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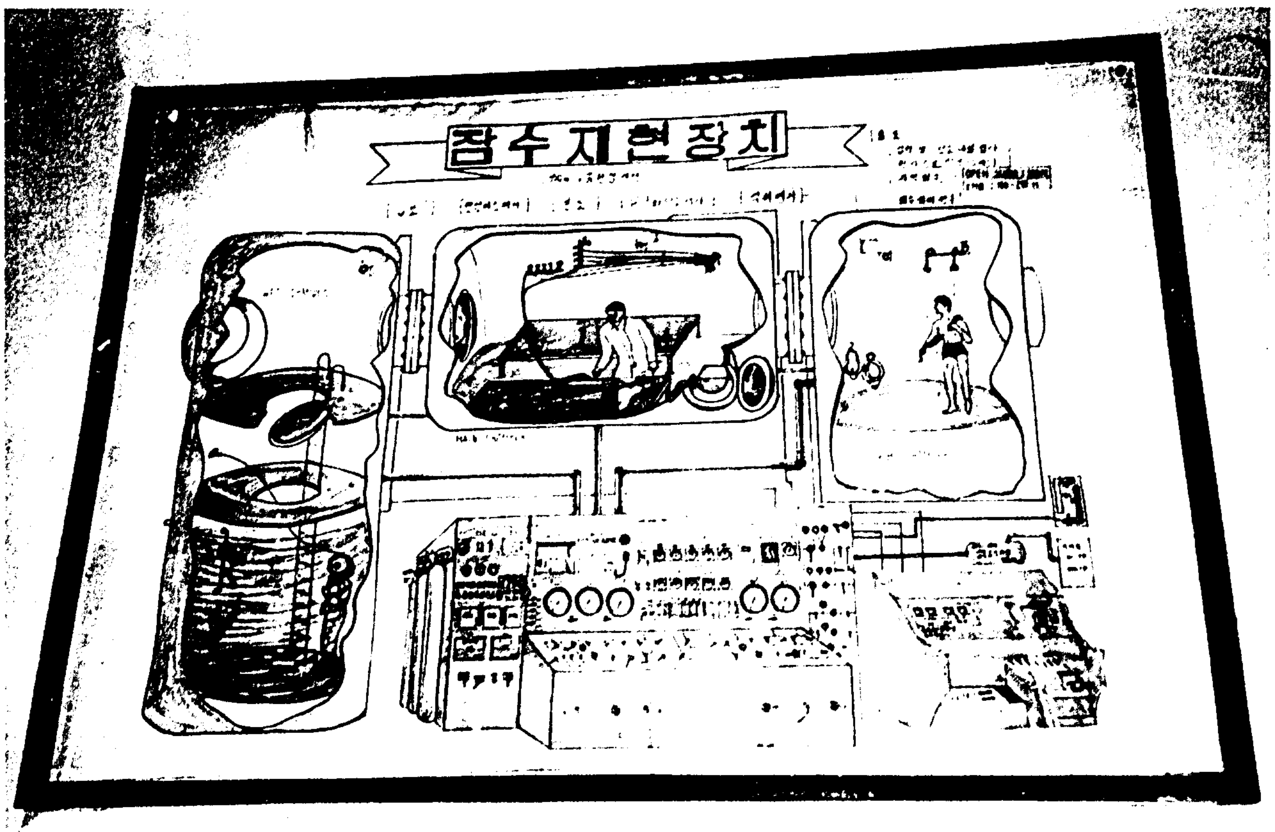

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## *General*



## *Life Science*

Cover: Drawing of the three-compartment saturation dive chamber complex at the Korean Navy Ocean and Underwater Medical Research and Training Center (OUMRTC). The complex consists of a main chamber that houses the living quarters for mission personnel, a subchamber that contains shower and toilet facilities, and a wet diving pot. Courtesy of Neal A. Naito. See his article on OUMRTC on page 115.

SIBRIEFs

Scientific Information Briefs

## SUPERCOMPUTING AND PARALLEL COMPUTING AT FUJITSU AND NEC

### Fujitsu

Fujitsu computers are heavily used in the mainframe world. The company's efforts in large-scale supercomputers are interesting. More than 100 orders have been received for computers in the VP2000 series. The most powerful model, the VP2600, has a maximum performance of about 5 GFLOPS. According to Fujitsu, at least one VP2000 has been installed in Kodak headquarters in Rochester, NY.

What follows is a brief summary of Fujitsu VP2000 series supercomputers. Fujitsu offers four models in this series, as follows:

| Model No. | Peak Performance (GFLOPS) |
|---|---|
| VP2100/10 | 0.5 |
| /20 | 0.5 |
| VP2200/10 | 1.0 |
| /20 | 1.0 |
| /40 | 2.0 |
| VP2400/10 | 2.0 |
| /20 | 2.0 |
| /40 | 5.0 |
| VP2600/10 | 5.0 |
| /20 | 5.0 |

Models designated as /10 have one scalar and one vector arithmetic unit. Models designated as /20 have two scalar and one vector arithmetic units. Models designated as /40 have four scalar and two vector arithmetic units. The /10 and /20 systems are uniprocessor, the /40 is multiprocessor. Their nomenclature is mildly confusing, as the designation /x0 corresponds to the number of scalar rather than vector units, even though the latter determine peak performance.

Fujitsu is deeply interested in multiprocessing; one indication has been their Ministry of International Trade and Industry (MITI) sponsored joint research with NEC and Hitachi, called informally the HPP project, involving four VP2600s each operating as a uniprocessor attached to a very large shared buffer memory. Fujitsu claims that such a large multiprocessor was developed mainly to demonstrate their success with room temperature HMET devices (see below) as the communications drivers between the computers and memory. Nevertheless, using this, a NEC researcher was able to solve a very large system of 32K linear equations in less than 11 hours.

Fujitsu is probably experimenting on a /40 multiprocessor for the VP2600, but has not released any public information about this. Without a /40 for the VP2600, Fujitsu's VP2000 series peak performance (however unrelated to actual performance) will fall short of current competition from NEC as well as new machines from Cray, and perhaps others. In the meantime though, the VP2000 series comes in a variety of colors, including Elegance Red, Future White, and Florence Green.

Peak performance values of the /10 and /20 models in any line are the same, as this is determined entirely by vector processing. Peak performance can easily be computed once the machine cycle time and the maximum possible number of simultaneous floating point operations are known. For example, the VP2400/40 and VP2600 each have cycle times of 3.2 ns. To achieve the advertised 5.0 GFLOPS peak implies 16 simultaneous floating point operations. For the VP2400/40 this requires 8 per vector unit, while for the VP2600/20 16 simultaneous operations are required. Each of Fujitsu's vector units is described as having two arithmetic pipes, but in reality they are more complicated. Each pipe is capable of simultaneously performing both an addition and a multiplication. In addition, the pipes effectively deliver twice (VP2400/40) or four times (VP2600/20) as much data. Thus each pipe on the VP2600/20 can produce four floating point additions and four floating point multiplications per cycle. This is similar to the "superword" concept on the ill-fated Cyber 205. Of course, if a calculation is dyadic, that is, does not involve both a multiplication and addition, then the peak performance will be reduced by 50%.

By studying the performance of VP2000 machines on typical job streams, it has been observed that when the scalar unit is 100% in use, the vector unit is about 50% to 75% busy. Thus, the addition of a second scalar unit can significantly increase throughput, and was presumably Fujitsu's reason for adding it. However, for any single user problem it might not be possible to keep the vector unit constantly busy. Thus, the most practical environment for such a setup would be a computing center or other multiuser job shop, where several user jobs can be run simultaneously. Kyoto University, a typical busy university computing center, will be getting a VP2600/10 soon.

/e asked why they were getting only ne scalar processor. Although the niversity made a very strong case for vo scalar processors, the Ministry of ducation decided (based on budgetary, r other, grounds) to only support the ne scalar processor system. However, is an easy field upgrade to add the econd scalar unit. The choice of a 'P2600/10 rather than a VP2400/40 as a matter of policy; Kyoto has always ried to purchase the fastest machine vailable. It is also possible that they vould like to upgrade eventually to a nultiprocessor 2600 when this is available.

As is the case with most of today's ector supercomputers, data to and from he vector arithmetic units need to pass hrough vector registers. In the VP2600 hese registers have a capacity of 128 KB 64 elements times 256 registers times byte data) but can be concatenated in 'arious ways, for example, as 2048 imes 8 times 8 instead. Thus, the organization of the registers is very lexible. To get data between memory and the vector registers, Fujitsu only provides two load/store pipelines. This could be a bottleneck, although the egister flexibility may alleviate it to a certain extent. Memory to register bandwidth has been criticized in the VP2000 series, but at least one new benchmark, given below, suggests that Fujitsu has been making efforts to deal with this. The computation of interest s that of multiplying large matrices A=B*C, each of which is 4096 by 4096, with real 64-bit floating point components. The source program is written in 100% standard Fortran but s organized to take advantage of the two-pipe structure of the VP2000 architecture in a very clear way. The essential segment of the source program consists of first zeroing the target array.

```
      DO 4000 J=1,4096
       DO 4000 I=1,2048
         A(I,J)=0.0
         A(I+2048,J)=0.0
4000  CONTINUE
```

Then the actual multiplication is as follows.

```
      DO 5000 L=0,1
       DO 5000 J=1,4096
        DO 5000 K=1,4096,4
         DO 5000 II=1,2048
           I=II+(2048*L)
           A(I,J)=A(I,J)+B(I,K)
                 *C(K,J)+B(I,K+1)
                 *C(K+1,J)
     *           +B(I,K+2)*C(K+2,J)
                 +B(I,K+3)*C(K+3,J)
5000  CONTINUE
```

In this case the matrices are large enough that there is significant memory to register to memory traffic. Nevertheless, Fujitsu's FORT77/VP compiler is able to vectorize this effectively and generate 4.8 GFLOPS, 96% of peak performance.

## NEC

I visited this factory in March 1990 and reported on the SX-3 in a previous issue of the *Scientific Information Bulletin* ["NEC's new supercomputer, the SX-3," 15(3), 4-6 (1990)]. Then the only running system had one processor. Now, several one-processor machines are being tested prior to shipment and a two-processor system has been set up and is being debugged. Chief designer Watanabe stated that a one-processor system, depending upon peripheral options, would cost in the neighborhood of $10M. He claimed that the four-processor system will be up in a few months, and we have heard estimates that it will cost roughly $25M.

Peak performance of a uniprocessor system is 5.5 GFLOPS, based on a cycle time of 2.9 ns and 16 simultaneous operations (16/2.5=5.5). The vector unit in such a system consists of one, two, or four sets of vector pipelines. Each vector pipeline set consists of two add/shift and two multiply/logical functional pipelines. Each of the functional pipelines can be operated simultaneously; thus, the arithmetic processor in a uniprocessor system with four vector pipeline sets can execute up to 16 floating point operations per machine cycle. To get near peak performance, all 16 pipes must be kept busy. Data are fed to and exit from the arithmetic pipes to vector registers, with a maximum capacity of 144 KB. It is unlikely that an SX-3 system would be purchased without all four pipes in each processor.

The four-processor system is thus capable of 22 GFLOPS peak, although this assumes that all the data can be kept in the vector registers. To the extent that data must be brought from main memory to the registers, performance may degrade. The bandwidth between memory and the registers depends on the memory hardware technology, and on how the data are arranged in the memory banks, but serious applications must keep data in registers to get good performance. Further, 22 GFLOPS requires 64 simultaneous operations, and this will mean that different operations have to occur simultaneously. Also, unless the user program can be divided up into simultaneous, independent tasks that use the same data in the vector registers, arrays will have to be quite long to absorb the startup penalty of being parcelled out to several processors. The most effective environment for such multiprocessors is a busy multiuser computer center, similar to that for other large multiprocessors. Most computer centers will charge a penalty for single users who want to grab all four processors. Yoshihara also discussed some aspects of this in benchmark calculations earlier this year [H. Yoshihara, "Performance of Japanese supercomputers vis-a-vis Cray computers," *Scientific Information Bulletin* 15(3), 65-74 (1990)].

At least three or four uniprocessor systems have been sold, in Europe. We were not told about sales of two- or four-processor systems.

Users can write Fortran without any special directives. NEC provides an automatic parallelizing and vectorizing compiler option. We had no opportunity to test this. Watanabe showed us results of running 100 by 100 LINPACK (all Fortran), giving performance on the SX-3 model 13 (uniprocessor) and several other supercomputers as shown in Table 1. He also showed some corresponding figures for 1000 by 1000 linear system and for 1024 by 1024 and 4096 by 4096 matrix multiplication. The last two columns correspond to what Dongarra calls "best effort." There are no restrictions on the method used or its implementation. Matrix multiplication runs almost at theoretical peak speed. The large linear system runs at slightly less than 70% of peak, while on the Cray the same calculation runs at just above 80%. The differences are probably associated with bandwidth from memory to the vector registers. Nevertheless, at 3.8 GFLOPS the SX-3 is 80% faster than the Cray. To the best of our knowledge, figures for the NEC and Fujitsu machines are new. We asked Watanabe if the SX-3 four-processor performance would scale up, and he only exclaimed "God knows."

NEC's chip technology is very good. Using ECL, they have crammed 20,000 gates with 70 picosecond switching time onto one chip. We think that this is better than in the United States. A 1,200-pin multichip package can hold 100 such chips and dissipate 3K watts. Packaging, carrier, and cooling technology is about as good as in the United States. NEC claims that they have taken extra care to design in error testing capability and that about 30% of their chip area is associated with diagnostic functions. (This is certainly different from some U.S. manufacturers.) The memory system uses 20-ns, 256-Kbit SRAMs. A memory card can hold 32 MB. Thus a memory cabinet with 32 memory cards has 1 GB. Two peripherals are worth noting. NEC makes a cartridge tape unit (IBM-compatible tapes), fully automated, with 1.2 terabyte capacity. NEC also makes a disk array made of eight byte-interleaved disks. Used as a single disk drive, the disk array has a 5.5-GB capacity. The burst transfer rate is 19.6 MB/s, whereas the sustained transfer rate is 15.7 MB/s.

NEC has begun publication of a newsletter about the SX-3, *SX World*. Interested readers can obtain a copy by writing NEC, 1st Product Planning Department, EDP Product Planning Division, 7-1 Shiba 5-chome, Minato-ku, Tokyo 108-01, Japan. In this their view of supercomputing is stated explicitly

Table 1. Performance Figures for Selected Supercomputers

| Computer | Measured Performance (GFLOPS) for-- | | |
|---|---|---|---|
| | Ax=b LINPACK[a] | Ax=b Best Effort[b] | A=B*C Matrix Mult. |
| SX-3/14 | 0.216 | 3.8 | 5.1[c] |
| Fujitsu VP2600[d] | 0.147 | 2.9 | 4.8[e] |
| Hitachi S-820/80 | 0.107 | | |
| Cray Y-MP8 (8 processors) | 0.275 | 2.1 | |
| Cray Y-MP1 (1 processor) | 0.090 | | |
| Cray X-MP4 | | 0.8 | |

[a]All Fortran, matrix order 100.
[b]May use nonportable program, matrix order 1024.
[c]1024 x 1024
[d]VP2600 model was not specified for the Ax=b figures and was /10 for A=B*C, but both 2600/10 and /20 have the same peak performance, 5 GFLOPS.
[e]4096 x 4096

'he actual performance of a upercomputer is determined by ts scalar performance ... NEC's pproach to supercomputer rchitecture is clear. Our first riority is to provide high-speed ingle processor systems which ave vector processing functions nd are driven by the fastest echnologies, while giving due onsideration to ease of programning and ease of use; we also eek to provide shared memory nultiprocessor systems to furher improve performance.

The SX-3 looks like an exciting :hine that is on a par with the best 'ently available U.S. products. There new U.S. supercomputer from Cray earch nearly ready to be released, vell as perhaps models from Cray nputer Corporation and others, but have no concrete information about ir performance. In its four-processor sion, the SX-3 might be the fastest e-scale supercomputer, but this will entirely dependent on the applica- and the skill of the compiler writers. ii and Tamura ("Capability of curt supercomputers for computational d dynamics," Institute of Space and ronautical Science, Yoshinodai -3, Sagamihara, Kanagawa 229, an) note that "basically the speed of computations simply depend on en the machines were introduced the market. Newer machines show ter performance, and companies ing older machines are going to oduce new machines."--*David K. taner, ONRASIA*

* * * * *

## KANAGAWA SCIENCE PARK

Kanagawa Science Park (KSP) is an urban science park in Kawasaki. It was completed a year ago and is the largest of eight research core parks built or being planned under the Private Sector Resources Utilization Law. The eight are KSP, Eniwa Research Business Park (Hokkaido), 21st Century Plaza (Sendai), Tsukuba Research Support Center, Kurume Techno Research Park (Kyushu), Senri Life Science Center (Osaka), Toyama Advanced Industry Base, and Nagaoka Research Core. Of these, the last three are not yet complete. These research parks provide research and development (R&D), training, conference, and management facilities to promote R&D and new innovative industries in various regions of Japan.

KSP is a very impressive modern facility consisting of two large buildings. It was built for ¥65B ($500M at ¥130=$1). The funds were provided by the Governments of Japan, Kanagawa Prefecture, and Kawasaki. The Japanese Government monies came from the Ministry of International Trade and Industry (MITI). The research park is owned by KSP Inc. (19%), Tobishima Corp. (30%), Nippon Life Insurance Co., Meiji Mutual Life Insurance Co., and Nippon Landic Co. (about 17% each). The facility serves four primary functions: (1) to lease space to established companies to set up their research facilities, (2) to provide laboratories and equipment for new or other companies to conduct research or to test concepts and ideas (Incubation Business), (3) to provide a very comprehensive materials characterization laboratory, and (4) to conduct its own basic research. In addition, KSP has a hotel and a number of technical and office support services. Laboratories of the established companies are housed in the larger of the two buildings, a 12-story structure. NEC, Fuji Xerox, and Fujitsu are a few of the companies with laboratories here.

The Materials Characterization Laboratory is part of the Kanagawa High-Technology Foundation, which was formed by Kanagawa Prefecture to support and provide service to industry in the region. This laboratory is large and extremely well equipped. Our hosts said it was the best in Japan. The equipment in their surface characterization facility includes a Rutherford backscattering spectrometer, an X-ray photoelectron spectrometer, scanning Auger spectrometer, Fourier transform infrared spectrophotometer, and two electron probe microanalyzers. In addition, there is equipment for instrumental elemental analysis, thermal analysis, environmental testing, material structure analysis, and mechanical property testing.

Their in-house research laboratories are part of the Kanagawa Academy of Science and Technology, which was established in 1989. At present, there are three research laboratories; three more will be established next fiscal year. They plan ultimately to have 10 laboratories. Each laboratory has a staff of seven to eight. In addition, they accept about 10 researchers from industry to be trained in research and a smaller number of graduate and undergraduate students. They presently have four foreign researchers from Korea and Taiwan, and next year one of the laboratories will have an American researcher. I visited the Molecular Spectroscopy Laboratory and the Biology Laboratory. The former is headed by Dr. Hiroo Hamaguchi. Some of the current work is on time-resolved Raman spectroscopic study of photochemical reactions and the development of an ultrasensitive multichannel Raman system. The Biology Laboratory is headed by Dr. Toshihiro Akaike; in his absence, Dr. Chia-Wun Chang briefed us on the group's work on molecular recognition membranes. They are working on a liver cell mimic and are designing membranes to be used as molecular sensors. Both laboratories are spacious and extremely well equipped, but because they are only a year old, there were no major accomplishments to report. However, the researchers are all young and enthusiastic, and I believe they will accomplish much in the near future. The third laboratory is headed by Dr. Norimasa Iida and is conducting research in support of the development of a two-cycle ceramic methanol engine.

In commemoration of the first anniversary of the opening of KSP, an international forum was held on 24 October 1990. The forum was titled "Japan and the World in the 21st Century: Road to Creating a New Scientific and Technological Civilization and Japan's Role." The invited speakers were Gavriil Popov, Mayor of Moscow; Prof. Rustum Roy of Pennsylvania State University; and Keiichiro Hirata, chairman of the Japan Comprehensive Development Council (Sogo Kenkyu Kaihatsu Kai). Prof. Emeritus Shigeto Tsuru of Ishibashi University chaired a panel discussion with the speakers.

In conclusion, KSP is truly an impressive and very well equipped research and development facility. There is a good mix of laboratories, conference rooms, meeting halls, and support services to encourage good interaction among researchers from various companies and organizations. Because the KSP laboratories are so new, there isn't much in-house progress to report. Also, I did not visit any of the laboratories of the established companies, so I cannot comment on how they interact with each other. What KSP does tell us is that the Japanese have ample resources and are willing to invest a great deal of that into encouraging R&D and developing new high-technology industries.--*Sachio Yamamoto, ONRASIA*

* * * * *

# DEQSOL AND ELLPACK: PROBLEM-SOLVING ENVIRONMENTS FOR PARTIAL DIFFERENTIAL EQUATIONS

*A number of integrated problem-solving environments for the solution of partial differential equations have been developed in recent years. Such systems permit very-high-level descriptions of the mathematical problem and its solution algorithm. These descriptions are translated into efficient Fortran programs that produce solutions in both tabular and graphical forms. In this paper we compare and contrast two such systems: DEQSOL, a Japanese project, and ELLPACK, an American project. For each system, we present a brief history, describe its capabilities, and present several examples of its use.*

by Ronald F. Boisvert and David K. Kahaner

## INTRODUCTION

The numerical solution of partial differential equations (PDEs) was one of the earliest applications of electronic digital computers, and it remains the source of many challenging computational problems today. Such problems can be found in every scientific discipline. They range from computing the currents and fields in very large scale integration (VLSI) devices to determining the flow about an airfoil.

Due to the importance of mathematical models based on PDEs, and their general resistance to analytical treatment, the numerical solution of PDEs has been the focus of a great deal of research over the years. In spite of great algorithmic advances that have been achieved, very few general-purpose software packages for solving PDEs have appeared, and those that have tend to concentrate on very narrow problem areas. General-purpose PDE software is just extraordinarily difficult to build. This is due to difficulties in designing both solution algorithms and user interfaces.

Since PDE problems exhibit such a wide range of behaviors, no software package built upon a single numerical method can succeed. As a result, the internal structure of such a solver must be very sophisticated. PDE problems cannot be expressed naturally in an algebraic language such as Fortran, which remains the computer language of choice for scientific computation. Because of this, the user interface must either be very complex, or a new high-level language must be designed and implemented for describing PDE problems and their solution. A traditional Fortran subprogram cannot do this job; instead, an integrated problem-solving environment must be designed. Such systems must be designed by computer scientists in close collaboration with the numerical analysts who develop efficient methods and physical scientists and engineers who need to use them.

The potential payoff for the development of such systems is great. Solving PDE problems by writing Fortran code is a very time-consuming and error prone task that often duplicates work of many previous programmers. Scientists and engineers may not be aware of the most appropriate algorithms to use, and hence the programs produced by these efforts may well be very slow or even produce erroneous results. Such difficulties are increased in the face of vector and parallel processing computers, which are very difficult to make efficient use of by the casual user. Using software parts from existing program libraries can alleviate some of these problems, but this still requires much low-level programming effort, even to solve easy problems.

A number of researchers have made efforts to produce integrated problem-solving environments for the solution of PDEs (see the short bibliography at the end of this article). Two major systems that remain active foci of research are DEQSOL, a Japanese project, and

ELLPACK, an American project. These systems have many overt similarities. Both are preprocessor based; they read very-high-level descriptions of PDE problems and solution algorithms and produce a Fortran 77 program as output. When linked with their respective run-time libraries and executed, the generated programs will solve the given PDE problem. Both support graphical output. Linear second-order steady-state PDE problems in fairly general domains in two or three spatial dimensions are the most straightforward to solve using each system. Nonlinear problems, time-dependent problems, and systems of equations are also solvable, but doing so requires more of the user. There are, of course, many differences between DEQSOL and ELLPACK. In what follows we will try to give you a feeling for these two projects in more detail.

To illustrate the use of the two packages, we will present programs designed to solve two simple problems. (Note that $\nabla^2$ represents the Laplacian in cartesian coordinates, i.e., $\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial y^2$.)

*Problem 1*: Stress distribution in a thin plate containing a hole.

The domain for this problem is the square (-2,2)x(-2,2) with a circle of radius 1 removed from its center. The stress function satisfies

$$\nabla^2\phi = -2$$

on the plate, with $\phi=1$ at the outside edge and $\phi=0$ at the edge of the hole. Due to symmetry we need only consider the region $x>0$, $y>0$, with

$$\partial\phi/\partial n = 0, \text{ for } x=0 \text{ and } y=0$$

*Problem 2*: Thermal diffusion problem.

Find the function T(t,x,y) that satisfies

$$\partial T/\partial t = a\nabla^2 T$$

on the rectangle (0,1)x(0,1.2) for $0<t<1$ with initial condition

$$T(0,x,y) = 100\exp\{-[(x-0.5)^2 + y^2]\}$$

and boundary conditions

$$\begin{array}{ll} \partial T/\partial n = 0 & \text{for } x=0 \text{ and } x=1 \\ T = 200 & \text{for } y=0 \\ \partial T/\partial n - \lambda T = \mu & \text{for } y=1.2 \end{array}$$

for the constants $a=0.62$, $\lambda=0.8$, and $\mu=50$.

## DEQSOL

The DEQSOL project, headed by Dr. Yukio Umetani, is based at the Central Research Laboratory of Hitachi Ltd. The laboratory employs about 1,300 people in a heavily wooded park-like setting about 30 minutes by local train from central Tokyo. Contributions to the system have also been made by staff at Hitachi VLSI Engineering Ltd. From the outset, the goal of the DEQSOL project was to develop an easy-to-use system in which practical PDE models could be expressed and solved while taking the best advantage possible of the supercomputer performance possible using Hitachi's vector processors.

The project began in 1980, with language design. Umetani set to work on DEQSOL after many years developing vectorizing compilers for Hitachi. Thus he had a language designer's understanding of how user Fortran needed to be structured in order for it to compile into efficient vectorizable code. He also felt that Fortran was too low level a language to allow scientists to express concepts that would vectorize and parallelize easily, and that a higher level language would not only make it easier for scientists to develop algorithms but also make it easier for compilers to generate efficient code. The earliest version (1982) only dealt with two-dimensional diffusion problems on rectangular grids, but by 1983 three-dimensional problems and more general PDEs could be solved. In 1986 a "Basic System" was officially available as a product from Hitachi. This included the ability to solve linear partial differential equations using either finite difference or finite element methods. A separate "Enhanced System" with many additional features was released in 1987. Solution functions to support the solution of fluid flow problems were added to the Enhanced System in 1989 and 1990.

The DEQSOL project currently has more than 20 people involved in research, development, and commercialization. DEQSOL runs on Hitachi's M680 and S810 supercomputers, for which approximately 70 copies of the package have been sold, all in Japan. Umetani claims that it would be very easy to modify the DEQSOL source to generate efficient Fortran for other vector computers, but that it would require more work to take advantage of multiprocessors.

DEQSOL's Basic System is designed to automatically solve linear elliptic problems on fairly general two- and three-dimensional domains with general linear boundary conditions. The system easily handles problems with material interfaces. Nonlinear problems and time-dependent problems may also be solved, but the user must program an iterative scheme to solve the problem. This is quite natural to do in DEQSOL.

The language syntax allows differential equations to be expressed in a natural mathematical syntax. Scalar, vector, and tensor variables are supported, and differential operators such as first partial derivatives (DX, DY, DZ), the normal derivative (NGRAD), the Laplacian (LAPL), the divergence (DIV), and the gradient (GRAD) are defined on them. A variety of declaration statements allow users to specify the problem geometry (e.g., DOMAIN, POINT, REGION, FREGION), the finite difference or finite element mesh (MESH), problem variables and constants (e.g., VAR, VEC, CONST), initial conditions (ICOND), and boundary conditions (BCOND). The solution algorithm is specified in the SCHEME block, which comprises the executable portion of a DEQSOL program.

Both finite difference (FDM) and finite element (FEM) discretizations are supported. For finite differences, boundaries must be made up of straight lines (or planes in three dimensions) parallel to the coordinate axes. Second-order accurate differences are supported for general linear differential operators. For finite elements, boundaries in two dimensions (2D) may be made up of straight lines, circular arcs, or cubic splines. In three dimensions (3D), boundaries can be built using cubic or tetrahedral parts. The problem is discretized using the Galerkin method on linear triangular elements.

Graphical output is available via the SGRAF postprocessor. SGRAF allows users to obtain output in various forms including contour plots, surface plots, vector plots, and intensity plots. Plots of domains with superimposed grids may also be obtained; color output is supported.

DEQSOL's Enhanced System provides a number of additional capabilities in geometry processing, types of equations handled, and numerical techniques supported. Among these improvements are:

- A boundary-fitted coordinate transformation method (BFM) permits general domains to be automatically mapped to rectangular ones where FDM techniques may be applied.

- An interface to a computer-aided design (CAD) system allows easier description of complex domains for the FEM.

- Coupled systems of elliptic equations may be expressed and solved automatically.

- Language enhancements allow block iteration schemes to be easily expressed.

- Staggered grids and up-wind differencing may be selected for the FDM.

- Higher-order basis functions and up-wind techniques may be used in the FEM.

The DEQSOL preprocessor is written in Pascal and generates Fortran 77 code. The form of the user interface to DEQSOL is illustrated by the following DEQSOL solutions to the two sample problems.

*Problem 1*: Stress distribution in a thin plate containing a hole.

The problem is solved by Galerkin finite element method on linear triangular elements. A nonuniform triangular mesh is defined. The linear equations are solved using Gaussian elimination for banded matrices.

```
PROG POIS;
METHOD FEM;
DOMAIN X=[0:2], Y=[0:2];
POINT  A=(0,2), B=(2,2),
       C=(2,0), D=(1,0),
       E=(0.7071,0.7071),
       F=(0,1),
       I1=(0.5,0.8660),
       I2=(0.8660,0.5);
REGION AB=LN(A,B), BC=LN(B,C),
       CD=LN(C,D), AF=LN(A,F),
       DE=ARC(D,I2,E),
       EF=ARC(E,I1,F),
       BE=LN(B,E),
       ABEF=QUAD(AB,BE,EF,AF),
       CBED=(CB,BE,ED,CD);
FREGION ABEF+CBED;
BOUND  AB+BC+CD+DE+EF+AF;
MESH   AB=D(A,8), BE=D(B,7),
       EF=D(E,5), AF=D(A,5),
       BC=D(B,8), CD=D(C,5),
       DE=D(D,5), ABEF=AS(A,B),
       CBED=AS(C,B);
VAR    PHI;
BCOND  PHI=0         AT AB+BC,
       PHI=1         AT DE+EF;
       NGRAD(PHI)=0 AT CD+AF;
SCHEME;
  SOLVE PHI OF LAPL(PHI) + 2 = 0
    BY 'GAUSS';
  PRINT X; PRINT Y; PRINT PHI;
    SAVE PHI;
END SCHEME;
END;
```

*Problem 2*: Thermal diffusion problem.

The problem is solved using a finite difference spatial discretization and a backward Euler implicit time step. At each time step the implicit equations are solved by a conjugate gradient iteration with preconditioning by an incomplete LU factorization.

```
PROG   THERM;
METHOD FDM;
DOMAIN X=(0:1), Y=(0:1.2);
TDOM   T=(0:1);
MESH   X=(0:1:5), Y=(0:1.2:6),
       T=(0:1:0.02);
VAR    TEMP, TOLD;
REGION LEFT=(0,*), RIGHT=(1,*),
       BOTTOM=(*,0),
       TOP=(*,1.2), TOTAL=(*,*);
ICOND  TEMP=100*EXP(-(X-0.5)**2
       -Y**2) AT TOTAL;
BCOND  DX(TEMP)=0 AT RIGHT+LEFT,
       TEMP=200 AT BOTTOM,
       DY(TEMP)=LM*TEMP+MU AT
       TOP;
SCHEME;
  ITER NT UNTIL NT GT 50;
    TOLD = TEMP;
    SOLVE TEMP OF (TEMP-TOLD)/DLT
    = A*LAPL(TEMP) BY 'ILUBCG';
    PRINT TEMP EVERY 10 TIMES;
  END ITER;
END SCHEME;
END;
```

The Fortran code to discretize the problem is generated by the DEQSOL preprocessor. This code is expressed in such a way as to be easily vectorized by Hitachi vector processors. Solution of linear equations in implicit equations (the SOLVE statement) is done by calling library routines; several methods are available, including banded Gauss elimination and preconditioned conjugate gradient iteration. The library routines are also highly vectorized. DEQSOL does not have any explicit method to allow the user to indicate parallelism in the problem description, but Umetani and other Hitachi colleagues are also working on a new programming language PARAGRAM that does. At the moment DEQSOL and PARAGRAM are independent projects.

Considerable effort has been expended to apply DEQSOL to realistic mathematical models in a variety of application areas. Some of these include (the number of spatial dimensions and the solution method are given in parentheses):

- impurity distribution analysis in LSI process CAD (2D-FDM)
- device simulation of well layer in LSI (2D-FDM)
- air cooling analysis for a baseball dome (2D-BFM)
- electric field analysis of sheet resistor (2D-BFM)
- analysis of flow past an automobile (2D-FEM)
- magnetic field analysis of Josephson junction device (2D-FEM)
- field potential analysis of electron beam tube (2D-FEM)
- magnetic analysis for Japanese Institution of Electrical Engineers (JIEE) model (3D-FDM)
- flow analysis of chemical vapor deposition (3D-FDM)
- magnetic field analysis of a disk head (3D-FEM)

Some of the models were quite complex, requiring hundreds of lines of DEQSOL input. The resulting Fortran programs were highly vectorized (more than 90% of the loops vectorized in each case).

In addition, DEQSOL has been evaluated by its authors for several application problems for which hand-coded Fortran programs exist. DEQSOL programs were 1/10th the size of these hand-coded Fortran programs, illustrating the potential for increased programmer productivity using DEQSOL. In some cases the DEQSOL programs ran faster than the hand-coded programs due to the high level of vectorizaion in the DEQSOL-produced codes.

An example of a moderately difficult problem that is easily expressed using DEQSOL's Enhanced System follows. The model is of viscous (low Reynold's number) incompressible fluid flow from a channel to a larger cavity in two dimensions (see Figure 1).

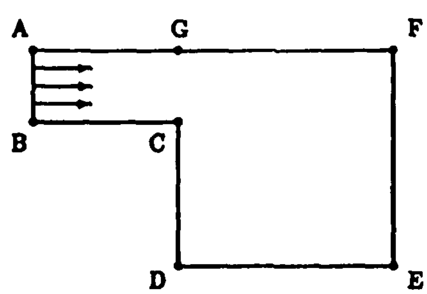


Figure 1. Domain for Stokes problem.

The equations representing the velocity vector (u,v) and the pressure p are the steady-state Stokes equations,

$$-\partial p/\partial x + \nabla^2 u = 0$$

$$-\partial p/\partial y + \nabla^2 v = 0$$

$$\partial u/\partial x + \partial v/\partial y = 0$$

The DEQSOL program for this problem, shown below, illustrates the ease with which simultaneous linear time-independent equations may be solved in DEQSOL. Note that DEQSOL assumes no-flux boundary conditions for all variables where boundary conditions are left unspecified. It also illustrates how finite element basis functions may be selected (linear for p, quadratic for u and v). A triangular mesh is automatically generated by DEQSOL; users control the meshing by specifying boundary nodes in the MESH statement. The phrase CF=R(C,3,1.1) inserts three nodes on the segment DE such that the ratio of distances between successive points is 1.1 (geometric series). The function D is used to specify equispaced nodes.

```
PROG    STOKES;
METHOD  FEM;
DOMAIN  X = [0:50], Y=[0,30];
POINT   A = ( 0,30), B = ( 0,20),
        C = (20,20), D = (20, 0),
        E = (50, 0), F = (50,20),
        G = (50,30), H = (20,30);
REGION  AB = LN(A,B),
        BC = LN(B,C),
        CD = LN(C,D),
        DE = LN(D,E),
        EF = LN(E,F),
        FG = LN(F,G),
        GH = LN(G,H),
        AH = LN(A,H),
        CF = LN(C,F),
        CH = LN(C,H),
        ABCH = QUAD(AB,BC,CH,AH),
        CFGH = QUAD(CF,FG,GH,CH),
        CDEF = QUAD(CD,DE,EF,CF);
```

```
FREGION ABCH + CFGH + CDEF;
BOUND   AB + BC + CD + DE + EF
        + FG + GH + AH;
MESH    AB = D(A,2), CH = D(C,2),
        FG = D(G,2),
        DE = R(D,3,1.1),
        AH = R(A,2,0.9),
        CD = R(D,3,0.9),
        GH = R(H,3,1.1),
        BC = R(B,2,0.9),
        EF = R(E,3,0.9),
        CF = R(C,3,1.1),
        INSIDE=AUTOSIM;
VAR     U, V, P;
ELMTYPE LINEAR FOR P
        QUADRIC FOR U, V;
BCOND   U = -0.04*(Y-20)*(Y-30)
        AT AB,
        U = 0 AT BC + CD + DE
        + AH + GH,
        V = 0 AT AB,
        V = 0 AT BC + CD + DE
        + AH + GH,
        P = 0 AT EF + FG;
SCHEME;
  SOLVE U, V, P OF
    -DX(P) + LAPL(U) = 0
    -DY(P) + LAPL(V) = 0
    DX(U) + DY(V) = 0 BY 'GAUSS';
  PRINT U, V, P;
END SCHEME;
END;
```

A still more complex example is presented in the Appendix.

DEQSOL remains under active development at Hitachi. Continuing effort is being expended to make the user interface both more flexible and also easier to use and to build databases of problems and solutions that will be useful as templates for users. Further work in workstation-mainframe interaction and in the application of DEQSOL to parallel computers is also underway.

## ELLPACK

The ELLPACK project began in 1975 as a cooperative research project among Purdue University, the University of Texas at Austin, Yale University, and others. Headed by Professor John Rice of Purdue, the aim was to develop a research tool to evaluate and compare mathematical software for solving elliptic PDE problems. The idea was to create a system where individuals could contribute software modules that either completely solved a class of PDE problems or performed one of the major steps in a numerical method, e.g., discretization or linear algebraic equation solution. All the software would operate in a rigidly defined environment. Some 40 researchers and programmers have been associated with the project in one form or another since its outset. The development of the system was supported by the National Science Foundation, the Department of Energy, the Office of Naval Research, as well as many of the participants' institutions.

Considerable efforts to make the system easy to use led to the development of the ELLPACK language and its preprocessor at Purdue. The resulting flexibility and ease-of-use of the system has made it a popular tool not only for the comparison of methods but also for education and actual problem solving. The first release of the ELLPACK occurred in 1978; the system was completely redesigned and re-released in 1984.

The ELLPACK system routinely solves linear elliptic equations with general linear boundary conditions in two and three dimensions. Arbitrary two-dimensional domains may be specified by describing the boundary in parametric form; holes and slits in the domain are allowed. Only rectangular boxes are supported in three dimensions. Unequally spaced rectangular grids are supported.

The equation to be solved, the domain, and the boundary conditions are expressed using a natural mathematical syntax. The reserved word U is defined to be the unknown function, and UX, UY, UZ, UXX, UXY, and so on are its partial derivatives. Expressions use Fortran syntax, and any Fortran or user-defined functions may be part of an expression.

Users specify the solution algorithm by simply naming a DISCRETIZATION module and a linear equation SOLUTION module or by naming a combination discretization-solution module (called TRIPLE modules, these are used to implement fast solvers for special problems). Other types of modules implement various utility tasks such as computing the eigenvalues of discretization matrices, displaying their non-zero structure, or reordering their rows and columns to provide for more efficient solution. Many problem-solving modules are available: 11 DISCRETIZATION, 18 SOLUTION, 13 TRIPLE, and 18 other. These may be easily combined in many ways to provide alternate PDE solution algorithms. Functions U(X,Y), UX(X,Y), etc. are automatically available after SOLUTION or TRIPLE modules execute to evaluate the solution or its derivatives. Both tabular and graphical output are supported. Graphics primitives are defined that allow ELLPACK to easily interface to a wide variety of graphical display systems.

One feature that considerably extends the range of applicability of ELLPACK is the fact that users may insert arbitrary Fortran code in ELLPACK programs. This allows expert users of the system to solve nonlinear problems, time-dependent problems, and systems of equations by designing iterations in which the basic operation is the solution of a single linear elliptic problem.

The form of the user interface to ELLPACK is illustrated by the following ELLPACK solutions to the two sample problems.

*Problem 1*: Stress distribution in a thin plate containing a hole.

The problem is solved using finite element collocation on piecewise cubic rectangular elements with one continuous derivative. The generated equations are solved by Gaussian elimination for banded matrices.

```
EQUATION.   UXX + UYY = -2
OPTION.     CLOCKWISE=.TRUE.
BOUNDARY.   U = 0 ON LINE 0,2 TO
            2,2 TO 2,0
            UY = 0 ON LINE 2,0 TO
            1,0
            U = 1 ON X=COS(PI*T),
            Y=SIN(PI*T) FOR T=0 TO
            0.5
            UX = 0 ON LINE 0,1 TO
            0,2
GRID.       8 X POINTS 0 TO 2
            8 Y POINTS 0 TO 2
DISCRETIZE. COLLOCATION
SOLVE.      BAND GE
OUTPUT.     TABLE(U)
         PLOT(U)
END.
```

*Problem 2*: Thermal diffusion problem.

The problem is solved using a finite difference spatial discretization and a backward Euler implicit time step. At each time step the implicit equations are solved by a conjugate gradient iteration with Jacobi preconditioning. Note that U(X,Y) is, by definition, the most recent solution of the PDE problem. SET (U = U0) initializes U(X,Y) to be the function U0(X,Y) defined below.

```
GLOBAL.
            COMMON /PARAM/ ADT,
            ALAM, AMU
EQUATION.   UXX + UYY - ADT*U =
            -ADT*U(X,Y)
BOUNDARY.   UX = 0    ON X = 0
                      ON X = 1
            U = 200   ON Y = 0
            UY - ALAM*U = AMU
                      ON Y = 1.2
GRID.       5 X POINTS
            6 Y POINTS
TRIPLE.     SET (U = U0)
FORTRAN.
            ALAM = 0.8
            AMU  = 50.0
            A    = 0.62
            DT   = 0.02
            ADT  = 1.0/(A*DT)
            DO 100 ITER=1,50
DISCRETIZE. 5-POINT STAR
SOLVE.      JACOBI CG
FORTRAN.
            IF (MOD(ITER,10)
            .EQ. 0) THEN
OUTPUT.       TABLE(U)
FORTRAN.
            ENDIF
              I1LEVL = 0
 100        CONTINUE
SUBPROG.
            FUNCTION U0(X,Y)
            U0 = 100.0*EXP(-(X
            -0.5)**2-Y**2)
          RETURN
          END
END.
```

The entire ELLPACK system, including the preprocessor, is written in portable Fortran 77 and runs on nearly every type of computing device that supports Fortran. ELLPACK is an "open system"; a complete internal specification for the system is found in Rice and Boisvert (1985). It was designed to be easy to modify and enhance, and others are free to do so. ELLPACK is distributed in source form for a nominal charge by the Purdue University Research Foundation. Since 1984 about 100 copies have been distributed in the United States and about 60 outside the United States. Proceeds from the distribution help to maintain a small staff that provides a nominal level of support for the system at Purdue.

The ELLPACK system is being used at Purdue as the basis for ongoing research in the design of problem-solving environments for scientific computing. Three such systems are currently under development: XELLPACK, Parallel ELLPACK, and Elliptic Expert.

The XELLPACK project has two goals: (1) to develop an interactive, graphical interface to ELLPACK for the X11 window system; and (2) to adapt the internal operation of the system to facilitate distributed computation. In XELLPACK problem-solving modules run as a separate processes, possibly on different machines. The X11 interface provides menu-based dialogue, with interactive grid generation and function plotting. XELLPACK is expected to be available for external distribution by early 1991.

The goal of the Parallel ELLPACK (//ELLPACK) project is to design a uniform programming environment for implementing parallel multiple instruction/multiple data (MIMD) PDE solvers. A new user interface based upon X11 facilities for composing, editing, and executing //ELLPACK programs is being developed. These include graphics-oriented tools to specify the problem domain, to generate a grid, to decompose it for parallel execution, and to visualize the solution and data about the performance of parallel solution algorithms. General three-dimensional domains will be supported in this version. The user interface runs on an X11 workstation, with the PDE solution modules executing on a parallel machine connected through a wide bandwidth network. Specialized problem-solving modules for the NCUBE have been developed; modules for other parallel machines such as the SEQUENT and ALLIANT are planned.

In spite of its high-level user interface, ELLPACK users still face many difficulties when using the system. An example of this is the selection of modules to solve the PDE problem. ELLPACK's wealth of problem-solving modules admit 1,147 distinct solution paths. For the casual user choosing a single valid path is difficult, while selecting the best method is nearly impossible. A rule-based expert system, called Elliptic Expert, is being developed to provide advice to users on problem formulation, algorithm and machine selection, and solution assessment. A prototype system based upon the OPS5 system is currently operational. A related system, called ATHENA, is being developed to provide expert advice to users of //ELLPACK. Plans for this system make extensive use of a database of performance profiles detailing the performance of solution algorithms for benchmark problems on available parallel machines.

## CONCLUSIONS

DEQSOL and ELLPACK represent two successful approaches to the design of PDE problem-solving environments, each with its own domain of applicability.

The development of DEQSOL has been driven by the desire to solve PDE systems resulting from relatively complex mathematical models. Problems with challenging features such as those in fluid mechanics or problems with material interfaces are straightforward to express. The expression of solution algorithms for nonlinear, time dependent, and systems of equations is also more naturally achieved in DEQSOL. Much attention has been paid to obtaining high performance of the generated code on the Hitachi vector processor.

ELLPACK is better suited as an experimental tool such as in education, in solving small prototype problems, and in evaluating the performance of software modules. Simple linear problems are more succinctly expressed in ELLPACK. Its large library of problem-solving modules allows users to easily experiment with a variety of numerical methods and assess their performance. Its open system aspects allow users to easily modify the system for their own use, allowing the system to become a basis for experimental research in problem-solving environments for prototype mathematical modeling problems.

The reasons for the chosen emphasis in each of these projects arise from the driving forces behind them. DEQSOL, being a commercial product, must be useful to potential customers who need to solve realistic problems. Since DEQSOL is developed by a computer manufacturer, perhaps there is little motivation to make it available for systems other than Hitachi's own. In fact, it can be claimed that it is necessary to keep the system closed to protect the company's investment. Unfortunately, this means that one group must be relied upon to follow all new developments in numerical methods for PDEs and to get them correctly implemented--a very difficult task. Further, there is mounting evidence that open systems benefit everyone in the long run, including the developers. ELLPACK, on the other hand, was developed as a university-based research project under government support. Since there are no real "paying customers," there has been little motivation to demonstrate the performance of the system on difficult real-world applications, or to add features that would make the solution of such problems easier. Unfortunately, this has restricted the practical applicability of the system. The system's open, extendable nature follows from the desire to evaluate the performance of PDE software on model problems where it is necessary to be able to easily import external software. Portability is also crucial to reduce maintenance and to make the fruits of the research available to as wide an audience as possible. These properties are also necessary if the system is to be successful as the basis for ongoing research in the design of problem-solving environments.

Surely, if the state of the art in mathematical problem-solving environments is to be advanced, there is room for efforts of the types embodied by both DEQSOL and ELLPACK.

## ACKNOWLEDGMENTS

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## DISCLAIMER

Certain commercial products are identified in this report in order to adequately describe the DEQSOL and ELLPACK systems. Identification of these products does not imply recommendation or endorsement by the National Institute of Standards and Technology, the Office of Naval Research, or any other agency of the U.S. Government, nor does it imply that the identified products are necessarily the best available for the purpose.

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# Appendix

## DEQSOL ENHANCED SYSTEM

The following illustrates the use of : DEQSOL Enhanced System for : solution of a more realistic model. particular, we present a DEQSOL ogram for the solution of the non- ear time-dependent Navier-Stokes uations for incompressible viscous iid flow. The equations to be solved e

$$\partial u/\partial t = -u\ \partial u/\partial x - v\ \partial u/\partial y - (1/\rho)\partial p/\partial x + \nabla^2 u$$

$$\partial v/\partial t = -u\ \partial v/\partial x - v\ \partial v/\partial y - (1/\rho)\partial p/\partial y + \nabla^2 v$$

$$\partial u/\partial x + \partial v/\partial y = 0$$

iere (u,v) is the velocity vector, p is e pressure, and $\rho$ is the (constant) insity. The equations are defined in a ctangular region (0,22)x(0,10) with a rcular hole of radius 1 centered at ,5). The hole could represent an ›struction in a pipe; the boundary ›nditions are chosen to model fluid ›wing in from the left (see Figure 2).

In order to reduce discretization error in the numerical processing, it is desirable to transform the system to the following equivalent conservative form

$$\partial u/\partial t = -\partial[u^2]/\partial x - \partial[uv]/\partial y - 1/\rho\ \partial p/\partial x + \mathrm{div}(A\nabla u) + \mathrm{div}(B\nabla v) \qquad (1)$$

$$\partial v/\partial t = -\partial[uv]/\partial x - \partial[v^2]/\partial y - 1/\rho\ \partial p/\partial y + \mathrm{div}(B^T\nabla u) + \mathrm{div}(C\nabla v) \qquad (2)$$

$$0 = \partial u/\partial x + \partial v/\partial y \qquad (3)$$

where

$$A = \begin{bmatrix} 2 & 0 \\ 0 & 1 \end{bmatrix},\ B = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix},\ C = \begin{bmatrix} 1 & 0 \\ 0 & 2 \end{bmatrix}$$

Since the problem is time-dependent (and nonlinear), an iteration scheme for solving the problem must be expressed in the SCHEME statement. The following three-stage algorithm is used to advance the solution from time level n to n+1 (here superscripts refer to time levels):

(a) Predict (u,v) from Equations 1 and 2 using explicit Euler steps:

$$\bar{u} = u^n - \Delta t\{\partial[(u^n)^2]/\partial x + \partial[u^n v^n]/\partial y + 1/\rho\ \partial p^n/\partial x - \mathrm{div}(A\nabla u^n) - \mathrm{div}(B\nabla v^n)\}$$

$$\bar{v} = v^n - \Delta t\{\partial[u^n v^n]/\partial x + \partial[(v^n)^2]/\partial y + 1/\rho\ \partial p^n/\partial y - \mathrm{div}(B^T\nabla u^n) - \mathrm{div}(C\nabla v^n)\}$$

(b) Correct (u,v) so that Equation 3 is satisfied:

$$\text{Solve } \nabla^2\phi = -\partial\bar{u}/\partial x - \partial\bar{v}/\partial y$$

$$u^{n+1} = \bar{u} + \partial\phi/\partial x$$

$$v^{n+1} = \bar{v} + \partial\phi/\partial y$$

(c) Correct p so that Equations 1 and 2 are satisfied:

$$p^{n+1} = p^n - \rho\phi/\Delta t$$

The DEQSOL program that describes this problem and solution algorithm follows. The operator ".." is defined to be matrix-vector product, as in A..GRAD(U). The function N(W) is defined for vectors W to be the dot product N.W, where N is the outward-pointing unit normal vector. The notation U[LM] refers to the variable U with the "lumping" option applied. Lumping is a common technique used in the finite element method to reduce discretization matrices to diagonal form, resulting in more efficient processing.

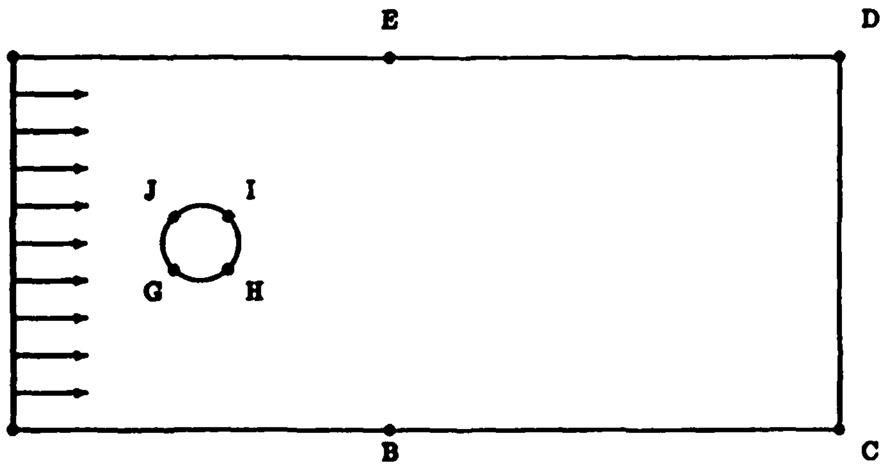


Figure 2. Domain for Navier-Stokes problem.

```
PROG     NAVIER;
METHOD   FEM;

/* ---------------------
   DEFINE TEMPORAL DOMAIN
   --------------------- */

TIME     T = [0:0.4];
TSTEP    DLT = [0(0.001)0.4];

/* --------------------
   DEFINE SPATIAL DOMAIN
   -------------------- */

DOMAIN   X = [0:22], Y = [0:10];

POINT    A = ( 0, 0), B = (10, 0), C = (22, 0),
         D = (22,10), E = (10,10), F = ( 0 10),
         G = (4.293,4.293), H = (5.707,4.293),
         I = (5.707,5.707), J = (4.293,5.707),
         K = (5,4), L = (6,5), M = (5,6), N = (4,5);

REGION   AB = LN(A,B), BC = LN(B,C), CD = LN(C,D),
         DE = LN(D,E), EF = LN(E,F), FA = LN(F,A),
         AG = LN(A,G), BH = LN(B,H),
         EI = LN(E,I), FJ = LN(F,J),
         BE = LN(B,E),
         GH = ARC(G,K,H), HI = ARC(H,L,I),
         IJ = ARC(I,M,J), JG = ARC(J,N,G),
         ABHG = QUAD(AB,BH,GH,AG),
         BEIH = QUAD(BE,EI,HI,BH),
         EFJI = QUAD(EF,FJ,IJ,EI),
         FAGJ = QUAD(FA,AG,JG,FJ),
         BCDE = QUAD(BC,CD,DE,BE);

FREGION  ABHG + BEIH + EFJI + FAGJ + BCDE;
/* -------------------------
   DEFINE FINITE ELEMENT MESH
   ------------------------- */

MESH     AB = D(A,10), BC = D(B,12), CD = D(C,15),
         DE = D(D,12), EF = D(E,10), FA = D(F,16),
         AG = R(A,15,0.8), BH = R(B,15,0.8),
         EI = R(E,15,0.8), FJ = R(F,15,0.8),
         BE = D(B,15),
         GH = D(H,10), HI = D(I,15),
         IJ = D(J,10), JG = D(G,16),
         INSIDE = AUTOSIM;
```

```
 ----------------
 DEFINE VARIABLES
 ---------------- */

NST     RHO = 1.2;

ENS     A  = ( 2, 0, 0, 1 ),
        B  = ( 0, 0, 1, 0 ),
        BT = ( 0, 1, 0, 0 ),
                 C  = ( 1, 0, 0, 2 );

R       U, V, P, PHI, U2, V2, UV, PSI;

C       VEL = (U,V), PA = (P,0), PC = (0,P);

MTYPE  LINEAR FOR U, V, PHI, PSI

AT FOR P;

 -------------------
 BOUNDARY CONDITIONS
 ------------------- */

OND
               PSI = -1 AT AB+BC,
               PSI = 1 AT DE+EF,
               PSI = 0 AT GH+HI+IJ+JG,
        NGRAD(PSI) = 0 AT FA+CD,

        NGRAD(PHI) = 0 AT FA,
        NGRAD(PHI) = 0 AT AB+BC+DE+EF+GH+HI+IJ+JG,
               PHI = 0 AT CD,

                 U = 100 AT FA,
                 U = 0 AT AB+BC+DE+EF+GH+HI+IJ+JG,

                 V = 0 AT FA,
                 V = 0 AT AB+BC+DE+EF+GH+HI+IJ+JG,

 (1/RHO)*PA - A ..GRAD(U) - B..GRAD(V) ) = 0 AT CD,
 (1/RHO)*PC - BT..GRAD(U) - C..GRAD(V) ) = 0 AT CD;
```

```
/* ---------------
   SOLUTION SCHEME
   --------------- */

SCHEME;

         /* SET INITIAL CONDITIONS */

         SOLVE PSI OF LAPL(PSI) = 0 BY 'PCG';
         U = DY(PSI);
         V = -DX(PSI);
         P = 0;

         /* TIME STEPS */

         ITER NT UNTIL EQ 401;

         U2 = U*U; V2 = V*V; UV = U*V;

         /* PREDICT (U,V) */

         U[LM] = U[LM] - DLT*( DX(U2) + DY(UV) + DX(P)/RHO
                       - DIV( A..GRAD(U)) - DIV(B..GRAD(V)) );
         V[LM] = V[LM] - DLT*( DX(UV) + DY(V2) + DY(P)/RHO
                       - DIV(BT..GRAD(U)) - DIV(C..GRAD(V)) );

         /* CORRECT (U,V) */

         SOLVE PHI OF LAPL(PHI) = -(DX(U)+DY(V)) BY 'PCG';
         U[LM] = U[LM] + DX(PHI);
         V[LM] = V[LM] + DY(PHI);

         /* UPDATE P */

         P[LM] = P[LM] - RHO*PHI/DLT;

         /* OUTPUT */

         PRINT NT EVERY 50 TIMES;
         PRINT VEL EVERY 50 TIMES;
         PRINT P EVERY 50 TIMES;

END ITER;

END SCHEME;
END;
```

# TWO JAPANESE APPROACHES TO CIRCUIT SIMULATION

*We review research at Toshiba in vectorizing the circuit simulation program SPICE and research at NEC at building a special purpose multiprocessor for circuit simulation modeling.*

by Iain S. Duff and David K. Kahaner

## INTRODUCTION

Circuit simulation is heavily used in electronic design. It allows engineers to evaluate and alter design parameters to obtain high performance or cost effective utilization of parts. One of its most important applications is in the design of memory chips, because it is the only way that chip designers can study variations in metal oxide semiconductor (MOS) transistors. Naturally, the more detailed the design, the more computationally intensive the simulation. Even on supercomputers such as Cray, simulations can take hours, as it is often necessary to repeat computations with various parameter values. Since these simulations are done frequently, it is not surprising that large electronics companies are engaged in a variety of research to improve their simulation algorithms with respect to computer time, accuracy, and other performance characteristics. This report describes two different approaches taken by NEC and Toshiba, both large Japanese firms with substantial circuit design requirements. The authors of this report are numerical analysts, not circuit designers or computer architects, and the article reflects this orientation.

Toshiba's approach was developed by

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Fukui begins with the well known program SPICE 2G6 (Ref 1) and rewrites it for Cray X/MP and Y/MP computers. He reports performance gains of up to 300 (see below) compared to old versions of public domain SPICE. Toshiba does not manufacture a supercomputer, but they have a great many circuit design problems that are usually run on one of their Crays. Fukui's work has already paid off for Toshiba, as the code is being used by engineers as a production tool.

NEC's work is spearheaded by the following researchers:

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Nakata essentially rewrites the circuit simulation algorithms from scratch and runs them on a specially designed 64-node multiprocessor. He feels that vectorization has only limited potential for speed improvements and that the rate of vectorization will decrease as more detail is added to the circuit models because of growing numbers of conditional statements. The NEC project is the more experimental of the two but has the potential for greater payoffs in the future. On two models of dynamic random access memory (DRAM) circuits, Nakata reports parallel speedups of over 20 with 64 processors; he feels, however, that he can increase that by future improvements (see below). As a very large electronics organization, NEC has many circuit design problems. One of the specially designed circuit simulation machines has been installed in NEC's VLSI CAD Engineering Division.

The description and comments about these projects are based upon discussions with Fukui and Nakata, as well as reviews of published papers and preprints. In all cases we asked not to be told about any confidential activities.

## BRIEF REVIEW OF CIRCUIT SIMULATION

The circuit to be modeled is specified by describing its components and their connectivity. Kirchoff's current voltage laws are used to make ements about conservation and total rent flow. These laws are static, that hey hold at all times. In addition, re are equations describing the time : of change of circuit voltage and rent, due to conductance, capaci- ce, and inductive effects. The result hat circuit voltage and current are cified as the solution of a system of inary differential equations,

$$Ay' = f$$

:re A is a large, sparse (many zero ries) matrix determined by the physi- structure of the circuit. This system lifferential equations must be solved letermine the evolving characteris- of the circuit. The equations are >wn to be "stiff" because of the large :uit time-constants, and hence can y be solved by special techniques. In ticular, it is necessary to use implicit egration, such as backward Euler, or her order backward differentiation ear) methods (Ref 2). This even- lly results in a system of nonlinear iations to be solved for the solution t each time step. The solution of se equations is done by iteration, ially employing Newton's method. every time step, each iteration uires the solution of a system of ar equations. The matrix of the linear iations is formed by adding the ntity to a scalar multiple of the obian matrix. The latter is the matrix partial derivatives of the right-hand e of the differential equations, ioted f above.

Thus, the essential ingredients in forming transient circuit simulation ilysis are

Setting up the problem. This includes formulating the matrix. It also includes computing equivalent conductances and current sources for linear reactive circuit elements.

(b) Integration, including error control and time step strategy.

(c) Solving the nonlinear equations by iteration. Each iteration requires solution of a sparse system of linear equations. Circuit designers think of the Newton Raphson iteration as a process that linearizes the nonlinear circuit elements.

In practice, deriving the Jacobian matrix often accounts for most of the computation time. In a specific case cited by Nakata, this amounted to more than 80% of the total computation time. About 16% of the time was spent solving the sparse linear equations. These figures will vary with the complexity of the model. Nevertheless, to make large reductions in the CPU time, all aspects must be accelerated. Parts (b) and (c) are related because if the integration time steps are chosen carefully, Newton's method will converge rapidly and the computed values will be acceptably accurate. Small integration steps give more accuracy and require fewer iterations to converge but require more computer time. If the step size is chosen too large, it can take many iterations to converge or actually diverge, and, of course, larger steps can reduce accuracy. There is a delicate balance between these, and most simulation programs undergo a large amount of experimental "tuning"; many do not use the most modern step size selection strategy.

## SPEEDING UP CIRCUIT SIMULATION

The two major approaches to increasing the performance of circuit simulation programs are (1) to take advantage of the partitioning suggested by the physical circuit in order to perform certain functions in parallel, and (2) to take advantage of the structure of the Jacobian matrix to perform as many operations as possible in parallel or in vector mode, in particular assembling and solving the sparse system of linear equations. Of course, the physical circuit also determines the structure of the matrix. NEC focuses on parallelization by use of a specially developed 64-CPU multiprocessor. Toshiba has parallelized portions of their program and also made major strides in vectorizing the solution of the linear equations.

Many portions of the overall computation can be performed in parallel, in particular, the setup or assembly phase. Often the circuit is partitioned into subcircuits, each of which is independently calculated, with an iteration until the various parts converge. This is often called a "relaxation algorithm" (Ref 3). However, if there is substantial feedback between circuit parts, convergence may not occur. Another approach is to subdivide the circuit but force the subcircuits to interact via a network whose parameters are determined anew at each iteration. Nakata calls this "modular simulation" (Ref 4).

## NEC'S APPROACH

Nakata and Tanabe have concentrated on rearranging the circuit simulation algorithm to take advantage of those aspects of it that have inherent parallelism. They have designed the algorithm to allocate subcircuits to different processors, each of which independently performs a simulation using local memory. The determination of the interconnection between various subcircuits must be performed, serially, at every iteration by one "interconnection" processor. This processor is locked until all the subcircuits are finished. The actual algorithm is recursive, so there is a tree of such processors. The essential function of the interconnection processor is to solve a system of linear equations. The size of the interconnection matrix is determined by the number of interconnections. For example, in a DRAM circuit with 7,000 transistors, broken into 191 subcircuits, the interconnection matrix is about 200 by 200, with about 20% of its entries nonzero. [Research based on the same mathematical foundations, but without the multiple hierarchy of subcircuits, is being done at Texas Instrument Corp. (Ref 5).]

Consideration of the form of the algorithm suggested that for many problems the subcircuit processors would compute independently and then all communicate to the interconnecon processor, which would then compute and finally communicate back to the subcircuit processors. Thus it will mostly be the case that communication is many-to-one or one-to-many. Nakata felt that a bus structure had better throughput than more general organizations, such as a hypercube. He also felt that shared memory would be more efficient than message passing systems. In 1987 the NEC group developed a prototype system composed of four processors. From that experience they have developed a 64-processor system, called Cenju, after the Buddhist goddess with 1,000 arms. (Nakata feels that the maximum number of processors that can effectively be used on circuit problems is about 100.) He decided to use a distributed-shared memory. This means that there is a unique global address for the local memory in each processor, and that each processor has a local memory bus so it can access its local memory without worrying about bus contention. Since some interprocessor communication occasionally takes place, and building a common bus with high data-transfer-rate suitable to so many processors was difficult, he has designed the data bus in a hierarchical (tree-like) form.

Cenju is thus composed of 64 processors. These are divided into eight "clusters." Processors in a cluster are connected by a bus that is connected via a multistage network. Each processor is built around a 20-MHz Motorola MC68020 CPU that has 4 MB of dual-ported local memory connected by a local memory bus. The cluster bus only needs to be accessed when communicating with other processors. The design allows up to 256 processors. Since floating point computation is a fundamental part of circuit simulation, Nakata decided to use fast Weitek WTL1167 chips instead of the Motorola MC68882 chips that are most commonly used with MC68000 systems. An MC68882 is on the board and is used for math functions such as sin, cos, exp, etc., but floating point addition, subtraction, multiplication, and division are done through calls to the Weitek chip. Other details of the hardware organization can be found in Reference 6.

Nakata is a computer architect, not a numerical analyst or a circuit designer. In developing Cenju, he collaborated heavily with Norio Tanabe, who has been doing circuit simulation for many years and is in NEC's VLSI CAD Engineering Division Some of the aspects of the algorithm were done in collaboration with other scientists in NEC's Computer and Communication Systems Research Division and Scientific Information System Development Ltd. (a subsidiary). For complete addresses, see References 4 and 6.

Nakata has tested the running system on two circuits, one with about 1,700 transistors and another with about 7,000. Both are part of the control circuitry for DRAMs. Speedups were initially reported as 15 for the small circuit and 16 for the larger. The system designer enters the circuit. With respect to domain decomposition, Nakata and Tanabe feel that it is best to take advantage of hierarchical design used by the designers. When that cannot be done, a domain processor should be available to automatically generate the subcircuits, although for these examples they utilized the designers' hierarchical design, 64 subcircuits for the first and 191 for the second. When there are more subcircuits than processors, there is quite a bit of extra overhead and Nakata feels that this accounted for some degradation in performance; the matrix problem to be solved for the interconnection matrix is larger and the matrix has about 20% nonzero elements. Its solution is done serially with respect to the other phases of the calculation. Nakata feels that additional improvements would occur if the domain decomposer was more sophisticated and produced fewer subcircuits as this would directly reduce the size of the matrix. He has also made some initial efforts to parallelize solving the matrix problem, and work in this direction has improved the speedup for the large problem to over 20. Nakata has not done as much work on solving the matrix problem as Fukui at Toshiba (below), because most of the original sparse matrix solution has been parallelized in the subcircuit processors; what is left is the sparse matrix solution for the interconnection points. However, he feels that by utilizing better domain decomposition, he can substantially increase the speedup.

Nakata originally built Cenju as a special-purpose computer, but now he is studying the possibilities of using it for other applications. Nakata notes that intercluster read access is very slow due to overhead in bus-error interrupt handling and timeout control. He dealt with this in circuit simulation by utilizing, whenever possible, algorithms in which the producer of data writes that data to its consumer.

## TOSHIBA'S APPROACH

One of the early applications of direct methods for the solution of sparse linear systems was in the solution of problems from circuit simulation. In particular, this was the main reason for the interest in sparse matrix research of scientists from the Mathematical

Sciences Department at IBM Yorktown Heights. This group, which included Bob Brayton, Gary Hachtel, Fred Gustavson, Werner Liniger, and Ralph Willoughby, conducted much fundamental research into sparse matrix techniques in the late 1960s and early 1970s. In 1970, Gustavson et al. published a paper (Ref 7) describing the use of a code-generation approach, which they termed GNSO (GeNerate and SOlve), to the solution of sparse equations. The idea of the code-generation approach is to perform a factorization of the sparse matrix using Gaussian elimination and to record each arithmetic operation involved in a linear (loop-free) set of statements. This could be Fortran, assembler code, or in a compressed coded format (interpretative code approach). The initial elimination might be a regular factorization or a symbolic one, depending on sparsity alone and not on the numerical values. As mentioned above, in the circuit context (and in many other application *areas) during the Newton iteration it is* required to solve several systems with a coefficient matrix of the same structure; thus, this list of operations can be used for these subsequent factorizations. In the Toshiba experiments, sometimes about 900 iterations with a Jacobian matrix of the same structure were required so, in common with most other experiments using this scheme, the initial cost of generating the loop-free code is not reported.

Duff (Ref 8) conducted some comparisons on the early code of Gustavson, for example, and concluded that their approach was of limited use for general problems. Duff and his coauthors also comment on this approach in Reference 9 (section 9.6), where the main problems are stated to be storage (with consequent speed problems if data have to be held on auxiliary devices) and stability. Additionally, loop-free code is not well optimized by most current compilers and may not be vectorized by them. Since about one line of code is generated for each entry of the factors, this approach is most attractive when the factors can be kept relatively sparse. Thus it would not be of interest in the solution of elliptic partial differential equations but is much more suited to the types of matrices occurring in power systems and circuit simulation problems. Additionally, in many circuit problems, and especially for memory modules, there is a natural stability in the devices and this is reflected in the equations, so that diagonal pivoting is usually stable.

These features make the code-generation approach potentially interesting in this application. We now discuss the improvements that Fukui et al. have made to the basic method to give them a competitive code. The improvements are:

(1) generation of assembler code using vector operations

(2) packing of integer index information

(3) use of block elimination

We discuss each in turn.

Using the example from their paper (Ref 10), a fragment of generated code (in Fortran) may look like

```
A(1) = A(1) - B*C(2)
A(3) = A(3) - B*C(4)
A(5) = A(5) - B*C(6)
........
```

and, if the programmer groups these statements suitably, one can see that the indirectly addressed vector A (addressed above through index vector 1 3 5...) is updated by a scalar multiple of the indirectly addressed vector C (index vector 2 4 6...). Thus, using a GATHER on A and C and a final SCATTER on A, the code can be vectorized on nearly all current vector computers. This gives significant gains in both the storage of the generated code and the speed of execution. On the examples in their paper (Ref 10), the savings are a factor of just under three in both storage and time. It should be noted that the difference between generating Fortran code and assembler (scalar assembler) is a factor of about 30 in time.

If two integers are packed into a 64-bit CRAY word, the constituent integers can be quickly recovered using a shift instruction. This device is used both to decrease the memory required by the address data and to speed up the code through a reduction in memory references. A 30% speedup in CPU time is reported by the authors through this device.

Fukui says that his block elimination was similar to the use of matrix-vector or level 2 BLAS (Basic Linear Algebra Subroutines) in Gaussian elimination on full systems. However, it is not clear how he would do that with his current approach and it does not appear to be illustrated in the paper. From the example there, it would appear that what is done is to hold the pivot row in vector registers and use it to update all the appropriate nonpivot rows without further memory references for the pivot row. It would also be possible to update several rows as a single vector operation, but it is also not clear if this is done. The gains reported for block elimination are a factor of 1.5 in both storage and time over the vector assembler code.

Fukui et al. also discuss (Ref 10) other issues in their adaptation of SPICE-GT, based on SPICE 2G.6 from Berkeley. The one other area of main interest is in the assembly or formation of the circuit simulation matrices. It is like the assembly of a finite-element matrix and thus can easily be parallelized.

Vectorization is not so easy because of complicated conditionals. They vectorize by grouping together (using indirect addressing) elements satisfying the same condition and then vectorize these subsets using vector GATHER/SCATTER. This is very similar to techniques used by Miura and others (for example, see Reference 11) in vectorizing Monte-Carlo codes. (At NEC, Nakata claims that the matrix setup phase is difficult to parallelize in a naive manner using a great many processors because of high overhead associated with shared memory contention.)

The gains over a 1984 code (which generated Fortran) were a factor of 4 in matrix assembly, 100 in solution, and under 2 in other parts of the code. The overall gain of the 1989 code is a factor of around 10. A factor of 300 compared with the original SPICE is claimed, presumably because of other algorithmic (or machine!?) changes not reported in Reference 10.

## SUMMARY

The NEC-Nakata-Tanabe approach is essentially one of understanding the physical problem and then developing a hardware-software solution. Toshiba-Fukui focus much more directly on the sparse matrix problem that needs to be solved.

Nakata's work really begins with a clean sheet. Many of the relatively special needs of circuit simulation such as many-to-one and one-to-many communication, noncontentious local memory access, fast floating point, etc. are designed into the Cenju multiprocessor. More work still needs to be done on the serial portion of the algorithm, the sparse linear equation solver for the interconnection points, which is a bottleneck. Work is also going forward on automatic domain decomposition. Nevertheless, the current speedups of over 20 are impressive. The Cenju design does not seem so specialized that it cannot be useful for other problems. This looks like a exciting project with a substantial amount of room for further research.

Fukui's work is very interesting, not least because it illustrates the use of a technique thought impractical by many sparse matrix researchers. It does not seem, however, to be suitable for a wider range of applications because of stability and storage issues. Also, there is a great deal of machine dependence, although code-generation routines are usually in two parts, the first being machine independent. This seems to be the case here, so that potentially a separate code generator (and index packer) could be used for each machine. It is difficult to say from the data provided how good the generated code is. The improvements recorded are impressive but would need to be benchmarked against other current codes or on standard test problems to obtain an accurate picture. Fukui has indicated his willingness to collaborate in benchmarking experiments. It should be pointed out that compilers are getting much better at generating vector code from standard matrix factorization routines, so that their output may not now end up so different from the code generated by the Fukui approach!!

Circuit simulation programs such as SPICE have a reputation of being difficult to vectorize or parallelize effectively, primarily because the type of circuit as well as the type of usage specified by the user have a significant impact on the "route" through the program. This will certainly be true when problems with long versus short transient simulation times are compared. For example, Mark Johnson (Ref 12) reported to us some statistics associated with running a standard public domain version of SPICE on two specific test problems. He observed that a few lines in the matrix decomposition routine occupy 34% of total execution time for one problem but only about 3% for another, and also that in one problem 15 times as much CPU time was spent in index operations processing the sparse matrix as in the floating point portion of the Gaussian elimination step. Thus, the improvements reported by both Nakata and Fukui are dependent on problem specific details and may not be representative of performance on other problems.

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# FLEXIBLE AUTOMATION

*A summary of the 1990 Japan-U.S.A. Symposium on Flexible Automation, 9-13 July, in Kyoto, Japan, is given. Plant visits to IBM's 3090 manufacturing plant, Sumitomo Electric, Mitsubishi Heavy Industries, and Matsushita Electric are described.*

by David K. Kahaner

## INTRODUCTION

Several hundred scientists from almost 10 countries met in Kyoto to present research in the area of flexible automation. This term refers to techniques that enable automated manufacturing to change from producing one type of product to another, rapidly and at low cost. It also includes simulation of the manufacturing process from the design stage to finished product. Many other related topics, such as robotics, quality control, fuzzy logic, etc., are also subsumed under this rubric. This report summarizes the major papers that were presented at this meeting and assesses them in the context of current work in the United States. For details on the papers presented, see the Appendix.

Following the meeting, several tours were arranged to interesting manufacturing facilities in the Kyoto-Osaka-Kobe area. These are also summarized and evaluations of the activities are given.

## COMMENTS AND ASSESSMENT OF IMPORTANT SPEECHES

Zadeh, who is the father of fuzzy logic, remarked that he expected to see many new devices with high "MIQ" (machine intelligence quotient) appearing in the near future. He stressed that level I applications of fuzzy logic were to replace skilled human operators with fuzzy logic controllers and that this was already happening, but that level II applications, involving the replacement of human experts with fuzzy logic systems, had still not appeared. There are certainly plenty of examples of products in the first category here in Japan. However, at this conference there were only a very few papers related to fuzzy logic (for example, on placing a peg in a hole), so Zadeh's presentation, however interesting, seemed oddly out of place.

Yamazaki Mazak Corp. is a $1B, 3,800 people company that manufactures flexible manufacturing systems for small cubic parts (120 of them have been sold overseas), as well as other automated machine tools. Nagae is its director of engineering. He spoke from the Japanese manufacturing perspective. His talk emphasized the issues to be confronted by Japanese manufacturing companies today, vis, a labor shortage in midsized companies due to low Japanese birth rate and movement of university graduates away from manufacturing into finance-related industries. Interestingly, he mentioned a problem of lack of pride associated with manufacturing in Japan (and we thought that this was only in the United States!). He felt that the responsibility of the companies was to create an environment that encourages the use of computers to take up the slack of a lessened workforce. He credited the success of his company to four main factors: (1) large capital investments, (2) continual succession of new products, (3) a president who aggressively has pursued development of world-class machine tools, and (4) heavy use of advanced semiconductor technology. His company does no mathematical modelling or simulation. He cited several difficulties with U.S. manufacturing companies:

(1) The U.S. desire to sell flexible manufacturing systems (FMS) to other companies, but not much in-house use of this technology in U.S. machine tool manufacturers. Associated with this he mentioned that his company must reinvent 20 to 30 new machine tools each year and hence has a strong desire to use FMS, while U.S. machine tool manufacturers are still using many old machine tools. (FMS means a machine tool that can easily be reconfigured to produce a number of different tools.)

(2) The unwillingness of U.S. manufacturers to realize that to understand global needs research and development (R&D) must be in many other countries.

(3) Too much U.S. research on software, especially associated with concurrent systems, and not enough on hardware. (In my opinion Japan has exactly the opposite problem.) He ended his talk with the following statements.

It seems that the predominant current research subjects relating to production technology concern computer networks, notably manufacturing automated processes (MAP). However, considering that things are actually produced on the shop floor, prospects for factory automation will undoubtedly be discouraging if due consideration is not given to the automation of operations performed on the shop floor. It is most likely that growing importance will be placed on the automation of machines used on the shop floor since automated machine operation is essential to producing better products using a smaller number of operators. The main requirement to translate this production theory into reality is the development of more intelligent numerical controlled machine tools and FMS peripheral equipment, including robots.

Taguchi methods have been extensively discussed, including a recent article in the *Scientific Information Bulletin* [K.O. Bowman et al., "Statistical quality control technology in Japan," 15(1), 57-73 (1990)]. They are used not only in Japan but in many other countries, too. For example, at this conference a paper by researchers at Auburn University illustrated its use in studying robot process capabilities.

## SPECIFIC PAPERS AND SESSIONS

Europeans, both east and west, were very well represented (perhaps associated with the Esprit projects) at this conference, particularly Italians. Expert system tools such as Prolog, LIST, C++, etc. were in common use, and there were discussions of expert subsystem cooperation for several researchers, including several from the Computer and Automation Institute in Budapest. The Italians, in particular, seemed unimpressed with the Japanese research and felt that their manufacturing technology was at least as advanced. There were several papers on FMS simulation with authors from Europe and Japan. There were also several papers on "humanizing" automated manufacturing, by appropriately injecting human decision into the process at key steps. This was called "bionic" manufacturing and requires excellent access to the knowledge database by the human in the control loop.

From a computer science (CS) point of view, a good paper was presented by A. Inamoto, who presented Mitsubishi's conceptual and architectural ideas. Their view is that computerized industrialized manufacturing (CIM) should focus on integrating heretofore heterogeneous islands of automation into a manufacturing system for the entire company. His talk proposed a specific CIM system-requirement-specification methodology based on conceptual and architectural descriptions. For a conceptional description, he stated that objectives, scope, and basic management cycle should be defined. Only with reference to this conceptual description should functional and information architecture be framed. A network should be designed to interconnect existing systems, and finally a physical architecture needs to be configured to establish the methodology. For example, he defines CIM objectives in terms of four major factors (productivity, quality, cost, and delivery) and defines CIM scope in terms of management system, sales and distribution system, production planning and production control system, design and engineering system, production line operating system, etc. A rather lengthy example suggested that this approach has been implemented, at least at one part of this huge corporation. I liked this paper because it tried to generalize and abstract the manufacturing process, rather than focusing on one particular product or production line.

Several papers discussed extensions to Petri net methods to express operational functions in sequence control, such as synchronization, interlock, and concurrency. These extensions can provide temporal information and other token attributes that are lacking in traditional methods. An impressive example of this was given by researchers from Kawasaki Heavy Industries in the development of control software for autonomous ground vehicles (AGV). A more academic example was given by Hatono and others from Osaka University, who use hierarchical stochastic Petri nets to encapsulate some of the same temporal data.

There was the usual bevy of papers on robot dynamics and fine motor control and manipulation, all highly detailed. There did not seem to be any country bias in the emphasis of this research. The placement of a peg in a hole seems to be a favorite application example, as there were a number of papers discussing that, primarily in two dimensions. One scientist from the United Stats felt that there was too much emphasis on detailed movement planning on the assumption that input data are accurate, and that a great deal of work needs to be done on sensors, especially for hostile environments such as radioactive, vibrating, underwater, etc. Ohio-based Robotics Research Corp. described a "17 degree of freedom" manipulator that they emphasized is not a simulation. Korean researchers described a rule-based approach to alternator assembly using expert system ideas to produce a precedence diagram for assembly.

As far as I could tell the Mitsubishi paper described above was one of the only ones from an industrial laboratory that described a general framework, rather than a particular application. Almost as high level a view was presented by Futagami and colleagues from Sharp Corp. They have developed a two-dimensional computer-aided design (CAD) system that separates the design database from the geometric constraint mechanism. In other words, the design database stores and manipulates design object knowledge and provides an easy way to develop tools for interactive design. The constraint mechanism evaluates and satisfies geometric constraints and the attributes of geometric entities. This latter is rule based.

On the other hand, a large number of the university researchers tried to abstract their ideas to discussions of knowledge representation (mostly frames) and various reasoning techniques, such as Mandami reasoning. For example, Bossink and Gaalman, from the University of Twente, The Netherlands, described general planning and scheduling manufacturing systems. There were plenty of expert systems developed and various methods for developing knowledge bases. From the United States, a few papers had a particular application in mind but developed their methodology from a general viewpoint. A notable example was the paper titled "The Development of an Intelligent Dimensional Inspection Environment in Manufacturing," by C. Menq from Ohio State. Some papers used an object-oriented approach for rule-based reasoning, for example, for production scheduling.

Of the university papers, one of the most general was by Murayama from Hiroshima University, who has a goal of integrating computer-aided design, engineering, and manufacturing by proposing a real time design operation to perform concurrent processing of the modelling step at the same time the integrated manufacturing is occurring. I think that this is an important approach because it recognizes that information from the manufacturing process is needed to correctly model complicated manufacturing. Nevertheless, there were no concrete applications of this work presented.

There was one full session on global programming languages. This is an effort to provide a standard to describe the entire computerized manufacturing process. A great deal of work has apparently been done in this area and there are several ISO standards that have been published. Using one of these programming languages would allow a user to specify factory function as well as the networking between various parts of the manufacturing operation from administration down to physical equipment and would include process planning as well. Several of the papers were in the form of proposals. For example, IBM Japan writes:

> Since 1987, our domestic [working group] has continually proposed and promoted international standardization and technical information exchange about factory automation. As a result, we reached the conclusion that a global programming language for describing a data model of cells, machines, and parts and a cell environment for processing the data model were very important for standard activities. We hope that our proposal shows one direction for future system and standardization activities. The advent of standardization will accelerate the establishment of future shop floor production systems and will not impose limitations on the construction of such systems.

Although this seems to be an international activity, all the papers were from Japanese researchers. I was unable to decide to what extent other countries participate in this research, although I recall that the National Institute of Standards and Technology has also been studying this problem.

In the area of visual processing, an interesting paper was by Kitajima, Tokyo University of Agriculture and Technology. Kitajima claims that there is plenty of research on both geometry and topology separately but very little on their integration. He would like to develop intelligent robots with three-dimensional (3D) sensors. One step is to generate both shell descriptions and solid model descriptions. He has been studying how to do this from two displaced views of 3D objects. His results are positive but still very primitive.

There were many, many talks about applications. One of the most dramatic was by representatives from Sumitomo Metal Industries. (I visited another Sumitomo facility--see below.) They have developed an expert system tool that they have applied to a steel wire finishing line plant which is approximately 700 by 150 meters in area. The particular expert system they developed has more than 300 rules and was developed and implemented within 10 months. It has real time control that supervises the movement of more than 20,000 coils of steel wire each month.

There were a few robot systems described in detail. A particularly novel idea is that of a collection of robots that each operate independently but know of each other's existence--a "cellular robotic system." This is obviously related to the notion of parallel task execution. Each robot is programmed to perform a particular task. In some research no system-wide centralized mechanism, synchronous clock, or shared memory is assumed. Each robot in such a system makes decisions solely based on its sensed information and its current state. Nevertheless, all the robots have to cooperate to accomplish a prespecified global task. Some very elegant theoretical work on this was presented by Beni and Wang from the University of California at Santa Barbara. They postulate a one-dimensional ring of robots with certain given properties and in one of two states and study under what conditions an arbitrary set of states can be generated by each robot acting independently. Similarly, a group from Brussels, Genoa, and Pisa discussed the advantages of other self-organizing collections. The related topic of multi-fingered robot hands was discussed by Nguyen and Stephanou from George Mason University, who have developed algorithms for reasoning about objects and contacts. It seems to me that this research has applications to biological models and perhaps to neural networks, too. In other papers a master robot and several slaves were assumed. Task planning, structure planning, coordination, and communication have to be performed. Researchers from Nagoya demonstrated such a system.

A robot developed by the artificial intelligence laboratory at the Massachusetts Institute of Technology that could navigate autonomously in a cluttered room was demonstrated by videotape. I thought this was well done, but an Italian colleague remarked that the distinction between a robot that walks in a cluttered university office and one that moves coils of steel pretty much described the state of robotics in the United States and Japan. Luckily for me, there were a few talks about numerical computation in various contexts. For example, Haurie and van Delft from the University of Geneva use optimal control to develop and solve flow control models. Their approach leads to an optimization problem subject to given differential constraints. The numerical solution is given by a variant of Newton's method which, in this specialized case, is called the method of Robbins-Munro. A number of other optimal control papers were also presented.

## SUMMARY EVALUATION

Overall it seemed that research is healthy in this area, with no obvious "winners." Nevertheless, the Japanese papers clearly demonstrate that they are willing to implement their research ideas in practical factory environments. Readers should not get the impression this means all Japanese factories are automated with gleaming robots replacing people. In fact, discussion with Japanese scientists at the conference who work in manufacturing environments, as well as observations on the plant tours, convinced all the participants that the state of affairs is much more complex, with a very wide range of automated processing going on not only between factories but within them, too.

## PLANT TOURS

### IBM's Yasu Plant

This is one of IBM Japan's two development/laboratory plants, and it was established in 1971 in the Kansai area between Kyoto and Nagoya. This is only a few kilometers from Lake Biwa, Japan's largest lake. Approximately 2,500 employees work here, many since its inception, with average seniority around 10 years. This particular plant is interesting as it produces everything from semiconductor chips to complete 3090 systems including modules, thermal conduction modules, printed circuit boards, workstation motherboards, and other components. I was told the plant produces more than one complete 3090 system a day and that most of these are sold in the Japanese or Asian market. The entire plant is controlled by a CIM system with a network that not only allows communication between various manufacturing aspects but management information systems, quality assurance systems, design systems, and distribution control systems. The plant is connected into various IBM worldwide communication networks. Nevertheless, we were told that the warehouse had not yet been integrated into the system, although this was to happen in the near future. More than 6,000 people tour this plant each year, and so tours are very well organized and sequenced. We were shown many details of chip manufacture and assembly, but neither I nor the other participants were in a position to assess these. The general impression of the tour group was that although many individual aspects of the plant were well automated, there were still a number of gaps and room for implementation of even more integration. A curious aspect of the pretour presentation as well as the literature we were given was the emphasis on water usage and quality in the plant. Lake Biwa is a drinking supply for millions of Japanese as well as a recreational center, and IBM Yasu is proud of its commitment to maintaining very high standards for its water use.

### Matsushita Electric Works, Hikone Plant

This plant, with 1,500 employees, produces more than 1,000 different electrified consumer products, including hair dryers, shavers, curlers, toothbrushes, clocks, timers, watering devices, intercoms, lawnmowers, massaging reclining chairs, vibrators, hedge trimmers, blood pressure meters, pedometers, power supplies, hand-held tools, and many other items. We were given a series of catalogs showing a bewildering array of products in an astonishing number of variations of size, color, shape, and minor features. This company is one of a large number of factories in Japan that markets under its own name as well as National and Panasonic labels. The company produces complex electronic devices such as video cameras, but these are not produced at the plant we saw. Virtually every small part from motor bearings to windings to plastic housings is produced here. Many items are inexpensive to moderate in cost, although some, for example, electric razors, seem of very high quality. A multipurpose hand-power wrench produced here is used on the U.S. space shuttle. The plant's sales are almost $1B annually. The tour participants were impressed with several aspects of this plant:

(1) The variety of machine tools needed to keep up with the incredible diversity of products manufactured here.

(2) Although conveyer belts were everywhere and the plant is bright and airy, a very large number of workers (mainly women) seemed to be busy doing very repetitive labor-intensive tasks such as sorting, testing, and packaging. Although one view of this was surprise at how unautomated this facility was, my own thought was that if this plant is as productive as it is claimed to be, their room for improvement is staggering.

## Sumitomo Electric

This company is over 90 years old and had sales last year of over $40B. Their primary business remains electric wire and cables, but they are active in all types of connecting materials as well as sintered alloy products such as cutting tools, disk and antilock brakes, etc. For the future they see optoelectronics, optical fibers, and applications as key, as well as materials such as gallium arsenide, synthetic single crystal diamonds, and ceramics. They are also anticipating growth in various electronic and communications systems, traffic control systems, and medical and cable TV (CATV) devices, and they are enthusiastic about producing what they call "Japan's first domestically produced high-performance engineering workstations." These are either older M68000 based or two newer series that are built with custom RISC chips (R3000) with 18 MIPS and 3.0 MFLOPS performance. They all run UNIX System V + 4.3 BSD with special capabilities for Japanese character processing. They run X Windows and have networking capabilities, fast graphics, etc. We had an opportunity to see an area of about 1,500 $ft^2$ where these workstations are put together and tested. Some of the testing procedures were impressive, such as subjecting each unit to run-in in extreme heat and cold conditions within a specially designed variable temperature chamber. The pace, loving product care, and activity level in this portion of the factory did not suggest that workstations are sold in large quantity. Sumitomo staff explained that most of their workstations were customized to user specifications. If price were no object I would like to buy one of these--it would be like buying a fine watch. But, frankly, some aspect of this production process will have to be substantially altered if sales volume is going to increase.

The main interest in visiting this plant was to have a demonstration of their automobile location/navigation system. Several other competing systems have been introduced, and I have seen them on cars in the Tokyo area, but this is the first one that I have been able to see in actual operation and ask technical questions about. Approximately 100,000 cars have been equipped with these devices in Japan. Typically they will be installed in higher priced models such as Nissan's Cedric, Mitsubishi Diamante, etc. Currently, more than 1,000 Nissans are being sold each month with this $2,500/unit option. The system includes a color CRT display that is integrated into the car dashboard. (The CRT can also receive ordinary TV programs.) There is a keyboard unit in the passenger compartment either just adjacent to the screen or between the seats. A system unit mounted in the trunk contains one or more CD-ROM disks with map information (540 MB), a display controller, and a locator. Sensors are mounted on the front wheels and a geomagnetic field sensor is located at the center of the roof.

The tour participants were placed two or three to a car in a collection of vehicles so equipped and sent off for about a half-hour ride with a driver. The route was more or less random on the streets around the laboratory site, including some that would be classified as "alleys" in the West. By keyboard control it is possible to select one of three scales of display, 1/400,000, 1/100,000, or 1/25,000. At the same time a vehicle position marker is displayed at the center of the screen. As the vehicle moves the marker traverses the map. The vehicle location normally shows at the screen center with the map scrolling underneath it. Two display modes are available, "north up" or "head up." Users can scroll the map manually to see other sections and can enter a destination point if they wish. If this is off the screen an arrow and distance indicator show which way to go, otherwise the destination appears on the current screen. Major hotels, department stores, auto dealers, etc. are stored on the CD, which can display them on the map and also display their addresses and telephone numbers. Destinations can be entered either graphically or by referring to one of these prestored data. Users can also store frequently used destinations such as their home, office, etc. Similarly, the vehicle position changes continuously, but under some conditions it must be set by the user, for example, if the vehicle has been moved by towing or on a ferry. This can be done in several ways, including graphically or by specifying that the vehicle is now at some location (hotel, etc.) already in the database.

Map information is currently available for three metro areas, Tokyo, Nagoya, and Osaka--this region accounts for about 30% of Japan's population and about 70% of the system's unit sales. The finest scale display can only be used where detailed road network data are available; the map scale changes automatically if the vehicle leaves the fine scale area.

During our ride the system worked perfectly, showing the car's location even on very small streets. Backing up, going through parking lots, etc. seemed not to faze it in the least. The screen is busy even though some fine detail information is automatically removed while the vehicle is moving and many keyboard functions are also inoperative at that time. But such a system would not be permitted presently on the dash in the United States, but the concept makes excellent sense in many urban areas.

Later I had an opportunity to talk to some of the engineers. Prototype software is developed in C, although most of it is eventually rewritten in assembler after it is debugged. Program size is almost 400K. The key questions are how well it works and how reliable it is. Of course, I didn't have access to the real details of their programs and can only guess about hardware, but I was very impressed with the care that had gone into their planning for this device. A few examples follow. A gold CD disk is used for reliability. It is waterproof and is claimed to have more than 10 years of life expectancy. (Knowing how often streets in Tokyo are rebuilt, this seems about five times longer than the data will remain valid.) Map data on the CD-ROM are organized by latitude-longitude mesh coordinates and occupy more than 300 MB. There are over 21,000 meshes. On the disk, data are stored repeatedly for speed of access. (The master database is maintained on a Sumitomo workstation in Osaka.) To prevent excessive heat from ruining the disk and driver, a special voltage regulator is used that will only power the unit if the temperature is within its normal operating range.

Since the vehicle location is not determined by satellite or other external inputs, sophisticated "dead reckoning" techniques need to be used. The data input and program to manage this are in the locator portion of the system. This is basically a 16-bit CPU with floating point coprocessor. The two wheel rotation sensors are in the front wheels because tests showed that they are less susceptible to the distorting effects of traction power on the rear wheel drive vehicles in which the system is presently installed. The locator detects distance by averaging the right and left wheel pulses and detects turns by measuring the difference between rotation on the two wheels. Some slip checking is also included. The magnetic field sensor is on the roof to reduce effects from the vehicle. A rotation test is made to calibrate the roof sensor and eliminate bad data from tunnels and bridges. Each vehicle is initialized by running it for 500 meters in a straight line which can then be used to calibrate tire imbalance to within 0.05%. Various calibration coefficients are stored in an EEPROM in the locator. Every dynamic RAM is temperature tested to insure that it will function at low enough temperatures for practical use. I didn't have an opportunity to ask what would happen if the tires are changed, for example, after a flat.

Where is the vehicle? A first approximation is made comparing tire rotation and magnetic field output, after some Kalman filtering. This usually gives location correct to within 5% (say 500 meters in 10 km). The next step is by "map matching," which is really pattern recognition. If by dead reckoning the vehicle is not on a road, the system must adjust. Some correlation coefficients are computed between the computed location and mapped roads. The distance error and direction error between roads and current location are computed in an effort to find the most likely road nearby. All nearby roads are investigated along with their branches. Once the vehicle turns there is a good chance that location information can be obtained much more accurately. In Japanese urban areas there may be more than 400 intersections per km, thus map matching needs to be accurate to under 25 meters at worst. Location information is updated on the screen every second. In use, one may see the vehicle "spot" deviating slightly from a road while driving in a straight line, but it always places itself back on a road after a turn.

The Sumitomo engineers expect that their system will improve in several ways. First, they are actively keeping up to date in pattern matching research to be sure that they are using the best techniques currently available. (As this product is clearly profitable I see substantial opportunities for practical applications of research here.) Second, this year receivers/transmitters are being placed on major streets in Tokyo which will provide reference location data to the onboard car systems. Third, they expect to provide computerized route guidance and traffic information (some of this is already available), integrate phone and fax services, and allow users to make hotel and restaurant information from the database on the CD. The price of this system is bound to decrease not only because of efficiencies of production but also because merchants will scramble to be included in the database--"what is the closest Chinese restaurant to my current location and can I get a table in half an hour?" On the other hand, there are questions about keeping the data up to date (perhaps one will be able to purchase CDs like maps at gasoline stations) and its utility in nonurban environments.

The tour participants (about 40) agreed that this was a well-thought-out product, solidly built.

## Mitsubishi Heavy Industries, Kobe Shipyard and Machine Works

Last year Mitsubishi had sales of almost ¥2 trillion. The Kobe Shipyard is only a small portion (about 12%) of the company's current overall activities, although Mitsubishi was founded 85 years ago as a shipbuilder. More than half of Mitsubishi's sales are now in power systems, nuclear energy, or machinery. There are six research and development centers; I have not visited any of these yet. The Kobe Shipyard occupies a major portion (over a million square meters) of the Kobe waterfront and employs about 6,000 people. Major activities are shipbuilding (passenger and cargo ships, oil tankers, bulk carriers, ferries, destroyers, submarines), including about 30 container ships, ship repair, and other types of heavy construction, such as steel structures (bridges, pools, domes), nuclear and thermal power plants, diesel engines, tunnel boring machinery, various deep submergence research vehicles (including a new manned vessel built mostly of titanium that recently exceeded the 6,500-meter depth mark), as well as excursion submarines, etc. During the week we visited this facility, Mitsubishi christened their superconducting electromagnetic thruster ship, with appropriate press releases, but we had no opportunity to view this. About 30% of Japanese electricity is generated by nuclear power, and Mitsubishi produces most of the pressurized water reactors for Japan. I have no background in heavy manufacturing and can only report the impressions of the other tour members who were more accustomed to such operations. They were exceptionally impressed with (a) the cleanliness, quiet, and order of the big shops; and (b) the very large scale equipment that was being handled, including millers, welding, and casting machines for titanium and superalloy products. There was a consensus that this kind of manufacturing technology is very rare today at private facilities in the United States.

# Appendix

## STATISTICS ON THE 1990 JAPAN-U.S.A. SYMPOSIUM ON FLEXIBLE AUTOMATION

This meeting brought together searchers from around the world to iscuss manufacturing automation and elated technologies. The participant nd manuscript breakdown is as follows.

Of the 235 papers accepted for the ieeting, 165 were from Japan and 70 rom the United States. Of the 220 apers published in the Proceedings, he major contributors were as follows: apan 105, U.S. 61, China 17, Korea 8, taly 6. During 38 technical sessions here were 203 presentations, with 9 joint apers from the Japan and the United states and 7 between other countries. Jniversities provided a larger percentage of papers than industry for all ountries, as the following ratios show: lapan, 66/34; U.S., 93/7; Europe, 94/6, Asia, 76/24, others, 100/0. The 38 technical sessions can be grouped into the ollowing general topics (with number of sessions on each topic): robotics (9), nanufacturing (9), computer integrated nanufacturing (CIM) (7), control (5), vehicles (4), others (4).

### Keynote Speeches

(1) "Fuzzy Logic in Control and Decision Analysis," L. Zadeh, University of California at Berkeley

(2) "Market-Oriented FMS and CIM: A Megatrend for '90's Manufacturing Industries," T. Yamazaki & A. Nagae, Yamazaki Mazak Corp.

### Plenary Speeches

(1) "Environment Surrounding Flexible Automation," H. Edmondson, Hewlett-Packard Co.

(2) "The Role of Quality Engineering (Taguchi Methods) in Developing Automatic Flexible Manufacturing Systems," G. Taguchi, Japanese Standards Association

### Session Titles

- Design and Tuning of Robotic Systems
- Robot Manipulator Control
- Technology of Mobile Robots
- Autonomous Mobile Robots in Unstructured Environment
- CIM and FMS Concepts
- FMS and FMC Technology
- Mechatronics-Micro Mechanics and Fine Motion Control
- Modelling and Identification for Dynamical Systems
- Control of Manipulators with Redundancy
- Artificial Intelligence Application for Flexible Automation
- Motion and Force Control of Robot Manipulators
- Motion Planning and Control in Automated Systems
- Path Planning and Concept Formation for Vehicles
- Intelligent Vehicle Navigation In and Out of Factories
- Dynamical Systems and Control
- Adaptive Control Applied for Mechatronics
- Learning Control in Robotics
- Manufacturing Process Sensor Systems
- Manufacturing Process Monitoring and Control
- New Manufacturing Process Control and Analysis
- Flexible Assembly and Theoretical Analysis
- Robot Cell Planning and Control
- FMS and Intelligent Simulators
- Robot Control in Constrained Environment
- Control of Flexible Manipulators
- Robot Hands and Manipulators with Compliance
- Quality Issues and Flexible Automation
- Automatic Inspection
- Distributed Parallel Robot Systems
- FMS Planning

- Scheduling in Automated Factories
- Flow Shop Control and Optimum Batch Size
- Intelligent and Integrated CAD Modelling
- CAD/CAM Systems and Software Practices
- Global Programming Languages for CIM and Intelligent Robots
- Sensor and Vision for Autonomous Systems
- Visual Pattern Recognition
- Intelligent Robot Systems

# OPTICAL COMPUTING IN JAPAN

*Optical computing activities in Japan are surveyed.*

by David K. Kahaner and H.J. Caulfield

## INTRODUCTION

In recent years, the field of optical computing has been rapidly broadened into various areas, such as investigations of optical analog and/or digital data processing and optical and optoelectronic phenomena and devices for optical computation. An optical computer is a computer in which light is used somewhere. This can mean fiber optical connections between electronic components, free space connections, or one in which light functions as a mechanism for storage of data, logic, or arithmetic. The main motivation of many recent studies of optical computing is the increasing interest in developing a new parallel computing system capable of processing large amounts of data at high speed, and my own interests in the subject are centered on this potential application.

My aim was to discover how close optical computing is to being of use to the constituency of numerical computing that I represent and to gain some understanding of the ways digital optical computing and neural computing overlap. In my opinion, most scientists engaged in mainstream scientific computation have little knowledge of neural computing and even less of optical computing. Nevertheless, these are well established scientific fields with thousands of researchers, professional societies, journals, and international meetings. For example, Optical Computing '90, held in Kobe, Japan, 8-12 April 1990, was a major conference on this topic with almost 500 attendees. (See below for my summary and evaluation and an overview of this meeting by a leading expert in optical computing, Prof. H.J. Caulfield.)

Optical computing is seen by a number of Japanese as an essential direction for computing research. Here are some examples of their comments:

- The Ministry of International Trade and Industry (MITI): "Electronics is the science of the 20th century, and optics is the science of the 21st."
- Dr. Izuo Hayashi, Director of the Optoelectronics Technology Research Laboratory (OTL) in Tsukuba: "The combination of photons and electrons will create new kinds of system which we cannot imagine just using an extension of today's technology. For instance, imagine real 3D integration, by which I mean wafer-to-wafer communication, vertically, by light, so that we can make stacks of hundreds of wafers by integration. Once we master optoelectronic integration technology we can begin to imagine new architectures."

Concerning the research activities in Japan and the United States:

- Prof. Takeshi Kamiya, Department of Electronic Engineering, University of Tokyo: "Compared to the U.S. we have a wider variety of research groups in Japan that are developing devices dedicated to optical computing. ... In the U.S., I think there is a wider variety of groups looking for new architectures for optical computing."
- Dr. Ken-ichi Kitayama, supervisor at NTT Transmission Systems Laboratories: "[ATT Bell Labs] are looking at the short term target rather than the longer term target, and it seems that all their efforts are now concentrated on 1995. ... But NTT's long term goal is to establish optical processing technology and to fully exploit massive parallelism by optical means. This will produce new types of optical devices and an optical architecture. We expect that in the long run, research in a broad range of areas will be fruitful. So for now, we consider this to be a basic research phase, not the practical development phase. ... The photoelectronic or optoelectronic computer is the direction of the future."

## WHAT IS OPTICAL COMPUTING?

The concept of passing light through lenses to perform computations is not new. I took a course on this in the 1960s. The fundamental idea can be illustrated by noting that a simple lens essentially performs a two-dimensional Fourier transform of its input in real time for arbitrarily complicated image, whereas using digital computation the effort increases rapidly with the number of data points or pixels. Using a lens in this way is an entirely analog process, and most of the early research considered computation in analog terms very much like it was described in the days of analog computing.

In recent years, developments have centered on digital calculations, by using optical devices for logic, memory, or arithmetic. A stumbling block in this research is that it is necessary to find optical materials that react nonlinearly to input, and thus far sufficiently nonlinear materials have not been available, or their nonlinearities are too weak for practical application.

Work is also continuing on using optics to connect traditional circuits. Optical communication has already made a significant impact in computer communication via optical fibers. It is well known that optical fibers have much lower attenuation during transmission than electrical wires in coaxial cables. In addition, they are more resistant to electromagnetic radiation along their length. Optical cables are already being used as input/output (I/O) channels in Japan (Hitachi in 1987, Fujitsu in 1988, and NEC in 1989). Such channels have data transmission rates up to 9 MB/s and may be improved to more than double that. In addition, they can be used over much longer distances, up to about 1 km for disk channels, about eight times as far as electrical channels. Prof. J. Goodman (Stanford University), for example, believes that "optical interconnects" in general are promising areas for real products. Further, if these interconnects can be utilized to connect one chip to another (optical output pads), it is speculated that performance in the 10 GB range will be possible.

Laser beams can cross in arbitrarily complicated ways without losing their individuality, or experiencing crosstalk, at least on larger dimensional scales. Again the Fourier transform provides an excellent example. Each point value of the transform is obtained by integrating over all points in the source plane; that a lens can do this easily is, in one sense, the ultimate in parallelism. It is estimated that optics can achieve at least 50 times the parallelism or connectivity of electronic devices. The Japanese expertise in device technology may enable them to capitalize on it better than others. This was aptly summarized by Kitayama in describing research at NTT in optical computing:

> Although the applications in the future may be diversified, special purpose hardware may first come in processing images at data rates which are unobtainable using all electronics. ... One of the promising schemes would be a combination of optical devices and VLSI. Optical neuro-chips may be a longer-term goal. ... Practical application of optical hardware still seems to stand at the far end of the time line.

There seem to be four categories of optical computers:

(1) Optical analog. These include two-dimensional (2D) Fourier transform or optical correlators and optical matrix-vector processors.

(2) Optoelectronic. These do not yet exist but would be constructed using optical logic gate devices or 2D photo diode arrays. The main interest in this type of computing device would be to shorten the pulse delay in chips and other logic elements by using optical interconnections.

(3) Optical parallel digital computers. These would use the inherent parallelism of optical devices along with digital electronics for flexibility.

(4) Optical neural computer. Specifically designed to implement the massive interconnection requirements of neural networks optically.

## GENERAL REMARKS

Optical computing is still a branch of experimental optics, with the usual trappings of physical science, i.e., careful attention to fine detail of setup and analysis. The research is not localized in any single country. Early work by scientists at Bell Labs and other U.S. laboratories is now complemented by comparable work in many other countries. As long as optical devices utilize free space, the research results are clearly dependent on the planning, creativity, and care of the individual research group rather than on access to technology that is not widely available. To the extent that scientists are beginning to think of optical computing "chips," the Japanese researchers have the advantage of access to the substantial resources and basic technological device infrastructure of large Japanese industrial laboratories. The same may apply to work at a very few U.S. laboratories such as Bell Labs. Thus far, concrete applications are several years away from being useful to the numerical computing community. There seems to be a healthy competition between major researchers. For example, Huang at Bell Labs is working on optical logic gates based on a principle he calls SEED, but Kamiya thinks that the NEC approach might have certain advantages such as ability to amplify optical signals.

## RELATION TO NEURAL COMPUTING

A neural computer, or neural network, is a special kind of highly parallel computer with many computing elements or nodes performing simple operations (usually just matrix vector product) in a very repetitive manner. In some models of neural computer (which have never been implemented), there are postulated to be tens of thousands of nodes, each one of which is connected to all the others. Neural computers compute in the sense that they have streams of input and output bits. They do not require anything resembling ordinary programming; if programming is done at all it is by dynamically changing the degree to which the individual nodes are connected.

An important aspect of a neural network is the high degree of parallelism associated with it. Thus, it is natural that new parallel computers should seek to implement neural networks as an application (but not the only application). Optical computing researchers believe this parallelism can often be implemented best using optical devices rather than traditional wired circuits. Thus, optical computing and neural computing are fields that have developed independently and now sometimes come together for their mutual benefit.

Today, most applications of neural computing, and in particular those in which optics play a role, are related to image processing, character, target, or voice recognition and similar situations. However, several researchers have demonstrated optical devices that can multiply matrices and solve small systems of linear equations, and papers are appearing that attempt to apply neural models to more general reasoning situations. At this time neural networks have not been applied to numerical modeling problems, and I have seen nothing on any of my visits to suggest that this is likely. Perhaps these models are fundamentally different from what we usually think of as algorithms.

As mentioned above, the fundamental operation of a neural computer is multiplication of an input vector (array) into a matrix with elements called the network "weights." Both input array and weight matrix are assumed to have non-negative elements. Let the matrix elements W(i,j) be associated with a two-dimensional light mask and the input with a light-emitting device array. Let the vector information of the input, v, be radiated as optical intensity from laser diodes or light-emitting diodes in such a way that v(j) is radiated uniformly to the j-th column of the matrix W in such a way that W(i,j)v(j) is the light intensity on the back, or output side of the mask at point i,j. This is usually described as "fan out." Then let the light intensity of the i-th row of W be converged onto the i-th component of a light receiving device array, also in a uniform way. By superposition, the i-th component of the output array is then the inner product of the i-th row of W into v, and in this way the matrix vector product is formed. The technical issues to be dealt with include developing appropriate fan out light-emitting beams and a mechanism to permit variation of the values of the components of W(i,j). The matrix vector multiplier above is usually part of a "neuron," which takes each output component and returns 1 if it is large enough, 0 otherwise. To do this optically requires optical "thresholding."

## OPTICAL COMPUTING '90 (OC90)

The 1990 International Topical Meeting on Optical Computing was held 8-12 April 1990 in Kobe, Japan. Almost 500 scientists attended this meeting. A related meeting on photonic switching was held immediately after. Participants came from Japan, the United States, the U.S.S.R., France, the United Kingdom, FRG, China, Switzerland, Finland, Australia, Bulgaria, Korea, the Philippines, Sweden, Canada, Belgium, and Italy. The meeting was held in the International Conference Center at Kobe, on an island in the Port of Kobe. There were no parallel sessions and the first day was exclusively devoted to three tutorials, by J. Goodman (Stanford Univ.), D. Miller (ATT Bell Labs), H. Szu (Naval Research Laboratory). A proceedings, in English, is available from the International Society for Optical Computing by referencing ISBN 4-980813-37-9. I also have a copy of the proceedings. Many of the papers presented at OC90 are variants or extensions of papers that are published in journals such as *Optoelectronics* or *Applied Optics*. I am not a physicist and cannot evaluate such aspects of this work.

## Optical Devices

An extensive collection of reprints (in English) was sent to me by Professor Yoshiki Ichioka, Department of Applied Physics, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565, Japan, for which I am very grateful. Ichioka and colleagues have been concentrating on building optical devices that will perform fundamental logical functions, AND, OR, NOR, etc. The group has created several new ways to implement some logic devices. Their computer design using these techniques is called OPALS. Work on this has been going on since at least 1983 and is well known outside of Japan. However, implementation requires development of several new kinds of devices, so this research is several years away from practical application.

Goodman and colleagues from Stanford presented a paper on a simulated 64-node shared memory multiprocessing system, the IBM RP3, with optical interconnects. Similarly, a paper by staff (Matsumoto, Sakano, Noguchi, Suwabe) at NTT Transmission Systems Laboratory, 1-2356 Take, Yokosuka-shi, Kanagawa-ken, 238-03 Japan, described a system composed of 36 T800 transputers running a parallel processing system with optical connections in "free space," i.e., in a box rather than in a chip. The technique looks promising but is also at a very early stage.

A different view of optical devices was given by Dr. Peter Davis, who works at the Advanced Telecommunication Research Institute (ATR) laboratory. See my report on this institute in the *Scientific Information Bulletin* ["The Advanced Telecommunication Research Institute (ATR)," 15(4), 4-5 (1990)].

## Optical Neural Computing

One of the most interesting papers was on Mitsubishi's optical neural neurocomputer. A paper was presented at this meeting and several other related papers have also been given at various neural network meetings during the summer months. The principal researchers are Kazuo Kyuma and J. Ohta at Mitsubishi Electric, Central Research Laboratory, 1-1 Tsukaguchi-Honmachi 8-chome, Amagasaki, Hyogo 661, Japan. While there are many research activities, both in academia and industry, on the development of optical chips, Mitsubishi's looks very impressive to me because they have actually been able to fabricate a device that they claim can be mass produced. An important aspect of this chip is that there are only two layers rather than the three in other designs, by use of what they call a sensitivity-variable photodiode. Further, the chip allows for a dynamic alteration in the interconnection weights between input and output. This last feature is essential for "learning," in neural networks, i.e., adjustment of interconnection weights in order to obtain specified output for given input. The ability to vary the weights is lacking in many other projects. The Mitsubishi group estimates that they can build this chip to contain about 1,000 neurons in a 1 cm square with acceptable power requirements (less than 1 watt), large dynamic range (20 dB) for the weights, and low optical crosstalk. Although light beams do not significantly interact at large scales, at chip level scales they do and this issue must be addressed. They estimate that such a chip can perform more than one tera connection per second, 10**(13).

## Expert Summary of OC90

This reviewer feels safe in saying there were no "breakthrough" papers. Accordingly, I offer this impressionistic assessment of work by regions.

The European work is dominated by Germany, Israel, France, and the United Kingdom. In my judgment, this is the least dynamic of the groups.

The Japanese work was short on innovation but long on practice. There were numerous papers on components they have manufactured, especially spatial light modulators (SLMs). The Seiko SLM was discussed the most. Most of the other Japanese work was on systems they had implemented. In general, they seem to be working on parts and system manufacturing methods, leaving the innovation primarily to the United States and the Soviet Union. I regard this as very clever on their part. Money and jobs stem from building things, not inventing things.

The Soviet Union was well represented--nearly all Russians. I was particularly impressed by their innovation. V. Morozov's work on waveguide holograms coupled to diode lasers is symbolic of important work so far done only in Russia.

America was well represented in number and breadth. Like the Soviet work, the U.S. effort has no unified theme and even no agreements as to what is important. Alan Huang and many of his AT&T coworkers presented their well publicized but controversial (as to its current or potential value) work on digital optical computers. Optical neural networks, quantum mechanical effects, and hybrid analog-digital processors were other major themes. Overall, the field is growing in numbers and support, but no certain winner as a technology has emerged. The United States and the Soviet Union are the innovators. Europe is the monitor. These are caricatures, but they are not misleading.

## CONCLUSION

Optical computing appears to be a research area that has already provided a few practical applications. Its real potential for general computation lies several years away. There are many steps from discussion of AND gates to Fortran compilers. Nevertheless, this seems like a research topic with high payoff potential and only modest risk (cost). The Japanese Government has set up an optoelectronics laboratory at Tsukuba and it would be natural for them to enlarge the scope of its research into optical computing, perhaps in conjunction with the activities that are present at the industrial laboratories.

**Dr. H. John Caulfield is the founder and director of the Center for Applied Optics of the University of Alabama in Huntsville. He is the author of four books, a dozen book chapters, hundreds of technical papers, and many popular articles, e.g., the 1984 *National Geographic* cover story on holography. A Fellow of OSA and SPIE, he has been called one of "America's 10 Top Scientists" (*Business Week*, 1989) and one of "The World's Most Influential People in Minicomputers (*BYTE*, 1990). His work has been described in *Newsweek*, *Time*, *Fortune*, *High Technology*, *Popular Science*, *American Way*, *Delta Sky*, and other popular journals. Among the 10 journals on whose boards he sits are 2 in neural networks and 3 in optical computing.**

# FUZZY LOGIC

*A survey of recent developments is given, with particular emphasis on Japanese contributions. There is worldwide interest primarily due to the success of Japanese industry in producing real applications. Many new products are expected, but the next major step will be to combine fuzzy logic with more general inferential methods. Basic research capabilities are well distributed around the world. The International Conference on Fuzzy Logic and Neural Networks (Iizuka '90, 22-24 July 1990, Iizuka, Japan) illustrates most of the conclusions.*

by David K. Kahaner, Walter J. Freeman, and Armando Freitas da Rocha

## WHAT ARE FUZZY SETS?

A fuzzy set is a set and a function (membership function) f mapping elements of the set into the interval [0,1]. If x is an element of a fuzzy set then f(x) is called the grade of x. We say that f(x) describes the degree of compatibility of x with the concept represented by the fuzzy set; grade 0 denotes total incompatibility, grade 1 total compatibility. A fuzzy set is "crisp" if all its elements have grade 1. For example, if the concept is "tall person" and the set elements are heights then f(x) describes to what degree x represents a tall person. There are subjective issues here, in particular, the grade, but for applications it does not seem to make much difference what the specific membership function is, only its general shape. When the set elements are scalars, such as distances, membership functions (when they are used to represent concepts such as tall, close, hot, and so forth) are often linear, piecewise linear, or piecewise quadratic. Membership functions can also be multivariate, and this is sometimes a good way to express the logical AND of two concepts.

## EXAMPLES

Most of the definitions and operations associated with fuzzy sets are straightforward extensions of those from ordinary set theory, although often there are several alternative definitions possible. Thus the notions of subset, union, intersection, and properties of commutativity, associativity, and distributivity are easily described for fuzzy sets. It is also possible to define fuzzy relationships, essentially a subset of the cartesian product of two fuzzy sets. The "extension principle" defines functions of fuzzy sets and it can be used to define the degree of membership of one fuzzy subset in another. Fuzzy numbers can also be defined. For example "about 5" might be the fuzzy set {1,2,3,4,5,6,7,8,9} with grades (.2,.4,.6,.8,1.,.8,.6,.4,.2).

Much of the work in fuzzy logic has developed from seminal papers by L. Zadeh (University of California, Berkeley) beginning in 1965. As a practical tool, an important step occurred around 1970 with the work of Mamdami on fuzzy or approximate reasoning. We illustrate one concrete implementation of this below, although a great many other technical variations and extensions are possible, such as reverse truth quantification, fuzzy Modus Ponens, predictive fuzzy control, etc.

Approximate reasoning allows inferences to be made on the basis of input information through fuzzy sets via membership functions. This deals with the fundamental notion of "knowledge," "production rules," or IF-THEN rules. In traditional expert systems, rules are of the form

> IF pressure, p, is greater than
> 10 pounds per square inch THEN
> open valve by 10+0.7p radians

Expert systems usually contain large numbers of such rules, which are then combined. Often LIST or PROLOG is used to implement these rules. Fuzzy production rules allow rules of the form

> IF pressure low THEN open
> valve a little

Here "low," "little," etc. are fuzzy sets. Mamdami's approximate reasoning proposed the following scheme which we illustrate here. Suppose we have two fuzzy production rules

IF pressure high THEN velocity very small

IF pressure slightly high AND current medium THEN velocity slightly low

Each of the five terms, "pressure high," "velocity very small," "pressure slightly high," "current medium," and "velocity slightly low," corresponds to a fuzzy set and membership function. For example, "pressure slightly high" might have a membership function that is a piecewise linear "tent" function; the membership function for "pressure high" is frequently defined as a function that is 0 for p<p0 and 1 for p>pmax, increasing linearly between p0 and pmax. These are called "linguistic fuzzy sets." To obtain numerical output, consider the case where the input pressure is measured as p. Mamdami's min-max reasoning method operates as follows:

(a) Use the input p to obtain grades *for the IF part of each relevant* production rule. The grade for the second rule above (AND rule) is the minimum of its two operands.

(b) The membership function of each corresponding THEN part is limited to the smaller of its defined value and the output IF grade.

(c) Compute the logical sum (OR) of all the limited membership functions for the THEN parts.

(d) Compute the center of gravity of the function computed in (c). Its abscissa is the numerical output of the reasoning.

If pressure high was represented by a discrete rather than a continuous set, it would be possible to build hardware that would map the grade values of the set into, say, a collection of line voltages. Similarly, the operations described above can also be applied via hardware. This is the approach taken by Takeshi Yamakawa, of Kyushu Institute of Technology, and the chairman of the Fuzzy Logic Systems Institute:

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## APPLICATIONS AND EXTENSIONS

In Japan, the most direct and immediate applications for fuzzy logic have been to the development of control devices. These range from controllers for subway systems and blast furnaces to antishake control for video cameras and color control within copiers. The significant reason for this is that to use traditional control theory one must be able to describe mathematically the system to be controlled. A famous example is a controller that will balance a pole on a cart whose forward and back motion can be controlled (pole-sitting). The controller must adjust the motion of the cart. To model the motion requires the solution of a second order differential equation. If large deviations beyond the vertical are to be described, the approximation of sine theta by theta becomes inaccurate. The more correct equation is nonlinear and needs to be solved numerically. To find a solution to the equation that balances the pole is not really possible, as the solution point is unstable with respect to the system's initial conditions. On the other hand, it is possible to develop a controller using fuzzy logic without anything more sophisticated than codifying the membership functions for rules such as

IF pole angle positive medium
THEN cart speed positive medium

This requires experience but only elementary mathematics; the equations of motion are not needed by the controller. Other very complicated control problems can be tackled in this way. For example, M. Sugeno

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is studying use of fuzzy logic in full size helicopter control systems; the techniques had already been publicly demonstrated in a scale model helicopter. The latter has four blades, so the motion is overdetermined. Control of the pitch and thrust of these is very difficult for a human operator without any assistance.

Much deeper extensions are also possible. For example, Sugeno has also been working for more than 10 years to formalize the concepts of fuzzy measures and fuzzy integrals, which he has shown recently to be related to Choquet integrals, studied in classical analysis. An important part of this work is that the ideas such as "possibility," "necessity," "belief," and "plausibility" can now be defined in a rigorous way.

George Klir (State University of New York at Binghamton) has been probing the meaning of uncertainty. There is a lively debate about its relationship to probability. For example, Lindley writes, "Anything that can be done with fuzzy logic, belief functions, upper and lower probabilities or any other alternative to probability can better be done with probability," and Peter Cheesman (NASA Ames) also feels that fuzzy logic will be unable to provide rapid control over high precision devices, and more analytic models will be needed. Contrarily, Professor Bart Kosko (University of Southern California) has a theoretical description of fuzzy logic that is claimed to subsume probability. Researchers are certainly of mixed opinions on these ideas and may even try to mix the two, as does Uemura (Nara National College of Technology) discussing fuzzy-Bayes decision rules. Nevertheless, it is clear that to state "68 inches has grade .6 for tall" is not at all the same as saying that this is its probability.

## TRENDS

I believe that the next major research thrust related to fuzzy logic will try to extend its use to more general reasoning, inference, and learning situations. This includes topics such as multicriteria decision making (Ronald Yager, Iona College), interpolative reasoning (Zadeh), recognition (classification and clustering), connectionist expert systems, supervised and unsupervised learning, knowledge acquisition, etc. In this regard fuzzy logic complements and parallels neural networks, and it is not surprising to see a great deal of research work trying to capitalize on the best characteristics of each. This involves the possibility of cascading two devices or otherwise merging them. For example, Kosko describes how fuzzy systems behave as associative memories, and it is fairly common to consider using neural nets to learn membership functions of fuzzy sets. There is some friendly competition here, too, as researchers try to assure that their view will not be eclipsed. Kosko mentions truck and trailer backing-up control using fuzzy target tracking, and Bernard Widrow (Stanford University) uses truck and two-trailer backing-up using an adaptive nonfuzzy neural network. There are also attempts to bring in other significant ideas such as quantum mechanics (T. Nishio, JUKI Corp.), nonlinear dynamics (Y. Aizawa, Waseda University), information theory (I. Tsuda, Kyushu Institute of Technology), and others, but at the moment these associations are at the very early stages.

There is also considerable activity trying to understand how fuzzy logic and neural networks are associated with knowledge or reasoning and there are several conflicting and divergent views. Some researchers, such as Walter Freeman (University of California, Berkeley), Elie Sanchez (Neural & Fuzzy Systems Institute, Technopole de Chateau-Gombert, Marseille, France), or Armando Freitas da Rocha (Jundiai, Brazil), who specialize in brain function and neurophysics, have been emphasizing that the precise models of neurons usually presented in computer science reasoning research have almost no relation to the vastly more complicated real nervous system, and that fuzzy rules are much better at describing real physiology. But not everyone agrees that the best approach is to focus so much on brain mechanisms. For example, Shun-ichi Amari (University of Tokyo) states that human information processing principles "may have been discovered and realized in the brain through a random search in the process of the evolution, so that they might not be a very sophisticated realization. This makes it difficult to study the principles from biology and by experimental methods only. On the other hand, we may invent a technological realization of these principles in a different and more sophisticated architecture." Amari's work is primarily in mathematical models for neural networks and is highly regarded as among the best Japanese basic science. But the brain function group feels that biology has acquired an impressive amount of knowledge about brain biochemistry, physiology, and pharmacology that may be very useful in developing a highly sophisticated theory about neural networks. For example, modern genetics is discovering the effect of the guiding influence the external world has on random evolution.

If we consider neural networks as only numerical processing tools, and knowledge-based systems as symbolic processing tools, then we might regard fuzzy logic as somehow buffering these, or providing the mechanism to interface the imprecise world with computer precision--eliciting information from and providing it to human operators. From that point of view fuzzy logic seems to be more associated with higher-order (cognitive) processing, while neural networks can learn and are data driven. Fuzziness is easy to understand while neural networks are not; neural networks can learn or adapt while this is more difficult for fuzzy systems.

On the other hand, where is symbolic reasoning done? Unless we assume it is performed by an entity other than the brain, then neural nets developed taking into consideration biological knowledge about the neuron must be able to perform some symbolic reasoning. So in that context, neural nets should not be delegated to only low level tasks and fuzzy logic cannot be viewed as buffering symbolic reasoning with low level activity of neural nets.

Fuzzy sets can be perceived as a novel designing technology to be utilized for complex and human-oriented applications. Fuzzy logic tries to emulate some properties that humans use in their control and decision processes. In this there arises a need to incorporate many sensors to input information. These will be inevitably needed in order to gather the vast amount of additional data usually available to humans. Thus it is important not only to talk about fuzzy sets alone but to become aware of the sensor inputs that are necessary to create algorithms based on fuzzy sets.

It is fair to say that fuzzy logic has not been spectacularly received in the United States, while it has had a major impact in Japan. Why? It has been claimed that fuzzy logic fits well into the Japanese culture, which is attuned to lack of precision. While this may be true I do not think it is the essential reason. Membership function subjectivity seems to be one important aspect. My own assessment relates to where research is being performed in these two countries. In the West most basic research occurs in universities, national laboratories, etc., while in Japan a much larger fraction is in industrial research laboratories. As the example above illustrates, at the elementary level fuzzy logic has a certain apparent imprecision that might put people off, especially in a university environment. But it is easy to grasp its rudiments and allows the solution of problems in standard ways that would require much more technical mastery to deal with by other means. This is especially true for problems in control where most of the practical applications have appeared. Thus where applications count as they do in industry, any approach that solves the problem, especially if it is simple, will be accepted. There is no doubt that the Japanese play a key role in the development of this technology.

Japanese interest in fuzzy logic has permeated their society. Newspaper and magazine articles, often written by respected academics, are frequent. (Specialist written, general interest articles are common in Japanese media.) There are also several textbooks containing elementary theory, specific applications worked out and contrasted with traditional techniques, as well as exercises for practice. In the United States, most undergraduate engineers have never heard of fuzzy logic.

# IIZUKA '90

## Kahaner's Comments

The International Conference on Fuzzy Logic and Neural Networks (Iizuka '90, 22-24 July 1990, Iizuka, Japan) illustrated many of the points made above. The conference was held at a new branch campus of Kyushu Institute of Technology in Iizuka that is entirely devoted to computer science and systems engineering. Total student enrollment will be about 2,000 when the facility is finished (about another year). Professor Takeshi Yamakawa chaired the conference, which brought together nearly 600 scientists from more than one dozen countries presenting 220 papers in almost 50 sessions. The large number of well known researchers coupled with well publicized applications in fuzzy logic meant that the media was also well represented. To add even more glamour, on the last afternoon dual sessions were held in Iizuka and at NASA Ames (where it was the middle of the night) connected by television and billed as a teleconference.

The conference dealt with three basic topics, namely, fuzzy sets, neural nets, and chaos, with some emphasis put on exploration of possible and the most fruitful links between these three fields.

As Freeman describes below, applications exhibits stole this show. There were so many Japanese applications that it would be easy to fail to notice that they also presented a great many solid basic research results. With some exceptions the Japanese papers do not normally go for the large scale theory or encompassing frameworks. This contrasts directly with perhaps the more fundamental work of Zadeh, Kosko, Freeman, Pedrycz, and others from the West. Nevertheless, from their applications, it is clear that many researchers see that for multi-degree-of-freedom control problems, simple common sense membership functions and intuitionistic fuzzy production rules will not be enough; more formalized inference mechanisms are needed. The Japanese approach to theory seems to be to push it forward enough to anticipate and solve some emerging problems rather than to make great leaps.

From the United States the most "Japanese-like" work was by F. Hadipriono (Ohio State University), who has been studying the very practical problem of determining the kind of foundation that new buildings need. He has used traditional fuzzy logic and then extended the idea to angular fuzzy set models which use angular rather than linear measure to represent linguistic values. Mildly new theory thus deals with a concrete application--this was quite different from other U.S. papers.

Although out of my field, one of the most exciting papers was presented by A. Grinvald (Rockefeller University, New York), who described two experimental techniques for monitoring properties of active brain tissue--a big step forward. There were also a significant number of papers on chaos and nonlinear dynamics, particularly in biological systems. Human brain activities such as memorizing or evoking emotion are thought of as being the output of vastly complicated nonlinear processes built up of simple elements. Freeman and colleagues have found chaos in the brain of higher animals. Researchers are still struggling to find ways to relate the chaos that is widely observed in nonlinear phenomena to information and signal processing, and the Japanese seem mostly to be staying on the sidelines.

## Freeman's Comments

Tutorials were given on fuzzy logic (FL), neural nets (NN), neurocomputation, and nonlinear dynamics and chaos. They were poorly done and not well received, with the exception of those on chaotic dynamics (Crutchfield) and neurocomputing (Amari). No strikingly new developments or new directions were reported in either FL or NN at the meeting. In his address, Zadeh described his procedures for interpolative reasoning by quadratic interpolation between three fuzzy points using a fuzzy parabola. Widrow elaborated on his truck backer-upper from one trailer to two and threw in an obstacle to go around.

The star of the show was applications, notably FL control devices for operating sessile robots, automobiles, automobile engines, washing machines (using sensors for levels and rates of change of turbidity in wash water, rotational inertia and mass of clothing, and color spectral distributions), film and video cameras, and optical character recognition (OCR). Adeline and the Neocognitron were clearly out-classed. The most imaginative applications were:

- A Panasonic system for image stabilization of hand-held video frames. This system locked the frame onto a set of 128 points, calculated the vector for successive frames, compared across the set, and shifted the image in accordance with the global common change. There were two cameras mounted on a shake table, one with and the other without vibration. I lifted the whole table and shook it--the image held firm!

- An orthodontic FL evaluator used to score dentists (a dental GPA!). Twelve measurements can be entered before and after treatment.

- A FL system to optimize "color harmony" for interior decorators.

FL has clearly outstripped NN mainly because it is so accessible to nonspecialists. As one student told me, he became adept at FL programming in 6 weeks instead of having to spend a couple of years doing mathematics in graduate school.

Many talks focussed on the complementarity of FL and NN, using FL to design membership functions and rule structures and to interpret the "black box" of neural weight matrices. Similarities were noted between the NN operation of product-sum and FL IF-THEN rules, NN sigmoid curves and FL membership functions, and NN weight matrices and FL look-up tables. Kosko claimed that forward NN (Perceptron-like with or without backprop) are homeomorphic with FL (fan in-fan out) architectures, and that FL is clearly superior. I'm in agreement with him. He also demonstrated the slight superiority of a FL filter over a Kalman filter in regard to jitter and speed of convergence.

This conformance does not apply to NN architectures with feedback, such as the Hopfield network and related architectures from Anderson (brain-state-in-a-box), Amari, Kohonen, Grossberg, and Freeman, which have a set of attractors corresponding to a classification memory set, basins of attraction corresponding to generalization gradients, and minimization functions that reflect the convergence to an attractor with recognition. For the most part these are simple dynamic systems with equilibrium attractors or in a few cases admitting inhibitory elements to give limit cycle attractors. Few papers here addressed these systems, reflecting their poor reputation because of limitations on their performance, even on the Travelling Salesman Problem and other classic problems in combinatorial optimization. Only one such system was described by Freeman using chaotic dynamics and strange attractors for successful classification of data from industrial sources not classifiable by Bayesian, Hopfield, or parallel distributed processing (PDP) methods.

Scientifically the most interesting reports at the conference were on nonlinear dynamics and chaos. Human and animal brains are clearly recognized now to be deterministic systems operating in chaotic domains. They are unstable, nonstationary, nonlinear, non-Gaussian, and continually evolving and updating through self-organizing processes. Several reports described the appearance of chaotic time series from single heart cells and neurons, the cerebral cortex, and whole brain. Simulations of chaotic brain activity were shown from solutions of coupled nonlinear ordinary differential equations and visual patterns of chaos from closed circuit TV. Measures of complexity that peak between the minima of steady state and pure randomness were described by Crutchfield and Aizawa. The phase portraits and geometric structures of chaotic attractors were described by Freeman, Basti, and Kaneko. The phase space of spatially distributed coupled oscillators was described by Kaneko, with domains ranging from equilibrium and limit cycle through weak (spatially coherent) chaos to extreme chaos (turbulence). Basti reported on schemes for describing the emergent and evolving order within self-organizing systems that create their own frames of reference. Tsuda listed six functions that chaos may contribute to brain operation:

(1) Owing to the inseparability of the initial conditions from the equations of motion for nonuniform

strange attractors, mutual information can be transmitted without attenuation. This is in opposition to the Shannon-Weaver rule for transmission in nonchaotic or uniform systems, that there is ALWAYS attenuation, and it reflects the fact that chaotic dynamics CREATES as well as DESTROYS information during transmission and other operations.

(2) Chaos "prevents falling into obsession," meaning degeneration to fixed point attractors.

(3) Chaos can retrieve patterns by rapid search through phase space.

(4) Chaos can control a system dynamically and "buffer" it against unexpected stimuli, replacing "homeostasis" with "homeodynamism."

(5) Chaos can generate the patterns (which Freeman calls "carrier" waves) that encode information (and, as Freeman noted, decode as well).

(6) Chaos can facilitate the reorganization of functional units in brains that are needed for flexibility, insight, and creation.

The relations of chaotic dynamical systems to NN are clear: massively parallel input and output lines; linear integration with massive convergence at nodes (but with second order equations not first order as in most NN, because the second delay term is essential in real brains for the requisite instability); the sigmoid nonlinearity; and multiple types of local feedback. The relations to FL are superficial. The membership function is distributed and may have unclear boundaries, and the chaotic attractor may have fractal separatrices around its basin. However, the profound differences are that FL systems are operator-determined by sets of experts and they are entropic and entail degradation of information, especially during the operations of max and min and of "de-fuzzification"; chaotic systems, on the other hand, are self-organizing (their "rules" emerge from within under training with examples) and they create order and information (in the Shannon-Weaver sense).

In his keynote address, Zadeh expressed optimism that in the near future this field would reach the goal of "voice in/voice out" technology (speech recognition, translation, voice control of robots, confirmation of orders received, etc.). Those of us working in nonlinear dynamics believe that this goal will not be achieved until we have understood and mastered the dynamics of high-dimensional systems operating in unstable, evolving chaotic regimes.

Thanks were extended to the organizer, Prof. Yamakawa, for his foresight in devoting a substantial part to nonlinear dynamics and to Prof. Tsuda for making that part so successful. Another conference is tentatively planned for 1992 or 1993, in which it is expected that nonlinear dynamics and chaos will be even more prominent, perhaps even with applications in pattern recognition and machine control, which at present are only barely above the horizon.

## da Rocha's Comments

After Iizuka '90, I attended the American Association for Artificial Intelligence (AAAI) meeting at Boston. The conferences were completely different.

At Iizuka '90, the fields of fuzzy logic, neural nets, and chaos were combined to try to discover the correlation between them. The fuzzy logic people stressed that neural nets may provide a way of easily defining the membership function (the most criticized point in fuzzy set theory), while fuzzy logic may furnish a strong semantic for neural nets (the weakest point in classic neural nets). The connectionists, in turn, showed that the real neuron is a fuzzy device in contrast to the crisp modelling derived from the McCulloch-Pitts neuron, and that adaptive learning may be applied to discover fuzzy rules.

Good solutions were presented in Japan on using fuzzy neural nets for reasoning and recognition from both the software and hardware points of view. Special attention was to be focused on handwriting character recognition.

While discussions resulted in some well established links between neural nets and fuzzy logic, they were inconclusive regarding the role of chaos in neural nets, and no link was discovered between chaos and fuzzy logic. In this context, it was noted that we have to be aware that machines cannot profit from chaos.

The AAAI workshop was organized within a more restricted view, questioning the feasibility of integrating symbolic and neural nets--a dead issue at Iizuka. All papers but ours timidly proposed some sort of hybrid system in which symbolic reasoning was reserved to solve the most important questions and neural nets were delegated the role of dealing with low level problems.

Uncertainty was another key difference between the two conferences. At the AAAI meeting, only a few words were heard about partial matching without any further attempt to present a suitable tool for handling it. Because of this, crisp neurons were the only actors on the stage. As a matter of fact, the predominant view at the AAAI meeting was that probability (Bayesian systems) at most could provide some hope for dealing with uncertainty. The word FUZZY was, in general, used within its naive meaning or at most linked to a bizarre theory. The invited speech on "Knowledge Representation" further stressed the (almost official) position of AAAI on these points and noted that artificial intelligence in the last decades has moved away from any correspondence with the human mental phenomenon, drifted away from practice, and focused attention on the sophistication of the mathematical language.

Iizuka, on the contrary, showed us practical examples of applying fuzzy logic even to washing machines and vacuum cleaners and of using neurons to recognize handwritten characters.

The comparison of the two conferences stresses the differences between two cultures and starts my neurons thinking about the reasons for the actual success of Japan in our high-tech world.

## CONCLUSIONS

Basic research in fuzzy logic is not limited to any single country. The Japanese have the lion's share of applications, primarily in controllers, although many other countries are active, particularly the United States, Europe, and Korea. The Japanese also have a good handle on the theory and can extend it where necessary to deal with anticipated new and more sophisticated applications. An excellent example of both these points is the work of H. Takagi (Matsushita Electric) surveying fusion of fuzzy theory and neural networks. Work in chaotic systems is strongest in the United States, especially those aspects that relate biological activity with understanding our higher brain functions.

New directions are cognition and knowledge, but most of this work is spread around the world. Fuzzy reasoning, database queries, etc. will be next to be explored. Scientists in the United States, Europe, South America, the Soviet Union, and Eastern Europe are at least on par with the Japanese in this area because the application areas have not yet been developed.

Neural nets in conjunction with fuzzy sets may enhance their processing properties. Nevertheless, it seems that those studies are at their infancy and they have not produced any meaningful industry-oriented results. Joint projects coupling fuzzy logic and neural networks should be encouraged to take advantage of the best properties and discover the limits of each.

Some essential points are still not explored sufficiently and need to be worked on further, for instance, a comparison of the design time and effort using fuzzy sets compared with some traditional approach. How significant is the claimed increase of productivity, what about robustness of results (i.e., control actions), and what about the system's ability to tolerate incomplete information? There are also healthy disagreements on how much we can learn from biological studies, and it is important to continue research in these areas.

## ACKNOWLEDGMENT

I would like to acknowledge the advice of Professors W. Pedrycz, W. Freeman, and A.F. da Rocha. Their written opinions and conversations were important to my understanding of this topic.

**Walter J. Freeman is Professor of Neurobiology in the Department of Molecular and Cell Biology at the University of California at Berkeley. He specializes in experimental brain research on memory and learning in the olfactory and visual systems, simulates nonlinear brain dynamics with coupled differential equations, and applies these models to problems in pattern recognition and generation. Prof. Freeman has authored over 200 reports and a monograph titled *Mass Action in the Nervous System* (Academic Press, 1975). He holds several key patents in the field of neural networks.**

**A.F. da Rocha received his M.D. in 1970 and his Ph.D. in neurophysiology in 1972. During the first years of his career, he did experimental research on sensory physiology and language neurophysiology, the results of which were published in books and journals. Fuzzy set theory attracted his attention at the end of the 1970s and he published several papers on fuzzy models of neurons and neural circuits. Dr. da Rocha's interest in reasoning resulted in development of new techniques for knowledge acquisition and analysis as well as development of neural expert systems. He is presently engaged in several international joint programs in artificial intelligence and neural nets.**

# OBSERVATIONS ON COMPUTATIONAL MATHEMATICS IN JAPAN

*The International Symposium on Computational Mathematics, held at Matsuyama (Shikoku Island) from 30 August to 4 September 1990, is summarized, with special emphasis on the contributions from Japanese and Chinese researchers. Visits by Kelley to Kyushu University, Kyoto University, and the Institute of Statistical Mathematics, with special emphasis on optimization research, are described.*

by David K. Kahaner and C.T. Kelley

## INTERNATIONAL SYMPOSIUM ON COMPUTATIONAL MATHEMATICS

### Introduction

The International Symposium on Computational Mathematics (ISCM) was held at the ANA Hotel in Matsuyama, Japan, from 30 August to 4 September 1990. Matsuyama is on the island of Shikoku, across the Inland Sea from Hiroshima on the main island of Honshu. The local organizing committee of T. Yamamoto (chair), T. Kitagawa, and M.-T. Noda from Ehime University in Matsuyama and X. Chen from Xi'an Jiaotong University in China worked for 2 years to plan and attract support for the meeting. A number of corporate and government sponsors from Matsuyama and Japan supported the meeting and most of the overseas visitors. Approximately 100 invited scientists attended, including about a dozen from the United States, seven from China, and others from Germany, Austria, The Netherlands, France, Switzerland, Finland, and Czechoslovakia. The meeting was timed to immediately follow the very large (4,000 attendees) International Congress of Mathematicians in Kyoto. (Kahaner attended a small portion of that as well, but found almost nothing relating to computation.)

ISCM was important because it brought together numerical analysts of international reputation, many of whom had never been to Japan before, and was to our knowledge the first such meeting to be held here. The invitees were well selected and representative, and the areas covered were reasonably diverse. The distinction between computational mathematics and scientific computing was maintained. Generally, the participants represented the analytical side; there were only a few talks about computing. In a recent *SIAM Review* article, Steven Smale characterized numerical analysts as the theorists of scientific computation, and this meeting well illustrated this. Also, there was little participation from the younger Japanese researchers. The meeting was conducted entirely in English.

### Discussion

The sessions began with an opening address by Prof. R. Glowinski of the University of Houston on domain decomposition methods. The formal sessions covered topics including eigenvalue problems in numerical linear algebra, preconditioning methods for solution of linear and nonlinear equations, acceleration methods for iterative schemes, continuation and bifurcation, inverse problems, monotonicity methods, boundary element methods, complex variable methods and numerical conformal mapping, quadrature rules, ordinary differential equations, finite element computations, computational fluid dynamics, interval methods, and many other topics in numerical analysis and scientific computations. A list of titles and authors is available by writing to D.K. Kahaner.

Special informal sessions were held in the evenings on nonlinear equations, harmonic methods, and interval arithmetic. These informal sessions were well attended and lasted until quite late. Some of the most spirited discussions took place at this time.

There were a number of talks and one informal session organized by Prof. T. Torii (Nagoya Univ.) on Durand-Kerner (DK) like methods for the computation of roots of polynomials. This is a fascinating topic that has engaged scientists for more than 100 years. The DK scheme essentially applies Newton's method to the symmetric functions of the roots as expressed by their coefficients. It was first proposed by Weierstrass and has reappeared every few years since. Generally, DK-like methods were considered rather extensively during the whole meeting. From a point of view of pure numerical analysis, there were several interesting results, particularly on the behavior of the methods in the presence of multiple zeros and on interconnections with approximation theory. Other than for intellectual reasons, though, why should one study methods for polynomial zeros anymore? One reason for the Japanese interest is that M.-T. Noda (Ehime University) has been considering combined symbolic and numeric computation, a very good idea in our opinion. One of his prototype problems is evaluation of integrals and he demonstrated convincingly that for some problems numeric quadrature is inefficient or incapable, and pure symbolic computation is theoretically insufficient. At the moment these hybrid methods are still very primitive, but the concept of combining these techniques has been a goal for many years. Some symbolic systems, such as Mathematica, revert to numerical approximation whenever they cannot make progress, but Noda's idea is to develop new hybrid algorithms that will combine the best features of both approaches. With respect to DK methods, though, some of the Western scientists felt that more attention was paid to them than they deserved, and that numerical continuation methods, such as global Newton methods, are suited to handle more general problems more efficiently. On the other hand, one of us (Kahaner) has used DK methods over the years and they have performed very well in practice, whereas continuation methods are often troublesome and frequently require special tweaking.

Another informal session was on "Methods for Enclosing Zeros of Systems of Nonlinear Equations," organized jointly by A. Frommer and G. Alefeld (Univ. of Karlsruhe). They were requested to organize this session by several scientists at the meeting, and, correspondingly, the audience was large, indicating that there was a good deal of interest. There were three lectures in this session:

- "On the Convergence and Divergence of Krawczyk-Like Methods" (G. Alefeld)
- "Efficient Modifications of the Interval Newton's Method" (A. Frommer)
- "Centered Newton's Method" (K. Tanabe, Inst. of Stat. Math., Tokyo)

The first two lectures tried to give an introduction to the basics of enclosure methods for systems of nonlinear equations as well as some advanced results on the convergence, speed of convergence, and computational complexity of state-of-the-art algorithms in this field. One of the things that appears to be fundamental for all enclosure schemes to work properly is that precise floating point arithmetic must be available. At the plenary lectures of H. Stetter (Tech. Univ. of Vienna) and Alefeld, it was pointed out that this has actually happened in several languages such as FORTRAN-SC and -XSC, PASCAL-SC and -XSC (developed in Karlsruhe by Kulisch), and ACRITH-XSC (an IBM product).

Tanabe's lecture discussed a modification of Newton's method. The principal idea is that in the case of an initial guess which is far from a zero, instead of reducing the step-length of the Newton-correction, it can be very advantageous to perform a step of full length, but in an altered direction which is determined in a well-defined manner through the solution of an easy minimization problem. Several examples shown by Tanabe demonstrated that this modification of Newton's method is particularly useful when solving nonlinear programming problems.

Many of the speakers from Japan and China spoke on topics related to the solution of nonlinear equations when the Jacobian is singular at the root. This was an active research area in the West in the late 1970s-early 1980s and some activity continues in East Germany. This topic was directly addressed in N. Osada's talk (Nagasaki Inst. of Applied Sci.) on extrapolation methods and indirectly discussed in the talks on bifurcation by X. Sun (Harbin Institute of Electrical Technology) and T. Tsuchiya (Kyushu Univ.). Discussions with X. Chen and Sun on this area made us aware that there is substantial Japanese and Chinese literature on this topic.

The technical issues center on the fact that if the Jacobian is singular at the root, then (1) the convergence rates of Newton-like methods are degraded and (2) the set from which the initial iterate can be taken is no longer a ball about the solution but a special set whose form depends on the structure of the singularity. Research problems are (1) to describe the regions of attraction and convergence rates for Newton-like methods and (2) to accelerate their convergence.

In Japan, Osada, Tsuchiya, N. Yamamoto (Kyushu Inst. of Tech.), and T. Yamamoto (Ehime University) have worked on this. In China, Dr. X. Chen, Prof. X. Sun, and Prof. Z. Pan, all from the Harbin Institute of Electrical Technology, have published in Chinese. The work by X. Chen or T. Yamamoto was new to us. Tsuchiya's and N. Yamamoto's work is described below after a visit to Kyushu University. Osada's work uses general sequence acceleration methods and his results look promising, but he has only considered a limited class of singular problems.

The Chinese work follows work of Decher and Kelley in the United States. These references, all in Chinese, are:

1. X. Sun and Z. Pan, "King-Wevener's method at singular points," *HIET Journal* 9, 269-273 (1986).

2. Z. Pan and S. Zhou, "Chord method for solving non-linear equations at singular points," *HIET Journal* 12, 302-309 (1986).

3. X. Sun, Z. Pan, and S. Zhou, "Newton-Moser's method for a class of singular problems," *HIET Journal* 13, 208-212 (1990).

HIET is an abbreviation for Harbin Institute of Electrical Technology. It is not clear if the *HIET Journal* is externally refereed.

Space does not permit a summary of all the talks. Here we only mention a few that were particularly interesting to us.

There were a number of papers related to boundary element methods. Two of the best were by K. Onishi (Fukuoka Univ.) and M. Sakakihara (Okayama Univ. of Sci.) according to E. Allgower. Onishi's, in particular, seemed fundamental. There were several excellent talks on computational fluid dynamics, by R. Krasny (Univ. of Michigan) describing computational experiments studying vortex sheets, by M. Tabata (Univ. of Electrocommunications) on a third-order upwind finite element scheme for incompressible flow at high Reynolds numbers, and by T. Ushijima (Univ. of Electrocommunications) on a very complete mathematical analysis of the linear water wave problem. M. Mori (Univ. of Tokyo) described an extension of the double integral transformation that is suitable for the evaluation of oscillatory and slowly damped integrals, and his results compared very well with Western computational methods, such as Quadpack. Mori has been working on this technique since 1970 and it now appears that software produced using this method will be extremely effective. Similarly, X. Liang (Jilin Univ., China) described an extension of an algorithm for bivariate Lagrange interpolation that has direct application to finite element computation; he published the original technique in 1965! L. Collatz (Univ. of Hamburg), one of the originators of functional analysis applied to numerical computation and just past 80 years of age, gave a lecture on methods with guaranteed lower and upper bounds for boundary value problems. Our reaction was that if it takes Collatz's insight to analyze such problems then there is little hope for the rest of us. Collatz is still in vigorous health, told jokes at the reception, and presented several of his water colors to friends.

One simple but effective talk was by S. Fujino (Inst. of Comp. Fluid Dynamics), who studied memory bank conflicts in certain matrix calculations on common vector computers. He concluded with a prescription for the relation between the number of mesh points in the three coordinate directions for most efficient memory access. This talk was not on the same level with many of the other more abstract presentations, but it nevertheless appeared to be of significant practical use.

K. Murota (Univ. of Tokyo), who writes mostly in English, gave a summary of his work on combinatorial canonical form. This was new to us but seemed to be potentially very useful. The idea is that in solving certain systems of linear equations repeatedly, say, for example, the equations for Newton's method, the actual matrix elements vary but the zero/nonzero structure remains fixed. Using graph theoretic methods it is possible to rearrange the equations and the variables to obtain a block-triangular form of the matrix, or a hierarchical decomposition of the system of equations. Then each time the system is to be solved the individual subsystems may be solved by LU decomposition of some iterative method. There are many generalizations of this idea and the range of applications are extensive. This approach ought to be better known in the West.

## Conclusions

Several points were clearly established to us by the Japanese (and Chinese) papers. First, these researchers had really done their homework. Although they occasionally were unaware of some work in the West, by and large they were very well versed in Western literature and had read the relevant papers with exceptional care. Second, they occasionally seemed to go off in directions that were questionable, but often this perseverance pays off. Third, the best work is on a par with first rate research elsewhere; excellence knows no national borders. Although adopting a low profile, the Japanese were nonetheless quite evident in revealing how well they have penetrated to the very core of the foundations of algorithmic, mathematical, and numerical analysis. Finally, another meeting perhaps emphasizing computation would be very worthwhile.

Virtually every participant agreed that ISCM was one of the best (if not the best) organized meetings they had ever experienced, and that Prof. Yamamoto and his staff really did an outstanding job!

## SITE VISITS BY KELLEY

### Kyushu University, Fukuoka

My host for this visit was Dr. Hidemi Kawasaki. I am familiar with some of his work on nonsmooth optimization that has appeared in the Western literature. While at Kyushu University I also met with Dr. Takuya Tsuchiya. Both Kawasaki and Tsuchiya assistants in the Mathematics partment. Kawasaki received his D. in 1988 under the direction of of. Furukawa of Kyushu University. ıchiya received his Ph.D. under the ection of Prof. Babushka at the iversity of Maryland.

The Mathematics Department at ushu University has about 30 faculty ofessors and assistants) and 45 grad- te students. There are roughly 10,000 dents in the university.

I was given tours of the computing ilities in the Mathematics Depart- nt and in the computing center during visit. The Mathematics Depart- nt has several IBM-PC compatible mputers, several Macintosh com- ters, and a SUN Sparcstation. The mputing center has a Fujitsu VP-200 ctor supercomputer.

Dr. Kawasaki's work is in theoreti- l optimization. His goal is to formu- e necessary conditions for optimal- for general nonlinear constrained timization problems with very weak fferentiability assumptions. In addi- n to Dr. Kawasaki and Prof. Furukawa Kyushu, others in Japan working in is area include Prof. Fukushima at oto University; Prof. Kojima at Tokyo chnological University; Prof. Tanaka Hirosaki University; and an assis- nt, Mr. Shiraishi, who is working on a ctorate under Prof. Furukawa and is w at Toyama University.

Kawasaki's work is related to sev- al efforts in the West in nonsmooth timization and semi-infinite program- ing. Ioffe in the Soviet Union and owe and Hettich in Germany work related problems.

My discussions with Kawasaki cused on his work on directional rivatives for sup-type functions and e application of that work to prob- ms in semi-infinite programming. This ork is based on more fundamental eas in Reference 1 and has appeared r will appear) in References 2 and 3.

To briefly discuss the technical issues, let $f(x,t)$ be a smooth function of the variables $x\in R^n$ and $t\in T$, where $T$ is a compact metric space. Define

$$S(x)=\sup\{f(x,t),\ t\in T\}$$

The problem of minimizing S, a non-differentiable function, is equivalent to the constrained problem of minimizing r subject to the inequality $r-f(x,t) \ge 0$, for all $(x,t)$. Second-order necessary conditions were formulated in References 1 and 2 by computing directional derivatives of $S$.

In a similar way, semi-infinite programming problems may be expressed in terms of sup-type functions. Kawasaki has done this in a paper that will appear (Ref 3). His current work is on certain Tchebycheff approximation problems.

Kawasaki's work has appeared in the Western literature in such journals as *Mathematical Programming* and *Mathematics of Operations Research*. His work is of high quality and provides valuable references to Japanese literature.

Dr. Tsuchiya's degree is in the area of finite element methods for partial differential equations. In particular, he is interested in finite element methods for path following. I am not an expert in finite elements, but I do have some knowledge of path following and bifurcation, and my comments on this work will therefore be brief and focus on the path following aspects.

Consider a map $F(x,g)$ from $X\times R \to Y$, where $X$ and $Y$ are real Banach spaces. The parameter g is often a physical parameter, such as a load on the Reynolds number is a computational fluid dynamics problem. The goal in path following is to compute the solution arc, $x(t)$, for $F(x(t),t)=0$ over a range of values for $t$. Tsuchiya approximates $F$ by a finite element approximation $F_h$, thereby obtaining an approximate solution arc, $x_h(t)$. He obtains $H^1$ and $W^{1,p}$ error estimates for this arc near points where there is no bifurcation.

I had a more detailed discussion with Dr. Tsuchiya about some work he did at Kyushu University before he went to Maryland for his doctoral thesis. This work (Ref 4) represents an approach to bordering methods for singular systems of nonlinear equations.

Tsuchiya's research on singular systems (Ref 4) is a reformulation and extension of a method called "bordering" in the Western literature. In this approach additional equations are added to the system to eliminate the singularity of the Jacobian at the solution. Prof. N. Yamamoto of Kyushu Institute of Technology in Fukuoka began the Japanese work in this area. The Japanese research on bordering extends work by Griewark and others in the West by admitting the possibility of high order singularities. Their algorithms add more equations if the first pass of bordering fails to resolve the singularity. Tsuchiya's work gives a mathematical characterization of the number of terms that must be added.

Other work on singular systems in Japan is being done by Prof. T. Yamamoto and Dr. X. Chen at Ehime University. Dr. Chen is a visitor from Xi'an Jiaotong University in China. Prof. X. Sun of the Harbin Institute of Electrical Technology in China is also active in this area. In the West, Decker, Griewark, Keller, Kelley, and Osburne did a good deal of work in the early 1980s, and groups led by Werner and Schwetlik in Germany are active now.

## Kyoto University, Kyoto

My host for this visit was Prof. Masao Fukushima, an associate professor in the Department of Applied Mathematics and Physics at Kyoto

University. He works in an Operations Research group led by Prof. Toshihide Ibaraki. Much of Prof. Fukushima's work appears in the Western literature. I am particularly interested in the work on nondifferentiable optimization (Ref 5-7) and our technical discussions focused on that work. During my visit I was also able to visit a group led by Prof. Nogi that has designed a distributed memory multiprocessor, ADENA.

Aside from the work listed above, Fukushima is active in several other areas in optimization. I will list some of these areas and provide a recent reference to the literature if one is available. These areas of activity include finite dimensional variational inequalities (Ref 8) with applications to traffic and market equilibrium problems, nonlinear network flow problems (Ref 9), homotopy methods (Ref 10), and ongoing work on combinatorial optimization and parallel methods for optimization. This latter project is joint work with Profs. Nguyen and Strodiot at the University of Namur in Belgium. All of Fukushima's work is directed toward numerical results.

The method of sequential quadratic programming (SQP) for nonlinear constrained optimization problems is a generalization of Newton's method as applied to nonlinear equations and unconstrained problems. In the case of equality constraints, one may think of SQP as the application of Newton's method to the gradient of the Lagrangian. A single SQP iterate solves a quadratic program that has as its objective function a quadratic model of the objective function at the current point and as its constraints the linearized constraints at the current point. Like Newton's method, if the initial data are sufficiently good, the iterates will converge quadratically, to the solution if typical smoothness and nonsingularity assumptions hold.

When the initial iterate is far from the solution, however, line search or trust region methods are used to modify the Newton step in the unconstrained case to force "sufficient decrease" in the objective function. In the case of constrained optimization, the constraints require that decisions on step modification be based on how well the constraints are satisfied as well as the size of the objective function. Hence, steps are modified when the unmodified SQP step does not give sufficient decrease in a "merit" or "penalty" function. Such functions are constructed to measure a combination of constraint satisfaction with the value of the objective function. So called "exact" penalty functions, which are in general not differentiable, have the desirable property that their local minima coincide with those of the constrained problem to be solved.

Nonsmooth exact penalty functions may suffer from the "Maratos effect" when the merit function will not allow a full SQP step to be taken near the solution and therefore only q-linear convergence takes place. Fukushima's work (Ref 5) addresses this problem in the line search case by changing the linearized constraints for the QP subproblem in an appropriate way. He has extended this work to trust region methods (Ref 6) and to the case of nonsmooth objective function and equality constraints (Ref 7). He has a Fortran program that implements the algorithm as reported in Reference 5.

Fukushima's work in this area is related to work in the West by Fletcher, Powell, and Ynan, among others, in the United Kingdom and by Tolle, S.J. Wright, and others in the United States.

## The Institute of Statistical Mathematics

My host for this visit was Prof. Kunio Tanabe, director of the Department of Prediction and Control. I have been aware of Prof. Tanabe's leading role in Japanese optimization for several years and discussed optimization in Japan and his own work in development of a geometric framework for globally convergent optimization algorithms. While at the institute I also spoke with Prof. G. Kitagawa, who works in large scale time series analysis, and Dr. T. Tsuchiya, who works in automatic differentiation. I was impressed with the breadth of activities at the institute and the commitment the scientists there have to solving problems that are relevant to Japanese Government and industry. The institute has a 40-year history of success in solving problems for Japanese industry. According to Prof. Tanabe, this tradition encourages Japanese business to share data with the institute and rely on it for help.

Prof. Tanabe added to my list of people working on nonlinear optimization in Japan. Prof. T. Nakayama of Konan University works on nondifferentiable optimization and multiobjective programming. In the area of unconstrained smooth optimization, Tanaka mentioned N. Yamaki and M. Yabe of Tokyo Science University, noting that Yamaki is now in private industry; N. Sagara of Aichi University; K. Shimizu at Keio University; K. Tone at Saitama University; and M. Yamashita in private industry. As in the United States, the nonlinear optimization community is healthy and active but not as large as many other specialties in pure or applied mathematics.

Prof. Tanabe's research interests include numerical optimization and applications to such area as medicine, seismology, and statistics. Our conversations were about a geometric approach that he takes to the construction of globally convergent methods for nonlinear optimization that is motivated by interior point methods in linear programming. Key references are References 11-13.

In Reference 11, Tanabe introduces what he now calls a "center flattening transformation" in the context of singular systems as a way to numerically follow the trajectories of the continuous Newton dynamical system to the solution. He has expanded these methods in subsequent work by describing a "center curve" subject of the feasible set of a constrained nonlinear programming problem. His "centered Newton" method (Ref 13) makes a connection between these geometric ideas and interior point methods in linear programming. The centered Newton method differs from conventional line search or trust region methods for optimization in that if a full Newton step fails to give sufficient decrease, then a new search direction biased toward the center curve is used. Tanabe believes that this approach will allow for longer steps to be taken than in more conventional implementations.

## ACKNOWLEDGMENT

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# THE GERMAN NATIONAL RESEARCH CENTER FOR COMPUTER SCIENCE IN TOKYO

*The Tokyo liaison office of the German National Research Center for Computer Science is described.*

by David K. Kahaner

## DESCRIPTION OF THE GERMAN NATIONAL RESEARCH CENTER FOR COMPUTER SCIENCE

The German National Research Center for Computer Science (GMD), Gesellschaft fuer Mathematik und Datenverarbeitung, has a liaison office in Tokyo that was established about 15 years ago. It has an annual budget of about $1.5 million.

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GMD is jointly "owned" by the Federal Republic and the Ministries of Science and Research of two German states. They support a collection of laboratories, research institutes, computer centers, etc. at seven locations in Germany together totaling about 1,400 people (about 850 are in their main office). Total GMD budget for 1990 is about 160M German marks. GMD performs research in the general area of information technology, which includes hardware devices, applied mathematics, computer science, etc. They are also involved in laboratory to industry activities and have an Institute for Technology Transfer. I have not visited GMD, only the Tokyo office, but brochures they provided to me mention the following topics:

(1) Operates in the field of conflict existing between science, manufacturers, and users.

(2) Makes the results obtained available for new production processes, products, and services.

(3) Fosters national cooperation with industry, universities, and users as well as international cooperation, not restricted by short-term economic constraints. Can therefore pursue long-term aims and break new ground in research and development work even if this involves a high risk.

GMD literature specifically points out various U.S. universities as well as Japan, Brazil, and China as places where some of this international cooperation is taking place, beside the intensive cooperation within the European Community (ESPRIT projects, etc.). GMD also initiated the foundation of the International Computer Science Institute (ICST), headed by Jerome A. Feldman, at the University of California at Berkeley. This is a basic research institute for massively parallel systems, distributed systems, and the foundations of informatics.

The liaison office in Tokyo has three to four professionals. At the moment there are four; one is to rotate back to GMD in February 1991. Three have Ph.D. degrees, in physics, economics, and mathematics. (The director, Dr. Wattenberg, was away from the office when I visited.) A German-speaking Japanese administrative staff perform "research" and other tasks, and one person is also responsible for gathering and distributing government and other difficult-to-get documents relating to information technology. GMD also has a Washington office, larger than the one in Tokyo.

The director has been here since the office's inception, about 15 years. The remaining professional staff come for periods of 3 to 5 years. Except for the director, all of them expect to go back to an administrative arm of GMD.

During the first 6 months of a new person's tour, he/she spends about 2 days each week for 2 months each at different Japanese public organizations affiliated with the Ministry of International Trade and Industry (MITI). These organizations include MITI headquarters; the Japan Information Processing Development Center (JIPDEC), which administers some of the MITI projects including the Institute for New Generation Computer Technology (ICOT), at least in the initial phase; and the Database Promotion Center (DPC). (This is permitted because the liaison office has the official sanction of both the German and Japanese Governments.) This gives new staff an opportunity to meet many key people and get national perspective. It is a tremendous orientation opportunity that would have been very valuable to me (still would be, even after a year). This, plus the continuity provided by the director's long tenure, assures that the staff do not step on each other's toes. The remaining 3 days each week are spent sharpening language skills and also doing "real" work. The main focus of the office is claimed to be research in computing, but they are also watching new releases in supercomputing, semiconductor technology, etc. that have commercial value for their laboratories back home. Although there is a science councillor in the German Embassy, some computing related liaison functions are handled in this office.

The office subscribes to a translation service that provides timely information about information technology news. One of the German professionals is responsible for transmitting a weekly summary, in German, and also providing an up-to-date list of meetings that have been announced. I think that the news service would be valuable because the compiler is a specialist who can rapidly check questionable or uninteresting items and get additional details when necessary. I was told that our office here tried a news service in the past but it was very expensive and not used much. Perhaps it was too general, or the scientists were not interested. I will consider subscribing to a similar service again to see how useful it would be to me.

A major activity of the office is planning a workshop, formally titled "Japan-German Forum on Information Technology," held every 18 months, alternating between Germany and Japan, with about 100 participants. Three topics are covered: microelectronics, computers, and new media. The workshop is a closed shop organized at the level of the German and Japanese Governments, and each country is responsible for supporting an appropriate number of their researchers. A Proceedings is produced, but it is only circulated to workshop participants, in government circles, and to certain industrial and academic research centers. The small GMD office staff would find it difficult to distribute copies of the individual papers to outside requestors, but at the end of this article is a list of titles from the previous workshop to illustrate the material discussed. What is impressive about this list is that the level of papers allows most of them to be ofdirect interest to not only researchers but to those one step removed. As those of us who attend conferences know, carefully written survey papers are very rare.

The office also organizes most scientific visits for GMD staff and also of others from the German research community. The professional staff attend many meetings, participate in laboratory visits, write reports, etc., very much like I do. To the best of my knowledge, their reports are only distributed internally.

The office is housed in the German cultural center. GMD pays no rent for most of its space, but one overflow office is required and is expensive. The office has an internal computer network so that staff can communicate, print, etc. The office manager backs up files each week. They also have available electronic mail in three separate forms: (1) a commercial local line to a service that allows them to contact GMD directly, (2) a commercial mail service, and (3) an x-400 mail service at a local commercial computer that is also connected to GMD. Their news translation services are sent to them electronically by (2) above. Current plans are to become a node on the rapidly growing Japanese equivalent of Internet. To maintain this requires a high level of sophistication. Luckily, each of the professionals is interested in computing and so they are willing and eager to take on this responsibility. (An equivalent activity in my office could be done but might be difficult because of the wide range of computer interests and expertise within the scientific staff.)

The GMD offices are attractive although not extravagant, looking more or less like those in the U.S. Embassy. Because they are in the cultural center, and open to everyone, they have a very benign feeling. This is helped by being next door to the equivalent of the German National Science Foundation, which is responsible for more general scientific exchanges. Overall, the offices give a very positive impression, in a country where these things count for more than they do in the United States.

The acting director informed me that a very rough estimate for their annual budget is DM1.5 million. For comparison, I am told that the equivalent budget for our office is about $1.0 million, although I am sure that an accurate comparison would require much more care.

This office impressed and surprised me, particularly the level of commitment with which a government laboratory is going after scientific information, research, and commercial opportunities. There are aspects of its operation that we should study carefully. This would be a worthwhile and easily arranged place for Western scientists to visit.

## SUMMARY OF PAPERS AND SPEECHES FROM THE GERMAN-JAPAN FORUM ON INFORMATION TECHNOLOGY

What follows is a summary of papers and speeches from the Germany-Japan Forum on Information Technology 1990. The list below gives titles only and should be thought of as providing a sense of level and composition of the program. An asterisk (*) after a title indicates that the paper was from a Japanese participant. The forum was organized over a 5-day period as follows:

- Two keynote speeches
- Three parallel workshops on new media, computers, and semiconductors
- Two plenary sessions on research cooperation and workshop summaries
- Technical visits

**Keynote Speeches**

- Computation in Neural Nets
- Recent Trends in Optical Fiber Communications Research: Increasing Resemblance with Radio Communications (*)

**New Media Workshop**

- Three-Dimensional Imaging and Television
    - State of the Art in Japan (*)
    - State of the Art in Germany
    - Two-Channel 3D-TV Using Polarizing Glasses, with demo
    - 3D Display System with Motion Parallax and its Visual Effects (*)
    - Discussion about steps towards collaboration
- Application of Neural Computing to Speech Recognition
    - State of the Art in Germany
    - A Neural Network Model Extracting Features from Speech Signals (*)
    - Speech and Neural Networks

**Computer Workshop**

- Neurocomputing, Theoretical Models, Applications to Optimization and Learning Problems, Pattern Recognition
    - Pattern Recognition with Dynamical Neural Nets
    - Character Recognition with Artificial Neural Networks (*)
    - Relation between the Approaches in Pattern Recognition and Neural Net Computations
    - Mobile Robot Control by Neural Networks (*)
    - Biological and Artificial Neural Networks for Motor Control
- Man Machine Communication Interfaces
    - Standards, Applications, and Perspectives
    - Outline of FRIEND'21 Project (*)
    - Object-Oriented User Interfaces with Standard Functions
    - Approach to Continuous Speech Recognition using Time-Delay Neural Networks and Learning Vector Quantization (*)
    - Discussion about steps towards collaboration
- Asynchronous Transfer Mode (ATM)
    - State of the Art in Germany
    - A Future Flexible Transport Network Based on ATM Techniques (*)
    - Discussion about steps towards collaboration
- Intelligent Picture Coding
    - Intelligent Image Coding for Future Human Communication Systems (*)
    - Object-Oriented Analysis-Synthesis Coding of Moving Pictures
    - Discussion about steps towards collaboration

**Semiconductor Workshop**

- Contamination Control
    - The Impact of Impurities in Chemicals on the Performance of DRAMs
    - In Situ Characterization Si MBE by Microprobe RHEED (*)
    - Depth Profile Analysis by Secondary Neutral Mass Spectrometry

- Contamination Control in VLSI Wafer Processing (*)
- Present States and Future Needs of Impurity Analysis in Silicon Wafer Processing

- Mesoscopic Systems
  - Individual Interface Defects and Noise in Sub-mu MOSFETs
  - Mesoscopic Electronics (*)
  - Two-Dimensional Mesoscopic Systems of Compound Semiconductors
  - Atomic Layer Epitaxy by Chloride Gas Sources (*)
  - Nanolithography Principles for Mesoscopic Systems
  - Discussion

- Neural Networks
  - Fuzzy Logic and Neural Networks in CMOS Technology
  - Neural Devices and Networks (*)
  - Hardware Implementation of Artificial Neural Networks
  - Optical Neural Computing (*)
  - Neural Networks and Fuzzy Logic
  - Fully Digital Neuro-Chip (*)

## ACKNOWLEDGMENT

I learned about this office because Dr. Thomas Hagemann was on my mailing list for reports. At that time, Dr. Hagemann was at GMD in Germany; he has now been transferred to the liaison office here in Tokyo. Dr. Hagemann has been very helpful in providing information to me and correcting details of this report.

# FOURTH INSTITUTE FOR SUPERCOMPUTING RESEARCH SUPERCOMPUTING WORKSHOP

*This report describes the Fourth Institute for Supercomputing Research Supercomputing Workshop: The Road to Parallel Applications, held from 29-31 August 1990 in Hakone, Japan. In addition, some observations on the trends and characteristics of parallel supercomputing research in Japan are presented.*

by David K. Kahaner and Tony F. Chan

## INTRODUCTION

The Institute for Supercomputing Research (ISR) is a private nonprofit research institute established in 1987 to "conduct research on issues in supercomputing and parallel processing ... and to strengthen ties with universities and research centers in Japan." It is funded by the Recruit Corporation, which is a multibillion dollar company in Japan whose main business is in recruiting college graduates for the major corporations, but it also has a division that sells computer services. The director is Dr. Raul Mendez, who has a Ph.D. from the University of California at Berkeley under Alexander Chorin and who is well known for some of the earliest benchmark tests on the Japanese supercomputers in the early 1980s.

ISR has been organizing a series of annual workshops on various topics in supercomputing. Typically, both Japanese and U.S. researchers are invited. Last summer it was held in Hawaii and this year the venue was Hakone, a resort about 2 hours from Tokyo, famous for its hot springs and the view of Mt. Fuji. There were about 40 registered participants, mostly Japanese, with three speakers from the United States: Olaf Lubeck of Los Alamos, John Levesque of Pacific-Sierra Research, and myself (Kahaner). There were 13 talks total and a panel discussion on the future and evolution of scientific computing. An informal proceedings was available at the conference. The atmosphere was relaxed but intimate, and there were many lively discussions both during and after the formal lectures.

## LECTURES

Four main themes of the conference can be identified: parallel algorithms [with emphasis on partial differential equations (PDEs)], hardware (both general and special purpose) for scientific computing, dataflow, and computing environments (languages, networks, programming tools). This reflects the organizers' attempt to cover the main issues in parallel supercomputing and it mostly succeeded because there were many discussions during the workshop on how these areas should interact.

### Algorithms

The numerical solution of PDEs represents a major demand for supercomputing resources and they are widely employed in many areas of science and engineering, as a result of the fundamental fact that most physical laws are expressed as PDEs mathematically. It therefore makes sense to look at some of the basic PDE algorithms more carefully, especially in view of the advent of parallel computing. Several speakers addressed this issue. Prof. Toshio Kawai of Keio University tried to convince the audience that nature is the best parallel supercomputer and it also provides a very powerful class of algorithms for these machines. He calls these "natural algorithms"--namely explicit in time algorithms that are based on local interactions in space. He has produced a programming system called DISTRAN (written in PROLOG and publicly available), an ELLPACK-like system that allows the user to easily specify the PDE and obtain reliable results quickly. [See also my article (Ref 1) in which this topic is mentioned. At that time I thought the idea was too good to be true. Perhaps someone can request the program and perform a critical evaluation.]

On the other hand, Chan tried to argue that the most appropriate class of algorithms for massively parallel computers is hierarchical (multilevel) ones. He based his arguments on the observation that many problems in nature are hierarchical in nature (e.g., having many different scales in time and space) and, therefore, the most efficient algorithms require some form of global communication. Hierarchical algorithms are a reasonable compromise between explicit algorithms, which are highly parallelizable but slowly convergent, and fully implicit algorithms, which are fast convergent but difficult to parallelize. Besides, they can be implemented efficiently on hierarchical parallel computers, such as the CM-2, the hypercubes, and clustered hierarchical shared memory systems.

Very often, existing algorithms for a particular problem are not naturally parallelizable and one has to devise novel parallel algorithms. Prof. Yoshizo Takahashi of Tokushima University presented several such algorithms for an automated wire-routing problem specifically adapted to the Coral parallel computer, a binary tree, distributed memory, multiple instruction/multiple data (MIMD) machine based on the MC68000 chip. These algorithms are particularly interesting because they are true MIMD algorithms for a realistic unstructured problem running on a real parallel machine and they outperform the best commercial software running on a SUN 3/260.

A central issue in the design of parallel algorithms for MIMD computers is how to map the data into the processors so as to minimize data communication. George Abe of ISR presented results on comparing a ring mapping to a two-dimensional (2D) mapping for a semiconductor device modelling problem on the iPSC/1. Comparisons with similar results on an Alliant FX/8-4 are also given. He concluded that in two dimensions the difference in performance for the two mappings can be large, with the 2D mapping being more efficient.

## Hardware

With the advent of multiprocessor systems with a relatively large number of off-the-shelf inexpensive processors, it has become increasingly easy and cost effective to build special purpose hardware for special applications, as an alternative to conventional mainframe general purpose supercomputers. Prof. Yoshio Oyanagi of the University of Tsukuba calls these "multi-purpose" computers. Japan, long recognized for its manufacturing prowess, especially in electronics and computers, is primed for following this approach.

Physics seems to be the primary field for which special purpose computers have been built. Three machines of this kind were discussed at the conference. The first is QCDPAX, which is for quantum chromodynamics (QCD) lattice simulations. Apparently, the worldwide physics community has recognized the potential of parallel computing, and several countries (including Italy, the United States, and Japan) have initialized projects to build special purpose hardware for this application. QCDPAX is a MIMD machine with 432 processing units, connected through a 2D nearest neighbor grid and a common bus. Each processing element consists of a 32-bit microprocessor MC68020, a floating point chip L64133 and large scale integration (LSI) for vector operation, 2 MB of fast memory, and 4 MB of slow memory. Measured peak performance is 12.25 GFLOPS. For matrix vector multiples, 5 GFLOPS is attainable. For the QCD problem, a preconditioned conjugate gradient method is used. The project was funded at a level of about $2M for FY87 to FY89. A commercial product is now being marketed by the Anritsu Corporation (model DSV 6450, four sold) (Ref 2 and 3).

Another special purpose machine discussed (by J. Makino of the Department of Earth Sciences and Astronomy of the University of Tokyo and ISR) is the GRAPE-1 (GRAvitational PipE) developed at the University of Tokyo for gravitational N-body problems. It is not really a computer in the usual sense because it is not programmable, but instead it is viewed as a backend computational processor for performing only the N-body force computations. Effective performance of 120 MFLOPS has been achieved. The high performance derives from the use of three arithmetic pipelines corresponding to the three spatial coordinates. An interesting feature is the use of variable precision: 8 bits for force calculations, 16 bits for positional data, and 48 bits for force additions. A general purpose interface bus (GPIB) connects the GRAPE-1 with the host (a Sony workstation). This project is most impressive in its speed of completion. The design started in March 1989, the hardware was ready by September 1989, and production runs began at the same time. A follow-up GRAPE-2 project is now in progress, with parallel pipelines and improved precision (64/32 bits). Makino estimates that a 50-board, 15-GFLOPS system can be built for $100,000 and a 500-board, 150-GFLOPS system for $300,000. A GRAPE-3 system is also under design. Following Makino, Junichi Ebisuzaki (Department of Earth Sciences and Astronomy of the University of Tokyo) talked about adapting other many body simulations for the GRAPE system. The basic modification needed is to accommodate the different forms of the force law. He discussed applications in plasma physics and molecular dynamics.

Prof. Nobuyasu Ito of the Department of Physics at the University of Tokyo gave a seemingly exciting and entertaining talk (judged only from the reaction of the audience, since it was given in Japanese!), in which he described the m-TIS (Mega spin per second University of Tokyo Ising Spin) computer for simulating the many body problem arising from Ising systems. A successor m-TIS II system has also been built.

Lest you think the Japanese supercomputer field is only producing special purpose hardware, rest assured that the really big boys have also been doing their homework. Akihiro Iwaya of NEC described the NEC SX-3 computer, which was widely reported in the U.S. press as the fastest general purpose supercomputer today. He reported that the performance ranges from 0.68 to 22 GFLOPS, depending on the particular computation performed. The machine has a single instruction/multiple data (SIMD) architecture (which he estimated is sufficient to handle more than 80% of all applications), with shared memory (because "FORTRAN is based on shared memory") and up to four processors (he estimated that 16-32 such processors is within practical limits), each with multiple pipelined arithmetic processors. He also discussed several system issues such as synchronization primitives, ParallelDo and ParallelCase statements, and micro/macro-tasking--all in all a very Cray-like machine with blazingly fast peak performance (Ref 4).

Finally, Shin Hashimoto of Fujitsu described the high speed parallel processor (HPP), which has been developed under a joint project between the Ministry of International Trade and Industry (MITI) and six computer companies (including Fujitsu, NEC, and Hitachi) from 1981 to 1990. The main idea is to connect several conventional supercomputers (e.g., Fujitsu VP2000) via a common storage unit (CSU) and a large high speed storage (LHS). The data transfer rate between the HPP and the LHS is 1.5 GB/s. The peak performance is over 10 GFLOPS. It comes with its own parallel language Phil, which has the usual parallel-do and lock and barrier statements, and a very user-friendly programming environment with execution viewers, cost analyzer, and a parallel verifier. Surprisingly, there has been no plan yet for turning it into a commercial product.

## Dataflow

One of the most difficult tasks in designing parallel programming systems is the automatic detection and extraction of parallelism in programs. The dataflow approach has long been advocated as one model for achieving this goal, and in a fundamental way it is very attractive because it looks at the basic level of computation. While the dataflow approach has not yet been demonstrated to be competitive in practice (practical dataflow machines are not exactly proliferating at this moment), we should aim for the ideal nonetheless, as Olaf Lubeck of the Computing Division at Los Alamos National Laboratory implored us to do in his talk. He has been working closely with both the group led by K. Arvind at the Massachusetts Institute of Technology (MIT) and the SIGMA-1 group at the Electrotechnical Laboratory (ETL) of Japan. He claims that the main advantages of dataflow are that it produces deterministic computations and it extracts maximum parallelism. In addition to some general comments about dataflow, he also discussed a more technical problem concerning how to "throttle" loop activations so that loop statements do not generate a big demand on system resources (i.e., memory) in the early iterations in a dataflow model (Ref 5).

Toshio Sekiguchi, also from ETL, described his efforts in designing the parallel dataflow language DFC II for the SIGMA-1 dataflow computer currently being developed. The SIGMA-1 is an instruction-level dataflow machine, with 128 processing elements, 640 MIPS, 427 MFLOPS, and 330 MB of memory. DFC II is C-based (functional languages were deliberately not chosen because they want the language to be useful "for practical problems") and allows synchronization, global variables and, of course, automatic detection of parallelism. The motto is: "sequential description, parallel execution." Applications that have been run include QCD, PIC, Keno, and LINPACK.

## Environment

It is widely recognized that one of the potential stumbling blocks on the road to the utopia of parallel computing for the masses is that parallel programming is an order of magnitude more difficult than vector programming, not to mention sequential programming. Without user-friendly and yet powerful programming environments, parallel computing may never reach the promised land. One of the main themes of the workshop is environments.

John Levesque of the Pacific-Sierra Research Corp. (PSR) was the main speaker on this issue. John is one of the leaders in this field and he had just published a book on optimization techniques for supercomputers. He described the philosophy behind the FORGE and MIMDizer systems that have been developed at PSR. FORGE is an integrated environment consisting of program development modules, static and dynamic performance monitors, sequential and parallel debugging, memory mapping modules, automatic optimization, and a menu-driven interface. John stressed the importance of building a database of information about the program and collecting both static and runtime statistics in order to optimize performance. MIMDizer is a brand new system scheduled to be delivered in October 1990. As the name suggests, it is designed for easing the porting of programs to distributed memory MIMD machines. The key idea is "array decomposition," i.e., the user specifies the mapping of data arrays and MIMDizer handles automatically all communication interfaces. This appears to be a very practical approach between automatic parallel compilers and explicit data mapping and message passing by the user.

Any one of us who uses electronic mail realizes the importance of networks. But networks can also play a critical road in the computing environment for supercomputing in the near future, according to Raul Mendez in his banquet talk. His dream is "supercomputing from a laptop"--and the way to achieve that is through networks. He discussed the existing networks in the United States and Europe, as well as the several networks being developed in Japan and over the Pacific.

## PANEL DISCUSSION

The most lively discussions of the whole workshop occurred during the panel discussion, which should come as no surprise when one considers that the theme was "The Future and Evolution of Scientific Computing," obviously a subject matter very dear to every participants' heart. The panelists were: Genki Yagawa (Dept. of Nuclear Eng., Univ. of Tokyo); Katsunobu Nishihara (Inst. of Laser Eng., Osaka Univ.); Kida (Kyoto Univ.); D. Sugimoto (Univ. of Tokyo); and four of the speakers, Lubeck, Levesque, Chan, and Oyanagi.

Mendez led off with the three main topics for discussion:

1. What will computational requirements be like in the next decade?

2. What is the outlook for SIMD and MIMD architectures? Shared versus distributed memory?

3. What other trends will come to play a significant role: dedicated machines, dataflow architectures, microprocessors, etc.?

Concerning question 1 above, it is clear from the discussions that everyone thinks that there is no foreseeable upper bound to the computational requirements for supercomputers; in fact, the demand is limited by the current supercomputers at any one moment in time. Even with a teraflop machine, practical engineering computations ($100^3$ grids, with three variables for point) could still require 1 hour of CPU time. And it will require an enormous amount of memory. In fact, the cost of memory may be a major barrier to building a teraflop machine: assuming a scaling law of 1 MB/ 1 MFLOPS, a teraflop machine will require about $20B today just for the memory! Developments in algorithm design will also have to follow the pace of hardware and architectural advances (as it has been throughout the history of computing).

Concerning question 2, some interesting consensus emerged. While some panelists think that the SIMD architecture is sufficient for many problems (e.g., QCD), many personally prefer MIMD machines for their flexibility. The most likely trend will be hybrid (or cluster, hierarchical) architectures, with MIMD at the higher levels and SIMD at the lower levels. Concerning memory architecture (shared or distributed), many believe that hiding the storage structure of data will undoubtedly lead to performance degradation and therefore some user input is essential. No one believes we'll see automatic and efficient compilers for parallel machines in the foreseeable future.

Concerning question 3, our representative from the dataflow camp (Lubeck) said that ignoring dataflow will be settling for second best and we should be "going for the gold," even though that may take some time. Someone pointed out also that while current research has primarily focused on the solution techniques, other aspects of the scientific computing process, such as mesh generation and visualization, will be playing a more important role in the future. And finally, while parallel machines are much more difficult to use than vector machines, users are willing to plunge in when given sufficient incentive (e.g., cost effectiveness of the CM-2).

## OBSERVATIONS

### Chan

As someone who works on parallel algorithms, the most obvious thing was the small number of talks on this topic. I realize that this could be just a feature of this particular workshop, but in general I have not been aware of an active research community in parallel algorithms development in Japan. On the other hand, the hardware development in Japan has been truly impressive, both in terms of raw power and the speed and low cost at which special purpose machines are built. However, I did not see much in architectural innovations, and most of the designs follow trends already established in the industry. During the banquet, I was informed by a Fujitsu engineer that the company is building Japan's first commercial distributed memory MIMD machine--from the terse description it resembles the several U.S. hypercubes (1K processors, SPARC chip, grid connection topology, and "wormhole" routing).

Another observation that I made was that many of the talks were based on work by interdisciplinary teams, consisting of physical scientists who have real problems to solve and hardware and software computer designers. In fact, Japanese physicists seem to play a very active role in parallel computing--all the special machines mentioned were built for physics problems. Even though there were several academic engineers on the panel, I could not tell how big an influence they have had in this field in Japan.

## Kahaner

Chan's observations mostly echo my own feelings, and I have often made similar remarks in my reports. In fact, readers should note that many of the presentations describe work very close to that published or presented elsewhere. However, I do not agree entirely with the comment about architectural innovation. There are only a few really different computer organizations. Innovation (as opposed to revelation) comes from figuring out how to design so that all the pieces work harmoniously. The Japanese researchers seem at least as capable as those in the West in finding methods to do this.

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# JAPANESE DATABASE ACTIVITIES

*The activities of the Japan Database Promotion Center are described and the current state of affairs is summarized with respect to databases in Japan, especially those of interest to scientists.*

by David K. Kahaner

## PREFACE

I am not an active database user, nor have I ever done database research. Nevertheless, it is apparent that databases are having a growing impact on science. This report is based on information from the Database Promotion Center, colored by my own personal impressions here in Japan.

## INTRODUCTION

Japan is far behind the United States in the use and development of databases, particularly for science. The situation is well known and there is a strong effort being made to correct it. The Japan Database Promotion Center (DPC), established in 1984, has as its goals the promotion of database construction, research and development of the basic technologies related to databases, establishment of efficient clearing services, education propagation and training associated with databases, and international information exchange informing other countries about Japanese databases.

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Japanese online databases in science and technology were first developed by the Japan Information Center of Science and Technology, and the Japan Patent Office, in the mid-1970s. Business databases were established a few years earlier. This is about 10 years behind corresponding efforts in the United States. Partly this was technology driven, but it was also partly driven by early reluctance on the part of the Japanese to sell intangibles, in this case information, as a product. The Japan Database Industry Association (DINA), established in 1979, now has over 100 members and is quite active. Further, since the early 1980s, both the information industry through its member organizations and the Japanese Government have been attempting to promote database development and use. Since 1983, the Ministry of International Trade and Industry (MITI) has been publishing an annual *Database Directory*, which provides a comprehensive list of databases that can be accessed in Japan, both Japanese and foreign. The DPC is the official database arm of MITI.

There is no question of the growing importance of information in Japan's future economy. This is associated with interactions between (1) trends in Japanese industry, (2) the rise of the database industry, and (3) problems of database development.

Traditional Japanese manufacturing (iron, shipbuilding, etc.) is not growing rapidly. There are problems of yen inflation relative to other currencies, trade frictions, offshore production, and a decrease in interest among young Japanese in going into "dirty" industries. On the other hand, the information industry is expected to account for more than 20% of Japan's gross national product by the year 2000, reaching ¥144.5 trillion (more than $1 trillion). (It is also estimated that this industry will be almost one million skilled workers short of its real requirements, and it is hoped that some of the excess from manufacturing can find a happy home in the information industry.)

MITI estimates the following trends in information services (the figures are in hundreds of millions of yen):

| Year | Software | Info. Proc. Serv. | Info. Vend. Serv. |
|---|---|---|---|
| 1990 | 16.3 | 12.2 | 3.3 |
| 1995 | 37.5 | 23.6 | 10.6 |
| 2000 | 78.7 | 45.7 | 33.9 |

The last category, Information Vending Services, essentially means database services, including producers, distributors, value-added network vendors (VAN), and information brokers. In any units, it is obvious that its growth is expected to be very great. The DPC notes that in the West these groups are clearly defined, but not so in Japan, perhaps because this is still an immature industry. Most data originate in public organizations, government laboratories or agencies, or as a by-product of commercial activities or research. VAN vendors take these data, process it further, add their own experience, and ultimately distribute it. Most accessible databases in Japan (76%) are of foreign origin; thus the specialist who is trained to search these can provide substantial value-added service. Most database users (90% in a MITI survey) wanted lateral access with the same commands, that is, the ability to search several different databases using a uniform search process, and this is clearly an area in which there will be many new services provided. The new technological developments, such as laptop computers, data on compact discs, portable telephones, etc., will make pressure for databases even greater.

There are still many problems slowing the growth of Japanese database activities. Some of the "we don't pay for information" philosophy is still at work, although this is rapidly changing through urging by the Japanese Government, via trade fairness pressure from other Western countries, and associated changes in the legal system. As we noted, most databases are of foreign origin and access overseas is limited and expensive, especially from outside Tokyo. Japanese scientists provide data to the Japanese Information Center of Science and Technology (JICST) and the National Center for Science Information System (NACSIS). The latter is linked to the National Science Foundation (NSF) in the United States. However, information from Japanese sources is simply not available to the extent that it is in the West, and it is not distributed throughout the country in nearly as uniform a manner. Further, most Japanese universities are not as active as their U.S. counterparts in providing courses in database utilization and production.

## SCIENTIFIC DATABASES

In 1987 there were almost 1,800 databases accessible in Japan. Of these about 1,400, or 76%, were of foreign origin, i.e., from outside Japan. Almost half of the accessible databases were business related, and slightly more than one-quarter (27%) were associated with science or technology. The number of scientific databases has been increasing rapidly, but not as rapidly as other kinds of databases. Business databases associated with high technology, such as communications, energy, chemical industry, etc., have been increasing particularly rapidly. Table 1 shows the breakdown of scientific databases. The greatest growth in databases has occurred in "fact" (which contains primary data) compared to "reference" (which contains bibliographic data) databases. The primary reason for this is that the former now typically contain "full text," resulting from the lower cost of storage devices and communications. Essentially all databases are now "online," meaning that they can be queried directly.

There is also rapid growth in the use of databases within Japan.

## GOVERNMENT'S ROLE

MITI has formulated a database policy as follows:

(1) Study and research into production and organization of databases

(2) Taxation adjustments to encourage database producing corporations

(3) Production of official databases as needed

(4) Creation of *Database Directory*

Table 1. Breakdown of Scientific Databases

| Subject | Foreign | Japanese | Total |
|---|---|---|---|
| General Sci/Tech | 32 | 10 | 42 |
| Patents | 44 | 11 | 55 |
| Med/Pharm/Bio | 88 | 16 | 104 |
| Chemistry | 52 | 6 | 58 |
| Physics | 3 | 1 | 4 |
| Mathematics | 4 | 0 | 4 |
| Electronics | 60 | 4 | 64 |
| Machine | 10 | 1 | 11 |
| Civil Engineering | 8 | 5 | 13 |
| Space/Earth/Marine Sci | 17 | 0 | 17 |
| Atomic Energy | 2 | 0 | 2 |
| Environmental | 28 | 0 | 28 |
| Energy | 22 | 1 | 23 |
| Agriculture | 16 | 1 | 16 |
| Meteorology | 5 | 7 | 12 |
| Metals | 11 | 0 | 11 |
| Food | 6 | 1 | 7 |
| Fiber/Timber | 4 | 0 | 4 |
| Other | 18 | 2 | 20 |
| TOTAL | 429 | 66 | 495 |

The Ministry of Education, Science and Culture is actively promoting the organization and production of databases in science and education. These include databases for national universities and various education research centers. Grants are also provided to academic researchers for appropriate scholarly research. The NACSIS system, mentioned above, is already accessible through NSF to disseminate Japanese scientific data.

The Science and Technology Agency has accepted the National Information System for Science and Technology (NIST) report. JICST will be the organization dealing with distribution of scientific and technical data. Funding, through Scientific and Technical Information Promotion Funds, is planned for advanced and basic research; encouragement of research and development between several organizations; strengthening cooperation between industry, government and academia; joint international research; and evaluation of research.

## UTILIZATION OF DATABASES

Surveys show that about two-thirds of Japanese corporations use databases, with numbers of users and costs increasing around 10% per year, the iron/steel industry being the only one showing a decreased use. Naturally, the information processing industry is still the most heavy user, but financial industries also show rapid growth and actually spend the most money on databases. The most used databases in terms of cost are the Scientific and Technological Document File, Japan Patent Utility Model File, NIKKEI, MEDLINE, and CA-Search. Of course, users want easier-to-use database queries, more standardization, and more information. There is still a need to inform users about copyright issues. Those who do not use databases cite no need, or nonexistence of needed databases.

Three years ago an international conference on the use of Japanese information on science, technology, and commerce was held in Warwick, United Kingdom, sponsored by the British Library, the U.S. National Technical Information Service (NTIS), and JICST (Japan). The proceedings of this conference are a good place to read about problems of language, information quality, utilization, and access issues of Japanese databases. A survey conducted at that conference indicated five issues concerning Japanese databases:

(1) Many Japanese databases cannot be accessed from outside of Japan.

(2) There is no Japanese counterpart to the American Center or British Council for public information services.

(3) Overseas users have to rely too much on document delivery services.

(4) There is no comprehensive business related database in Japan.

(5) There is no service allowing access to a number of databases.

As of July 1988, it was determined that only 83 databases from within Japan are offered for overseas use, including only 20 related to science and technology and 51 to business, although about another 2 dozen were in the planning stages. Overseas users noted serious cost issues in the use of Japanese databases, associated with translation and communication.

## PROBLEMS IN ACQUISITION OF JAPANESE INFORMATION OVERSEAS

The DPC notes that "the provision of Japanese information to the international market via online services is a national priority which must be dealt with jointly by government, industry, and academia." They have identified four major problems:

(1) International information frictions. Domestic and foreign efforts are separate with little cooperation. International standards are needed so that overseas users are considered even during the initial design of Japanese databases. Efforts to improve the distribution and publicity of academic Japanese journals in science and technology are very weak. Improvements need to be made during the writing, editing, and publication stages. Technical reports and government publications are difficult to access (these are sometimes called "grey literature").

(2) Production, distribution, and utilization of Japanese information needs to be internationalized. Standards for information on science and technology need to be established and followed. Relationships must be forged with overseas database service organizations. Basic information, such as tables of contents, titles, etc., needs to be translated into English. As a case in point, I would like to mention the difficulties that I have had with papers from the Japanese Information Processing Society. At each of this year's semiannual meetings, more than 1,000 papers were presented. The papers were mostly in Japanese, but over 98% had English titles. Nevertheless, the only place these English titles appeared is at the bottom of each article in the proceedings, currently six volumes per meeting. The society can only extract the titles by manual keyboard entry. If the organization representing Japan's most advanced computer technology has not come

to grips with this problem, it is not surprising that other fields are even further behind.

(3) Online databases must be made easier to use by providing access via networks, 24-hour support services, appropriate communication software, a supply system for document information to libraries and others, and a mechanism to reduce the telecommunications costs.

(4) Publicity should be increased and intermediaries between the end user outside Japan and the Japanese database producer are needed. New media such as CD-ROMs, video disks, and electronic publishing need to be actively used.

## NEW TRENDS RELATED TO DATABASES

(1) Integrated services to allow access to data and then action, such as product ordering.

(2) Globalization of databases, mostly through new trade agreements allowing vendors of VAN to offer dedicated international lines.

(3) Multimedia databases with figures, video, and sound. One important aspect of this in Japan is the rapid push to ISDN and associated communication technology. At the moment Japan seems to be several years behind the United States in the practical use of networks, but this is seen as a key technology by both government and industry and the pressure is really on to provide these services quickly.

(4) An urgent need--standardization. There is an international organization (ISO/TC46) working on this but the Japan Database Promotion Center feels that the Japanese response to this has been very negative.

(5) Personalized databases because of links between mainframes and the increasing number and power of workstations, as well as interactive CDs, and more portable laptop computers.

(6) Growing connection to artificial intelligence and expert systems to support ease of use.

(7) Growth of electronic publishing.

(8) Growth of networks.

# HITACHI'S VARIOUS RESEARCH LABORATORIES

*Hitachi's research plan for the 1990s and computer-related research in the company's research laboratories are summarized. At the Advanced Research Laboratory, the long term view is explicitly manifest in the General Manager's office and also evident in the researchers' plans.*

by David K. Kahaner

## SUMMARY

Hitachi is one of the largest companies in the world. It operates nine major research laboratories in Japan. The author visited several of the laboratories to learn about details of computer and computer science related research. This report gives a brief overview of Hitachi's business and corporate plan and describes the major functions of each of the laboratories. In those cases where substantial computing research is occurring, specific information about the projects and the research staff is presented.

## INTRODUCTION

Hitachi was founded in 1910 by Namihei Odaira and is now the world's fourth largest electronics firm, with more than $50B in sales and 275,000 employees worldwide. These figures include both Hitachi and associated companies such as Hitachi Chemical Corp., etc. Through most of its history, Hitachi has viewed itself as a composite electronics producer with a heavy hardware slant. In real terms this means large, heavy, electrical machinery. Currently, about 40% of Hitachi's business is in electronics--computers, communications systems, and electronic devices. In the last few years consumer products have decreased as a percentage of company sales, primarily due to the high competitive nature of that market, while information and communication products have increased.

Looking forward to the 1990s and beyond, Hitachi is hoping to capitalize on its strengths and move into new user-friendly products. Rather than being a strongly focused company such as IBM, Hitachi feels that its broader base will enable it to move profitably into many other areas.

About 16,000 employees are engaged in some form of research and development (R&D) at 33 laboratories, amounting to almost 6% of sales, around $3B. R&D as a percentage of sales has almost doubled since 1980. But this includes Hitachi as well as its associated companies. When Hitachi is considered alone, it has approximately 80,000 employees; over 12,000 are scientists and engineers working in research and development. Of these about two-thirds are at "Works," with the remainder at one of nine corporate research laboratories. Over one-third of the latter (more than 4,000) are designated as "designers" or "researchers" and about 800 have Ph.D. degrees. (Readers should note that in Japanese industry, non-Ph.D. holding scientists are common in research and are often the principal investigators.) The remarks below apply only to Hitachi and do not include its associated companies.

Hitachi spends almost 10% of its sales income on R&D. In 1990 this amounted to almost $3B and is more than 1.6 times the company's estimated business profits. As for the consolidated companies, R&D as a percentage of sales has increased from about 6% in 1980 to almost 10% today. The fraction of researchers in various fields has changed slightly. A summary is as follows:

| Field | 1985 | 1989 |
|---|---|---|
| Power & Machinery | 25% | 23% |
| Consumer Products | 12% | 15% |
| Electronics | 43% | 43% |
| New Fields & Basics | 20% | 16% |

The increase in activity in consumer products accompanied by its decreasing fraction of company sales indicates the difficult market and Hitachi's efforts to penetrate it. The decrease in the last category is inexplicable.

When an organization this large describes research directions, the decisions can have significant impact. So I view it as important that Hitachi's Managing Director, Yutaka Sonoyama, recently stated that "we must conduct R&D from a different perspective than in the past, centering on basic research." This is a new view for Japanese industry, which in the past has been application and development oriented, but it is being echoed by other high tech companies here in Japan.

Hitachi's research thrusts are to evolve under two general policies: (1) new technology that is friendlier to humans and (2) technology that has a high degree of safety, reliability, and maintainability. Top management is remarkably frank about some company weaknesses. Our products are "substantive, but uninteresting. Our technology is stable and superior, but not 'people friendly'." "We have rather prided ourselves on development of technology that gave a sense of technology." Apparently now this is going to change.

Important areas for Hitachi's research in the 1990s are (a) resources and energy, (b) environment, (c) building infrastructures, (d) health care, and (e) information systems. Basic technology research will be in (a) semiconductors, (b) optoelectronics, (c) superconduction, (d) biotechnology, and (e) system software.

Researchers at Hitachi are organizationally placed in one of nine major laboratories. I suppose that they all try to fit their work into the general corporate framework, but each laboratory has its own policies and tries to be mostly autonomous. Below I summarize research objectives and other details of the nine laboratories.

## HITACHI LABORATORIES VISITED

### Central Research Laboratory

The Central Research Laboratory (CRL) (Chuken), in Kokubunji, suburban Tokyo, was established in 1942. Its staff now numbers about 1,200. Research is targeted toward company set goals 10 to 20 years ahead. Current research activities are related to energy resources, environmental conservation, building infrastructures, health care, and information systems. Base technologies are electronics and optoelectronics, superconducting materials, biotechnology, and system software. Koestler's notion of a "holonic, self-organizing system" is stated as an important part of cooperative research here. Computing research is focusing on "software electronics," voice and image recognition systems, neural computing, superhigh speed document search systems, and programless or extremely simplified computing. My own initial contact with this laboratory was with the DEQSOL research group. DEQSOL, a system for solving partial differential equations, fits comfortably in the last category. A detailed description of this is given in an article titled "DEQSOL and ELLPACK: Problem-Solving Environments for Partial Differential Equations" on page 7 of this issue. My contacts at CRL have been Dr. Y. Umetani and Mr. C. Konno, who have been developing DEQSOL.

There is also research work in languages for numerical parallel computation. Career promotion paths for researchers can be via a management route or a scientific route (researcher, supervisory researcher, chief supervisory researcher, chief engineer). Noteworthy is that evaluation of researchers mainly depends on three items: (1) academic-technical achievements, (2) contribution to Hitachi via patents, etc., and (3) social contribution.

In general, computer-related research here is to focus on "software electronics," with particular emphasis on interface. There is also some work on parallel processing in conjunction with the recent Ministry of International Trade and Industry (MITI) High Speed Computing Project. The only specific project that I am aware of here is associated with development of the parallel processing language PARAGRAM. Unlike DEQSOL, which is essentially a high level environment for numerical computation, PARAGRAM is a true programming language, specifically oriented for numerical computation on parallel computers.

### Advanced Research Laboratory

The Advanced Research Laboratory (ARL) (Kisoken) was established in 1985 on the site of the Central Research Laboratory; only last year it was moved to a new facility in Takasaka, about 90 minutes north of Tokyo. ARL now has a staff of about 100, with plans to grow to about 200 in the next 10 years. There are currently about 35 nonscientific staff, and this will only increase to about 50 when final expansion is complete. These figures are very low by U.S. standards but are consistent with other Japanese laboratories, which seem to have a low level of administrative and nontechnical staff.

ARL is the most individually driven of Hitachi's laboratories, with research themes selected by the research staff, "100% spontaneous." This means that scientists do no contract work for other Hitachi facilities. In contrast, CRL obtains about half its budget on commissioned research, and this figure increases to about 70% when all nine Hitachi research laboratories are averaged. Staff are chosen to have the consistency to deal with these themes on a 10- to 20-year scale. ARL sees its roles as watching for trends in very advanced science and technology, incubating highly original concepts, and participating in international research activities. Because of this it also has a unique position in the Hitachi organization. The research is deliberately basic and long range. The management style is simple; the General Manager directly manages all the groups. Funding is from the main office directly with no in-company sponsors or contracts. Research evaluation is via a small advisory committee of faculty from Japanese universities. International aspects are emphasized with visiting scientists, postdoctoral researchers, and an annual workshop; this year's workshop will be on knowledge acquisition. There are four major groups:

Software Science, Biotechnology, Materials, and Electron & Radiation Beam Physics. The latter group has a long history and is well known for research in quantum measurement technology and electron holography, synchrotron radiation, and spin-polarized scanning electron microscopy. Hitachi feels that some of this work is of Nobel Prize caliber. Nevertheless, this group has the fewest people, and Dr. Eiichi Maruyama, the General Manager, explained to me that there is plenty of other electronics research going on elsewhere in Hitachi, suggesting that other activities might be emphasized more in the future. I mentioned to Dr. Maruyama that the advisory committee did not list any computer scientists. He repliedthat many of the senior academic researchers were young, but that he expected to name an appropriate person in the near future.

Major computational activities are associated with natural language understanding, automated reasoning, automatic program production, and brain science. There is also some use of Hitachi's large computers for molecular modeling and genetic engineering related to the use of rhodopsin from an octopus eye. The biological group is studying the possibility of development of a biological photosensitive chip using this protein. The research is expected to take at least 10 years. The laboratory does not have its own supercomputer, but space is set out for one and I was told that a big Hitac will be installed next year. One use of the supercomputer is for a robotics study now just being formulated. The idea is to have a small robot transmit sensory information to the supercomputer, which would perform appropriate reasoning about the robot's environment and then transmit motion change information back. This group, led by A. Sakurai, is thus interested in minimum length descriptors of visual images and efficient and uncorrupted data storage. There is some neural network research here, too. Dr. Masami Yamasaki showed me a nice paper on a finite step method to generate the weights in backpropagation schemes. (Most backpropagation algorithms depend on iterations that converge only in the limit.)

Members of the software group led by Dr. Hiroshi Motoda are primarily interested in learning and cognition. One project is to develop a computer that is intelligent enough to learn about the user's needs and anticipate them. This is a general goal. They are looking for a method for hierarchical representation in a complex system which enables acquisition and simultaneous utilization of knowledge expressed at multiple levels, with different abstractions. At present they have been studying circuit diagrams and the various representations that are needed to make inferences about them. For example, a nor gate can be represented at a high level via its inputs and output, at another level as the digital equations describing the internal circuit, and yet at a deeper level as detailed analog equations. Associated work studies the process of constructing a proof in geometry and what students "learn" from one problem that can help them in another.

Most of the software work is nonnumerical, either written in Prolog, Lisp, or a similar language. There is a substantial collection of computers and workstations, including a Vax 8600, Silicon Graphics, large fast Suns, and several Symbolics. Interestingly, the Symbolics are not used much except by a few Western visitors. Similarly, there are a number of Hitachi workstations that are gathering dust because they do not run a version of Unix that will allow porting of much software. And, in fact, most of their software tools are from the United States.

Nonnumerical computation is well known to require large memory capacity. One of the most interesting research activities is the development of a very large memory computer suitable for reasoning and related computation. Current CPU chips, such as Intel 80486 series or Motorola 68000 series, cannot address more than 4 GB, and this is not considered enough. A current project is to design and build a prototype computer with 64-MB memory using MIPS chips. In a year they expect to build one with 4 GB and shortly after with several tens of gigabytes. They are even talking about terabyte memory! Memory limitations of Unix are much less than 4 GB, as many of the Unix kernels are built around an assumption of 256 or 512 MB. Thus a new operating system will have to be created, too. The only CPU chips known to the ARL group with large memory addressing capacity are produced by Matsushita, but at present these are not being sold outside that corporation. For the ARL development they are anticipating that Hitachi will provide them with 64 megabit DRAMs.

At the moment there is only one researcher (Dr. Atsuo Kawaguchi) working on this activity. When I commented to him that memory limitations were well known to Intel and Motorola, he explained that if the prototype is successful they are hoping to enlarge the support staff. I also asked about the possibility of performing numerical calculations with this kind of computer, and mentioned that in the supercomputer business bandwidth between memory and the CPU was as important as total memory. I was told that if the project was successful, there were very large numbers of engineers in the development laboratories that would be responsible for producing a marketable product, but that the ARL scientists were only looking at the concept and had no intention of building a supercomputer. This project is worth following. Further, although this laboratory is new, it would be a worthwhile place to visit. No expense seems to have been spared to build the facility, which is modern and open looking, on a spacious hilltop. It reminded me of the Gaithersburg National Institute of Standards and Technology (formerly the National Bureau of Standards) site in many ways. Western researchers who are considering postdoctoral or sabbatical positions are also encouraged to contact ARL. However, I would encourage long term visitor candidates to be sure that they know with whom they will be working. Japanese scientists, even the most westernized ones like those here, are private and similarly respect the privacy of others. My contacts are as follows:

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Dr. Klein is a postdoctoral researcher from the University of Illinois who is interested in machine-supported cooperation. He would be a particularly good source of information about the pros and cons of long term visiting positions.

Displayed prominently in Dr. Maruyama's office is the calligraphy by Hitachi's founder of a famous classical poem which states, "Though we cannot live 100 years, we should be concerned about 1,000 years hence." At ARL I saw ample evidence that the long term view is respected. In fact, Sakurai, who runs a new research group, told me that his group really had no results yet, as they had only been in business about a year and a half and had spent the first year deciding what they wanted to do.

## Hitachi Research Laboratory

The Hitachi Research Laboratory (HRL) (Nikken) sits on a hill overlooking the city of Hitachi and the Pacific coastline about 90 minutes north of Tokyo. Established in 1934, it now has a staff of about 1,200. This laboratory is more focused on composite or traditional Hitachi areas of strength in energy electronics and materials. The emphasis is on specific applications. There are three research departments at HRL: Energy, Electronics, and Materials. The Electronics Department works on distributed computer systems, large scale integration (LSI), image devices, software for computer graphics, computer aided design and engineering (CAD/CAE), as well as artificial intelligence (AI). Important projects are related to displays, magnetic levitation, printers, disks, automotive electronics, and high bismuth complementary metal oxide semiconductors. Associated computer projects include Hi-Bi RISC chip for image processing, large liquid crystal displays, natural three-dimensional graphical images, distributed processing and neural computing, and many subareas of materials technology. Researchers here, such as Shigeo Abe, have done first class theoretical work on Hopfield neural nets by the use of "traveling salesman" methods. Parallel neural computing is also targeted as an area for development. Research is also going to continue on magnetic and optical disks, which are already quite profitable for the company. The new rail project (Central Limited Express), which will link Tokyo and Osaka in 1 hour (500 km), is associated with several specific projects at this laboratory.

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and several other scientists in the same department, including Dr. Motoya Ito, Dr. Takao Takahashi, and Mr. Tomoyuki Hamada. Research in this group is application oriented, on topics such as magnetic levitation, linear induction motors, eddy current studies for fusion, quantum chemistry, optical switches, and others (see BIBLIOGRAPHY). The staff are primarily application trained, although they have plenty of computer experience. For example, they have collaborated with Umetani and others at the Central Research Laboratory in developing applications for the DEQSOL software system such as fluid analysis for air flow over automobiles and inside baseball domes and magnetic analysis for standardized magnetic coil models. They have also developed several electromagnetic field analysis software packages for studying eddy currents and charged particle beam trajectories as well as for more general use. Dr. Odamura explained to me that they would like to have someone in their group who is an expert in computational techniques; such a person would certainly be extremely useful. Nevertheless, they have access to a range of advanced workstations and supercomputers, and they demonstrated several computer graphic movies that they had made. Apparently these researchers are working with the computer graphics group, but I had no opportunity to speak to any of the latter.

## Energy Research Laboratory

The Energy Research Laboratory (ERL) is on the same site as the Central Research Laboratory. Established in 1978, ERL now has about 300 researchers and focuses on reactors and related technology such as system components, advanced boiling water reactors, reliable reactor systems, and nuclear fuel cycle. (In Japan, Hitachi builds most of the boiling water reactors; Mitsubishi builds pressurized reactors.) Scientists at ERL are looking for ways to apply some of the expertise and techniques originally developed for use in reactors. These application areas include diagnosis and inspection methods using radiation, laser, and radio frequency waves; robotics; and use of high energy accelerators to semiconductor ~~nufacturing and for medical purposes. The laboratory is divided into four departments associated with various aspects of nuclear reactor design, instrumentation, fuel cycle, etc. In addition, there is a Computational Physics Research Center, where all of my interaction occurred. The group manager is:

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Research activities in the group are naturally focused on applications, and also have a strong numerical analysis component, as can be seen by the representative list of publications in the BIBLIOGRAPHY. The group has done interesting work on techniques to analytically map curved boundaries onto rectangular grids (boundary-fitted coordinate transformations) and also on applications of the boundary element method (BEM), whereby the solution of a partial differential equation at spatial points is given as the solution of a lower dimensional problem on the boundary of the spatial domain. As with the group I met at HRL, the Computational Physics Group does not seem to have any specialist in numerical computing.

# HITACHI LABORATORIES NOT VISITED

## Design Research Laboratory

The Design Research Laboratory (DRL) (Feel) is also in Kokubunji. It was originally established in 1957 as the Design Center; the new name was set in 1989 to emphasize its research contribution. DRL now has about 200 staff members, with about half studying home electrical appliances, the remainder designing industrial machinery and data communications equipment. Research is conducted in the role of design in developing "easy-to-understand and beautiful presentations to humans." First-time visitors to Japan are surprised at the extremely large variety of electrical products that are available. Many of these are distinguished mostly by design (appearance). (A recent Hitachi advertisement in the local newspaper is for a home bakery that automatically kneads, rises, and bakes bread to your choice of crust color.)

## Mechanical Engineering Research Laboratory

The Mechanical Engineering Research Laboratory, in Tsuchiura, about 90 minutes north of Tokyo, was established in 1966. The current staff, which numbers about 600, is working in mechatronics, industrial machinery, and basic mechanical technology.

## Production Technology Research Laboratory

This laboratory is in Yokohama, just outside of Tokyo. Established in 1971, the current staff of over 500 works in development of new production processes, facilities, and systems, with an eye toward techniques for increasing productivity.

## System Development Research Laboratory

This laboratory, in Kawasaki, outside Tokyo, was established in 1973 and now has a staff of almost 400. They are involved in computer software research for banking systems and other Hitachi software products.

## Microelectronics Machinery and Instrument Development Research Laboratory

Also in Yokohama, this laboratory has a staff of 160 and engages in development of office automation equipment and peripherals.

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# OBSERVATIONS ON NEURAL NETWORK RESEARCH AND DEVELOPMENT IN JAPAN

*During the past few years, there has been a resurgence of research activities in neural networks in the United States and all over the world. Japan, with its very advanced VLSI technology capabilities, is in a very good position to capitalize on the advances in neural network research and neurocomputer architectures. These observations on the latest research and development activities in Japan are based on a recent trip to Japan and other readings of publicly available materials. Many of the neural network architectures in Japan are mostly based on the Neocognitron or multilayered Perceptron. On the other hand, because of their VLSI capability, hardware implementations of neural nets show a lot of potential for solving difficult pattern recognition problems such as kanji recognition.*

by Clifford Lau

## INTRODUCTION

"Neural network" is a term used for massively parallel computer architectures that are based on models of human brain information processing. Neural network research has its origin in the 1950s and 1960s when the ideas of Perceptron and Adaline were first developed. Recently, there has been a tremendous increase in research and development (R&D) activities in neural networks. Part of the reason is the realization that although digital computers are good at number crunching, the human brain and nervous system is much better at pattern recognition. The popularity of neural network research is reinforced by the fact that the International Neural Network Society, which was formed 4 years ago, now has over 4,000 members. In Japan, Prof. Shun-ichi Amari, Dr. Fukushima, and others have made significant contributions. There are over 400 members in the Japanese Neural Network Society within 2 years of its formation, and the number is rapidly growing. Much of the neural network research is funded by the Government through the Ministry of International Trade and Industry (MITI), and there are many development activities in the industrial laboratories. Japan, with its very advanced VLSI technology capabilities, is in a very good position to capitalize on the advances in neural network research and neurocomputer architectures.

This article is a brief summary of observations on the state of the art in neural network research and development in Japan. The observations are based on a recent trip to Japanese laboratories during 16-26 August 1990.

## LABORATORY VISITS

### Japan Broadcasting Corporation (NHK)

The NHK Science and Technical Research Laboratories (Dr. Sei Miyake, deputy director) are mostly involved in the development of advanced television systems, visual and auditory science research, and imaging devices research. In advanced television research, flat panel displays and high-definition large screens are under intense development and evaluation. Ultra-sensitive TV camera tubes, called high-gain avalanche photoconductors using amorphous silicon under a high intensity electric field, are under evaluation. In the area of neural networks, research is centered on image processing and speech processing. The goal is to develop an understanding of human information processing and the psycho-acoustics of speech so that neural network architectures can be developed for image and speech processing.

### Nippon Telegraph and Telephone Corporation (NTT)

The NTT R&D organization consists of 11 laboratories for fundamental and basic research and 2 development centers. I met with Dr. Hideki Kawahara, a senior research scientist in the Basic Research Laboratory, and Dr. Yukio Tokunaga (research group leader), Mr. Tadasu Uchiyama (research engineer), Mr. Katsunori Shimohara (senior research engineer), and Mr. Akira Hiraiwa of the Human Interface Laboratory. Neural network research is performed mostly at the Human Interface Laboratory in Musashino. They have developed a system called integrated neural network (INN) architecture for recognition of syllables. The network is similar to the popular multilayered neural net. Speech data are sampled at 12 kHz (at 16 bits) at a 16-ms timeframe. Hamming windows and pre-emphasis filters are used to preprocess the data. Then the linear predictive coding (LPC) (16th order) cepstrum of the data is used as input to the neural net. The training set consists of 62 syllables grouped into different sounds. The INN network is able to recognize the syllable at about a 95% level, a performance similar to a conventional backpropagation algorithm. Research will focus on developing nonlinear signal processing techniques, pattern processing, symbolic processing, and high level artificial intelligence. Other uses of neural networks are in electroencephalographic (EEG) topography recognition and in motor control for prostheses. Neural networks are also used in electromyogram (EMG) recognition for the control of finger movements.

## University of Tokyo and Japan Technology Transfer Association

Prof. Shun-ichi Amari is without a doubt the dean of neural network research in Japan. He is a mathematician who specializes in analysis and differential geometry, and he has done some pioneering work in the dynamical analysis of neural networks since the late 1960s. He is well respected in Japan and continues to be extremely productive. His paper on "Mathematical Foundations of Neurocomputing" appeared in the September issue of the *Proceedings of the IEEE*, which I edited. He is currently working on the concept of dualistic geometry of manifold of higher order neurons.

Following my visit to the University of Tokyo, we met at the Japan Technology Transfer Association (JTTA). JTTA is set up to promote the interchange and transfer of technologies. About 50 representatives from various companies attended this meeting. After listening to Dr. Barbara Yoon describing the DARPA Artificial Neural Network Technology (ANNT) program, the company representatives were asked to explain their interest in neural networks. It appeared that there was great interest in applications of neural network technology to various consumer products and systems, particularly in the areas of pattern recognition, speech processing, and robotic control.

## Laboratory for International Fuzzy Engineering Research (LIFE)

At LIFE I met with the following individuals: Dr. Toshiro Terano, executive director; Ms. Itsuko Fujimori, chief manager; Prof. Michio Sugeno, Tokyo Institute of Technology; Dr. Tomohiro Takagi, division director, 2nd Laboratory; and Dr. Masaki Togai, president and chief executive officer, Togai Infralogic, Inc. LIFE was founded in March 1989 by permission of MITI to concentrate on fuzzy theory basic study and to strengthen the ties between industry and academia in fuzzy theory applications. Three laboratories were set up at that time: fuzzy control, fuzzy intellectual information processing, and fuzzy computers. Eighteen national projects were defined, including fuzzy logic, algorithm for fuzzy reasoning, fuzzy programming languages, intelligent control of unstable systems such as helicopters, intelligent control of ill-structured systems such as fermentation plants, fuzzy neural systems for image understanding, recognition of handwritten characters, human interface for home robots, human interface for high-speed and unstable systems, evaluation of complex systems, fuzzy information retrieval, fuzzy association, reliability of large scale systems, fuzzy logic for management systems, earthquake forecasting, air pollution predictions, and modeling of plant growth. Many applications of fuzzy control are in consumer products such as washing machines, VCRs, and automotive engine control, although potentially fuzzy control may be applied to large complex systems such as nuclear power plant control.

Particularly interesting was the fusion of fuzzy technology and artificial neural network technology. The idea is to study fuzzy neural networks to take advantage of both neural networks, which are good at low-level processing, and fuzzy theory concepts, which are good at high-level intelligent reasoning.

## Fujitsu Laboratories, Ltd., Kawasaki

My contacts at Fujitsu were: Mr. Shigeru Sato, board director; Mr. Junichi Tanahashi, general manager, Information Processing Division; Dr. Kazuo Asakawa, section manager; and Mr. Hideki Kato and Mr. Shigemi Nagata, senior researcher, Computer Based Systems Laboratory. The research activities for neurocomputing at Fujitsu Laboratories consist of algorithms and architecture for neurocomputing, hardware implementations, and applications. They are investigating high speed learning algorithms, based on the popular backpropagation algorithm but with dithering to increase the speed of convergence. Self-supervised learning networks and artificial cerebellar neural networks are being investigated for motor control and robotic control. Combination of neural net and fuzzy system is also being investigated for use in expert systems. Most of these systems are intended for applications in robotic control, processor fault prediction, and stock market analysis. In the area of hardware developments, they have designed and fabricated a commercial neurochip using 2-mm BiCMOS technology. This neurochip consists of a single McCulloch and Pitts neuron (i.e., summation of input data and followed by a sigmoidal function). The chip has dime-division multiplexed data lines to reduce the amount of wiring. The weights are stored externally on 16-bit SRAM, and the input and output are fully analog signals. This neurochip can be interconnected to form multilayered neural nets. They are also designing a super neurocomputer called Sandy/8. This neurocomputer consists of 256 conventional floating point digital signal processor (DSP) chips connected in a ring network. The word size will be 32 bits with a 30-ns clock and 60 MB of memory. The computer is capable of 8.5 GFLOPS of computation and is about the same speed as the CM-2 connection machine, but at a fraction of the cost.

## NEC Corporation, Central Research Laboratories

The R&D group at NEC is composed of seven laboratories and four development centers (Dr. Kazumoto Iinuma, general manager, Information Technology Research Laboratories; Mr. Masao Watari, manager, Media Technology Laboratory). Neural network research is done at the Information Technology Research Laboratories located at Miyazakidai, as well as at the NEC Research Institute located at Princeton, New Jersey. Neural network applications are focused on: (1) written character (kanji) recognition, (2) speech recognition, (3) automated music synthesis, (4) stock market analysis, and (5) face recognition.

## Electrotechnical Laboratory (ETL), Tsukuba Science City

ETL consists of 14 laboratories and the Life Electronics Research Center located at Osaka (Dr. Toshitsugu Yuba, director, Intelligent Systems Division; Dr. Nobuyuki Otsu, section chief, Mathematical Informatics Section; Dr. Gen Matsumoto, Computer System Division). Neural network research is done mostly in the Information Science Division, which consists of the Mathematical Informatics Section, Neuroscience Section, and Cognitive Science Section. There appears to be some excellent research work on neural networks done at ETL. Dr. Otsu's idea of soft logic computation as the foundation of flexible information processing seems to be the basis of much of the future research work in neurocomputing. Soft logic is also sometimes called inductive probabilistic logic (IPL) or inductive stochastic logic, which has a more traditional mathematical foundation than fuzzy logic. His mathematical development for an optimal linear and nonlinear pattern classifier is also first rate. Dr. Matsumoto's work on neurocomputing based on his study of biological neurons is also outstanding. In April 1990, MITI put together a report on the new information processing technology as a guidance for future research and development. In this report, future research will emphasize two specific concepts: soft (flexible) information processing and massively parallel and distributed information processing. The expected typical applications are in pattern recognition and understanding, inference and problem solving, information databases, large scale socioeconomic system simulation, and robotic control.

## Hitachi Ltd. Central Research Laboratory and Systems Development Laboratory

Neural network research is mostly done at the Central Research Laboratory and the Systems Development Laboratory (Dr. Fumihiko Mori, manager, 5th Research Department). They have developed a fast optimization algorithm using the simulated annealing method. They have designed and fabricated a 5-inch wafer-scale neurocomputer. The wafer contains 576 neurons and 36,864 synapses. The neurocomputer is fully digital, with 8-bit weights. The wafer contains about 19 million transistors and is capable of interconnecting all 576 neurons in 267 ms, or 2.1 million weight updates per second. This 5-inch wafer-scale neurocomputer has been tried on the Traveling Salesman Problems (TSP) and was able to solve a 16-city TSP problem is less than 0.1 second, or about 10 times faster than simulation on the Hitachi supercomputer.

## ASSESSMENT

Although this trip was confined to the Tokyo area, a clear picture is beginning to emerge concerning the state of neural network research in Japan. Most of the research has a direct application in mind. Applications are mostly in the areas of image processing (written character recognition or object recognition), speech (or music) processing, robotic control, and stock market analysis. Due to the fact that we were treated mainly by the front office, we did not hear of any work in the area of military applications such as automatic target recognition (ATR), sonar signal processing, or multitarget tracking. The architectures are mostly multilayered Perceptron networks or Fukushima's Neocognitron network. This is clearly different from the United States, where there are many more innovative kinds of neural network architectures. Although they have not come up with new architectures, it is evident that they are well read and fully aware of the literature. They are particularly interested in stock market analysis (several companies are working on the problem) and written kanji recognition. This is understandable because of the fact that a single kanji can be pronounced several different ways. Therefore, automatic translation of kanji to phonetics (hiragana and katakana) is particularly difficult for the Japanese. On top of that, translation of Japanese to English and vice versa is also very difficult. Thus, it is understandable why they are devoting so much research effort to image and speech processing. Since Japan is the leading country in terms of production of industrial robots, it is also understandable that they have large efforts in robotic control using neural networks. Still, their neural network approaches are like that of the United States about 5 years ago. Possibly due to the fact that we visited mostly industrial laboratories, their approaches seem to be very engineering oriented. This is a little different from the multidiscipline approach and basic science oriented research in the United States. The overall impression from this short trip is that there are pockets of excellent research on neural networks in Japan. While Prof. Amari and Dr. Fukushima remain prominent figures in Japanese neural network research, many of the approaches such as backpropagation and multilayered Perceptrons are transplanted from the United States.

Subsequent to my visit to Japan and upon my return to the United States, a group of Japanese researchers representing MITI visited me in September 1990 to seek our opinion and advice on their planned research program on new information processing technology. The group included: Mr. Hideki Asoh, technical officer of MITI; Dr. Kazuo Nishimura, Toshiba; Dr. Yuzo Hirai, University of Tsukuba; and Mr. Atsushi Hori, Mitsubishi Research Institute. The New Information Processing Technology program is to be the follow-on program to the Fifth Generation Computer program. (David K. Kahaner has written a more detailed description of this program that will be published in the next issue of the *Scientific Information Bulletin.*) Two major concepts that allow the new information processing technology to cope with problems that are difficult with conventional "digital" information processing are to be emphasized: soft brain-like information processing and massively parallel distributed information processing. Applications areas are in vision (two-dimensional image) processing, speech processing, and kanji text processing. The program is scheduled to start in April 1992 once it is approved. Thus, it appears that neural networks will be the centerpiece of the new research program.

**Clifford Lau received his B.S. and M.S. degrees from the University of California at Berkeley and his Ph.D. degree from the University of California at Santa Barbara (1978), all in electrical engineering and computer science. Dr. Lau is presently a scientific officer in the Electronics Division, Office of Naval Research and is responsible for the funding and management of basic research programs in VLSI algorithms and architectures for signal processing, VLSI reliability, ultra-dependable multiprocessor computers, and electronic neural networks. He is the coeditor of a recently introduced book, *An Introduction to Neural and Electronic Networks*, and the guest editor of two special issues on neural networks for the *Proceedings of the IEEE* (September and October 1990). He will be the general chairman of the IEEE sponsored 1992 International Joint Conference on Neural Networks (IJCNN) at Baltimore, MD.**

# X-RAY LITHOGRAPHY IN JAPAN

*A study panel was formed by the Office of Naval Research and DARPA to evaluate the current status of x-ray lithography technology in Japan. A group of 11 people traveled to Japan and visited 20 industrial and national laboratories and research and development centers that have current activity or interest in x-ray lithography technology. The scope of the study included: sources, exposure systems, masks, resist, systems integration, and government-industry interaction. This article is a summary of the panel's findings. A comprehensive report will be available from the National Technical Information Service (NTIS) in the spring of 1991.*

by Kenneth L. Davis

## INTRODUCTION

In 1990, the Office of Naval Research (ONR) and DARPA initiated a study of x-ray lithography technology in Japan. The objective of this study was to assess the current Japanese technological status in x-ray lithography and their future plans for implementation and use. The study's focus was on all aspects of x-ray lithography, including x-ray sources (e.g., synchrotrons), x-ray optics, beam lines, mask aligners/steppers, masks, and resists, as well as comprehensive issues such as systems integration, manufacturing insertion, cost/performance trade-offs, government support, and the Japanese view of the critical technical issues for introduction of the technology.

To administer the study, ONR and DARPA provided funding to the Japanese Technology Evaluation Center (JTEC), an organization supported by the National Science Foundation and other government agencies, which has organized a series of panel studies to assess Japanese research and development (R&D) in a variety of topical areas (13 during the past 2 years).

The x-ray lithography panel consists of: James Clemens (chairman) of AT&T Bell Laboratories, Robert Hill (co-chairman) of IBM, Franco Cerrina of the University of Wisconsin, Gene Fuller of SEMATECH, Fabian Pease of Stanford University, and Henry Smith of the Massachusetts Institute of Technology. The panel was joined by Kenneth Davis of ONR, David Patterson of DARPA, Martin Peckerar and David Nagel of the Naval Research Laboratory, and Allen Lapore of the Army Electronic Device Technology Laboratory in a series of visits to 20 Japanese industrial and national laboratories and R&D centers that have current activity or interest in x-ray lithography technology (see Table 1). These visits were completed on 2 November 1990, and the gracious and forthright cooperation of the Japanese hosts was greatly appreciated.

The JTEC panel's findings were presented under the auspices of the Naval Studies Board at a 1-day symposium at the National Academy of Science, Washington, DC, on 24 January 1991. A comprehensive report is also under preparation and will be available from the National Technical Information Service (NTIS) in the spring of 1991. The NTIS order number is PB91-100073.

The following is a brief summary of the major conclusions of the group.

## SOURCES

The x-ray source of choice is clearly the synchrotron. Japanese work in point sources for lithography was not visible, and the previous known efforts have been stopped. Many people expressed the opinion to us that x-ray point sources won't be practical for VLSI lithography because of relative deficiencies in reliability, boundary positioning, and brightness. We saw several examples of synchrotrons that were commercial product quality, rather than developmental machines. Synchrotrons appropriate for x-ray lithography are designed, tested, and ready now for manufacturing, although further developments and improvements are continuing. Examples of such synchrotrons are:

- Warm ring:
  - SORTEC (manufactured by Mitsubishi and Toshiba)
  - IHI (Ishikawajima-Harima Heavy Industries)

Table 1. X-Ray Technology Emphasis

| Organization Visited | Synchrotron | Beam Line | Aligner | Mask | Resist | Device Fab. |
|---|---|---|---|---|---|---|
| Canon | | X | X | | | |
| Dai Nippon Printing | | | | X | | |
| Electrotechnical Lab | X | X | X | X | | |
| ETL/Sumitomo Elec. | X | | | | | |
| Fujitsu | | X | | X | | X |
| Hitachi | | X | X | X | X | |
| Hoya | | | | X | | |
| IHI Luna | X | | | | | |
| Japan Synthetic Rubber | | | | X | | |
| Matsushita | | X | X | | X | |
| Mitsubishi | X | | | X | X | X |
| NEC | | X | X | X | | X |
| Nikon | | X | X | | | |
| NTT | X | X | X | X | | X |
| Oki Electric | X | X | | X | X | |
| Photon Factory | | X | | X | X | |
| SORTEC | X | X | | | | X |
| Sumitomo Heavy Ind. | X | X | X | | | |
| Toppan Printing | | | | X | | |
| Toshiba | X | X | X | X | X | X |

- Superconducting compact ring:
  - SHI (Sumitomo Heavy Industries)
  - NTT (jointly developed with Toshiba and Hitachi)

Projected synchrotron selling price is about $20M, declining by roughly a factor of two in the future. Reliability is not seen as a technological issue; maintenance on some rings is currently limited to 1 to 2 weeks per year, and major failures are very rare.

## EXPOSURE SYSTEMS (BEAM LINES AND STEPPERS)

The R&D programs of several Japanese companies, when considered as a set, encompass all the key elements of production exposure systems. The current status is that a number of research exposure systems exist, and development systems are being installed at three locations (two by Canon and one by Nikon with NTT). The most significant technological problems lie in the x-ray beam optics.

## MASKS

Mask research is currently underway in many organizations. We frequently heard the view that the current shortcomings in masks are not showstoppers and can be closed quickly when necessary. The biggest technological problem, associated with the necessity for 1X proximity masks, is the E-beam pattern precision (errors in pattern feature position when made by electron beam systems). Another related problem is E-beam critical dimension control in patterning. Materials problems are viewed as more easily solvable. The overwhelming substrate material of choice is silicon nitride, based upon a technology developed by NTT and widely licensed in Japan. The widespread development efforts on nitride are resulting in steady improvements in the durability of masks in the presence of x-ray radiation, which is the most serious problem with silicon nitride masks. Some companies are investigating silicon carbide substrates, and all mask investigators to whom we spoke expressed the belief that this material represents the next generation beyond silicon nitride. Diamond is seen as a generation beyond silicon carbide, and there is little current effort on diamond x-ray masks. For the metal layer, everyone we encountered favored a subtractive process (etched refractive metal patterns, rather than the plated gold patterns popular in the United States) using tantalum or tungsten. The issue of mask inspection and repair seems to be largely unaddressed by Japanese organizations.

## RESIST

The sensitivity of x-ray resist is not emphasized; synchrotron sources with substantial beam intensity are assumed. The Japanese resist development efforts can be characterized as large, world class, and diverse, with involvement of many companies--not restricted to resist suppliers. The focus is primarily on optical ultraviolet (UV) and deep UV resists because no immediate market exists for specialized x-ray resist, and straightforward extensions of E-beam resists work well for x-ray exposure. Resist is not seen as a technological stumbling block.

## SYSTEMS INTEGRATION/ INSERTION POINT

The principal advantage of x-ray lithography is associated with the large available depth-of-field. For small geometry patterns, this translates to a simple, reliable single-layer resist process that is potentially much lower cost in production than state-of-the-art ultra high resolution optical lithography techniques. Because it is a distinctly different technology from optical lithography, there is a high initial facility investment that must be recovered by high volume production. Thus DRAM is the natural driving product type, since it uses the smallest pattern linewidth and is manufactured in the highest volume of any semiconductor product. Companies not heavily involved in DRAM would logically not have an interest in x-ray lithography at this time. The consensus opinion for the introduction point of x-ray lithography in production manufacturing is about 1998 for 0.25 micron lines. The product driver is the 256-Mbit DRAM. Advanced optical lithography techniques are expected to dominate through the 64-Mbit DRAM generation (to be introduced in roughly 1995-6) at about 0.35 micron, although some people told us they hoped to try making 64-Mbit DRAM devices as experimental test vehicles for x-ray lithography. This time line is clouded not by the capability of x-ray lithography but by competition from optical lithography. If eximer laser sources and new techniques such as phase shift masks (which permit the resolution of patterns smaller than the optical wavelength) manage to delay the introduction of x-ray lithography for one more DRAM generation, to 1 Gbit, then the entry point will slip about 3 more years. The problem is that an x-ray source cannot simply be inserted into an optical processing line; the steppers/aligners, masks, resists, and even the factory floor plan must be completely redesigned. Projected cost for an x-ray based semiconductor production facility exceeds $1B. Optical based facilities are also approaching this cost, so the financial investment alone isn't the primary stumbling block. X-ray lithography technology has not been demonstrated in production, and the risk of a new, untested (in production) technology is very hard to swallow at the $1B level. Pilot line facilities (priced more in the neighborhood of $200M) are essential for this type of demonstration. Worldwide, IBM (in the United States) and NTT have such facilities nearly operational. Mitsubishi has begun building one, the Japanese SORTEC consortium could potentially be used for this purpose, and Oki is planning construction in 1995. Other companies so far are waiting and watching and working on subsets of the technology.

## GENERAL OBSERVATIONS

The panel also made several general observations:

(1) In the large Japanese companies, there is a general willingness to invest substantially in several alternate, competing lithography technologies simultaneously.

(2) The level of private support for x-ray lithography is much higher than government support in Japan.

(3) Considering the total Japanese effort in x-ray lithography, all major development areas are well covered, although many organizations are content to focus on pieces of the problem and leave the rest to others.

**Kenneth L. Davis is Director of the Electronics Division of the Office of Naval Research (ONR). He received a B.S. in physics in 1969 from Iowa State University and an M.S. in physics in 1971 and a Ph.D. in electrical engineering in 1973 from Purdue University. From 1973-83 he worked at the Naval Research Laboratory (NRL) performing basic and applied research primarily in the area of surface acoustic wave devices. In 1981 he was appointed Head of the NRL Electronics Technology Division's High Speed Components Section. He has been in his present position since 1983, where he has responsibility for a basic research program that encompasses the areas of solid state devices and circuits, information systems theory, electromagnetics, and electronic environment of the ionosphere. In 1988 Dr. Davis was selected to participate in the President's Commission on Executive Exchange Program, where he spent 1 year working for the Motorola Corporate Director of R&D. He is a Senior Member of IEEE.**

# TRENDS IN MATERIALS PROCESSING IN JAPAN

*This paper briefly describes the latest trends in materials processing in Japan as reported at the Fifth International Symposium on Advanced Technology in Welding, Materials Processing, and Evaluation.*

by T.W. Eagar

## INTRODUCTION

On 17-19 April 1990, the Japan Welding Society held the Fifth International Symposium on Advanced Technology in Welding, Materials Processing, and Evaluation at the recently opened (and still under construction) international convention and business center in Makuhari, near Narita, outside Tokyo. This center is comparable to the largest convention/exhibition centers in the United States. Two 30-story trade center towers are under construction, which will make this area a focal point for international business and trade meetings in the Far East.

There were 190 papers and 300 attendees at this symposium with 25% of the papers and 10% of the attendees from outside Japan; however, most of what is reported herein deals with trends in materials processing in Japan.

Briefly, three major trends were evident from the 150 papers presented by Japanese authors:

- There is a strong shift away from heavy industries such as shipbuilding and pressure vessels toward high volume manufacturing such as the automotive sector.
- There is a sharp drop in interest in electron beam processing and a rapid expansion of research on laser processing.
- Many of the papers dealt with fabrication of advanced materials (ceramics, polymers, and composites), although the work in this area was disjoint and exploratory rather than being directed to specific applications for these materials.

## SHIFT FROM HEAVY INDUSTRY TO LIGHTER, HIGH VOLUME MANUFACTURING

Five years ago, a similar symposium would have been dominated with studies of welding of steels for shipbuilding or pressure vessel industries. Few papers would have been offered in support of joining technology for the automotive sector. At this conference, approximately 15% of the processing papers were directed toward reduction of metal spatter in $CO_2$ shielded gas metal arc welding of automotive assemblies or resistance spot welding of galvanized steel sheet. This is in spite of an increase in shipyard orders with a return to profitability for this industry. Shipyard utilization is near 60% after an industry downsizing during the past decade, which reduced the overall capacity by one-half. Nonetheless, it is clear that Japan does not expect to continue as a major force in these labor-intensive heavy industries. Sumitomo Metals announced a \$3B restructuring aimed at placing 10,000 employees in alternative industries.

Among the more interesting papers dealing with metals processing in these industries was a paper from Osaka University describing improved gas tungsten arc welding electrodes containing lanthanum, cerium, and yttrium oxides. These electrodes have up to 10 times greater life than thoriated electrodes in common use in the United States, making these new electrodes attractive for robotic welding applications. A paper from Kawasaki Heavy Industries described abrasive water jet cutting of 7-inch-thick stainless steel.

## INCREASED EMPHASIS ON LASER PROCESSING

In a prior *Scientific Bulletin* article [T.W. Eagar, "Electron beam and laser materials processing in Japan," 10(4), 21-41 (1985)], the intense Japanese effort from 1975 to 1985 in heavy section electron beam welding was described. The conclusions of that prior article, that the \$200M effort on electron beam was largely unsuccessful and interests were turning toward laser processing, are borne out by this symposium. No papers dealt with heavy section electron beam welding, whereas 25% of all processing papers involved lasers. In an invited presentation, Professor H. Maruo of Osaka University noted that 2,000 high power density lasers were sold in Japan in 1988 and 2,500 in 1989. These were divided approximately equally between YAG and carbon dioxide lasers. One paper from Nagoya University on laser welding of aluminum found that the porosity consisted of 80% hydrogen and 20% nitrogen. The source of hydrogen was traced to moisture in the atmosphere. Improved gas shielding eliminated much of the problem.

In another paper from the Institute of Research and Innovation, and Mitsubishi Heavy Industries, it was shown that a 3-kW carbon monoxide laser with 5-micron radiation will cut material of equivalent thickness as can be achieved with a 5-kW carbon dioxide laser operating at 10 microns. The cause of the enhanced cutting was not known, although it was announced that a 20-kW carbon monoxide laser is under development. During questioning it appeared that there is no work going forward to develop commercial carbon dioxide lasers of greater than 10 kW capacity, although at least two 20-kW units have been constructed for research purposes. Neither of these 20-kW units are being used for any purpose, including research, at present.

In another paper from Osaka University, the cutting and machining characteristics of silicon nitride were studied using carbon dioxide, YAG, and excimer lasers. The excimer laser was found to produce the least surface damage and hence the best mechanical properties in the ceramic.

## FABRICATION OF ADVANCED MATERIALS

There were a number of papers involving joining of advanced materials, although few of the approaches were unusual or produced joints of exceptional promise. One paper from Osaka University noted a doubling of the adhesive strength of a fiber-reinforced polymer composite when preceded by a laser surface pretreatment. Investigation showed that the laser exposed the fibers, which were later partially incorporated into the adhesive, thus providing greater strength.

There were a number of papers on transient liquid phase diffusion bonding and reactive metal brazing of ceramics, although none of these produced remarkable results. Generally, the research on these advanced materials represents a learning curve for the researchers rather than a major advance in joining technology. None of these studies appeared to relate to specific application of these materials except for two papers dealing with joining of first wall materials for tokomak fusion reactors.

## CONCLUSION

This symposium demonstrated the continuing strong interest in joining technology in Japan. However, there was no major theme or goal such as improved steel weldability for shipbuilding or joining of thick sections by electron beam, as one would have seen a decade ago. At that time, there were large national programs with specific goals and the research results appeared to be more focussed. The themes today of using lasers or joining advanced materials lack any specific application and hence are not well focussed. It appears that the Japanese have forgotten how to do research focussed to a specific goal. Much of the work appears to be done for its own sake; thus, it is not clear how any of it will be used in the future.

Thomas W. Eagar, a former liaison scientist with ONRASIA, is a Richard P. Simmons Professor of Metallurgy at the Massachusetts Institute of Technology. Dr. Eagar's professional interests are broadly in manufacturing processes for metals and ceramics with more specific interest in welding and joining technology.

# MARINE BIOLOGY AND BIOTECHNOLOGY IN JAPAN

*Japan's economy is perhaps the best example of the dependence on marine biomass resources for the national food basket. Marine products are present in the ingredients of the majority of the products. It is not surprising, therefore, that the Japanese Government and industries are expanding greatly their investment in research on all aspects of marine biology and especially on marine biotechnology. This article describes some of the research institutions conducting research programs in marine biology and the focal areas of interest.*

by Aharon Gibor

## INTRODUCTION

More than two-thirds of the surface area of the globe is covered with water; thus, the major portion of the solar energy reaching the planetary surface falls on the oceans. Global climate and ecology are, therefore, influenced if not dominated by the processes that take place in the ocean and especially at the ocean-atmosphere interphase. In addition, the biomass of the oceans plays an increasingly important economic role for many countries. With the projected increases in human population, it is inevitable that humanity will become increasingly dependent on the oceanic biomass for food and other resources.

Japan's economy is perhaps the best example of the dependence on marine biomass resources for the national food basket. In a typical Japanese food basket, marine products are present in the ingredients of the majority of the products. It is not surprising, therefore, that the Japanese Government and industries are expanding greatly their investment in research on all aspects of marine biology and especially on marine biotechnology. My definition of the term "marine biotechnology" will be the economic utilization of marine organisms, their products, or their constituents in a designed and controlled fashion.

The Japanese authorities consider the field of marine biotechnology as an area worthy of a national concentrated effort. They foresee that this effort will further the development of basic knowledge of biology as well as promote commercial enterprise.

Research in this area is proceeding in four venues:

1. Academic institutions and marine laboratories

2. Laboratories of governmental agencies such as the Ministry of Agriculture, Forestry, and Fisheries. This agency established recently a new research institute, the National Central Fisheries Technology Institute. They are constructing a new laboratory at Kamaishi, adjacent to a similar institute that is being constructed by another governmental agency [the Ministry of International Trade and Industry (MITI)] (see below).

3. Companies that are consortia of academic, governmental, and industrial entities are also being created. This last venue is exemplified by the creation by MITI of the Marine Biotechnology Institute Co., Ltd. (MBI). This institute operates two modern laboratories, one at Shimizu south of Tokyo and the other at Kamaishi in the north. A third arm of the National Government that supports marine biotechnology projects is the Science and Technology Agency (STA). This agency created the Japan Marine Science and Technology Center (JAMSTEC), which emphasizes oceanographic and deep sea studies. They are, however, actively studying deep sea organisms and the biological utility of deep sea waters.

4. The fourth venue is the research laboratories of industrial companies, e.g., Suntory Co.

## RESEARCH INSTITUTIONS

I visited a number of university laboratories as well as public and private research institutes where active research on different aspects of marine biology is in progress. I will limit my comments to those subjects of interest to the Office of Naval Research (ONR) biology and oceanography divisions.

## ACADEMIC MARINE STATIONS

Because of its intimate relationship to the ocean, the biology curriculum of Japanese universities invariably emphasizes marine biology. There are 19 marine stations and 3 hydrobiological research stations that are directly affiliated with universities. The Appendix lists the academic marine stations, their location, personnel, and subjects of studies.

The primary function of these stations is to teach visiting classes of undergraduate students. The permanent staff of each station is made up of a director, usually a senior professor, and one or two assistants. In most of these stations, facilities are also available for the staff to pursue research projects. Facilities for a number of graduate students are usually also provided. I visited several of these stations and obtained reprints of research conducted in others.

My overall impressions are that these stations serve well their primary goal, which is teaching basic marine biology. In this respect they are equipped as well as similar institutions in the United States. They are not to be compared with research institutions such as Scripps, Hopkins, Woods Hole, or Friday Harbour. The nature and quality of the research projects that are being conducted in these laboratories depend on the interests of the director and his abilities to receive financial support.

### Sugashima Marine Laboratory, Nagoya University

Of the academic laboratories that I visited, I was most impressed by the work of Prof. H. Sato of the Sugashima Marine Laboratory of Nagoya University. Prof. Sato worked in the United States for many years and he is a leader in the study of the organization of mitotic apparatus. He constructed highly efficient light microscopy instrumentation for following the assembly of microtubules in vivo. He continues to be a leader in the field. One of his students, Dr. Itoh, is now in the group of Dr. Hotani working on the ERATO project of macromolecular assembly and organization. Itoh is using the methods that were developed in Sato's laboratory for viewing the in vitro assembly of tubulin.

### Noto Marine Laboratory, Kanazawa University

The Noto Marine Laboratory of Kanazawa University also has an active research group headed by Prof. N. Suzuki. Their research is on the biochemical aspects of fertilization of sea urchin eggs. They are studying the biologically active peptides that are associated with the extracellular matrix around the eggs and that have activating effects on the sperm cells. This excellent work was started in cooperation with Prof. D. Garbers of Vanderbilt University, and they are continuing their cooperation.

A very closely related project is that of Prof. K. Aketa of the Akkeshi Marine Station of Hokkaido University. This group is studying the surface receptors that are responsible for the initiation of the acrosome reaction, an early step in the activation of the sperm for fertilization.

### Misaki Marine Station, Tokyo University

Another group that is studying sperm motility is that of Prof. M. Morisawa of the Misaki Marine Station of Tokyo University. A large number of the other "teaching" marine stations list as their research activities studies on the fertilization and early development of various invertebrates that are found in their specific area. Most of these laboratories are also engaged in describing the flora and fauna of their area and taking measurements of various ecological parameters of their environment. A number of such laboratories that are located near industrial centers are also engaged in assessing the degree and effects of pollution on the local ecology.

These laboratories teach undergraduate courses to students of their own institution and also host classes for other colleges and universities.

My overall impression is that the availability of numerous marine stations all over Japan indicates their academic interests and emphasis on the sea around them.

## PUBLIC COMPANIES

Beside academic institutes, there are a number of quasi-government and private sector research organizations that were created to promote research on marine sciences and technologies. Two important quasi-government-academic and private sector organizations that are engaged in marine research are the Japan Marine Science and Technology Center (JAMSTEC) and the Marine Biotechnology Institute Co., Ltd. (MBI). This section briefly describes each organization, and the following section discusses specific topics of research that are being conducted.

### Japan Marine Science and Technology Center (JAMSTEC)

JAMSTEC is supported by the Science and Technology Agency (STA) of the Government. Its mission is to promote the research and development of Japan's marine sciences and technologies with the cooperation of academia and the private sector. Beside direct research activities they are also involved in training, education, technical information dissemination, and construction and maintenance of specialized research facilities such as high pressure test facilities and undersea training facilities. I think that they probably resemble most closely the National Oceanic and Atmospheric Administration (NOAA) in the United States. The most famous activity of JAMSTEC is their deep sea exploration with *Shinkai 2000* and their new *Shinkai 6500*, which just became operational. They are at present in the midst of constructing a new high pressure biology facility to study the deep sea organisms that will be picked up by the *Shinkai 6500*. Attempts will be made to maintain such organisms at high pressures and temperatures similar to the environment in which they were collected. Prof. Horikoshi of "Superbug" fame is in charge of this project.

## Marine Biotechnology Institute (MBI)

MBI is supported by MITI together with a consortium of several dozen major private companies. MITI inaugurated a large scale project titled "The Manufacturing of Highly Functional Chemical Products from Marine Organisms." Two large research institutes, one in Shimizu (south of Tokyo) and the other at Kamaishi (northeast coast of Honshu island), were built and lavishly equipped to undertake research projects in marine biotechnology. The scientific director is Prof. S. Miyachi, who retired this year from the Institute of Applied Microbiology of Tokyo University. Prof. Miyachi is also the president of the Japanese Society of Marine Biotechnology. This interesting cooperative arrangement for undertaking economically risky research projects is regarded by some of the participants as an experiment. The degree and persistence of cooperation between the different sponsoring organizations are yet to be determined.

I cannot think of an equivalent organization in the United States that is dedicated to a specific research area, and certainly not one dedicated to marine research.

## FOCAL AREAS OF INTEREST

I do not claim expertise in all the subjects on which I will be commenting, thus restricting my "comparative assessment" of similar research activities in the United States. It is often argued whether research in what is called biotechnology is science or just technological innovation. It is my opinion that much basic knowledge is generated while pursuing an applied goal. A good example is basic biology, which was discovered by doing medical research.

## THE SEARCH FOR NOVEL NATURAL PRODUCTS

Searching for new biologically produced substances that could be of technological interest is a major area of activity in most of the institutions that I visited. This topic seems to be a focal point for much that is called marine biotechnology.

Some laboratories are involved in directly searching for substances with specific properties, i.e., adhesives, antibiotics, or pigments. Other laboratories, mainly at universities, also include more basic studies, for example, the biosynthetic pathways leading to the production of these substances and the genes responsible for their synthesis. Other laboratories pursue the ecological distribution of the unique substances from the primary producers to the concentrators, i.e., accumulation of toxins in marine animals.

### Laboratory of Marine Biochemistry, Faculty of Agriculture, University of Tokyo

This laboratory is under the directorship of Katsumi Yamaguchi. It is very well equipped for extraction and analysis of natural products. They are searching for the ecological origins and distribution of tetrodotoxin. Biologically active substances from dinoflagellates with antifungal properties were also recently isolated. They are also studying substances from sponges and other invertebrates. The production of pigments by planktonic algae is being studied as the natural sources of pigmentation of fish and shellfish.

### Ocean Research Institute of the University of Tokyo

Prof. T. Nomoto, the director of this laboratory, passed away recently. In the marine microbiology laboratory, research is being conducted on the synthesis of bioactive substances by isolated microorganisms. Antibiotics, toxins (especially neurotoxins), enzymes, and enzyme inhibitors were described. The laboratories have state-of-the-art instrumentation for analytical work. Many of the graduates from these two laboratories of Tokyo University are continuing to do essentially the same type of research work at other academic and nonacademic laboratories.

### Kitasato University School of Fisheries

Prof. H. Kamiya is studying antibiotics and antitumor agents from invertebrates such as *Aplysia* and *Haliotis* (sea hare and abalone). A polypeptide was purified that inhibits the biosynthesis of macromolecules by tumor cells within 2 hours after application of

3 ng/ml of culture medium. The extraction and purification of the extracted proteins and peptides are done locally; the bioassays, on cultivated tumor cells, are conducted in cooperation with the university medical school laboratory.

Prof. M. Kodama is studying the origins of the paralytic shellfish toxins. His recent findings indicate that the degree of toxicity of the dinoflagellate *Protogonyaulax* is related to the presence of intracellular bacteria in them. These bacteria, identified as *Moraxella sp.*, were isolated and cultured. The bacteria produce small amounts of toxins when cultured in vitro; much higher amounts are synthesized when the bacteria are in symbiosis with the dinoflagellate cells.

## Tokyo University of Fisheries

Prof. K. Shiomi is studying a number of venoms and toxins that are found in marine animals. He isolated and purified hemolytic venoms of six different species of fish. These seem to be relatively small glycoproteins. Similar toxins from corals and star fish are also being studied.

## Laboratory of Microbiology, Kyoto University, Department of Agriculture

Prof. Y. Ishida is studying growth of microorganisms in extreme environments. Special emphasis is on the production of bioactive substances by the communities of bacteria and microalgae. Substances that are produced by bacteria appear to control the growth, sexual reproduction, and metamorphosis of not only microalgae but also animals of the community including fish. They found that some algae produce active substances that affect the settlement and metamorphosis of fish larvae as well as their subsequent growth.

## University of the Ryukyus, Okinawa

Profs. K. Yamazato and T. Higa are studying coral reefs and the biology and bioactive substances derived from organisms of the reefs. Sponges and various species of coral are being extracted in search of cancer-inhibiting substances. Okadaic acid, from sponges, has apparently such properties and is being actively studied. They are also interested in a toxin produced by a tropical marine blue green alga that causes severe dermatitis. This is a heat stable, low molecular weight substance, probably phenolic in nature.

## Mie University

Prof. Amano is in the Marine Biochemistry Laboratory of the Department of Bioresources. The principal research theme of this laboratory is the search for novel substances from marine organisms. At present they are investigating the antitumor activity of a substance that they extracted from sea cucumbers. An indication of the stature of the Bioresources Department is the new building now under construction that will house this department.

## Ministry of Agriculture, Forestry, and Fisheries

Although I did not visit their research laboratories, I read their projected research plan for the near future titled "The Bemata Project." One of their many goals is the development of new technologies for the bioindustry for the manufacture of new useful materials such as bioactive substances and other biomaterials.

## Public Companies

**Japan Marine Science and Technology Center (JAMSTEC).** JAMSTEC is engaged in a wide range of oceanographic studies. Their primary interest is in deep ocean research, specifically submarine mineral resources, but they are also attempting to develop new marine biological resources. One of their most recent projects is "DeepStar," which is headed by Prof. Horikoshi. Its goal is to exploit the unique organisms found at great depths, especially those that are associated with the hot, mineral-rich springs.

**Marine Biotechnology Institute (MBI).** MBI is actively involved in the search for new utilitarian substances from marine organisms. The long list of the types of substances that they intend to search for reflects the interests of the group of private companies that invested to become partners in this organization. The list includes antibiotics, antitumor substances, central nervous system drugs (toxins), pigments, enzymes, antifouling materials, and adhesives. They are also interested in the accumulation of rare metals by marine organisms.

## Private Companies

I did not have the opportunity to visit the research laboratories of many private companies. I know, however, of the very active research group of Suntory Co., which is engaged in a search for novel products from marine organisms. They are especially interested in substances with pharmacological potential.

I visited the research laboratory of Shiono Co. of Osaka. They are interested in pigments, perfumes, and spices. They are searching for aromatic substances from marine organisms for the production of new spice concentrates.

## Assessment

The Japanese Government and the private sector, the chemical, pharmaceutical, and food industries, appear to be deeply involved, and it seems to me that they are committed to expanding this area of marine biology research. My general impression of the type of research that I saw is that it is not very imaginative or innovative. It simply requires hard work and perseverance and, of course, the investment of money. The Japanese technocrats are apparently willing to invest in this search. This Japanese gamble is based on the fact that there are a vast number of different organisms in the ocean whose biochemistry is still unknown. At the same time there is ample evidence that the complexities of marine communities are regulated by chemical signals. Such regulatory substances are of basic biological interest and they are likely to have technological applications.

A good example is the work of Prof. Yamada of Kyoto University on halogenated substances from red algae and the halogenating enzymes. These enzymes have important potential for the synthesis of halogenated pharmaceutical substances. Factors that control the blooms of planktonic organisms or the schooling of fish are other pertinent examples.

In the United States similar searches for biologically active marine substances are also proceeding, but to my knowledge (I am not aware of what is going on in the U.S. pharmaceutical industry) it is on a much lower scale in comparison to the Japanese effort. For example, Prof. Rita Colwell at the Maryland Marine Biotechnology Institute; Prof. W. Fenical at the Scripps Institution, San Diego, CA; and Profs. D. Morse and R. Jacobs at the Marine Biotechnology Center, Santa Barbara, CA, are engaged in searches for bioactive substances from different marine organisms.

I want to reiterate here the definition of the term "bioactive substances." It must be recognized that the discovery of such substances is a function of the type of bioassays that the experimenter chooses to use. There are many pitfalls in the reports that I saw from some laboratories in which they called "antitumor substance" any factor that inhibited the growth in vitro of HeLa cells. Little was done to show that indeed the substances are specific and are not just inimical to the growth of any cell.

## MARICULTURE

### Introduction

Farming of marine plants and animals is widely practiced in Japan, Korea, China, the Philippines, Southeast Asia, and Indonesia. It is truly an ancient marine biotechnology. I do not intend to describe the various techniques that are being used, but rather I will attempt to describe some of the more recent scientific innovations that are being integrated into the technology.

Mariculture is a focal area in the overall marine biotechnology enterprise. Ultimately, the cultivation of economically desirable plants or animals is the goal of the projects that I described above. Clearly, for technological exploitation, once a valuable substance is identified it will require the mass cultivation of the organisms that are responsible for its synthesis. Thus, many of the projects that I described above presently include or will include in the near future studies on the cultivation of the organisms that they are presently studying. For example, in the Okinawa study of coral, both the bioactive substances of coral and techniques for its cultivation are being studied.

### Marine Plants

There are two types of aquatic plants: (1) microscopic, usually planktonic (floating), plants and (2) large, usually benthic (attached), plants or the so-called seaweeds. There are a vast number of different plant species; each possesses unique substances and properties. Only a few, at most several dozen of these, were or are being studied; the rest represent a large unknown resource for new discoveries.

**Planktonic.** Of the planktonic algae, some can be manipulated to accumulate valuable substances. For example, the alga *Dunaliella* is now cultivated commercially for the production of beta-carotene.

Conditions were developed for other algae to accumulate the amino acid proline or the sugars sorbitol and mannitol. Cultivation of the unicellular red alga *Porphyridium* under conditions that maximize the accumulation of pigments in the cells is being studied.

The rearing of many valuable marine animal larvae depends on the availability of planktonic organisms for their nutrition. In many cases the success of animal rearing depends on the ability to grow the required unique algal species. Nutritional studies on algae that were grown under different conditions are being pursued. Also related to this aspect are studies on the different species of endosymbionts growing in the tissues of some cultivated animals (for example, *Tridacna*) for their possible effects on the quality of the produced animal tissue.

I found especially interesting the studies on the basic biology and possible technological usage of the photosynthetic apparatus of these organisms. At the Fermentation Institute at Tsukuba studies are being pursued on the production of hydrogen by cyanobacteria as well as by nonsulfur photosynthetic bacteria. They are attempting to isolate and clone the genes for the different enzymes of the hydrogenase system. Artificial membranes in which the chromatophores of these organisms were imbedded in an asymmetric oriented fashion were shown to cause charge separation across the membrane upon illumination.

Similar studies on the development of the photosynthetic membranes of cyanobacteria are being conducted by Prof. Y. Fujita at the Okazaki Research Institute. The development and integration of system II of photosynthesis, responsible for oxygen release, with the development of activity of an hydrogenase system that leads to nitrogen fixation is being studied.

An important active laboratory that is studying planktonic algae is that of Prof. S. Miyachi of the Institute of Applied Microbiology of Tokyo University. Comparative studies on the development of systems I and II of photosynthesis in the different groups of algae as well as other aspects of their photosynthetic activities are being conducted. Very significant for present interests is their emphasis on the properties of carbonic anhydrase and the enzymes for carbon fixation. These are of special importance because of the concern with the carbon dioxide balance in the atmosphere.

Another active laboratory is the Laboratory of Marine Biochemistry of the Faculty of Agriculture of the University of Tokyo. Prof. K. Yamaguchi's laboratory is studying different planktonic algae primarily in search of valuable secondary metabolites. They are studying also *Dunaliella* and *Spirulina*, which are already being commercially cultivated. There is also active work on the production of hydrocarbons by algae such as *Botrycoccus*. Conditions are being studied for improving the quality and quantity of the produced hydrocarbons. Another important aspect of their studies is the effect of feeding different algae to animals on the subsequent pigmentation of the harvested animals.

**Benthic.** Various seaweeds are being cultivated and a large number are being studied as potential crop plants. Research is concerned with genetic manipulations of the plants to improve their appearance and chemical composition as desired by the industry. Most of this activity is at marine laboratories of universities and the fisheries agency.

The cultivation of isolated cells and tissues of these plants for vegetative propagation of the plants as well as for use in the production of special secondary metabolites is being studied.

The potential use of seaweeds as a renewable biomass for solar energy conversion is also being studied.

## Marine Animals

A large number of animals, both vertebrates and invertebrates, are being cultivated in Japan.

### Invertebrates.

1. **Rotifers.** These are being cultured as a food source for larvae of other valuable animals. Thus, in every marine station where active rearing of fish takes place, large vats of rotifer cultures are maintained.

2. **Sea urchins.** The Ministry of Fisheries has undertaken research to promote large scale farming of sea urchins for their gonads.

3. **Shrimp and crabs.** Shrimp and crab cultivation is already a large industry, and active research on genetic improvements of the cultivated animals is in progress.

4. **Shellfish.** Abalone and oyster farming is a growing industry. Tropical species such as *Tridacna* are being introduced.

**Marine Vertebrates.** Hundreds of different species and varieties of fish are being reared in Japan. Active research on all aspects of their aquaculture is being pursued in many research stations. The most interesting of these research projects are those dealing with manipulations of the genetic complements of the fish, i.e., production of fish of different ploidity. It is possible with these techniques to produce only females or only male fish as desired. These genetic manipulations are done by inactivating the nucleus of one of the gametes by irradiation prior to fertilization or by disrupting the first or second miotic divisions of the eggs and inducing parthenogenetic development.

Another very active and interesting area of research is concerned with fish endocrinology and its biotechnological applications. Several phases in the life of fish that are controlled by endocrines are being studied. One of these is sexual maturation and spawning. Many important fish species do not breed in captivity; these are being studied for possible induction by gonadotropic hormones. The basic mechanisms by which gonadotropins affect the maturation of oocytes were studied. The role of several hormones in the growth and then maturation of the oocyte was established. Armed with the acquired new knowledge, it became possible to manipulate the reproductive cycle of some fish.

Another phase in the life cycle in which hormones appear to play an important role is the growth, development, and metamorphosis of the young larvae. It was established that the thyroid gland plays a crucial role in this phase of development of the larvae of flounder, a valuable marine flat fish. Injection of thyroid stimulating hormone into minute larvae (1 cm long) caused a surge in thyroxine in the tissues and accelerated the process of metamorphosis. More significant for the technological implications is that a similar effect could be achieved by the addition of the thyroxine hormones to the ambient seawater.

The rate of growth and final size of young fish are also affected by the pituitary growth hormone (GH). The GH gene from several fish was cloned and active GH was produced from transformed bacterial strains. The technology is thus at hand for mass production of fish GH for possible use in aquaculture. It was experimentally shown that oral application of the GH to young fish was effective in stimulating growth. I did not hear of experiments in which the transformed bacteria were fed to the fish in order to inhabit their gut and thus continuously stimulate their growth. I expect, however, that someone will soon do such an experiment and that there will be a public uproar against the use of such fish.

## Assessment

It appears that the Japanese accepted the premise that it is inevitable that sooner or later humanity will have to utilize more efficiently the marine biomass. The marine biomass is, of course, the product of the photosynthetic activities of marine organisms. Basic studies on the process of photosynthesis in marine plants are being conducted with the aim of enhancing the production of biomass. The Japanese are exploring the potentials of marine plants to produce food and secondary metabolites and to be used as a renewable source of energy. The extent of their commitment becomes apparent from the fact that four different governmental agencies are supporting research efforts in marine biology. The Ministry of Education (Monbusho) supports university research and training. MITI; the Ministry of Agriculture, Forestry, and Fisheries; and the Science and Technology Agency (STA) are pursuing elaborate research programs in marine biology. In some cases these efforts appear to be redundant, and two agencies are in direct competition. Apparently this internal competition is acceptable and encouraged by the system.

In the United States there are research projects on many aspects of marine biology, both basic and applied. My overall impressions are, however, that there is no comparable national scale effort in the United States. This is probably because we are still much more dependent on farming of the land for our food rather than on marine products. It seems to me that the Japanese are now repeating their successful accomplishments in the field of electronics in the novel field of marine biotechnology, especially mariculture.

## UNIQUE ORGANISMS FROM EXTREME ENVIRONMENTS

A vital strategy that is employed in the activities described above is the search for suitable marine organisms for particular technological requirements. In this section I want to emphasize the search for unique organisms that inhabit extreme environments, such as hot springs or ocean depths.

The motivation for studying the biota of extreme environments is the basic biology of the adaptation. In other words, what are the specific properties that enable such organisms to withstand conditions that are inimical to most other living things? The overriding reason, however, appears to be the technological potentials of such organisms. In the development of biosensors, for example, it was realized that enzymes of deep sea organisms that function at extreme pressures and temperatures could be of great advantage. Such organisms and enzymes derived from them are expected to be much more stable and thus also suitable for applications to biotechnological reactors.

The term "extreme environment" is vague; it suggests conditions that are limiting to the life of common microbes, plants, and animals. Oligotrophic lakes, which contain almost distilled water, are an extreme environment in which most common organisms cannot grow or survive. Organisms isolated from oligotrophic lakes are being studied in the laboratory of Prof. Y. Ishida, the Microbiology Laboratory of the Department of Fisheries, Faculty of Agriculture, Kyoto University. The ability of such cells to concentrate the required substances from their extremely dilute environment suggests that they possess on their surfaces very efficient receptors. Such organisms might prove valuable for the purification of waste waters or the concentration of rare elements from solutions.

Thermophilic microorganisms, those found in hot springs or similar niches, are being studied by several laboratories, including Profs. T. Oshima and K. Kakinuma of the Tokyo Institute of Technology, Profs. T. Imanaka and K. Urabe of the Department of Fermentation Industry of Osaka University, and Prof. K. Horikoshi of the Deep-Star group of the RIKEN Institute.

The interesting results from the laboratories at the Tokyo Institute of Technology illustrate the Japanese state of the art in this area of research. In the thermophilic eubacterium *Thermus thermophilus* and the archaebacterium *Sulfolobus acidocaldarius*, a thermoacidophilic organism, a group of unusual polyamines was discovered. These polyamines probably play a role in stabilizing such vital macromolecules as DNA and RNA. These polyamines also appeared to influence the assembly of ribosomes at elevated temperatures. The complex, branched polyamines inhibited the activities of many endonucleases; they influenced, therefore, the end products of restriction enzyme actions.

Another very interesting finding was the discovery of novel bipolar lipid molecules accumulating in the archaebacterial cells. These lipids are made up of long isoprenoid chains bound by ether rather than ester linkages to two polar heads, usually two glycerols or one glycerol and one nonitol. Upon sonication, these lipids formed stable unilamellar vesicles. The vesicles were up to 1,000 Å in diameter and their lamellae were about 50 Å thick. These vesicles were stable when heated up to 80 °C. Similar lipids were found in archaebacteria from nonextreme environments. The significance of these unique lipids to the temperature tolerance of the thermophils is yet to be established. The thermal stability of the liposomes produced by these lipids is, however, attracting the attention of biotechnologists.

To investigate the changes in the protein molecules that are associated with thermal stability, Oshima's group studied the isopropylmalate-dehydrogenase. The gene for this enzyme was cloned from extreme thermophils, moderate thermophils, and mesophilic bacteria. From the cloned genes they determined the amino acid sequences of the enzyme. They also isolated the enzymes from the different strains, and the shape of the molecules is being studied by x-ray diffraction analysis.

In another approach they are splicing segments of the highly thermal resistant genes onto the mesophilic gene. The chimeric genes are then expressed in *E. coli* and their thermal stability determined. They hope to determine by these studies which part of the molecule plays a vital role in maintaining the enzyme stability at the elevated temperatures. These studies on the dissection and analysis of the structure and function of a protein molecule are first rate, on a par with the best produced anywhere.

Another study that attempts to relate fine details of protein structure to thermal stability is that of Prof. I. Urabe of Osaka University. Urabe is studying the enzyme glucose dehydrogenase from the bacterium *Bacillus megaterium*. The active enzyme is a tetramer of identical units. It is inactivated in alkaline solution due to the dissociation of the active tetramer to inactive protomers. The gene coding for the enzyme was cloned. It was randomly mutagenized by chemical treatments in vitro. The treated genes were reintroduced into bacterial cells and mutants with increased heat stability were isolated. The specific amino acid substitutions that confer increased thermal stability were determined. Some of the amino acid substitutions also conferred alkaline resistance. This indicated that the increased stability can be attributed to the increased stabilization of the oligomeric structure of the enzyme. Substitution of the amino acid Glu at position 96 by either glycine or alanine, or substituting the tyrosine of position 253 by cysteine, stabilized the tetramer at pH 9. They suggest that the two positions are probably located at the surface of the molecule; when they become negatively charged at high pH they contribute to the repulsion between the protomers, thus causing the oligomer to fall apart.

Prof. Horikoshi's group is studying microbes, which are not only thermophilic but also alkalophilic, i.e., they grow at high pH values. Other bacteria they are studying include alkalophilic and psychrotrophic organisms, which grow at zero degrees and at high pH values. Besides these extreme environment organisms, they are also working with halophilic organisms.

Horikoshi's interests seem to be directed toward the technological applications of the organisms or their enzymes. Genes of enzymes that could be important for the fermentation of various carbohydrates were cloned. The industrial applications of the high pH and high temperature tolerance of these enzymes are under study.

Another unique type of microbe that is being studied by the Horikoshi group as well as by Prof. T. Matsunaga of the Department of Biotechnology, Tokyo University of Agriculture and Technology, is magnetotactic bacteria. These organisms can sense and respond to magnetic fields. The cells synthesize uniquely shaped magnetite particles, which are probably the sensors through which the magnetic signal is transduced within the cell. The microscopic magnetite particles are being studied for applications in medical and other technologies.

Prof. Horikoshi is now heading JAMSTEC's new Deep-Star project, which will investigate living organisms from the very deep ocean. These will be picked up by the submersible *Shinkai 6500* and maintained at the high pressures at which they were collected. They also are planning to grow high temperature and high pressure microbes and invertebrates from the deep ocean and study their biochemistry. It is quite likely that interesting new biochemical reactions will be discovered.

Organisms from extreme and unusual environments are also favorable organisms for study as model systems for exobiology. There is lively interest in Japan on the question of the origin of life and exobiology. I was surprised to find that even this area of research attracts imaginative Japanese private companies. Dr. Y. Ishikawa, who worked at NASA-Ames for several years, is working for the Ohbayashi Company, a major construction company in Japan, in their Space Project Department. They are designing systems for manned habitats for Mars. They are interested in living organisms that could survive or even grow under conditions that resemble those of Mars.

Prof. Hoshima (see above), who was previously employed by Mitsubishi Kasei Institute of Life Sciences, and Dr. H. Yanagawa of the Mitsubishi Institute also are working on prebiotic conditions for polymerization of amino acid mixtures to produce proteinoid-like structures.

In summary, I observed extensive interest among microbiologists in the study of organisms from extreme environments. The motivations are basic *scientific inquiry* as well as the perception that such organisms could be rewarding resources for valuable enzymes or secondary metabolites. For example, the unique ether linked and relatively temperature stable lipids of archaebacteria attracted considerable attention for possible applications in production of liposomes.

In general, the scientific methods and approaches that are being used here are not novel or unique. The heavy investment that the biotechnology industry is willing to undertake indicates that the Japanese truly believe that there is much future opportunity in the marine environment. I share with them this belief.

## ENVIRONMENTAL PROBLEMS, LOCAL AND GLOBAL

There is a strong and growing awareness and apprehension in Japan of anthropogenic detrimental effects on the environment. This concern encompasses several levels of environmental problems.

### Local Problems

Industrial pollution of the atmosphere, soil, and water is of concern to many local public agencies. The disposal of industrial wastes into coastal waters caused great public uproar when the levels of toxic elements, such as mercury in fish, were found to exceed the acceptable standards. Special public health concerns were expressed on several occasions when a biological research institution planned to build new laboratories in proximity to residential areas. For example, the Osaka Biological Institute had to install special air filtration devices to ensure that no biological, chemical, or radioactive hazardous substances are exhausted through the ventilation system. The special sensitivity of the Japanese public to radioactive materials is apparent when one learns about the strict regulations on the use of radioactive isotopes for scientific research. Special buildings to house the laboratory facilities for use of radioactive isotopes must be constructed. Entrance and exit from such facilities are closely monitored. In my observations these strict regulations tend to discourage the use of the facilities. One frequently finds a modern, well equipped facility practically empty while the adjacent science laboratories are overcrowded.

Monitoring the water quality of inland lakes and reservoirs is an important part of the activities of the hydrobiological stations at Itako, Suwa, and Otsu (see the Appendix).

Blooms of dinoflagellates, which frequently result in the red tide phenomenon, are being studied in many marine biological laboratories and in the laboratories of the Ministry of Agriculture, Forestry, and Fisheries. Correlation of the blooms of algae and the nutrient inflow into the coastal bays from urban sewage and from agricultural activities at the watershed was reported. Apprehension was also expressed on the effects of insecticides used by the farmers on aquatic organisms.

One of the suggested ideas is to scrub the nutrients out of rich sewage, for example, sewage from farm animal houses. The sewage in shallow ponds will serve as culture medium for desirable algae. The harvested algae, in turn, will be recycled to feed the animals.

These concerns and research on industrial, urban, and agricultural pollution of bodies of natural water are similar to those taking place in the United States and other countries. My superficial impressions are, however, that public concerns about these environmental issues have stronger political clout in Japan, perhaps because of the higher dependence on food from the ocean. I did not hear of any novel ideas on how to reconcile continuous urban growth and industrial development and protection of the environment, but I am impressed with the apparent concern of the public in these matters. My impressions are, however, limited to what I have read in the English language newspapers; whether they are truly representative of the public opinion is apparently questionable.

A very interesting research organization that is engaged in research on environmental problems is the Research Institute for Ocean Economics (RIOE). This is an incorporated organization under the jurisdiction of the Ministry of Agriculture, Forestry, and Fisheries and MITI. The objective of this organization is the promotion of industrial utilization of marine resources based on firm scientific and engineering research. This organization appears to be a competing organization to JAMSTEC.

The "Tokyo Bay Restoration Project" is one of the proposals that this organization has generated. This proposal is based on the premise that the tidelands, with their very intensive flora and fauna, serve an essential role in the ecology of the bay. The active urbanization of the Tokyo Bay area coastline caused the loss of 90% of the shallow water area. This loss deprived the bay of its natural self-purification activities and also caused the loss of breeding and nursery grounds for fish and shellfish. Thus, in order to restore the bay to a more "ecologically balanced" state, the proposal is to build artificial shallow tidelands and restore the seaweed forests and their fauna. This will be accomplished by dredging the sea bottom and by using landfill from construction sites in the surrounding cities. This plan differs from conventional land reclamation projects which, in fact, generated the problem. The creation of the artificial tideland not only in the estuaries but also in designated areas of the central offshore areas in the bay will contribute not only to the ecology of the bay but also to controlling navigational channels, tidal current flow, and creation of recreational facilities.

The beautiful brochure that describes this ambitious and imaginative project looks almost like futuristic science fiction, but looking at what happened to the larger Tokyo area in the last 50 years convinces me that it could be accomplished. Tamotsu Okabe and Hiroyuki Nakahara of RIOE are the persons behind this project.

Another of the ambitious projects of RIOE and the Fisheries Ministry is titled "Marine Ranching Program." This concept is different from intensive aquaculture in closed bodies of water in that the aim is to learn to control the marine organisms in their natural habitats; for example, the schooling and homing behavior of marine organisms could be utilized to facilitate their cultivation and capture. The behavior and neurobiology of many organisms, the induction of spawning, and conditioning to acoustic signals are among the subjects being studied under this project.

## Global Problems

Japan is strongly committed to participate in the international arena of activities designed to study and protect the global environment. Public awareness as reflected by the media coverage of these subjects as well as government actions indicates the concern in Japan with these international problems. Several issues that appear to be widely discussed are:

1. The greenhouse gases in the atmosphere
2. The substances that destroy the ozone layer
3. Ocean pollution, especially by non-biodegradable plastics

To reconcile the rapid and continued growth of Japanese industry with the environmental concerns, MITI is establishing a new research center, the Institute of Industrial Technology for the Global Environment.

The research programs planned for the next century are grouped into five categories:

1. Conventional energy; increased efficiency and conservation measures.
2. New clean energy sources.
3. Environmentally friendly technologies to maximize recycling and minimize waste.
4. New-Earth $CO_2$ sinks program, both land and sea sinks.
5. New-Earth future energy technology such as cold fusion and magma.

Under environmentally friendly technologies they list:

1. Projects that will minimize $CO_2$ release by promoting $CO_2$ fixation and reutilization. From what I could gather on the type of research they envision, it includes research on enzymes such as carbonic anhydrase and ribulose bisphosphate carboxylase from thermophilic and other microbes. This is probably the kind of work being done in the laboratories of Prof. K. Yamaguchi and Prof. S. Miyachi of Tokyo University. However, I did not hear of any dramatic innovations as yet. Many genes are being cloned for the potential synthesis of the super $CO_2$ consumer.
2. Development of new materials to substitute for harmful substances such as halogenated hydrocarbons. The hope is to completely phase out fluorocarbons by the end of the century.
3. Development of biodegradable plastics. Very intensive research in many laboratories on the development of biodegradable plastics is in progress. An International Symposium on Biodegradable Polymers was held in Tokyo on 29-31 October 1990. Prof. Y. Doi of the Tokyo Institute of Technology was the organizer. Japanese research emphasis is on the production of polymers by microbial fermentation of simple carbon sources and on silk production by engineering organisms containing cloned silk genes and the blending of natural polymers with synthetic polymers. The Fisheries Ministry is especially interested in developing biodegradable fishing nets to alleviate the criticism concerning lost drifting nets.
4. Energy savings. Develop biological reactions that occur at low temperatures to replace energy intensive chemical reactions in production processes. The budget projected by MITI for this program for fiscal year 1990 is about $40 million. The Environmental Agency of the Government received a boost in this year's appropriations for global studies. This agency also established a new center for global environmental research at the National Institute for Environmental Studies in Tsukuba, budgeted for ¥285 million (about $2 million).

Many private companies are also engaged in research in attempts to improve the efficiency of energy utilization and reduce the amount of carbon dioxide emission. Research on inorganic catalysts that facilitate the reduction of carbon dioxide was reported by Iseki Co. The use of an aluminum-porphyrin complex for photochemically reducing carbon dioxide by combining it with a ketone was reported by Prof. Inoue of Tokyo University. A larger number of workers are using biological systems, algae, or bacteria, especially thermophilic organisms, for fixing the carbon dioxide in combustion exhausts.

The "Green" Japanese also voice strong opposition to the role of Japanese industry in deforestation of the hardwood forests of Southeast Asia. They claim that the same companies use different standards for release of industrial wastes in their plants in Japan and in the Philippines. They also call for Japan to share with developing countries the technology that was developed in Japan for desulfuring and denitrating fuels that are used for power generation, thus helping to reduce air pollution in the emerging industries of the Third World.

## MARINE BIOTECHNOLOGY IN ASIA

There is much interest and activity in many countries of Southeast Asia in marine biology and biotechnology. I was only given the opportunity to visit Korea and Indonesia. I strongly recommend, however, that the activities in China, Thailand, Malaysia, and India be followed.

### Korea

Both Korea and Indonesia are emphasizing the development of their marine resources. The efforts in Korea are similar to those of Japan. Besides the universities, research on marine organisms and the marine environment is being conducted by the National Institute of Oceanography, the Fishery Research and Development Agency, and the Korea Advanced Institute of Science and Technology (KAIST). The major emphasis is on improving the aquaculture industry by improved breeding procedures and genetic selection. There is also considerable interest in protecting the coastal waters from industrial pollution; routine monitoring of water quality at a number of coastal stations is practiced. Construction of new research facilities at Pusan, the KAIST laboratories at Ansan, and the KAIST center at Seoul are indicative of the long term commitment of the Government to advance the marine sciences.

I was most favorably impressed by the facilities and high caliber of workers at the KAIST laboratories. Among others noteworthy are the activities of Dr. Byung-Hong Kim of the Applied Microbiology Laboratory. They are engaged in genetic engineering projects to utilize genes of unique microbes for the production of antibiotics and to improve the fermentation processes of the palm-oil industry. They are also concerned with the degradation of hydrocarbons, especially aromatics. Most of the KAIST scientists I met are young, ambitious, and well trained from abroad. I think it is well worth watching their progress.

### Indonesia

Indonesia, in comparison to Korea, is far behind. The Government realizes the importance of marine resources to their future and is investing in it. As I saw it, the primary effort is in educating young biologists by sending them to help farmers start aquaculture projects. The only serious research institution I saw is the new Interuniversity Center of Technology on the campus of Bandung Institute of Technology. Prof. Oei Ban Liang, a U.S. trained organic chemist, is the director of the Center on Biotechnology of this institute. Liang impressed me as a very capable scientist and administrator; he is eager to establish cooperative projects to help support his center. Cooperation with Japan, Australia, and the United States is anticipated. The impression I came back with is that the Government overemphasizes the training of young scientists abroad and does not build good research facilities for them. I saw several highly frustrated, bright, young Ph.D.s trained in Europe and the United States who came back to sit at desks in empty rooms. I assume it was cheap to send young people out on UNRRA fellowships, but it is much more expensive to provide them with adequate facilities upon their return.

## SUMMARY AND CONCLUSION

Because of its unique geography, the Japanese people, historically and at present, are intimately linked to the seas that surround their islands. Historically, the limited arable land and the abundant marine biota made the Japanese economy heavily dependent on marine resources. With this background it is understandable why the Japanese are investing so much in studies on marine biology. With the advent of modern biotechnologies and genetic engineering techniques, the Japanese vigorously have pursued efforts to exploit the new opportunities. There are at least four governmental agencies that actively support research in marine biology and are developing special projects to advance this field:

- The Department of Education supports academic research in a large number of marine stations throughout the country.
- The Science and Technology Agency of the Prime Minister's office sponsors the Japan Marine Science and Technology Center (JAMSTEC), famous for its deep sea investigations.
- MITI sponsors the Marine Biotechnology Institute (MBI) and is now in the midst of founding a research organization for studies of global environmental problems.
- The Ministry of Agriculture, Forestry, and Fisheries maintains a number of research stations and specialized research laboratories for studies on many aspects of marine biology.

The driving force behind the extensive research projects in Japan is the promising potential for new or improved products from marine resources. Marine organisms are being investigated:

- As sources of food.

- As sources of secondary metabolites for the pharmaceutical and related industries.

- As sources of enzymes and other biochemicals for industries, for example, special glues or polymers.

- For concentrating chemicals from the environment or scrubbing polluted industrial waters.

Special attention is also being paid to protecting the ocean and the atmosphere from man-made pollutants. Active research on the production of biodegradable plastics and on substitutes for the harmful fluorocarbons is being conducted. The increase in the level of carbon dioxide in the atmosphere also has become a major concern, and the Japanese Government is investing heavily in studies to alleviate this environmental problem.

There is no equal concentration of effort on problems of marine biology in the United States. There are research activities in all these areas in the United States, but there is no similar concentration of efforts as there is in Japan on developing marine resources. Perhaps this is because we still have at our disposal much terrestrial resources.

Aharon Gibor completed a 1-year assignment at the Office of Naval Research Far East in September 1990. Dr. Gibor is a professor of biology at the University of California, Santa Barbara. He received a B.A. degree in 1950, his M.A. degree in 1952 from the University of California, Berkeley, and his Ph.D. degree in 1956 from Stanford University. His thesis research was done at the Hopkins Marine Station. Dr. Gibor was involved in research on the genetic autonomy of cytoplasmic organelles of eukaryotic cells, especially chloroplasts and flagella. His present research is on the growth and development of algal cells and tissues and the role of cell walls of these plants in controlling their development.

# Appendix

## MARINE STATIONS AND LABORATORIES

### MARINE BIOLOGICAL STATIONS

Akkeshi Marine Biological Station
Hokkaido University
Akkeshi, Hokkaido 088-11
Director: Dr. K. Aketa
Research: Echinoderm development

Inst. of Algological Research
Hokkaido University
Bokoi Minami Machi
1-13 Muroran, Hokkaido
Director: M. Tatewaki
Research: Algal life cycles

Asamushi Marine Biological Station
Tohoku University
Sakamoto 9, Asamushi, Aomori 039-34
Director: K. Osanai
Research: Invertebrate physiology

Sado Marine Biological Station
Niigata University
Tassha, Sado Island, Niigata-ken 952-21
Director: Y. Honma
Research: Fish endocrinology

Noto Marine Laboratory
Kanazawa University
Ogi, Uchiura, Ishikawa-ken 927-05
Director: N. Suzuki
Research: Sperm activation biochemistry

Itako Hydrobiological Station
Ohu, Itako-machi, Ibaraki-ken 311-24
Director: H. Tamura
Research: Limnology

Suwa Hydrobiological Station
Koganodori, Suwa-shi, Nagano-ken 392
Director: T. Okino
Research: Limnology

Misaki Marine Biological Station
Koajiro, Miura, Kanagawa-ken 238-02
Director: K. Takahashi
Research: Cell physiology

Tateyama Marine Laboratory
Ochanomizu University
Ko-Yatsu 11, Tateyama-shi, Chiba-ken 294-03
Director: T. Miki-Noumura
Research: Development of invertebrates

Shimoda Marine Research Station
University of Tsukuba
Shimoda-shi 5-10-1, Shizuoka-ken 415
Director: T. Ikawa
Research: Invertebrate development

Otsu Hydrobiological Station
Kyoto University
Shimosakamoto, Otsu-shi, Shiga-ken 520-01
Director: Y. Tezuka
Research: Limnology

Sugashima Marine Biological Laboratory
Nagoya University
429-63 Sugashima-cho, Toba-shi, Mie-ken 517
Director: H. Hayashi
Research: Cell division mechanism

Seto Marine Biological Laboratory
Kyoto University
Shirahama 459, Nishimuro, Wakayama 649-22
Director: E. Harada
Research: Invertebrate ecology

Iwaya Marine Biological Station
Kobe University
Iwaya, Awaji-cho, Hyogo-ken 656-24
Director: S. Enomoto
Research: Algal cultivation

Ushimado Marine Laboratory
Okayama University
130-17 Kashino, Ushimado, Okayama-ken 701-43
Director: M. Yoshida
Research: Invertebrate development

Oki Marine Biological Station
Shimane University
194 Sesuka, Kamo, Saigo-cho, Shimane-ken 685
Director: T. Iga
Research: Fish pigmentation

Mukaishima Marine Biological Station
Hiroshima University
448 Mukaishima-cho, Mitsugi-gun, Hiroshima-ken 722
Director: H. Shimada
Research: Invertebrate taxonomy

Usa Marine Biological Station
Kochi University
Usa-Inoshiri, Kochi-ken 781-11
Director: K. Yatsuzuka
Research: Invertebrate zoology, systematics

Nakajima Marine Biological Station
Ehime University
Nakajima-cho, Onsen-gun, Ehime-ken 791-45
Director: N. Mizuno
Research: Ecology of fresh water fish

Aitsu Marine Biological Station
Kumamoto University
Aitsu, Matsushima-machi
Amakusa-gun, Kumamoto-ken 861-61
Director: R. Hirota
Research: Planktonology

Amakusa Marine Biological Laboratory
Kyushu University
Tomioka, Reihoku-cho
Amakusa, Kumamoto-ken 863-25
Director: T. Kikuchi
Research: Animal ecology and systematics

Sesoko Marine Science Center
University of the Ryukyus
3422 Sesoko, Motobu-cho, Okinawa 905-02
Director: K. Yamazato
Research: Coral biology

## NATIONAL LABORATORIES

### Ministry of Agriculture, Forestry, and Fisheries

Hokkaido Regional Fisheries Research Laboratory
116 Katsurakoi, Kushiro City, Hokkaido 085
Director: H. Kanno
Research: Commercial fish breeding and ecology, seaweed cultivation and breeding

Tokai Regional Fisheries Research Laboratory
Kachidoki 5-5-1, Chuo-ku, Tokyo 104
Director: M. Fujiya
Research: Management of fish resources, water pollution control, inland fisheries management

Tohoku Regional Fisheries Research Laboratory
27-5 Shinhama-cho, 3-chome
Shiogama City, Miyagi-ken 985
Director: O. Sano
Research: Ecology of fish resources, aquaculture of seaweeds and invertebrates, control of animal and plant diseases

Japan Sea Regional Fisheries Research Laboratory
Suido-cho, Niigata City, Niigata-ken 951
Director: Y. Fujii
Research: Ecology of resources, fishing management and technology of propagation

Far Seas Fisheries Research Laboratory
7-1 Orido 5-chome, Shimizu-ken 424
Director: S. Hayashi
Research: Assessment of the resources available in the far seas fishing areas and development of fishing gear

Nanbei Regional Fisheries Research Laboratory
Ohno-cho 7782-9, Saeki-gun, Hiroshima-ken 739-04
Director: H. Sasaoka
Research: Inland sea resources, cultivation of fish and crustacea, red tide organisms

Seikeai Regional Fisheries Research Laboratory
Director: S. Mito
Research: Fish ecology and recruiting mechanism of coastal fish resources, nori cultivation

National Research Institute of Fisheries Engineering
Director: M. Nakamura
Research: Fishing gear and methods, boats and instruments for port engineering as well as for aquaculture

National Research Institute of Aquaculture
Director: T. Nose
Research: Fish reproduction and development, fish pathology and nutrition; Nikko facilities--fresh water salmonoid fish biology, homing and migration; Ohmura facilities--bivalve growth and reproduction studies

## Science and Technology Agency (STA)

Japan Marine Science & Technology Center (JAMSTEC)
2-15 Natsushima-cho
Yokosuka City, Kanagawa-ken 237
President: N. Makimura
Research: Oceanography and deep sea research, ocean energy and resources, undersea operation technology

## Mixed Enterprise

Marine Biotechnology Institute Co., Ltd.
2-35-10 Hongo, Bunkyo-ku, Tokyo 113
Scientific Director: S. Miyachi
Research: Exploring marine organisms for new products and processes

# THE FIRST INTERNATIONAL CONFERENCE ON BRAIN ELECTROMAGNETIC TOPOGRAPHY

*The conference, held in Osaka, Japan, focused on two major areas: the recording and displaying of magnetic brain potentials (magnetoencephalography) and the recording and displaying of electrical brain potentials (electroencephalography).*

by J.W. Wolfe and S. Matsuoka

## INTRODUCTION

The conference, held in Osaka, Japan, on 12-14 September 1990 brought together leading scientists from over 23 nations. Although there have been seven international conferences on biomagnetism and four on topographic electroencephalography, this conference was broader in scope and included presentations on magnetoencephalography (MEG), electroencephalography (EEG), and evoked potentials (EP). The major theme of the conference was based on computer technology and mathematical and statistical procedures for analyzing and interpreting brain potentials in both normal human subjects and patients with clinical pathology. As the title states, this was the first International Congress of the New International Society for Brain Electromagnetic Topography.

There were 387 registered participants in attendance; approximately one-half of these were from countries outside of Japan. Of the 400 authors listed in the program, 45% were from Japan. The conference was divided into 8 special invited lectures, 3 major symposiums, 10 oral sessions, and 3 poster sessions. The eight special lectures (see the Appendix) were given by pioneers in the fields of magnetic and electrical brain recording (four by American scientists, two by Japanese, one from Belgium, and one from Switzerland). The conference was combined into one major session during the mornings and then divided into parallel sessions during the afternoons. This allowed for 59 oral presentations of 30 to 40 minutes duration. During the afternoons there were 73 *poster* presentations at the meeting. The major topics of the symposium included magnetoencephalography and the analysis of current dipoles and source localization; electroencephalography; topography of evoked potentials; and topography in neurology, neuropharmacology, and psychiatry.

This report highlights the following topics: (1) historical background of the development of magnetic recording technology, (2) topographic mapping of EEG and MEG potentials, (3) major advances in analysis techniques, (4) applications of topographic mapping, (5) magnetic stimulation of the central nervous system, and (6) future directions in biomagnetic and EEG research.

## BACKGROUND

The concept that human organisms emanate energy that cannot be directly measured but somehow is part of their persona has probably existed for many thousands of years. This theory reached one of its most structured forms in the late 1700s when the French physician Franz Mesmer proposed that the human body was polarized in a similar manner as a magnet and responded to an invisible fluid which permeated the whole universe. Mesmer believed that these poles could become misaligned and result in different disease processes. Treatment of these disorders involved exposure to iron rods or stroking by other individuals in order to realign the poles. The remnant of this theory is found in our language today as the term "mesmerized." However, with the development of physics, it became possible to demonstrate that whenever electrical current flows, a magnetic field is generated in the space surrounding the conductor. Since the transmission of information within the nervous system is due to ionic current flow, it follows that this process should lead to the development of "biomagnetic fields." Although it became possible in the early 1900s to use simple amplification systems to measure the electrical potentials generated by the depolarization of nerve cells and their axons, it was not until 1963 that the first reliable biomagnetic measurements were obtained (Ref 1). Baule and McFee used two side-by-side large coils to measure the magnetic field changes associated with the heart action in a human. In order to reduce the magnetic disturbances created by buildings and machinery, they made their measurements in a rural open field. In 1968, Cohen (Ref 2) developed a shielded room in order to decrease the magnetic background noise and was then able to detect and record magnetic fields from the brain.

Magnetic fields associated with neural activity of the brain are extremely small and are one million to one billion times weaker than the earth's geomagnetic field. The most sensitive instrument for detecting magnetic fields is a device called a superconducting quantum interference device or SQUID. This device was first developed by physicists in order to measure extremely weak magnetic fields. The superconductors must be cooled to extremely low temperatures in order to become nonresistive to electron flow; therefore, liquid helium (approximately -269 °C) has typically been used as a cooling source. Figure 1 shows a typical arrangement of a SQUID device for detecting weak magnetic fields. As pointed out by Williamson and Kaufman (Ref 3, p. 476):

> If the detection coil consists of two identical loops of wire wound in opposite directions but separated by a few centimeters (called a "first-order gradiometer"), it will not respond to a field that is spatially uniform, because the positive signal imposed on one loop is just canceled by a negative signal of identical magnitude imposed on the second loop. Since the field from a distant source is fairly uniform, this technique discriminates against such sources. Yet the detection coil retains sensitivity to a nearby source, such as a human subject.

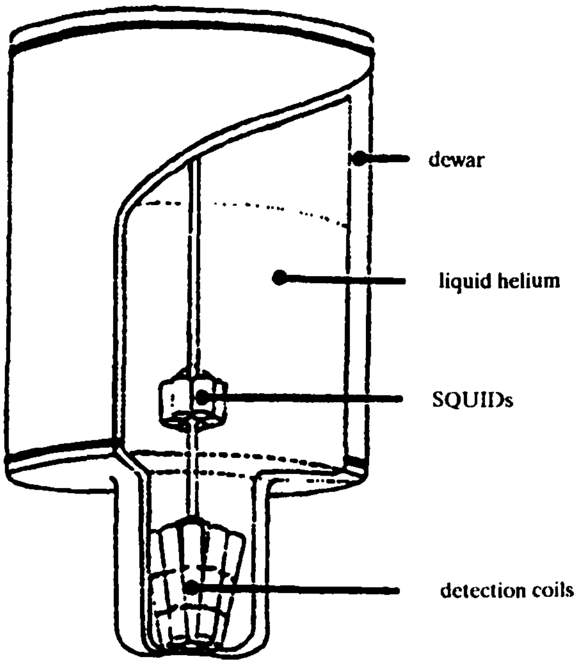


Figure 1. Cutaway view of a 7-channel system for detecting biomagnetic signals.

In recent years, gradiometers have been mounted back-to-back to provide second and third order gradiometers, which provide for increased rejection of unwanted signals. This improvement in technology has eliminated the need for very expensive shielded rooms and made the instruments more practical for both clinical and basic research settings. Figure 2 shows a subject seated under a 37-channel biomagnetic sensor system. Given the fact that it is possible to record magnetic potentials from the central nervous system, it is obvious that the critical question is how can these data be used to understand sensory processing of information in normal human subjects or subjects with brain pathology. Therefore, the major theme of this conference was the analysis and display techniques presently available for presenting multichannel data.

## TOPOGRAPHIC MAPPING

Topographic mapping employs a number of analysis techniques for converting electrical (EEG or evoked potentials) or magnetic field potentials into two-dimensional and/or three-dimensional displays. Typically, potentials from the brain are characterized by converting frequency and intensity information into power spectrums, which are then displayed in different colors on the color cathode ray tube. These two-dimensional maps provide a semiquantitative representation of the brain potentials and facilitate studies of the spatial distribution of the potentials (see Figure 3). In 1975, Ueno et al. (Ref 4) were among the first to develop this technology to the point that it was possible for an on-line computer system to provide automatic plots of topographic contour maps of the electroencephalogram (EEG). This system was subsequently made commercially available by the Nihon Kohden Kogyo Co. and later by the Nihon Denki Sanei Co. The availability of these systems led to a dramatic increase in the number of basic research and clinical studies conducted in Japan and abroad.

Figure 2. Subject seated under a 37-channel biomagnetic sensor system (photo courtesy of Biomagnetic Technologies).

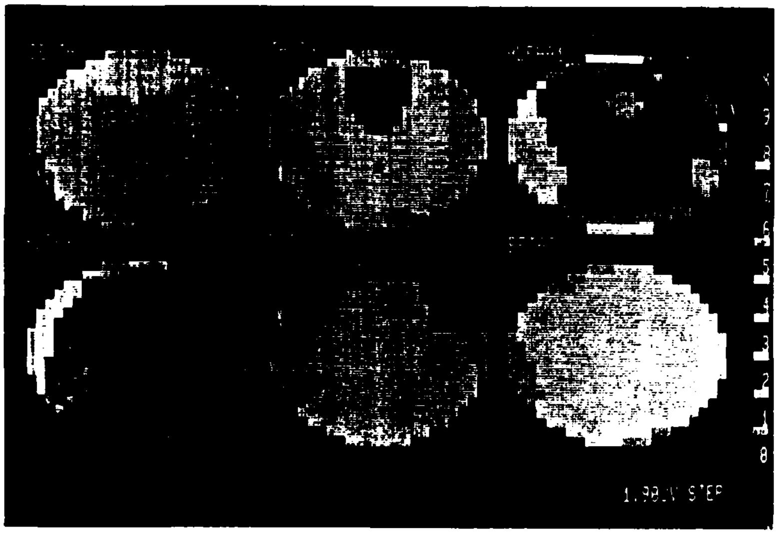

Figure 3. Typical EEG topographic map. These maps are generated in color and clearly show frequency distributions. However, the concentration of theta activity in the frontal region can also be seen in the black and white copy.

Although both EEG and MEG potentials are due to ionic current flow in neurons and their connections, the EEG is a record of voltage whereas the MEG is a record of current. In both cases, one is left with trying to solve what has been termed "the inverse problem," that is, trying to determine the source of these potentials based on signals reflected at the surface of the brain. In one of the special lectures, Dr. Samuel Williamson, of New York University (NYU) Medical School, made it clear that although early studies of the MEG had focused on temporal relations like EEG studies, multiple sensors now make it possible to use magnetic field maps "to yield quantitative information about the underlying source, without need for numerical analysis that takes account of the electrical properties of the intervening tissue." Furthermore, he stated that MEG localization procedures are revealing the sources of alpha activity in the brain and even complex tasks such as mental imagery can be monitored by measurements of the topographical distribution of the suppression of alpha rhythm.

It became clear early in the meeting that neuromagnetic topographic mapping and electroencephalographic topographic mapping are somewhat competing technologies. One of the main arguments presented by the neuromagnetic proponents was that MEG data have proven superior in the localization of the underlying neural sources in the brain. There were numerous oral and poster presentations directed at the problem of source localization; it became apparent that magnetic fields can be modeled using electromagnetic theorems and computer simulations can be used to study current dipoles. In a session on modeling and source localization of MEG activities, Dr. Shoogo Ueno showed the results of computer models of neural sources as single or multiple dipoles located in an inhomogeneous spherical conductor. His computer simulation results suggested four major points: (1) flux reversal phenomena can be observed in MEG topographic patterns in special cases where conductivities of the inhomogeneous regions change with pathological situations; (2) radically oriented dipoles produce magnetic fields outside the inhomogeneous sphere; (3) magnetic fields on the sphere generated by single dipoles are sensitive to the inhomogeneities; and (4) a pair of opposing dipole or circular current sources produces only very weak electric fields but generates high magnetic fields, which are less affected by inhomogeneities in the head. Essentially, these data imply that changes in tissue conductivity such as could be caused by brain lesions or tumors can be detected by the MEG recordings and, in certain cases, the electrical signals could be inversely related to the magnetic field potentials.

There was also a series of oral presentations and posters related to mathematical models and computer simulations of EEG data. One of the presentations by Drs. Michel, Henggeler, and Lehmann of the University Hospital, Zurich, Switzerland, pointed out that EEG recordings are typically assessed in the frequency domain via FFT-transformation, but the resulting power maps are not directly suitable for dipole source localizations, since the phase information is lost. These investigators proposed that the amplitude and phase angle for each frequency point can be displayed in a sine-cosine diagram; this information can then be used to determine the dipole source localization.

## MAJOR ADVANCES IN ANALYSIS TECHNIQUES

There are basically two major signals that represent neural transmission within the nervous system that can be recorded as surface potentials: (1) the continuous background activity, which typically involves potentials in the microvolt range and covers a bandwidth from dc up to 90 Hz; and (2) evoked potentials, which are discrete responses to external sensory or motor stimuli. Early studies of the EEG involved a limited number of channels of information and analysis of the data into different frequency bands. However, within the last 10 years, the increase in computer technology has made multichannel recordings of 20 to 32 channels fairly common in EEG research. Commercially available systems contain software which provides for on-line analysis of the power spectrums and computes absolute power, relative power, coherence, amplitude, and phase. In addition, color graphic outputs allow the investigator to generate topographic maps of these data.

There were a number of papers that stressed the application of statistical procedures for understanding the underlying structure of the EEG. Dr. Harner, Medical College of Pennsylvania, presented a technique using a multivariate linear analysis technique called "single value decomposition." Essentially, this technique breaks the data down into a spatial matrix composed of a temporal vector, a spatial vector, and an amplitude vector. This approach is similar to that used in vector cardiography. Dr. Harner concluded that 90% of the variance was contained within these three wave forms. One of the most intriguing invited lectures titled "Beyond Topographic Mapping: Toward Functional-Analysis Imaging with 124 Channel EEG's and 3-D MRI's" was presented by Dr. Givens, director of the EEG Systems Laboratory, San Francisco, California. It is Dr. Givens' thesis that functional information from EEGs can be integrated with neuroanatomical information from magnetic resonance images (MRI), yielding information, with high temporal resolution, about the localization of function in the brain. Using 124 scalp electrodes, his laboratory has demonstrated equivalent dipole localization in the visual, auditory, and somatosensory modalities. The localization had an accuracy at least equal to that obtained with MEG. Furthermore, the EEG data collection and analysis equipment cost about 25 times less ($100K) than a 37-channel MEG system. Figure 4 shows equivalent dipoles (small dark cylinders) for electrical stimulation of left and right middle fingers and the index finger. The dipoles have been registered with a model of the subject's brain shown in outline inside the head. The outer 11 millimeters of the model have been stripped away to visualize the three-dimensional position of the dipoles. The face and head surfaces were also reconstructed from the subject's MRI brain scan. It is evident that the dipoles are correctly positioned. Although single dipoles are convenient for characterizing simple sensory stimuli, they are not suitable for describing higher cognitive functions since it is well-established that even simple cognitive processes are widely distributed in the brain. EEG Systems Laboratory has developed a method called event-related covariance analysis (ERC) to characterize the parallel, distributed activity of cognition. The method is based upon an empirically tested mathematical model of brain neural action developed by Professor Walter Freeman at U.C. Berkeley which concludes that the macro-potentials of functionally related cortical regions will be highly coherent. The theory and method have been validated in many published experiments in animals and humans. The lines on the head shown in Figure 5 represent all of the ERCs, which are computed in each fraction-of-a-second analysis. Using this technique, Dr. Givens has shown that distributed neuronal networks are affected by sustained mental work several hours before performance deteriorates significantly. In a study with pilots performing a difficult task, of long duration, striking changes occurred in the ERC patterns after the pilots performed the task for 7 to 9 hours (middle) but before performance deteriorated (see Figure 6). Using neural-network pattern recognition technology, it was possible to distinguish the state of incipient performance impairment with an accuracy of over 80%. Dr. Givens believes that further development of the technology could lead to an early warning system to detect leading indicators of impaired performance in aircraft pilots or operators of other complex equipment.

## APPLICATIONS OF TOPOGRAPHIC MAPPING

As discussed by Dr. Lehmann, Department of Neurology, University Hospital, Zurich, Switzerland, "mapping has proven to be a superior way to comprehensively display three-dimensional data, e.g., multichannel EEG and MEG data, as momentary maps, FFT band power maps, momentary event-related evoked potential maps, and results of statistical electrode-by-electrode map comparisons."

In the case of normal human subjects, EEG and MEG data are being assessed as methods for examining individual differences in brain function, which correlate with one's ability to process information and solve problems. Furthermore, the effects of stress, drugs, environmental factors, etc. can be evaluated using topographic techniques. A number of papers dealing with topographic analysis and evoked potential techniques discussed significant changes correlated with learning and cognitive function. An interesting finding by Dr. Yamamoto of Dokkyo University, Japan, and his colleagues was that EEG studies could be used to determine the duration of work and rest periods. In their studies, operators of visual display terminals were subjected to psychological stress; they found that when the subjects complained of fatigue there was an increase in long-lasting theta waves in the EEG. Following a rest period the EEG returned to normal.

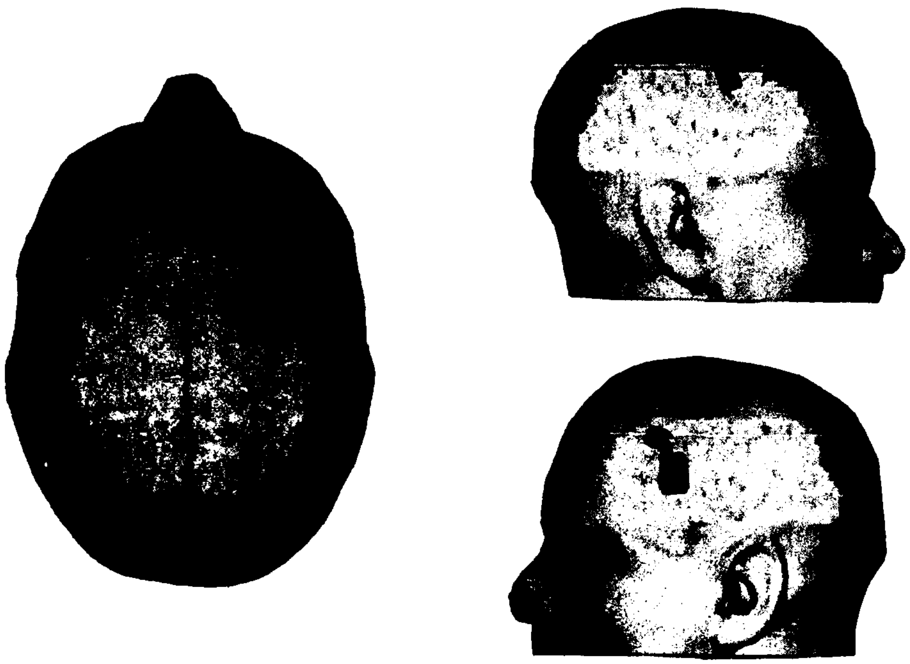

Figure 4. Equivalent dipoles (small dark cylinders) in response to electrical stimulation of the left and right middle fingers and the index finger. The face and head surfaces were reconstructed from the subject's MRI scan.

## ɪAGNETIC STIMULATION )F THE CENTRAL ɪERVOUS SYSTEM

Transcranial pulsed magnetic stimulation of the brain was first described y Barker et al. in 1985 (Ref 5). Single ɔils were used for these studies and, ; a result, broad areas of the brain ere stimulated simultaneously. At ɔout the same time, Ueno et al. (Ref 6) eveloped a system composed of a pair f coils that could concentrate the ɪduced eddy currents in a small area. ssentially, a pair of coils is positioned utside the head such that the timeɪrying magnetic fields pass through ɪe head in opposite directions around the target to be stimulated (see Figure 7). A pair of coils with windings of five turns of 5-mm-wide by 2-mm-thick copper wire is excited by discharge currents (4,000 to 7,500 A) that pass through a capacitor bank (600 to 900 V). The discharged currents produce time-varying magnetic fields which give rise to eddy currents of 50 $A/m^2$ with a duration of 0.1 ms. These currents are concentrated at a point 10 mm below the cross point of the paired coil; in the case of brain stimulation the resolution is within 5 mm. There were a number of papers presented at the meeting (using this technique) that reported the effects of magnetic stimulation in both animals and humans. Computer simulations and models of neural excitation have been developed which suggest that it will be possible to functionally and anatomically map the motor systems of the brain. Following the meeting, the senior author of this article (J.W. Wolfe) visited Dr. Ueno's laboratory at Kyushu University and experienced the magnetic stimulation of peripheral nerves in the arm and hand (I declined the offer of brain stimulation). This was a dramatic experience since, unlike direct electrode stimulation with needles placed in the nerves (which is the conventional method presently used in neurological evaluations), the stimulation was completely painless and without any sensation. In addition, the stimulus was very specific and could activate single muscles. There is little doubt that this technology will have a major influence in both the basic neurosciences and applications in clinical medicine.

## FUTURE DIRECTIONS IN BIOMAGNETIC AND EEG RESEARCH

One of the major impediments to biomagnetic research has been the extremely high costs of establishing a new facility. Modern systems, consisting of 31- to 60-channel SQUIDs and the associated analysis equipment, cost between $2.5M and $3M; a comparable number of channels of recording equipment for EEG costs between $100K and $250K. MEG recording is a fairly new technology; it is estimated that there are approximately 50 laboratories throughout the world studying biomagnetism, whereas EEG techniques have been used since the mid-1930s and there are literally thousands of EEG laboratories in the world.

In the United States, the Office of Naval Research (ONR) was one of the first agencies to provide basic research funds for the development of neuromagnetic recording technology. ONR has supported research at NYU Medical School, EEG Systems Laboratory, and the Navy Personnel Research and Development Center in San Diego, California, to name a few. The Air Force Office of Scientific Research has also supported the development of Laboratories at Wright-Patterson AFB, Los Alamos National Laboratories, NYU, and EEG Systems in San Diego.

EEG topography has proven extremely useful in clinical studies of epilepsy, stroke, and brain tumors. However, this technique has been hampered by its sensitivity to artifacts (due to volume conduction) and the difficulty of implementing more sophisticated analysis techniques. Neuromagnetic signals do appear more reliable in localizing the source of the potentials within the nervous system. In addition, biomagnetic techniques can be used to study other systems within the body such as cardiovascular, lung, liver, etc. (see Ref 1). There is no doubt that biomagnetic techniques will play a key role in the future in understanding brain function.

One factor that appears to hinder American scientists is the lack of a close working relationship between universities and private industry. It is interesting that in the case of EEG topography and biomagnetic technology, the Japanese scientists have been very successful at transitioning their technology to the commercial sector.

Figure 5. Lines on the head represent event-related covariances, which are computed in each fraction of a second from 124 scalp electrodes.

## ACKNOWLEDGMENT

The authors thank Dr. A.S. Givens, EEG Systems Laboratory, San Francisco, California; Dr. K.C. Squires, Biomagnetic Technologies, San Diego, California; and Dr. S. Ueno, Kyushu University, Fukuoka, Japan, for providing illustrations and information for this article.

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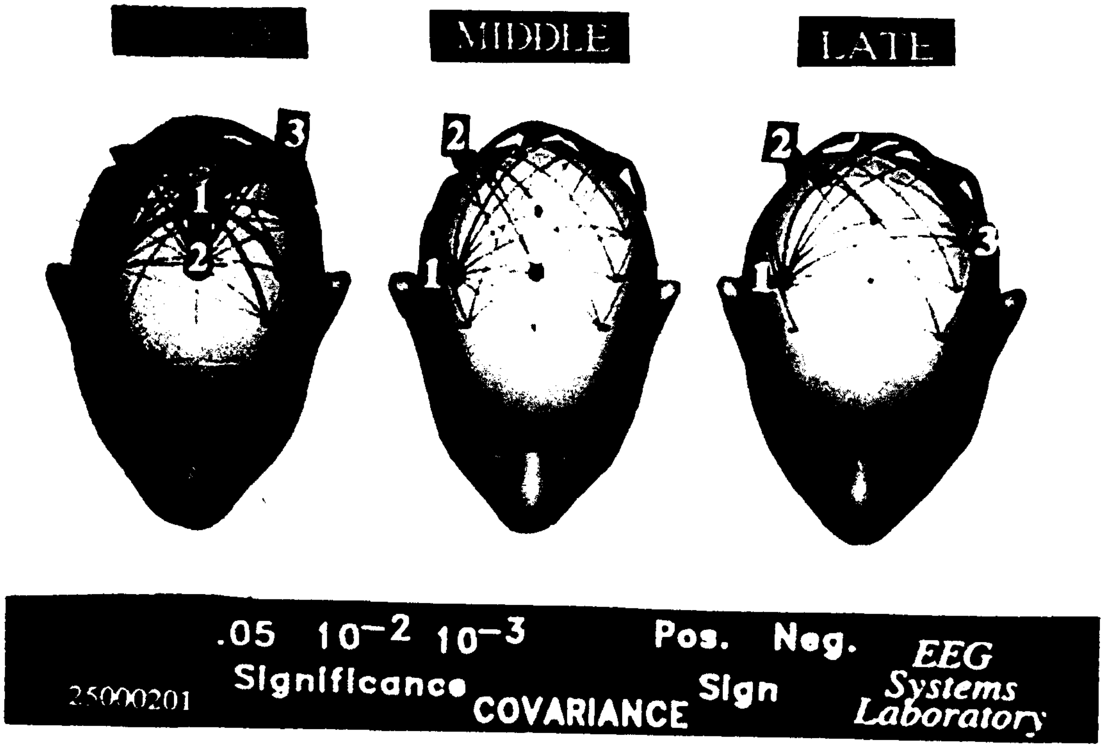


'igure 6. Event-related covariance patterns from five subjects during a memory task. In the early period, pattern strength is concentrated in the midline precentral areas and the left hemisphere; during the middle period (7-9 hours) pattern strength has decreased dramatically in these regions. During the late period (performance failure), there is even further reduction in activity.

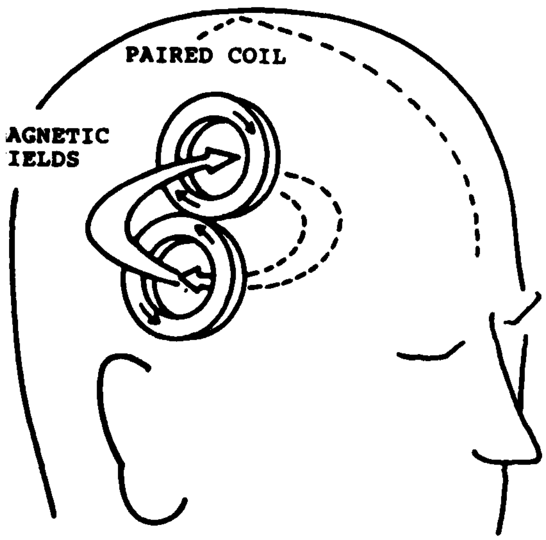


Figure 7. Principle of localized stimulation of the brain. A figure-eight coil is positioned outside the head so that magnetic fields pass through the head around a target, which is located beneath the cross point of the figure-eight coil.

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James W. Wolfe received his B.A. from the University of California and his Ph.D. in neurophysiology from the University of Rochester, Rochester, New York. He has 30 years experience in Government research laboratories and retired from Federal Service in 1988. At the time of retirement, he was the Chief Scientist at the USAF School of Aerospace Medicine in San Antonio, Texas. From 1985-86 he served at ONR-AFOSR Far East as a Life Sciences Scientific Liaison in the Far East for AFOSR. He is presently a Professor of Life Sciences at the University of Texas at San Antonio and also serves on a half-time appointment as a Visiting Professor in the Life Sciences Division, NASA Headquarters, Washington, D.C. Dr. Wolfe has received numerous awards over the years including the Department of Defense Award for Meritorious Service. He a member of the International Brain Research Organization and the Barany Society and is a Fellow of the Aerospace Medical Association. He is the author/coauthor of over 80 publications in biomedical research.

Shigeaki Matsuoka received his M.S. and M.D. degrees from Kumamoto University. He received postgraduate training at Montreal Neurology Institute, Canada, New York Medical College, and the University of Michigan. In March of 1990, he retired as the Chief of Neurosurgery, School of Medicine, University of Occupational and Environmental Health, Kitakyushu, Japan. He is one of the pioneers in EEG topography and is the author/coauthor of over 50 publications in English journals. He is presently serving as a consultant in neurosurgery to a number of hospitals in Kyushu and is still active in research.

# Appendix

## LIST OF TOPICS OF MAJOR SPECIAL LECTURES

| | |
|---|---|
| Theta Rhythm: State of Consciousness | S. Matsuoka<br>Kitakyushu, Japan |
| Evolution of Neuromagnetic Topographic Mapping | S.J. Williamson<br>New York, NY |
| Past, Present and Future of Topographic Mapping | D. Lehmann<br>Zurich, Switzerland |
| Quantified Neurophysiology with Mapping: Statistical Inference, Exploratory and Confirmatory Data Analysis | F.H. Duffy<br>Boston, MA |
| On the Controversies About Clinical Use of EEG Mapping | M.R. Nuwer<br>Los Angeles, CA |
| Beyond Topographic Mapping: Toward Functional-Anatomical Imaging with 124-Channel EEG and 3-D MRI's | A. Givens<br>San Francisco, CA |
| Neurosurgical Application of Topographic EEG Mapping | K. Matsumoto<br>Tokushima, Japan |
| Topographic Analysis in Brain Mapping Can Be Compromised by the Average Reference | J.E. Desmedt<br>Brussels, Belgium |

# A CHANGING PARADIGM FOR INDUSTRY-UNIVERSITY COOPERATION IN JAPAN

*Toyohashi University of Technology and its sister university in Nagaoka were created to provide new paths for advancement for students from technical high schools and colleges of technology. In addition, these universities encourage research of direct interest to industry. This has created a new paradigm for industry-university cooperation in Japan.*

by T. W. Eagar

## INTRODUCTION

In 1984, near the beginning of a 1-year position in the Office of Naval Research (ONR) Tokyo office, I asked a senior manager of a major Japanese firm what he considered Japan's greatest challenge for the future. He replied, "Reform of our educational system." It took nearly a year living in Japan to begin to appreciate the wisdom of his comment. Although Japan has an enviable record, both in terms of numbers of students completing high school and in the average test scores of these students, the educational system is rigid and inflexible. Students are placed on educational tracks early in their studies and movement between these tracks is very difficult, especially for students who do not begin to excel until the latter years of their education. In order to make the most effective use of their human resources, Japan requires new paths of entry into higher education for students who blossom relatively late in their studies.

Another, seemingly disparate, concern has been the lack of industrial relevance to much of the research carried out at Japanese universities. Although senior professors provide a binding influence among researchers from competing companies that assists in transfer of information between companies [see T.W. Eagar, "Technology transfer and cooperative research in Japan," *Scientific Bulletin* 10(3), 32-41 (1985)], most of the university-based research has remained separate from direct industrial needs. Indeed, many of the faculty feel that research which is directly supportive of industrial needs should not be performed at a university.

In recent years, the Ministry of Education, Science and Culture (Monbusho) has attempted to change the educational system. In at least one case, both of the problems noted above are being addressed through the same initiative, at least for students of engineering.

In 1978, Monbusho established Toyohashi University of Technology, near Nagoya. A sister university in Nagaoka was also formed at about this same time [see article by A.L. Dragoo, "The Technological University of Nagaoka," *Scientific Bulletin* 12(4), 45-47 (1987)]. These two universities form a new type of higher educational institution, emphasizing graduate education for students who have attended technical high schools and colleges of technology. Formerly, the 10,000 students who graduate each year from such schools were limited to no more than a junior college equivalency in the United States. There was no way in which students who began on these tracks, as early as the start of their high school years, could enter a 4-year college and continue for graduate studies. These two new universities provide a path for undergraduate and graduate studies through the doctorate for some of the top 10% of the students who are studying in the technical high schools and colleges of technology. In addition, Monbusho has created new faculties and facilities to encourage university research of direct interest to industry. One result is that approximately one-third of the research funded at these two new universities is directly supported by industry. This is a considerably larger fraction of industrial support than for any major research university in the United States and is double the current level of industrial support at other Japanese universities today and more than a ten-fold increase over the level of support from industry to Japanese universities a decade ago.

## THE EDUCATIONAL PROGRAM AT TOYOHASHI UNIVERSITY OF TECHNOLOGY

The educational approach at Toyohashi University of Technology (TUT) varies in several important ways from other Japanese engineering universities (except the sister university at

Nagaoka). Firstly, all undergraduates must work at least 2 months in industry. The demand for such students by industry is five times the supply. Secondly, emphasis is placed on graduate education. Thirdly, all work should have some industrial relevance. It is expected that a number of the doctoral graduates will enter industry whereas most doctoral students at other engineering schools in Japan go into teaching.

One of the goals of these new engineering schools is to develop engineers with broad backgrounds, which go beyond technological knowledge and skill. Aside from requiring significant amounts of study in the humanities, "economics and business management are indispensable for students studying in anticipation of their future role in management." Apparently, the Japanese recognized the need to educate technologically sophisticated managers more than a decade ago, whereas the United States is just now beginning to join the programs of engineering schools and management schools in order to create a broader, more well rounded engineering graduate.

Up to 200 students may enter these two universities (Toyohashi and Nagaoka) each year directly from technical high schools for a 4-year undergraduate program. Approximately 550 more may enter each year from the 2-year colleges of technology to complete their undergraduate program in an additional 2 years.

These universities differ from other universities in Japan in that "all students are able to enroll in the graduate school if they so desire. Some students do go straight into industry after they have obtained a bachelor's degree but they are an exception." With a graduation rate of 600 master's degrees and 36 doctorates in engineering each year, these two universities will supply nearly 10% of Japan's engineering work force with graduate degrees in the future. The effect of these new advanced level engineering graduates has not yet been felt as Toyohashi only graduated its first master's students in 1982 and the first doctoral students in 1989.

In addition to these graduates, these universities are discussing expansion of their numbers of graduates through continuing education graduate degrees for engineers who have worked in industry for a number of years. The exact format of the new graduate programs to retrain practicing engineers has not been decided, but it is clear that industry will bear the costs of this expansion.

In addition to a Humanities Department, which acts as a service department for the university, there are seven engineering departments:

*Undergraduate and Master's Departments*

1. Energy Engineering -- Mostly mechanical engineering
2. Production Systems -- Manufacturing systems and materials science
3. Electrical and Electronic
4. Information and Computer Science
5. Materials Science -- Mostly polymer science
6. Regional Planning -- Plus civil engineering
7. Knowledge-Based Information Engineering -- Artificial intelligence, computer-aided design/manufacturing

*Doctoral Programs*

1. Comprehensive Energy Engineering
2. Materials Systems Engineering
3. Systems and Information Engineering

With 1,544 students and 141 faculty (plus 66 research associates), TUT has a very favorable student/faculty ratio, equivalent to or better than most research-based universities in the United States. The buildings contain 78,000 $m^2$ of floor space and the library has 81,000 volumes. Research equipment is generally superior to that found at the best Japanese Imperial universities and rivals that found at some of the best U.S. research universities, although it is not equal to the better industrial research facilities in Japan. One professor estimates that his research budget has expanded by 5 to 10 times compared to what he had at a top Imperial university.

## THE INDUSTRIAL RESEARCH PROGRAM AT TOYOHASHI UNIVERSITY OF TECHNOLOGY

As noted previously, 30% of all research funding comes from industry, but the approach to the remaining research also has a strong industrial content. Although some of the work represents development of fundamental data, in every case the faculty and students can identify an industrial or commercial need for the research. There was no explanation of "science for its own sake," which is the nearly universal explanation at other Japanese universities. The faculty and students at TUT have a very different goal for their work as compared with other Japanese universities.

In 1980, a special building was constructed for the Technology Development Center. This center, and several others at TUT, acts as "an intermediary for the development of new technologies" to promote interdisciplinary research between industry, research institutes, and the university. Industrial equipment and personnel are housed in this center in order to work directly with faculty and students in development of new industrial processes. In addition, a panel of consultants has been formed to assist regional industries in application of new technologies. The encouragement of such close ties to industry, backed by facilities and technical support, provides a striking contrast to other Japanese universities, which only provide such assistance clandestinely.

## CONCLUSION

Toyohashi University of Technology and its sister university in Nagaoka provide new paths for advancement from technical high schools and colleges of technology. In addition, the strong industrial ties create a new paradigm for industry-university cooperation in Japan. This new paradigm is not significantly different from what has existed for many years in the United States, but it is a marked change for Japanese universities. Other Japanese universities are beginning to follow the lead of Toyohashi and Nagaoka, but their movement occurs out of necessity rather than a desire to move closer to industrial needs. The much greater financial support provided by both industry and by government is a strong incentive to cause all Japanese engineering universities to move toward more relevant research. It is a needed change, provided it does not go too far. It will be interesting to see how the Japanese manage the extent of this change over the next few years.

# THE REPUBLIC OF KOREA NAVY OCEAN AND UNDERWATER MEDICAL RESEARCH AND TRAINING CENTER

*Started in 1979, the Republic of Korea Navy Ocean and Underwater Medical Research and Training Center is the leading military institution in the country conducting submarine, diving, and hyperbaric medical research. The center has the only saturation diving chamber complex in South Korea and is currently preparing for the commencement of manned saturation diving experiments in 1992. With the planned future acquisition of diesel submarines by the Navy, emphasis on research in deep sea saturation diving as part of an overall submarine rescue and recovery capability will become stronger.*

by Neal A. Naito

## INTRODUCTION

The Republic of Korea Navy (ROKN) Ocean and Underwater Medical Research and Training Center (OUMRTC) is the sole military institution dedicated to submarine, diving, and hyperbaric medical research in the country. It contains the only saturation diving chamber complex in South Korea. OUMRTC is located in the seaside city of Chinhae approximately 1 hour southwest from Pusan by car.

Founded in 1979, it is part of the largest naval base in South Korea and includes the headquarters and training units for all the Navy diving commands, special warfare, explosive ordnance disposal, and salvage. Prior to the opening of OUMRTC, no other naval facility was conducting research in the area of underwater medicine and physiology. The main focus was on the medical treatment of civilian and military diving casualties. With the planned purchase of diesel submarines in the very near future by the South Korean Government, emphasis on research in deep sea saturation diving will come more to the forefront as part of an overall submarine rescue and recovery capability.

## PERSONNEL

The current commanding officer of OUMRTC is Commander In Gi Chun, a dermatologist who graduated from Chung Ang University Medical School in Seoul. The director of research is Lieutenant Commander Won Gyoon Park, who has an M.D. and a Ph.D. in physiology from Kyung Pook National University Medical School. Both physicians were attending a conference in Seoul at the time of the author's visit. Officers the author met during his tour of OUMRTC include Lieutenant Joon Ha Hwang, M.D. and M.S. in neurophysiology from Kyung Pook National University Medical School; Lieutenant Chung Won Lee, M.D. and M.S. in epidemiology from Kei Myung University Medical School; Lieutenant Chung Wan Hwang, M.D. from Kyung Pook National University Medical School; and Lieutenant Chang Yub Kim, director of training.

Approximately 20 officers and 70 enlisted personnel are assigned to OUMRTC. Almost all of the diving medical officers (DMO) who graduate from instruction are assigned to OUMRTC. Only the research director has done more than one tour as a DMO, while the commanding officer has had no formal training in undersea medicine. This situation is not surprising since very few DMOs and military physicians in general stay in the service beyond their 3-year obligation. This loss of experienced personnel is an impediment to the continued development of the research capability of OUMRTC. No OUMRTC diving medical officers have trained outside of the country despite the lack of experience among personnel in the field of saturation diving. Given the planned commencement of saturation diving missions at OUMRTC in 1992, South

Korea will probably initiate the exchange of personnel and information with other countries that possess an established saturation diving program. The United States would be a good first choice since it maintains close governmental ties with South Korea, and its military undersea medical research centers are well respected in the diving medical community.

## FACILITIES AT OUMRTC

The centerpiece of OUMRTC is the three-compartment saturation dive chamber complex manufactured by Ocean Systems Japan Ltd. (Figure 1). The complex consists of a main chamber that houses the living quarters for mission personnel, a subchamber that contains shower and toilet facilities, and a wet diving pot (see cover). It is capable of using gas mixtures including helium-oxygen, air, oxygen, and nitrogen-oxygen. Housed in an adjacent glass front room is the control center, which contains an automatic decompression system manufactured by Daido Company, Tokyo, Japan (Figure 2). Chamber carbon dioxide level, oxygen level, humidity, and temperature are monitored. Maximum depth of the system is classified and was not provided to the author.

Other chambers available at the facility include an old U.S. Navy shipboard chamber that is used for treatments and an experimental chamber capable of holding animals up to the size of a rabbit. The animal chamber is rated to a depth of 360 meters and can accommodate helium mixtures. OUMRTC also has a portable two-man Drager recompression chamber with the capability of a U.S. Navy Treatment Table 6A to be used for treatments at remote sites (Figure 3). It does not have the full system to lock out divers from the portable chamber into a fixed chamber.

In addition to the chambers, OUMRTC also has a four-story, 80,000-gallon freshwater free ascent tower for diving and submarine rescue training that is used approximately 15 times a year (Figure 4). The closest emergency recompression chambers are located in the main building, a 3-minute walk away. A submarine lockin/lockout simulator, built in at the bottom of the tower, can be used in conjunction with a submarine rescue capsule (SRC) stored at the top. The SRC, which is a research version that can hold only two people, is similar in design to the U.S. Navy McCann bell. U.S. Navy Mark XII and Mark I surface supplied equipment is being used to conduct training dives in the tower.

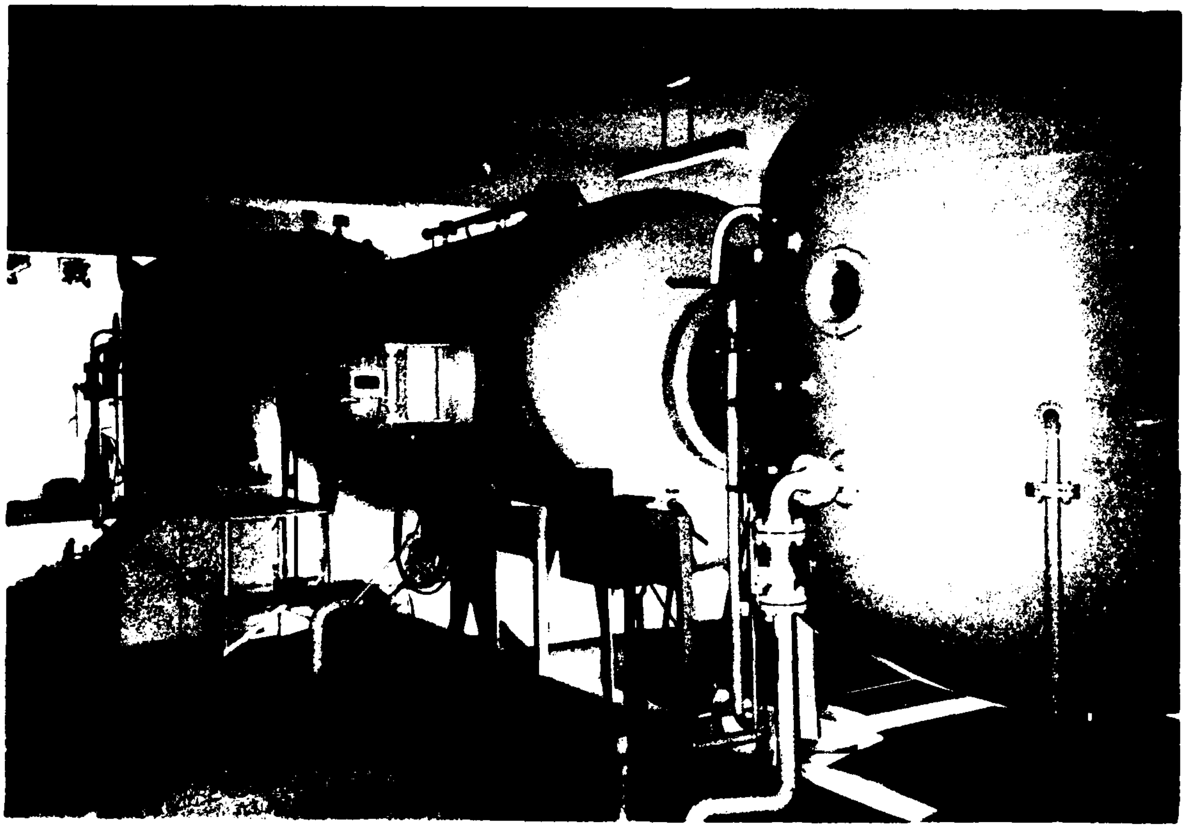

Figure 1. Three-compartment saturation dive chamber complex.

Figure 2. Automatic decompression system.

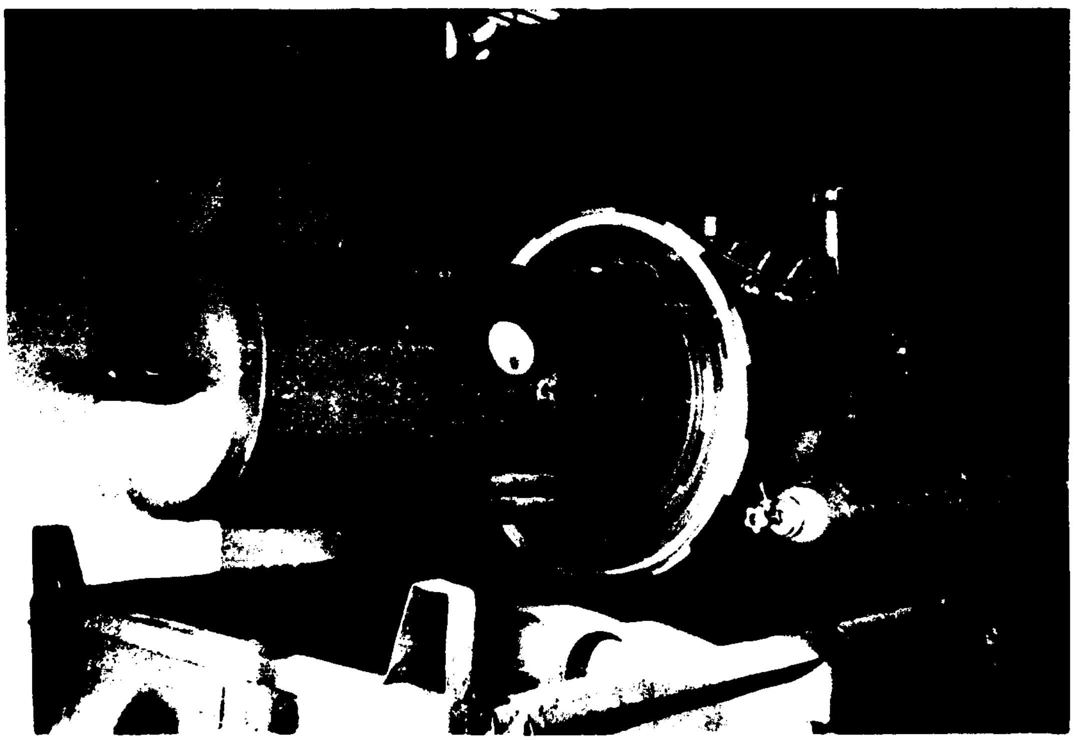

Figure 3. Portable two-man Drager recompression chamber.

Basic research equipment at OUMRTC is contained in three large laboratories. The equipment, a mix of American and Japanese made hardware, consists of a gas chromatograph, liquid chromatograph, flame photometer, spectrophotometer, and superspeed refrigerated centrifuge. There is also a basic chemistry bench setup. Medical equipment includes an old bicycle e.ectrocardiograph (EKG) stress tester, a recording spirometer, and an audiogram booth.

The library is limited to one conference room size space. Its small collection, supplemented by interlibrary loans with local civilian universities, contains mainly the authoritative reference texts in underwater physiology and in the medical specialties related to diving medicine. Journals subscribed to include the *Journal of Hyperbaric Medicine*, *Undersea Biomedical Research*, and the *Journal of Applied Physiology*. There is no librarian to assist in literature searches.

## FUNCTIONS OF OUMRTC

OUMRTC has several missions including the medical screening of diving school candidates, training of diving medical officers and diving medical technicians, administration of recompression therapy to injured divers, and medical research. The diving medical officer course is 8 weeks. It is similar to the U.S. Navy program and consists of a 2-week pretraining phase and a 6-week didactic and diving phase. The pretraining involves preparing the student physically for the rigors of diving. During the 6-week section, the student learns about all aspects of diving medicine and receives familiarization training in free ascents, scuba, and Mark XII and Mark I surface supplied systems.

A 24-hour bends watch is maintained at OUMRTC to treat both civilian and military cases of decompression sickness (DCS) and arterial gas embolus. Currently, they treat approximately 25 cases a year, with a ratio of 1 military per 10 civilian divers as patients. Interestingly, OUMRTC sees only a small number of the estimated total number of DCS cases that occur in South Korea since many injured civilian divers delay receiving help until they have traveled to medical centers in Seoul.

Figure 4. Free ascent tower.

Cho and colleagues in their article reported that over 486 cases of DCS were treated at a hyperbaric therapy center in Seoul during a 2-year period (Ref 1). They noted that the average delay in treatment was 18 hours. Suh et al. reviewed recompression treatment cases done at OUMRTC over a 2-year period and noted that a great percentage of them consisted of shellfish divers (Ref 2). Other findings were that the dive profiles often involved repetitive diving to a depth greater than 66 feet and inadequate surface intervals. In almost all circumstances, symptoms of DCS emerged within the first hour after surfacing, and a majority of the injured initially tried in-water recompression therapy. Overall these statistics reveal the need for increased public education on the prevention and proper treatment of DCS. It is an issue OUMRTC can play a major role in solving as military undersea research institutions elsewhere have done.

The annual research budget at OUMRTC is $100,000. Ongoing investigations are as follows:

1. Body fat distribution and hypertension in divers

2. Psychological and cardiovascular reactivity under stress

3. Activity changes of blood enzymes upon exposure to hyperbaric oxygen

4. Evaluation of decompression tables by agarose gel method; its application to living systems

5. Changes of blood atrial natriuretic factor in hyperbaric environments using the rat model

6. Morphology studies on wound healing with hyperbaric oxygen

For a partial list of past projects, as reported in OUMRTC's *Korean Journal of Underwater Medicine*, sec References 3-18. The journal is printed in Korean with English abstracts. Due to the absence of the research director, the author was unable to discuss in depth any of the present research activities at OUMRTC. However, a review of the journal abstracts reveals that the center can conduct sophisticated human and animal physiology studies.

A good combination of applied and basic science research is being performed at OUMRTC covering the breadth of undersea medicine including hyperbaric oxygen therapy, air diving, and saturation diving. With the expected acquisition of submarines by the ROKN, OUMRTC will probably also start reporting on problems associated with that unique environment such as atmosphere control, psychological adaptation of crewmembers, increases in compartment ambient pressures during emergency situations, etc. Although most of the studies expound on previous efforts by other investigators, they also form the foundation for quality pioneering research work in the future.

## SUMMARY

OUMRTC is symbolic of South Korea's industrial progress. As in many other countries including the United States, its creation within the military infrastructure provides it with a role and the necessary resources. Like Japan, saturation diving in the civilian sector has limited applications in South Korea due to the absence of any appreciable offshore oil industry. Relatively unknown in the international undersea medical community, OUMRTC will have to promote strengthened ties with sister institutions in other countries to increase its research and operational expertise, especially in saturation diving. Contact with OUMRTC can be made through the following address:

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Hyun-dong, Chinhae
Korea 645-798

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# SEMINAR ON AUTONOMOUS UNDERWATER VEHICLES

*Autonomous underwater vehicles (AUVs) are a new and rapidly developing tool for undersea science. This unique seminar brought together representatives from five countries who are currently developing AUVs. While AUV technology offers fascinating new capabilities, these capabilities will probably not be widely used by the industrial and scientific communities until development is complete in 5 to 15 years. The major technological problems for AUVs were identified: (1) a long-term power source and (2) the ability to repeatedly change buoyancy between servicing.*

by Gregory Stone

## INTRODUCTION

A unique conference was held in Tokyo on autonomous underwater vehicles (AUV) from 27-28 November 1990. The conference was organized by Mr. Ryoichi Sasakawa (Japan Foundation for Shipbuilding Advancement), Prof. Hisaaki Maeda (Institute of Industrial Science, University of Tokyo), and Yoshiro Matsumoto (Association for Structural Improvement of the Japanese Shipbuilding Industry). The conference had invited speakers from five countries and was attended by about 150 people. This conference was an excellent forum in which the current state-of-the-art in AUVs was reported, examined, and discussed.

## SPONSORS AND PARTICIPANTS

This conference was financially supported by the Association for the Structural Improvement for the Japanese Shipbuilding Industry. This association was founded (1978) when the Japanese shipbuilding industry reduced capacity by some 50%. One of the association's missions is to redirect and advise the shipbuilding industry on new markets and technologies. Representatives from the major civilian engineering laboratories in the world who are building or planning to build AUVs were invited at the expense of the conference. Over 90% of the participants appeared to be engineers and, except for the invited foreign guests listed below, most in attendance were Japanese. Invited guests and speakers included:

**United States**

- Dr. A.J. Healey, Naval Post Graduate School
- Dr. Bruce Robison & Mr. M.J. Lee, Monterey Bay Aquarium Research Institute
- Dr. D.R. Yoerger, Woods Hole Oceanographic Institute

**United Kingdom**

- Dr. J.H.A. Baker, J.P. Kenny Caledonia Ltd.
- Dr. P.G. Collar, Institute of Oceanographic Sciences

**Norway**

- Mr. O.J. Rodseth, SINTEF

**Canada**

- Mr. J. Ferguson, I.S.E. Research Ltd.

**France**

- Mr. J.L. Michel, IFREMER

**Japan**

- Mr. T. Fujii, University of Tokyo
- Mr. Y. Hashizume, West Japan Fluid Engineering Laboratory
- Mr. M. Hattori & Mr. H. Okada, Japan Marine Science and Technology Center
- Mr. S. Ishiguro, Mitsubishi Heavy Industries
- Mr. Y. Okuwa, Mitsui Engineering and Shipbuilding
- Dr. T. Ura, University of Tokyo

- Mr. T. Osanai, Advanced Robot Technology Research Association

## BACKGROUND

AUVs are underwater unmanned vehicles that operate without (or with limited) supervision from the surface. They carry their own power source, internal navigation, and intelligence. They are a daughter of the remotely operated vehicle (ROV), which is a tethered system that obtains power and supervision from a surface ship and the surface ship obtains real-time video and data from the ROV. Because radio transmissions are attenuated in water, present technology requires an untethered vehicle to be autonomous and data are usually stored and then retrieved or transmitted when the vehicle surfaces. While it is possible to use acoustic telemetry (encode information in sonic transmissions), the level of that technology is not yet high enough to allow adequate real-time two-way communication between an underwater system and the surface. For example, there is now research in Japan, France, and the United States on the transmission of video images by sonic telemetry through the water at the rate of about 1 frame per 6 seconds. That technology may bring untethered AUVs into the realm of near-real-time remotely operated vehicles within 5 to 10 years when it is expected that the rate of frames/second will increase to 1 frame/second.

At present, however, AUVs are like satellites of the sea without the benefit of radio communication except when they surface. While ROVs have, during the last 10 years, become common for scientific and commercial applications, AUVs are still very much in the developmental stage. If development continues at the current rate, there will be economical and reliable work systems in the ocean within 5 years, and their use will become widespread in about 10 years after the industrial and scientific community becomes familiar with them; this is a technological growth pattern similar to ROVs during the 1970s (technological development) and 1980s (widespread use).

AUVs are a frontier technology in underwater work systems. The main advantage of an AUV is that a tether connecting the system to a surface ship is not required, nor is a real-time operator or ship necessary. The tethers used with conventional ROVs can be a problem when working very deep because they become entangled, twisted, and are generally very hard to manage. In addition, the surface ship must continually track an ROV from above and this becomes particularly troublesome over long horizontal distances and in heavy weather. Thus, an autonomous vehicle eliminates the tether problems, reduces on-site crew requirements and, apart from launch and recovery, is unhindered by weather. Given the likely development of acoustic telemetry in the next 10 years, which will in effect turn an autonomous vehicle (AUV) into a remotely operated vehicle (ROV), the ultimate niche for true AUVs will be long-term and long-distance missions when a support ship is not required.

## PRESENTATION HIGHLIGHTS AND CONFERENCE OBSERVATIONS

The first day of the conference was devoted mostly to the non-Japanese invited guests and each spoke for 45 minutes with 15 minutes for questions. Each paper described an AUV system currently under development and past activities of that laboratory in AUVs and related technologies. Philosophical guidance for the seminar was perhaps best provided by the first speaker, Dr. Dana Yoerger of the Woods Hole Oceanographic Institute (WHOI). He emphasized the scientific application of AUVs and that the design of new systems should meet three requirements:

(1) The system should have the ability to gather data not currently available from existing underwater systems. The system should perform more efficiently and less expensively than an ROV, manned submersible, or towed system. The system also should complement existing technology.

(2) Given that there is limited research funding, the system should be cost effective.

(3) There should be moderate risk of failure.

Dr. Yoerger emphasized that his laboratory is entirely concerned with applying technology to scientific applications. His described the overlap of these two spheres as the focus of his work.

Given these parameters, Dr. Yoerger described the WHOI project to develop the autonomous benthic explorer (ABE), a system that will be able to make long-term observations of an area when a ship is not present. The study area will be a hydrothermal vent field. ABE will swim down to the area, conduct a photographic and physical oceanographic survey, then land and switch into a low power mode ("sleep") and then reactivate periodically to replicate the survey in order to collect a time-series database. The cost of development and construction is estimated at about $1 million and funding from the National Science Foundation has already been secured.

The AUVs from Britain, as reported by Drs. Baker and Collar, are for a fundamentally different mission. They have two conceptual designs: (1) deep ocean long path hydrographic instrument (DOLPHIN) and (2) deep ocean geological instrument explorer (DOGGIE). Both systems are in the development and conceptual stage with no guarantee of funding.

DOLPHIN will undertake large-scale hydrographic measurements by navigating across the oceans and surfacing every 30 km to transmit temperature data to the NAVSTAR satellite system. The argument is that DOLPHIN will provide data for the World Ocean Circulation Experiment (WOCE) more economically than that which can be obtained using conventional surface vessels, especially in rough seas. The authors acknowledged major problems with developing a power source for such long missions and the ability needed to change buoyancy for repeated dives and surfacings.

DOGGIE is also a long-range system, but it will stay submerged for 3 to 5 days and survey a 50- by 50-km area as it "flies" 500 meters off the bottom conducting a subbottom profile using multifrequency sonar. While this system does not have the buoyancy change challenge of the DOLPHIN concept, it does have the same power source problem.

Several researchers reported on AUV development in Japan. Dr. Ura from the University of Tokyo began the Japanese discussion with a look at the national needs for undersea research. He argued Japan needs subsea work systems for development of coastal areas, fishery research, and lithosphere observations. The only specific scientific target he mentioned for an AUV was to periodically survey scallop beds near Hokkaido. Instead of scientific application, he stressed the need to develop reliable prototypes first and then apply them to science missions. He described such a prototype system that he has developed called PTEROA. PTEROA is a fairly basic design that glides to the bottom with weight, deballasts, conducts a survey, deballasts once more, and surfaces.

Dr. Ura also coauthored another paper with Dr. Y. Okuwa of Mitsui Engineering and Shipbuilding Co. for a system that is still in the conceptual stage. This system is targeted to meet the data needs of the Ridge Interdisciplinary Global Experiment (RIDGE), which is part of the U.S. Global Change Research Program. A vehicle would eventually be developed to conduct water temperature and bathymetry surveys of spreading centers along the ridge systems of the oceans at a depth of 1,000 meters, although initial plans are to build a prototype (R1) that would operate at 400 meters around the Japanese archipelago.

R1 is scheduled to conduct sea trials in 1994. As with most other ambitious AUV concepts, the main problem is a long-term power source. R1 calls for a closed-cycle internal combustion engine. Dr. Okada from the Japan Marine Science and Technology Center (JAMSTEC) described the development of a full ocean depth ROV. The 10,000-meter ROV (10K), currently funded and under design development, is scheduled for completion in 1993. The 10K will be the deepest diving work system in the world with the ability to reach all but a very small portion of the world's ocean floors (the deepest ocean depth is estimated at 10,800 meters). The system is designed to act as a rescue system for the SHINKAI 6500 manned submersible and as a research vehicle for regions deeper than the SHINKAI 6500 can go. This was an engineering exposition with no specific science programs mentioned.

Another vehicle under development at JAMSTEC, presented by Dr. Hattori, is an "untethered ROV." This system carries its own power but is linked to the surface with a thin (0.9-mm) expendable fiber-optic cable for control and video image telemetry. The UROV-2000 is an interesting concept because the cable allows operators and scientists to maintain real-time contact with the vehicle, while tether management is easy and onboard intelligence requirements are low. However, the system still needs an onboard power source and a surface support ship. As the name suggests, UROV-2000 is designed for 2,000 meters, and sea tests to 515 meters were successfully carried out in March and September 1990. This is a prototype model, but based on experience with this system, a practical version is now under construction for use in fisheries surveys in the Sea of Japan.

## CONCLUSION

At present, AUVs are mainly a technological frontier and not yet within the purview of scientific or commercial users. While several presentations described systems tailored to particular applications or science missions, this was an engineering symposium and the lively exchange of ideas will certainly cross fertilize and stimulate this emerging field. The few scientists, such as biologist Dr. Bruce Robison, who attended the conference were openly excited by the kinds of new information AUVs can collect. It was the application of these new technologies that was the most compelling for this writer, because that will determine the growth of this industry and the ultimate design of individual vehicles. When AUVs "come of age," there is no doubt their use will become wide spread.

The variety of designs presented at this symposium can be classified into three types:

(1) A system that is partially supervised from the surface with initially a fiber-optic link and eventually sonic telemetry. These systems will have the same capability as ROVs but without the cumbersome tether management problems.

(2) A system that will stay in one area for days, weeks, or months at a time, moving around and collecting time-series observations and data without a surface ship in attendance.

(3) A system for long-range autonomous missions with a range from several hundred to thousands of kilometers.

One of the major engineering problems that emerged was the lack of a power source to enable a vehicle to take full advantage of its autonomy by traveling long distances during extended missions. This was temporarily resolved in some plans by considering a closed-cycle engine, while other designs avoided the power problem by targeting missions that will not require long-distance travel. It was clear from this discussion that a compact, efficient, long-term power source must be developed in order for AUVs to conduct long-distance, long-duration missions.

The other major engineering problem for several vehicles was the inability of the AUVs to repeatedly change buoyancy without deballasting. Buoyancy is an important consideration for all undersea work systems. Most submarines carry disposable ballast with some jettisoned after initial descent and more released before final ascent. Most large ROVs operate with positive buoyancy and use thrusters, powered from the surface, to keep the system underwater. Wasting energy on continuous use of thrusters is not an option for AUVs with a limited power source, and deballasting can only be done once or twice. Using a material with the ability to repeatedly change density seems to be the most likely solution for an AUV that would make repeated descents and ascents during one mission. But that is about as far as the discussion went concerning this buoyancy issue; nobody presented details of exactly how that would be accomplished.

Beyond power and buoyancy, there were no other major technological problems without a solution in sight. None of the engineers seemed concerned about adequate onboard intelligence, camera systems, or sensors; it seemed they could all be adapted from existing technology, mostly from submarines and ROVs.

The WHOI design was by far the most immediately rewarding concept in that within a couple years the system will be autonomously surveying hydrothermal vent fields, one of the most interesting discoveries in oceanography during recent years. What is so compelling about the WHOI design is that it will operate within the limits of existing technology and be entirely focussed on a fascinating scientific mission that cannot currently be conducted with other existing undersea work systems. Also, the total price tag from design to operation is only about $1 million.

The British designs were also quite intriguing and scientifically worthy, but the unresolved engineering problems of buoyancy change and power and lack of funding made them seem far off from reality. They might have been better off presenting a lower cost program using existing technologies in order to get more immediate results.

There is exciting growth and development ahead in AUV technology and application. Near-term expectations are to build reliable operational systems that will operate beneath a surface support ship (1 to 5 years), and longer term expectations are to build systems that can conduct long-distance and/or long-duration missions without a support ship in attendance (5 to 20 years). The ultimate system may be one that is programmed and launched at the research institute's pier to swim off into the world's oceans to conduct a research mission, perhaps with a curiosity/learning program, and then return, weeks or months later, to download its data files with the oceanographer not even stepping aboard a ship.

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# TECHNO-OCEAN '90

*TECHNO-OCEAN '90 was held in Kobe, Japan. TECHNO-OCEAN has emerged as the premier ocean technology conference for the Western Pacific region. Many of the papers and discussions addressed global climate change issues and the application of ocean technology to those issues.*

by Gregory Stone

## INTRODUCTION/ BACKGROUND

TECHNO-OCEAN '90 was held in Kobe, Japan, from 14-17 November at the International Conference Center on Port Island. The two major and distinct elements of the conference were the presentations and the exhibition hall. At the conference there were 416 attendees and 89 papers were presented. The exhibition hall hosted 114 companies and 12 organizations with reportedly 41,805 visitors. Ninety-five of these companies and 8 of the organizations were Japanese. The other 19 companies and 4 organizations were from Canada, England, Finland, France, Norway, and the United States. Most of the conference attendees were Japanese, with perhaps only 15% coming from other countries, and there appeared to be a fairly even mix of scientists and engineers. The entire conference was sponsored by the Kobe International Association and World Import Mart Co. Ltd., and the conference chairman was Toshitsuga Sakou, Professor, Tokai University.

This was the third annual TECHNO-OCEAN conference and it clearly belongs to the emerging family of conferences held throughout the world where ocean industries have an opportunity to display new merchandise, engineers talk about new technological developments, and scientists talk about the application of this technology to their respective disciplines. TECHNO-OCEAN appears to be the Japanese counterpart to the Marine Technology Society's annual Oceans and Intervention-ROV conferences held in the United States. This writer recognized many vendors and several speakers at TECHNO-OCEAN from these previous conferences. A European conference along these same lines, the International Ocean Technology Conference, is scheduled for 18-20 June 1991 in Glasgow, Strathclyde, Scotland.

These conferences usually have a central theme, but any topic that relates to ocean technology and science will also be considered. The theme of TECHNO-OCEAN '90 was "Perspectives of Ocean Development in the Age of Intelligent Industry." The 89 papers were divided into the following sessions:

- Marine Transportation Systems in Kansai
- Technology Development in the Deep Sea
- Marine Ranching Systems
- Ultra-Utilization of Coastal Areas and Ocean in the 21st Century
- Ocean Survey and Instrumentation
- Ocean Data Measurement
- Ocean Characteristics Utilization and Human Behavior
- Marine Biological Resources
- Environmental Protection and Waste Management
- Ocean Resource Utilization
- Ocean Space Utilization and Control Technology
- Floating Structures and Marine Transportation
- Ocean Structures and Construction Technology
- Submersible and Subsea Survey Technology

## INVITED LECTURES/ PRESENTATIONS

There were two invited lectures on the morning of the first day. Worth D. Nowlin, Jr. of Texas A&M began with a report on his research on the "Renewal of Deep Pacific Ocean Waters with Implications for Climate Variability." The oceans absorb gases thought to influence climate, including $CO_2$, chlorofluorocarbons, and methane. By taking these gases out of the atmosphere, the ocean may act as a buffer against excessive buildup and adverse climatological effects, such as "greenhouse warming." Some scientists argue that the oceans can and will absorb all the "extra" $CO_2$ currently entering the atmosphere from human sources and some scientists say the oceans won't. Nowlin argued that an important element in this discussion is the circulation of surface water (where this absorption will take place) with the deeper ocean waters (where the $CO_2$ will be stored). Surface waters eventually subside and then return to the surface after perhaps 700 to 1,000 years. The main point of his lecture was that this is an important research topic and the World Ocean Circulation Experiment (WOCE) plans to deploy 60 current meters for 2 years on an east-west line across the western boundary current at 32.5° south latitude. These meters, along with other measurements, will help estimate currents, circulation characteristics, and deep sea residence time of ocean waters.

Following Dr. Nowlin's presentation was a talk by John Craven, Professor of Law, from the University of Hawaii. The theme of his talk was that world energy problems (overdependence on oil), overpopulation, and global warming can eventually be solved with ocean technology. Energy can be obtained, he argued, from ocean thermal energy conversion (OTEC), which does not produce potentially harmful gases that may encourage atmospheric warming; overpopulation can be alleviated with artificial islands and floating cities. He felt that world planners failed by not adopting these technologies in the late 1960s. If they had, he said, we would not be experiencing a "world crisis" now. He urged quick development of OTEC energy systems. (In addition to Craven's talk, there was a paper by Patrick Takahashi, Hawaii Natural Energy Institute, University of Hawaii at Manoa, on OTEC.)

OTEC is the process where cold (4 to 5 °C), deep (1,000 meters) ocean water is pumped to the warm (22 to 29 °C) surface water in tropical regions. Using this temperature differential, a "working fluid" is then vaporized and condensed to drive a turbine generator system for electricity. Beyond generating electricity, the cold water can be used for air conditioning, growing cold water marine animals, and cooling agricultural land for more productive yields by condensing water from the atmosphere for irrigation. He described societies living in tropical regions using OTEC for all energy needs and eating sweet strawberries, salmon, and Maine lobsters. He said the cost of such energy systems was $2,500 to $3,000/kW including the installation of the pipe. However, his cost estimates (which are competitive with fossil fuel plants) disagree with other estimates, which range between $6,000 and $7,000/kW (see, for example, L.A. Vega and A.R. Trenka, "Near term market potential for OTEC in the Pacific Basin," available from Pacific International Center for High Technology Research, Honolulu, Hawaii). Nevertheless, he provided a lively and inspired discussion of potential solutions to some world problems that was reminiscent of the 1960s feeling that "technology will solve all problems."

After the keynote addresses by Nowlin and Craven, there were 2 days of papers that could roughly be divided between applied ocean technology and pure ocean technology.

## APPLICATION OF TECHNOLOGY PAPERS

The keynote addresses set the mood for the "application" papers--to utilize technology to heal, restore, and use the oceans in more sensible ways than in the past. Dr. Akimitsu Koganezawa, Director General of the National Institute of Fisheries Engineering of Japan, stated that it was the policy of the Japanese Government to restore depleted fish stocks. He outlined future directions including intensification of basic research in marine ranching, the use of nutrients in the deep sea for increased productivity at the surface, and exploring the concept of feeding wild fish schools. Mr. Yoshira Shimomura and Mr. Tatsuo Suzuki of Hazama Corporation proposed the use of "fly ash," a by-product of coal burning, for the construction of artificial fishing grounds. Katsumi Miyajima from the Hokkaido Industrial Center described electric barrier systems for abalone aquaculture in the ocean. There was also a presentation on the "Development of Pressure-Retaining Sampler for Deep Sea Microorganisms." There is intense commercial and scientific interest in deep sea microorganisms in Japan. Industry is interested in the commercial application of microbes, "marine biotechnology." Basic scientist are eager to describe new species and learn more about deep sea microbiological communities. There is growing speculation that the origin of life may have occurred or been related to the chemosynthetic microorganisms at deep sea hydrothermal vent sites. This paper was related to a much larger program that the Japan Science and Technology Agency is currently funding at the Japan Marine Science and Technology Center called "Deep Star." The Deep Star program will collect deep sea organisms and then cultivate them at the Yokosuka laboratory by maintaining the high pressure and very low temperatures found in the deep sea.

## PURE TECHNOLOGY PAPERS

Along with the application of technology papers were the engineering presentations. These were given mostly by engineers and covered a very wide range of topics including sonar systems, ship design, undersea cables, remotely operated vehicles, manned submersible operation, and coastal and port engineering and development.

## CONCLUSION

While this conference was very similar to other world-class ocean technology/science conferences, it was distinguished by its uniquely Japanese and Pacific Ocean perspective. Over the last 10 years the world's ocean community has been shifting its scientific and economic perspectives to the Pacific. Japan has also been taking the lead in certain sectors of the ocean technology field including deep manned submersibles, remotely operated vehicles, and some aspects of coastal reclamation and development. As this trend continues, TECHNO-OCEAN will probably be the major forum for Japanese ocean technology and the application of that technology to ocean issues. The scientific papers echoed world concern for safer, renewable forms of energy and fears of global climate change. There was a loud call to re-energize the OTEC scientific movement of the 1960s and 1970s to create energy abundant islands or seaside communities in tropical regions. There was also a trend toward adapting new technologies to fisheries that are important to Japan.

# SATELLITE REMOTE SENSING IN JAPANESE OCEANOGRAPHY

*Despite impressive progress in the technology of satellite remote sensing, the application of this information to scientific studies in oceanography is in its infancy. An inflexible academic system makes scientific innovation difficult and support for young scientists willing to learn this new field scarce. Because Japanese scientists are just starting to focus on global problems in earth science, there is as yet no demand for global data. Nevertheless, where there is support for remote sensing, talented scientists committed to using the data are forging ahead.*

by Kathryn A. Kelly

## INTRODUCTION

Japan is aggressively pursuing its space program in the areas of launch capability and instrument design (Ref 1) and in development of processing techniques (Ref 2); however, the incorporation of remote sensing data from satellites into scientific studies in oceanography is proceeding at a slower pace. A recent joint meeting (21-25 August 1990) of the major Japanese geophysical societies and the American Geophysical Union brought many of the Japanese scientists working with satellite data to Kanazawa, Japan. These oceanographers came from Tohoku University in Sendai, Kagoshima University in Kyushu, Tokai University in Shimizu, Kyoto University in Kyoto, and from the Meteorological Research Institute in Tsukuba. In addition to attending this meeting, I visited Tokai University and Tohoku University. The scientists I met were energetic and talented, and nearly all had made extended visits to the United States to study remote sensing technology. However, Japan's efforts to expand the use of satellite data in oceanography appear to be hampered by an inflexible academic system and the lack of demand for global data.

In contrast with Japan's legendary ability to foster innovation in engineering, Japan's academic system of one professor and one hand-picked associate professor in each university makes innovation by young scientists particularly risky. The ability to use remote sensing data requires a heavy investment by the individual scientist in acquiring technical expertise and hardware and developing software, generally at the expense of short-term scientific productivity. This, in turn, requires that the scientist have the support of visionary senior researchers and institutions with long-range outlooks. So far, support for scientists to obtain remote sensing analysis skills has been lacking at the top-ranked universities (Tokyo University and Kyoto University), but such support is available in the second tier of institutions. Tokyo University has a receiving station for satellite data and does extensive image processing; however, the facility is part of an engineering department and it is not used by the oceanographers there. Kyoto University has the hardware and software available for analysis of infrared images from the U.S. National Oceanic and Atmospheric Administration (NOAA) satellites, but no single scientist there is pursuing the analysis of satellite data.

As a nation trying to establish itself as a world power, Japan remains provincial in science, confining itself to studies of its coastal waters and nearby inland seas. Thus Japanese science lacks a basic driving force for the acquisition and use of remote sensing data: the need for global coverage. For example, Japanese meteorologists produce only local weather forecasts for which they have adequate in situ data. In contrast, U.S. meteorologists have been a strong force for a global perspective and for the use of satellite data. The most widely used operational instrument for remote sensing in oceanography, the passive infrared radiometer (AVHRR), was actually designed for U.S. meteorological applications. Japanese oceanographers generally study the nearby Kuroshio current and marginal seas for which they have extensive historical data archives. They are currently expanding their studies to the Kuroshio Extension farther offshore and are just beginning to run global ocean circulation models. The differences are particularly noticeable in comparing the remote sensing demands of similar groups in the United States and Japan. For example, the Meteorological Research Institute (MRI) in Tsukuba, where scientists develop numerical models for both the ocean and the atmosphere, would be similar in function to the National Center for Atmospheric Research in Boulder, Colorado. However, scientists at MRI have expressed no interest in assimilating remote sensing data into their numerical models, quite unlike their American counterparts. As another example, the Japanese science team for a joint U.S./Japan project to measure near-surface marine winds by satellite has no meteorologists. This is in contrast with the U.S. team, of which about half the members are meteorologists and half oceanographers.

Interaction between American and Japanese scientists is hampered by the scarcity of Japanese publications in international journals. The research efforts and plans that were described to me were frequently only written in internal reports in Japanese with English abstracts. This is no doubt in part because the Japanese academic system does not have a "publish or perish" ethic, that is, promotion is not heavily dependent on publications, and Japanese scientists must pay page charges for journals from their own salaries, rather than from their research budgets as in the United States.

## REMOTE SENSING INSTRUMENTS FOR OCEANOGRAPHY

There are a number of active and passive systems generally mounted on satellite platforms which are currently used in oceanography. The Japanese version of some of these instruments and some U.S.-designed instruments will be flown on Japanese satellites in the near future.

The mostly commonly used passive instruments are the visible and infrared radiometers, the color scanner, and the microwave radiometer. The most widely available data come from the Advanced Very High Resolution Radiometer (AVHRR) mounted on the NOAA polar-orbiting satellites; AVHRR data can be received by direct transmission to any of the many ground receiving stations throughout the world. The AVHRR infrared data are converted to sea surface temperature images and are used in Japanese oceanography, as in the United States, for qualitative descriptions of sea surface variability. No particular expertise is required for their qualitative use and several facilities exist in Japan to produce these images. However, the use of AVHRR for quantitative studies such as the statistics of sea surface temperature or air-sea interaction requires a much higher level of expertise and processing ability. The passive radiometers on the geostationary satellites are used for studies of heat flux between the ocean and the atmosphere, both in the visible and infrared portions of the spectrum. Japan has its own geostationary satellite and therefore also its own processing facilities for this instrument. The color scanner is primarily of interest to biologists because it produces an estimate of near-surface chlorophyll concentration and hence biological productivity in the ocean, but it is also important to marine chemists studying the carbon cycle. A color scanner will be flown on the Japanese Advanced Earth Observation Satellite (ADEOS). The passive microwave radiometer is the most versatile: depending on the frequency, it can measure wind speed, sea surface temperature (through clouds), atmospheric water vapor, and characteristics of sea ice. It is frequently used in conjunction with other radars to determine the appropriate water vapor correction.

The most commonly used active radar instruments are the altimeter, the scatterometer, and the synthetic aperture radar (SAR). The altimeter is the simplest instrument and measures the travel time between the satellite and the ocean surface to give a sea surface height estimate. The sea surface height fluctuations are used to infer near-surface currents, but the altimeter also produces an estimate of significant wave height and near-surface wind speeds. Recently the U.S. Navy flew an altimeter on the GEOdetic SATellite (GEOSAT) and data from the latter 3 years of that mission are available from NOAA. The scatterometer is a more complicated Doppler pulse radar that measures the backscattered signal from centimeter waves on the ocean surface to give near-surface wind vectors. A scatterometer will be flown on the European ERS-1 satellite, scheduled for launch in 1991, and the National Aeronautics and Space Administration (NASA) scatterometer (NSCAT) will be flown on ADEOS in 1995. The synthetic aperture radar is the most complicated instrument, collecting signals over hundreds of meters as the satellite moves to generate a composite image after extensive computer processing. SAR images ocean surface features, but interpretation of the images is difficult; mounted on aircraft or the space shuttle, it can determine the directional spectrum of surface gravity waves.

## WESTERN PACIFIC GEOPHYSICS MEETING (WPGM)

The WPGM in Kanazawa was cosponsored by the American Geophysical Union (AGU) and eight major

Japanese geophysical societies (Ref 3). The meeting followed the basic format of an AGU meeting with 20-minute talks in English held in each of eight sections, primarily solid-earth geophysics. The oceanography sessions included talks on marginal seas, deep and intermediate water circulation, waves, tides and turbulence, western boundary currents, and biogeochemical flux and cycling. The speakers were primarily from Japan, but there were numerous scientists from the United States and several from Canada, Australia, Taiwan, China, and Korea. One scientist used AVHRR images as part of his research, another described the growth of wind waves with fetch based on GEOSAT wave height observations, and two scientists looked at the dynamics of the Kuroshio Extension using the GEOSAT sea surface height data. A meeting of the AGU in the United States might typically have two to three times that many talks based on satellite data.

I spoke individually with a number of Japanese scientists working with remote sensing data. Dr. Shiro Imawaki, formerly of Kyoto University and now at Kagoshima University, is analyzing GEOSAT altimeter data for the Kuroshio Extension. Imawaki visited the Massachusetts Institute of Technology (MIT) a few years ago and worked with Dr. Carl Wunsch there. Another professor, Dr. Hiroshi Ichikawa, has made several visits to Woods Hole Oceanographic Institution to collaborate with Dr. Robert Beardsley, and he plans to use AVHRR data in future studies of the Kuroshio as part of the World Ocean Circulation Experiment (WOCE). Dr. Akira Shibata from MRI was not at the meeting, but he sent me reprints of his work with GEOSAT data in the Kuroshio Extension and the Tropical Pacific. Both Shibata and Imawaki are members of the newly organized Japanese NSCAT team.

## TOKAI UNIVERSITY IN SHIMIZU

In Shimizu the most active group in remote sensing is the Faculty of Marine Science and Technology, headed by Professor Yasuhiro Sugimori, although there is another oceanography group. Tokai University is private and therefore has a less rigid structure, so that there are two associate professors rather than the usual one. Associate Professor Masahisa Kubota works on a wide variety of problems including several using remote sensing data. Kubota spent a year at Florida State University working with Dr. James O'Brien and is a member of the Japanese NSCAT team. Graduate students of Sugimori and Kubota are doing their research with data from the AVHRR and the GEOSAT altimeter. Kubota and his students have developed a state-of-the art multichannel algorithm for flagging cloud-contaminated data in infrared images and are using the carefully screened data to study the statistics of the sea surface temperature front in the Oyashio. One of Sugimori's students is studying wave propagation in the Kuroshio Extension using GEOSAT data.

## TOHOKU UNIVERSITY IN SENDAI

Tohoku University is by far the most active university in remote sensing, and scientists there are proud of their international collaboration, the large number of foreign students, and their publications in international journals. The oceanography section of the Geophysics Department is headed by Professor Yoshiaki Toba, whose specialty is surface gravity waves. A direct link between waves and remote sensing is the effect of the sea state on radar backscatter. The Associate Professor, Dr. Kimio Hanawa, has some interest in remote sensing, but Dr. Hiroshi Kawamura is the apparent expert and is a member of both the Japanese NSCAT team and the team for the color scanner to be flown on ADEOS. To get around the promotion bottleneck, Kawamura was transferred to a recently formed Research Center for Atmospheric and Oceanic Variations and promoted to Associate Professor. Kawamura recently visited the Jet Propulsion Laboratory in Pasadena and NASA headquarters. Kawamura's thesis work was in surface gravity waves, but he has subsequently expanded his efforts, with Toba's support, to include the scatterometer and AVHRR. In his large wind-wave tank, he studies the effect of waves on backscatter and he has recently set up an AVHRR receiving antenna and processing facility with all optical disk storage and automated collection. Kawamura and his students study the effect of fetch on wave heights using the altimeter, the skin effect on sea surface temperature, and heat budgets using the geostationary satellites and longwave radiation from AVHRR. Kawamura also plans to use SAR data and altimeter data for circulation studies.

## WOMEN AND FOREIGNERS

My investigation of the remote sensing situation in Japan was occasionally overshadowed by my personal reaction to the lack of foreigners and women in Japanese science. The rigid academic hierarchy not only screens innovation, it also screens foreigners and women. The "climate" for women at the Kanazawa meeting was particularly chilling as there were only a few female attendees and the one scheduled female speaker could not attend the meeting. Male scientists rarely bring their wives or children when they travel to meetings. I was told that there ire some female graduate students in oceanography, although I did not meet any, but that they are not hired into the academic track. For the most part women do not work after they marry, so that women with higher education delay marriage in order to prolong their careers.

Some of these attitudes may change as Japan becomes increasingly exposed to foreigners. In conversations with a scientist from Taiwan I learned that recently Japan has been taking more of a leadership role in oceanography of the Western Pacific, inviting researchers from Western Pacific countries to visit Japan to learn new technologies. Recently it has become possible for Japanese universities to hire foreign scientists; however, it is unlikely that they would make much more progress in the academic system than women because of the promotion bottleneck.

## FUTURE COOPERATION WITH JAPANESE SCIENTISTS

Future cooperation with the Japanese would probably involve an exchange of expertise in remote sensing data processing or applications for access to the Japanese science resources. U.S. scientists increasingly have difficulty obtaining funding for field studies to both validate satellite data and to make complementary measurements. The Japanese have large historical and current data archives of nearby regions of the ocean as well as a number of research vessels, which are generally used for fisheries investigations, but could possibly be used for cooperative experiments. Their rapidly improving space launch capability has already benefitted U.S. scientists in that NSCAT has a platform after its original platform was canceled by the U.S. Navy. However, cooperation with Japan is not without pitfalls. For example, WOCE, which has received unprecedented international cooperation, was not entirely endorsed by the Japanese Government and, therefore, Japanese scientists are without institutional travel funds to attend the numerous WOCE planning meetings.

Japanese scientists are aware that they lag behind the United States and Europe in the use of satellite data and in processing software. A research plan was begun in 1989 to address this problem, *Better Understanding of Earth Environment via Satellite*, sponsored by the Ministry of Education, Science and Culture. The introduction to this plan states, "Unfortunately, however, in Japan the system for academic research to apply satellite data to basic researches (*sic*) on earth environment such as atmosphere, ocean and land has not been well established." This plan groups approved research proposals into five basic areas: microwave observations, global change of the biosphere, terrestrial water cycle, air-sea interaction, and data processing. Oceanographic remote sensing falls into the first and fourth groups, with the first group studying the characteristics of microwave measurements and their accuracy and the latter group using satellite data primarily to estimate sea surface fluxes and biological processes. Japanese scientists are trying to acquire U.S. software for processing satellite data. One scientist I spoke with was a strong advocate for the AVHRR processing system developed by the University of Miami, RSMAS; another scientist was purchasing a Toshiba clone of a SUN workstation in order to be able to use U.S. software written for the UNIX operating system. A third scientist was modifying an algorithm written for AVHRR data by NOAA scientists.

More direct communication between Japanese and U.S. scientists would help both countries: it would prevent the Japanese scientists from "re-inventing the wheel" and perhaps direct their efforts and resources to solving measurement and application problems. Communication between the United States and Japan is improving as more Japanese scientists connect with either the popular U.S. OMNET network or the Internet network for electronic mail. Oceanographers in remote sensing are notoriously proficient on computers, both in the United States and in Japan, and thrive on electronic communication. The NSCAT team will provide an opportunity for direct contact between Japanese oceanographers and their U.S. counterparts. The Japanese NSCAT team would like to see joint meetings, perhaps in Hawaii, but given the current funding shortage in the United States, regular meetings do not seem likely.

Increased contact between U.S. and Japanese scientists may have other unexpected effects because American culture has aspects which are attractive to the young Japanese. One Japanese scientist assured me that they now officially sanction a 5-day work week (although Japanese scientists usually work 6 days a week) due to the U.S. influence. Several young scientists at the more liberal Tohoku University go home at 5 p.m. because they have small children. The young scientists were particularly interested in U.S. academic policies for promotions and selecting department chairs, as well as the policy of providing on-campus housing to attract students. One scientist suggested that in the future he may bring his family to scientific meetings for a vacation.

The one-sidedness of U.S./Japan contacts, i.e., that nearly all the Japanese scientists I met had spent considerable time in the United States, could probably be best addressed by U.S. scientists making extended visits to Japanese institutions. This would probably be most useful with a close match between areas of research. Scientists at Tohoku University appear to be most receptive to such exchanges. An Australian scientist working with Toba was making one of several long visits when I was there. A graduate student from Scripps Institution of Oceanography was also visiting and intends to do postdoctoral work on a joint U.S./Japan program. His postdoctoral salary will be paid by the Japanese Government; selection of qualified U.S. candidates was done by the National Science Foundation. Exchanges at the postdoctoral level might be a good vehicle for ensuring future cooperation and they do not require long-term commitments. However, U.S. scientists and their families who wish to visit Japan need to be prepared for considerable culture shock.

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