, a new one is scheduled to be built soon.

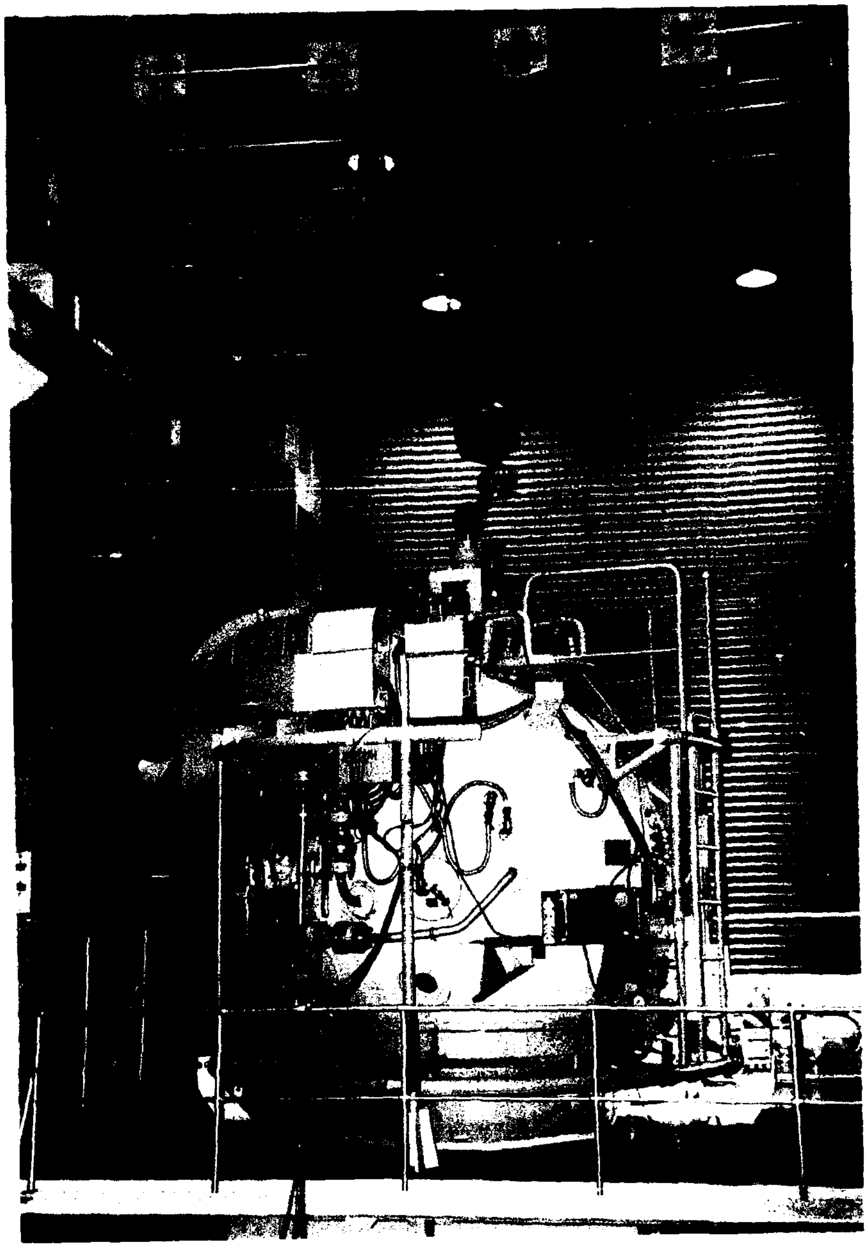


Figure 2. Personnel transfer capsule.

Figure 3. Wet pot with massive finger pin closure door.

Also on the grounds of UMC is a 10-meter free ascent tower used for mainly SCUBA training. Eight meters in diameter, it has a capacity of 250,000 gallons of water. Used 11 times annually, it can also be heated to allow for year-round operations.

With regards to research laboratories, UMC has seven of them including a modern, environmentally isolatable, lab animal holding facility. Basic research equipment available is a mixture of American and Japanese made machines such as mass spectrophotometers, gas chromatographs, and large capacity centrifuges. Medical equipment mainly consists of those types of units mentioned previously that can be hooked up to personnel inside the DDC (Figure 4). Data generated are stored and analyzed with sophisticated electronic recorders. Computer support is provided through numerous personal and laptop versions. UMC has a moderate size library containing most of the leading undersea medicine and physiology periodicals and textbooks. However, there is no permanent research librarian present to assist the staff.

MISSION

As stated in the Introduction, the overall purpose of UMC is several fold. Education and training focuses primarily on qualifying personnel to become saturation divers or DMOs. Started in 1985, the saturation diving course is held once a year, culminating in an actual short duration saturation dive to between 60 and 100 meters. Normally 12 students a year graduate from the program. The DMO course is held once a year and is patterned after the U.S. Navy course. Begun in 1989, it lasts a total of 8 weeks with 4 weeks of classroom instruction covering submarine and diving medicine principles held in Kurihama prior to actual dive training in Etajima.

Direct fleet support is provided by UMC DMOs, who embark on submarines during overseas deployments and minesweeper tenders participating in operational exercises with EOD diving teams. They also perform medical screening of submarine and diving personnel as needed. The number of injured divers treated in the UMC recompression chamber ranges from 10 to 15 per year with the ratio approximately 5 to 1 civilian to military. All the cases are decompression sickness.

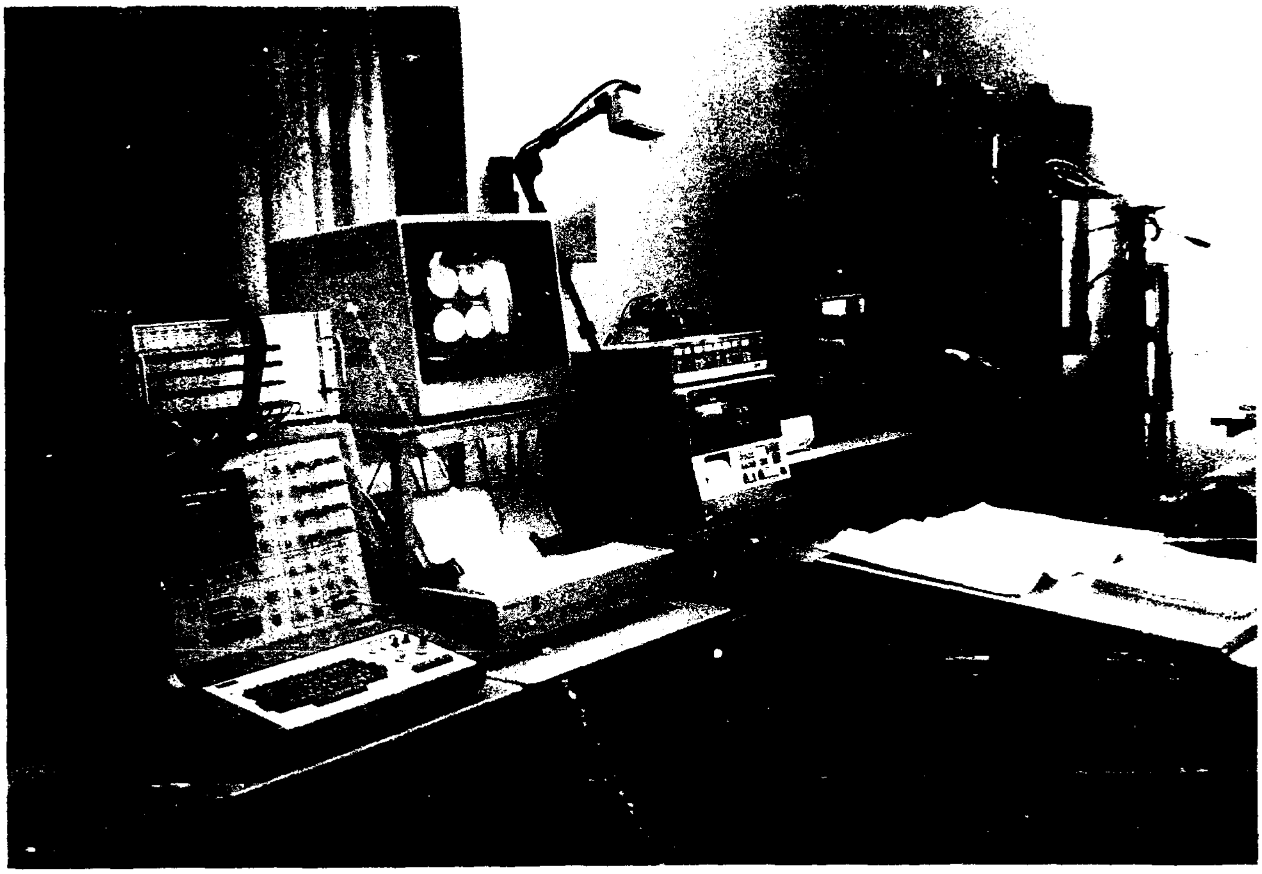


Figure 4. Adjacent DDS biological monitoring and data processing station.

In regards to research at UMC in undersea medicine and physiology, the central focus is on saturation diving. The deepest dive performed with the DDS to date took place in 1989 to a depth of 370 meters for 28 days. During the last dive in September 1990 to 330 meters, major changes were made to the compression/decompression method followed to see if a lessening of the high pressure nervous syndrome could be achieved along with prevention of decompression sickness that has occurred in dives twice before. Compression included two holding plateaus at 150 and 250 meters and, in comparison to prior dives, a reduction of the rate of pressurization by one-half from 250 to 330 meters (Figure 5). Consequently, it was noted that the high pressure nervous syndrome afflicted the divers to a lesser degree during compression and at the bottom than observed previously.

Excursion dives were limited to a depth of 10 meters. Previously, the U.S. Navy excursion table allowing for unlimited depths was used. As a result, divers seemed to suffer less psychological decrements.

During decompression, the British Royal Navy stepwise decompression schedule was substituted with the Duke-GKSS linear decompression procedure. Also, oxygen partial pressure was maintained at 0.49 ATA versus 0.42 ATA with only a mild reversible pulmonary oxygen toxicity induced. The direct outcome of these changes was that no decompression sickness occurred among subject divers (see Table 2 for a complete list of subject areas of investigations performed during this last saturation dive).

The maximum depth reached for an open ocean saturation dive directed by UMC is 300 meters. The submarine rescue ship *Chiyoda* (AS-405) is the diving platform used for these operations. The goal of UMC is to progress to doing dives to a depth of 450 meters.

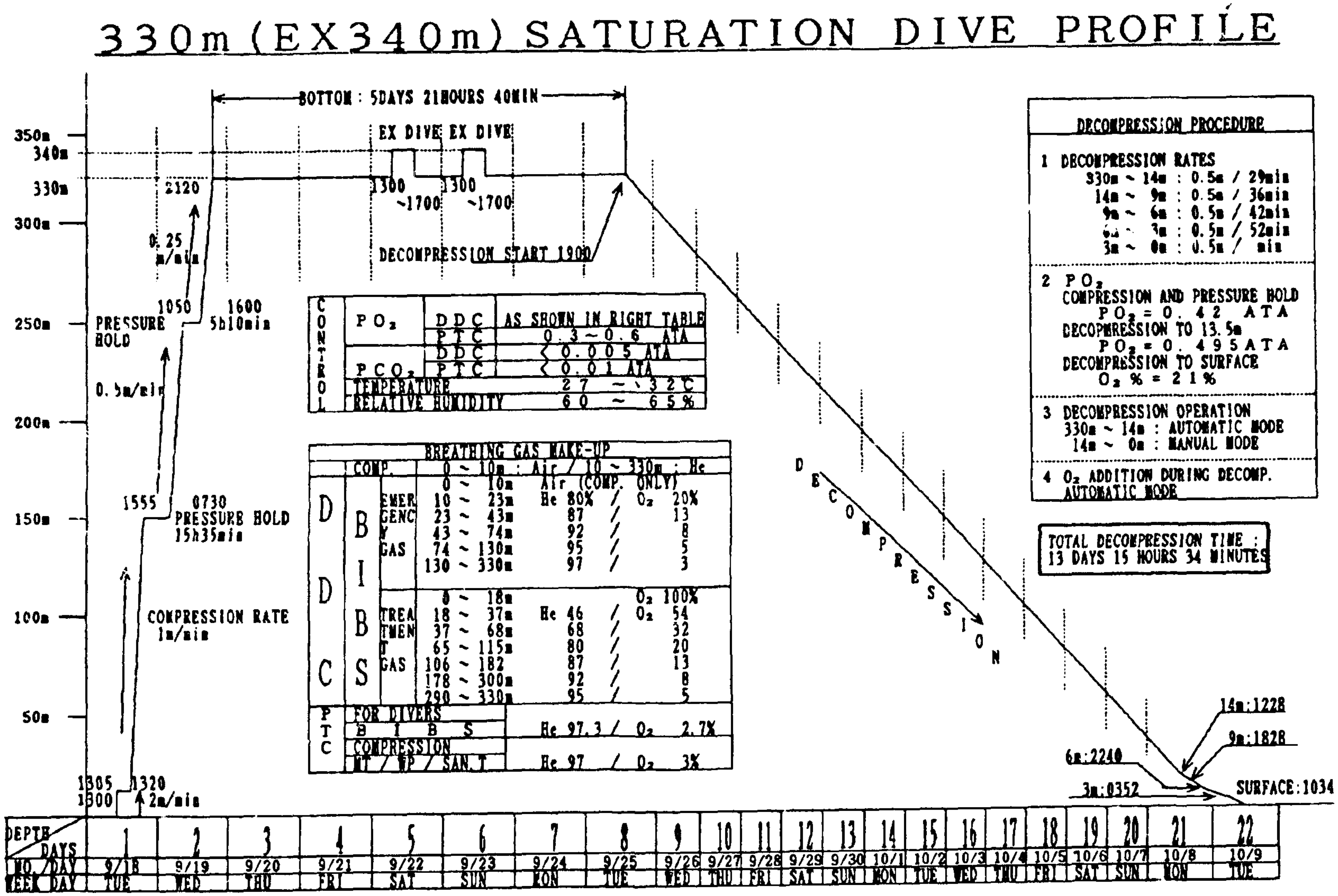


Figure 5. Profile for 330-meter saturation dive.

Table 2. Research Studies Conducted in 330-Meter Simulated Saturation Dive, September 1990

1. Study of High Pressure Nervous Syndrome Using Electroencephalographic (EEG) Topography and Vestibular Function Testing.
2. Use of the Duke-GKSS Linear Decompression Method During Current UMC Saturation Dive.
3. Use of M-Mode Echocardiographic Methods for Intracardiac Bubble Detection.
4. Study of Red Blood Cell Production Under High Oxygen Partial Pressure Environment.
5. Work Capacity of Divers in a High Pressure Environment.
6. Monitoring of Vital Signs and Body Heat Loss During a Saturation Excursion Dive.
7. Ventilatory Dynamics Under a High Pressure Environment.
8. Control of Carbon Monoxide in DDC During a Deep Saturation Dive.
9. Improvement of Electronic Voice Receiver Characteristics in Underwater Breathing Apparatuses.
10. Function Testing of Tear Secreting Glands in a High Pressure Environment.
11. Testing of Taste Sensation in a High Pressure Environment.
12. Standardization of Emergency Procedures for Decompression Sickness in a Saturation Diving Setting.
13. Adjunctive Therapy for Decompression Sickness During Saturation Diving.

The total annual budget for UMC is approximately $2 million, excluding salaries, with $140,000 set aside for research. Other major areas of research besides saturation diving include development of a new decompression schedule for the semi-closed circuit underwater breathing apparatus used by JMSDF EOD divers with the aid of personal computerized diving recorders, development of air saturation decompression tables for use during rescue of crewmembers from a sunk submarine with a pressurized environment, and continued investigation into the physiological and psychological effects of the sealed submarine environment on personnel with an emphasis on atmosphere control and efficient work-rest cycles.

Although a relative newcomer to the field of undersea medicine, UMC has steadily grown into a world-class undersea research center based on the strength of its facilities, in particular the DDS. During the last Undersea and Hyperbaric Medicine Society international meeting, UMC scientists were responsible for several presentations. Future successes will depend more on the capabilities of its research personnel. In this area, UMC is committed to having more investigators through addition of staff as noted above and increasing access to outside scientists. Beginning in 1993, NDMC will have an affiliated basic medical research institute. Personnel from this institution will be highly encouraged to use equipment at UMC to conduct experimental studies. Strong relations with the Science University of Tokyo, which has senior computer science students develop software for certain UMC projects, and the Department of Hygiene, Saitama Medical College will also be continued. Efforts are now underway to establish formal ties with foreign institutions such as Duke University in Durham, North Carolina; the Naval Medical Research Institute in Bethesda, Maryland; and GKSS in Germany.

CONCLUSION

UMC is an internationally respected undersea research center. Its facilities and equipment are some of the most up to date in the world. In the past, it has not always had the number of researchers one would expect an institution of its capability to have on staff. However, efforts are being made to change this situation, which should give UMC the ability to develop leading edge technologies in regards to saturation diving.

Neal Naito is a resident in internal medicine at Naval Hospital Oakland. He was previously stationed at Submarine Group Seven in Yokosuka, Japan, as an undersea medical officer. After graduating from the University of California at Davis with a B.S. in environmental toxicology, he attended the Uniformed Services University of the Health Sciences where he obtained his M.D. in 1986. He then did an internship in internal medicine at Naval Hospital Oakland prior to receiving training as an undersea medical officer at the Naval Undersea Medical Institute in Groton, Connecticut.

Kenneth C. Earhart, a lieutenant in the U.S. Navy Medical Corps, has been assigned to Submarine Group 7, Yokosuka, Japan, since January 1990. He practices submarine and diving medicine, both in Japan and throughout the Pacific. Dr. Earhart received a B.S. degree from Michigan State University, East Lansing, in 1983. From 1982-83 he was an exchange student at Konan University in Kobe, Japan. In 1988 Dr. Earhart received his M.D. from Wayne State University in Detroit. In 1989 he completed an internship at Bethesda Naval Hospital and also attended the Undersea Medical Officer School at Groton, Connecticut.

Cameron A. Gillespie is the head of the ENT Department at U.S. Naval Hospital Yokosuka, Japan. He obtained a B.A. in psychology in 1970 and an M.D. in 1974 from the University of Virginia. He did a residency in ENT surgery at Naval Hospital Oakland between 1976-79 and a Head and Neck Surgery Fellowship at Duke University Hospital in 1984. He has attended both NOAA and U.S. Navy sponsored hyperbaric and diving courses.

A VISIT TO THE JAPAN MARITIME SELF-DEFENSE FORCE SHIP Chiyoda

The Chiyoda *is a multipurpose submarine rescue and saturation-diving-capable ship belonging to the Japan Maritime Self-Defense Force (JMSDF). Built in 1985, it serves as the mother ship for the sole deep submergence rescue vessel (DSRV) in JMSDF. Recently, the authors were invited aboard the* Chiyoda *to observe a DSRV-submarine rescue exercise. This article reports on that visit in view of recent interest in the area of rescue of personnel from disabled civilian scientific research submersibles.*

by Neal A. Naito and Robert T. Appleby

INTRODUCTION

With a large fleet of modern, diesel-electric submarines, the Japan Maritime Self-Defense Force (JMSDF) also needed the parallel capability to rescue crewmembers from a disabled submarine. Thus in 1985, JMSDF commissioned the submarine rescue ship *Chiyoda* (AS-405). Built by Mitsui Heavy Industries, the *Chiyoda* carries a deep submergence rescue vessel (DSRV), a 300-meter saturation diving system, and a remotely operated vehicle (ROV). Information on the precise maximum depth of the DSRV was not available.

While owned by the military, the *Chiyoda* also serves a valuable role to the Japanese civilian undersea research community as an available resource for manned submersible rescue. Just in this past year, the first international conference on submersible rescue was held in Woods Hole, Massachusetts. Cosponsored by the Woods Hole Oceanographic Institution and the Japan Marine Science and Technology Center, the 2-day forum included representatives from the Soviet Union, France, and Canada. That this conference was held underscores the growing interest in this problem among civilian ocean research organizations.

By contrast, the military submarine community has been examining the problem since the early 1900s when submarines first came into widespread naval service. From the beginning of this century, more than 100 noncombat related submarine sinkings have taken place with several thousand lives lost. From these experiences, a twin approach to saving personnel trapped in a disabled submarine has evolved. The first method involves direct escape with crewmembers ascending to the surface wearing an environmental suit with an attached hooded breathing apparatus. This procedure has been validated to 180 meters but with the high likelihood of developing severe decompression sickness. The second method uses rescue with either a mini submersible or a surface tethered underwater bell that attaches directly to the entry hatch of the submarine.

Recently, the authors were invited to observe an actual DSRV-submarine rescue exercise aboard the *Chiyoda* off of Kyushu. The purpose of this article is to report on the authors' visit to the *Chiyoda* in the context of disseminating information on the kinds of capabilities available in the Western Pacific for rescue of personnel aboard disabled military and civilian submersibles.

THE *Chiyoda*

The *Chiyoda* is 113 meters long, 17.6 meters wide, and has a draft of 4.6 meters. It weighs 4,450 tons fully outfitted and has a top speed of 15 knots. At a speed of 13 knots, the *Chiyoda* has a cruising range of 6000 miles. Its propulsion system consists of two variable pitch screws and four through the hull side thrusters. Two thrusters are located aft and two forward. The screws are powered by two 6,000-hp engines, which can be disengaged and clutched into two 1,000-kW and two 850-kW electrical generators that run the thrusters. There are also three service support diesel generators for general electrical needs. The amount of force delivered by the thrusters is controlled by varying the angle of the propellers, which can be turned through an 180° arc.

The side thrusters are the key to the *Chiyoda*'s dynamic positioning system (DPS), which allows it to make a 360° turn around a single axis or to maintain a stable position without anchoring. In comparison, the U.S. Navy's most modern submarine rescue ship does not have side thrusters and uses a four point mooring system with a depth limit of 1,000 feet. In water over 1,000 feet deep, position cannot be maintained as precisely as with the *Chiyoda* since only the stern propellers are available. Control of the DPS is accomplished from the ship's combat information center (CIC). In the CIC, there are two consoles devoted to the DPS, one for automatic and one for semi-automatic control. With the semi-automatic mode, the console operator monitors several digital displays and lightly manipulates a small joystick until the desired position is reached or maintained. Precise location information for the DPS is obtained from shore transmitted signals or deployed underwater transponders.

The presence of the DPS makes the *Chiyoda* an ideal saturation diving platform. The *Chiyoda*'s mixed gas capable saturation diving system consists of two deck decompression chambers (DDC) and a personnel transfer capsule (PTC). A helium gas recovery unit is present also. The DDCs are matched systems and can hold six persons each. From the main control consoles environmental monitoring of O_2, CO_2, temperature, pressure, and humidity is performed. The DDCs are located below the open deck on the port and starboard side, respectively. With a maximum depth of 300 meters, the DDCs can accept personnel under pressure directly from the PTC or DSRV via a transfer lock.

The PTC is a spherical structure that can carry two divers and a tender to a depth of 300 meters or if unmanned 350 meters. It is lowered into the water through the same open center well used to deploy the DSRV using an overhead sliding bridge crane. This bridge crane contains five hydraulic ram tensioners that act like shock absorbers to decrease stress on the lift cables when the DSRV carriage or PTC is lowered into the sea. The four outer ones are used for the DSRV while the middle one is reserved for the PTC. Stability is maintained by having the PTC guided down using wires attached to a weighted stage below. In a submarine rescue situation, divers could connect communication and air supply hoses to the disabled submarine. It cannot mate directly with a submarine. The *Chiyoda* in coordination with the Undersea Medical Center conducts one or two open ocean saturation dives a year for research and operational proficiency purposes.

The *Chiyoda* also possesses an ROV that is deployed off of its bow. Round shaped, the ROV is an older model RCV 225 manufactured by Hydro Products of San Diego. A black and white video viewing system only, it has enough cable for excursions to a depth of 350 meters. The RCV 225 can work in a current up to 1 knot. It is controlled from the CIC and is launched tethered from a mother stage that is lowered via an armored cable. A new ROV with color viewing and greater speed is expected to replace the RCV 225 in the future.

The present commanding officer of the *Chiyoda* is Commander Nagashima. The crew is made up of 110 enlisted and 16 officers. There is additional berthing, living, and storage space to handle an extra 80 persons as the other mission of the *Chiyoda* is as a submarine tender. A large sick bay with an operating suite is also present. Coupled with the large helicopter pad that can accommodate up to a Sikorsky SH-3, the *Chiyoda* is ideally suited to be the center for rescue operations as it can accommodate the extra personnel who would be flown in to provide assistance.

DSRV

Manufactured by Kawasaki Heavy Industries, the JMSDF DSRV is patterned after the U.S. Navy version and cost approximately $70 million to build. One of a kind, it is housed permanently onboard the *Chiyoda* in an open bay hangar located in the forward superstructure. It consists of three interconnected pressure spheres made out of ultra high tensile strength steel surrounded by a streamlined outer hull assembled out of weight-saving titanium, titanium alloy, and fiberglass. It was built to perform rescues from a disabled submarine with an internal pressure of up to 5 bars. Overall length is 12.4 meters, with a width of 3.2 meters and a height of 4.3 meters. Displacement is 40 tons with a top cruising speed of 4 knots.

The maximum underwater current in which DSRV operations can effectively be undertaken is 2 knots. The usual crew complement is three with a pilot, copilot, and rescue assistant. Power to the DSRV is provided through two zinc-silver oxide based batteries located on top of the craft that last up to 7 hours. The *Chiyoda* has four pairs of them, which take 8 hours to fully recharge. Costing $1 million each, the batteries can sustain up to 50 recharges. Propulsion is generated by oil filled and pressure compensated ac motors. There is a single stern screw with two vertical and two horizontal thrusters located fore and aft. The stern screw is encompassed by a circular movable shroud that functions as a directional rudder. The DSRV is highly maneuverable with this system.

The front sphere is the control cockpit that holds the pilot and the copilot. With all the spheres having an internal diameter of 2.3 meters, space is limited, and persons over 6 feet tall have a difficult time moving about. In the control cockpit, one is faced with a large front console containing screens, digital displays, and switches. From here all of the DSRV functions including engineering, navigation, and detection are directed or monitored. U.S. Navy DSRV pilots who have toured it state the layout of the Japanese control cockpit is very similar to the U.S. Navy version. With five external television cameras, the crew can observe the whole DSRV and its surroundings from the TV screens in the cockpit. Contact location and navigation is accomplished through vertical, horizontal, and focused three-dimensional (3D) active sonars. For close-in viewing during mating with a submarine, there is a downward looking periscope.

To mate with a submarine there is a transfer skirt centered amidships below the middle sphere, which is the rescue compartment. This skirt attaches directly over the submarine's hatch. Water is then pumped out of the skirt and the hatches open, allowing transfer of submarine personnel into the rescue compartment. A total of 12 persons can be rescued by the DSRV per trip. This amount is half the capacity of the U.S. DSRV, but since Japanese submarines have a crew complement of 80 versus 120 for U.S. submarines, the number of trips required to rescue an entire crew is comparable. Also located outside of the middle sphere is the mechanical arm, which can be used to clear away debris from around a submarine's hatch or to guide the DSRV down to a disabled submarine following its released emergency signal cable.

The aft sphere is the engineering compartment and contains the propulsion, air conditioning, and electrical plants. It does not receive any oxygen. Oxygen is provided to manned spaces by a 47-liter storage tank. CO_2 removal is done chemically with canisters containing soda lime. Inside air is circulated through the canisters using an electrical fan. With both oxygen and CO_2 scrubbing systems working, the DSRV can support a full complement of rescuees and crew for 13.5 hours. Oxygen and CO_2 monitors are located in the control cockpit. There are emergency air breathing devices (EAB) for all the people embarked on the DSRV and additional oxygen breathing devices (OBA) for the pilots as a toxic atmosphere might be present on the disabled submarine.

DSRV-SUBMARINE RESCUE EXERCISE

Approximately four times a year, JMSDF launches the DSRV from the *Chiyoda* and has it mate with a submarine resting on the bottom of the ocean simulating a disabled unit. The DSRV is also involved in another 30 searching exercises a year. Homeported in Yokosuka, the *Chiyoda* traveled down to Kure for the start of the exercise. The authors boarded the vessel there. The *Chiyoda* then transited about 24 hours through the Inland Sea to reach the exercise site about 60 miles off of southern Kyushu. The sea and weather conditions were excellent with a clear sky and smooth surface. The DSRV was rolled out of its hangar about 8 hours prior to the start of the exercise to undergo launch preparations (Figure 1).

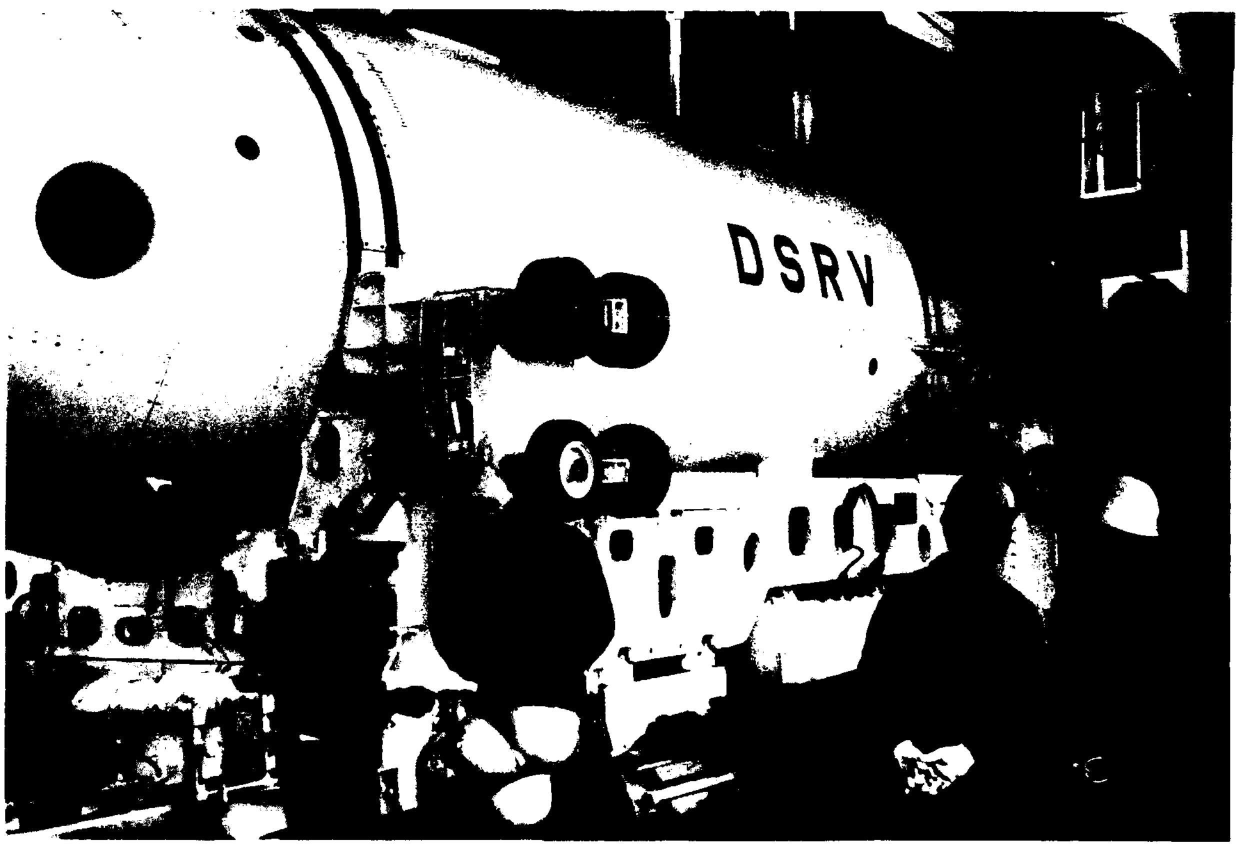


Figure 1. DSRV on carriage cradle being moved out of its hangar.

One of the first things to be done was the loading of two batteries into their bay on the top of the DSRV (Figure 2). Weighing several thousand pounds each, the batteries were recharged and stored in a work space adjacent to the central well. They were then moved from the work space to the central well area using a trolley system. The bridge crane was then used to hoist them up and into the DSRV.

Inside the DSRV, the crew put it through an extensive check-out of all systems. If something was found not working properly and could not be identified from the cockpit, a diagnostic computer could be hooked up to find the trouble. Once the DSRV had been thoroughly checked, the crew then reviewed the details of the planned mission. The exercise site was reached around 2300 and was marked by a green sea flare discharged by a submarine resting on the bottom at approximately 400 feet. The exercise commenced about an hour later with the DSRV and its crew lowered down through the center well resting on its hangar carriage (Figure 3). At about 125 feet, the DSRV reached its launch depth and moved off the carriage. There were TV cameras on the carriage to monitor the launch and recovery of the DSRV. This phase and the mating with the submarine require a great deal of piloting skill and experience.

Consequently, JMSDF has built a DSRV trainer in Yokosuka that uses realistic computer simulation to hone the skills of its DSRV pilots. Built at a cost of $8 million, the trainer consists of a control booth, computer center, and the trainer itself. The trainer has a full-scale mock-up of the control cockpit in the middle of a four legged support structure that can be hydraulically pitched and rolled to simulate the actual movements of the DSRV.

After the DSRV was launched, contact was maintained through an underwater telephone link. Position was tracked by the 3D sonar in the CIC on the *Chiyoda*. The first part of the exercise involved the DSRV mating with the simulated disabled submarine but not transferring any crewmembers off of it. This phase lasted approximately 2 hours. The DSRV returned to the carriage by use of its sonar and directions from the CIC. Upon sighting the carriage, it guided on to a target area using its cameras. On the side of the DSRV, two mechanical hooks opened up to snag the carriage cables. Once snagged, the pilot then lowered the DSRV onto its carriage cradle.

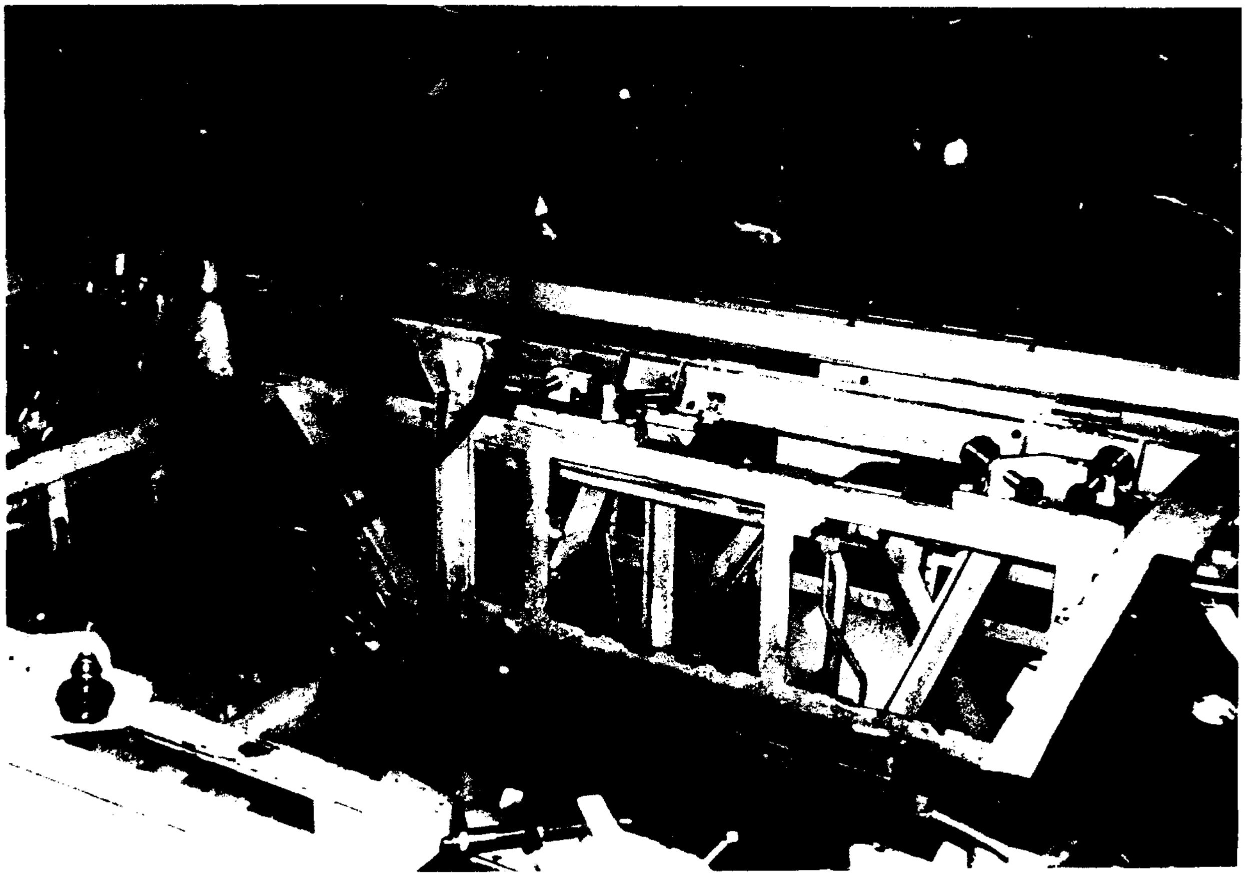


Figure 2. DSRV battery well.

The second phase of the exercise began an hour later after the batteries were replaced. This time submarine personnel were transferred off by the DSRV. It took 6 hours to complete this part of the operation because water had to be pumped out of the skirt after it attached to the submarine hatch and an equivalent amount of water ballast had to be transferred from the DSRV to the submarine as crewmembers came aboard. Upon returning to the *Chiyoda*, the submarine crewmembers exited from the DSRV on the well deck as the transfer of personnel from the DSRV to the DDC was not practiced. They were then sent back to their now surfaced submarine via small boat.

Our overall impression of the exercise was that it was well executed and of great training value to the crew of the *Chiyoda* and the DSRV. The favorable weather was a factor in its success, but the excellent performance of the *Chiyoda* and DSRV crews was the main reason. In a real situation where events never occur as planned, this type of experience is invaluable.

CONCLUSION

The JMSDF submarine rescue ship *Chiyoda* is one of the most modern and highly capable vessels of its type in the world today. Although none of the technology aboard her is revolutionary, the manner in which it was incorporated into the overall design and function of the ship is unique and makes her a model for ship architects in other countries to follow. Currently, JMSDF is reviewing plans to possibly build another *Chiyoda* class ship with a larger DSRV in order to have one on each coast and decrease response time to a disabled submarine

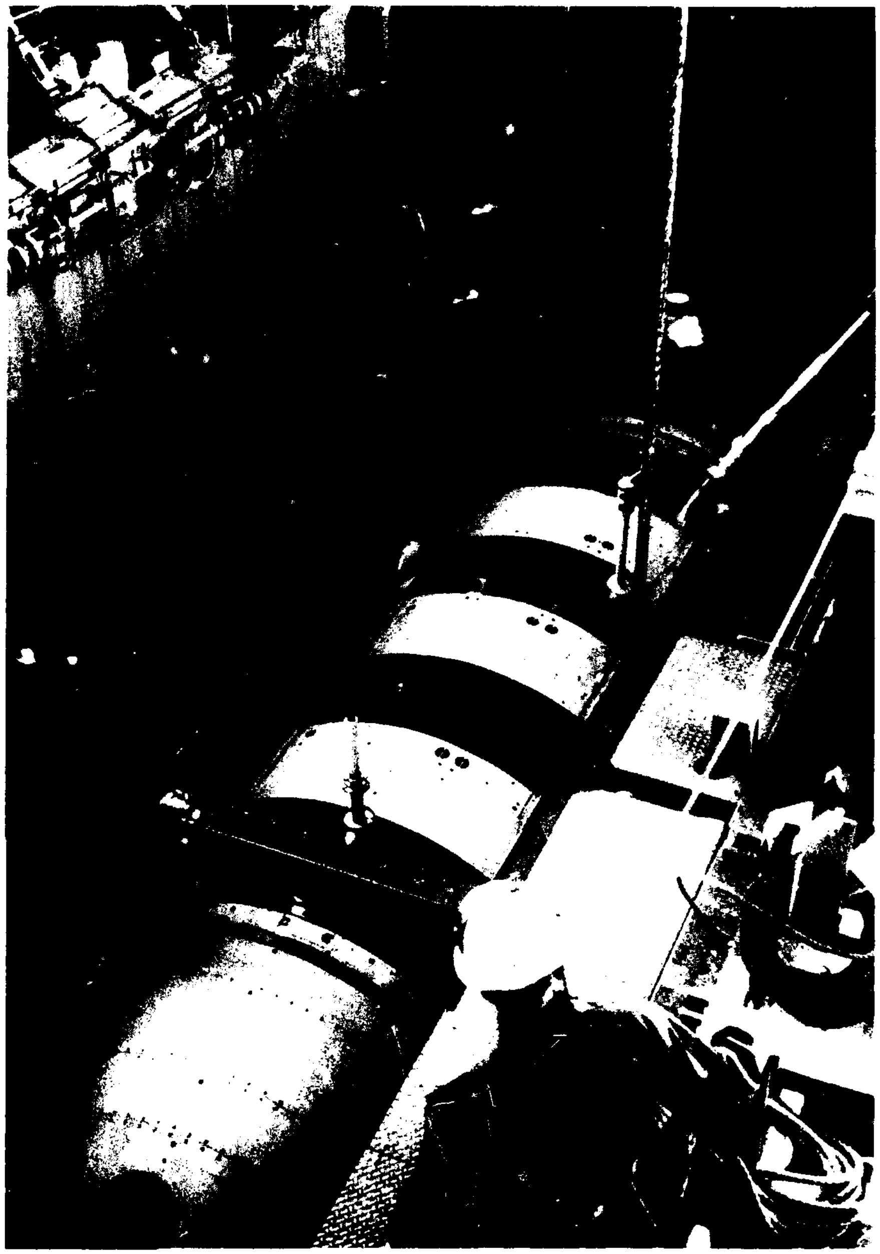


Figure 3. DSRV being lowered through the central well into the ocean.

Robert T. Appleby is presently assigned to Submarine Group Seven, where he serves as the head of Training and Readiness. Commander Appleby attended the University of Washington and graduated with a B.S. degree in chemical engineering in 1971. He was commissioned an ensign in the United States Navy that same year. Previous assignments have included the Deep Sea Diving Officer Curriculum at the Naval Diving and Salvage Training Center in Panama City, Florida; the Saturation Diver Course in San Diego, California; and Commanding Officer of the DSRV support ship USS *Pigeon* (ASR 21).

* U.S. G.P.O.: 1991-282-204:40004