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The European Science Notes Information Bulletin (ESNIB) 91-01 is a compilation of reports on recent developments in European science of specific interest to the U.S. research and development community, and is issued in support of the mission of the office of Naval Research European Office. Issue Number 91-01, in addition to European area news, notes, and abstracts, contains reports in the fields of Acoustics, Biotechnology, Computer Science, Electronics, Materials, Physics, and Remote Sensing. The value of the ESNIB to Americans is to call attention to current activity in European science and technology and to identify the institutions and people responsible for these efforts. The ESNIB authors are primarily ONREUR staff members; other reports are prepared by or in cooperation with staff members of the USAF European Office of Aerospace Research and Development or the U.S. Army Research, Development and Standardization Group. Scientists from the U.S. who are traveling in Europe may also be invited to submit reports.

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ESN INFORMATION BULLETIN

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This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large.

Commanding Officer ..... CAPT Victor L. Pesce, USN
Scientific Director ..... James E. Andrews
Editor ..... Ms. Connie R. Orendorf

ACOUSTICS

This workshop's objectives were to address how one uses acoustics to help understand oceanography, and how one develops new and appropriate oceanographic descriptions to aid acoustic understanding and prediction.

BIOTECHNOLOGY

Dr. Cooksey describes the current status of research on purposely immobilized cells. Although this area of sciences emphasizes the design and implementation of new biotechnological processes, it is also of direct relevance to studies of biological fouling, biocatalysis, bioremediation, microbially enhanced corrosion, and molecular biology in general. Scientists involved in the microanalysis of biological phenomena will also find this article of interest.

COMPUTER SCIENCE

The purpose of this article is to provide a guide to the Europen Strategic Programme for Research and Development in Information Technologies (ESPRIT) Basic Research Actions and Working Groups in computer science. Dr. Ryan presents essential information--who, what, and where--quickly available to ESNIB readers who have not yet acquired the original material.

The Swedish Institute of Computer Science is now 4 years old and produces world-class research, educates students, and contributes directly to the competitive position of Swedish industry.

Dr. Malek reviews European progress in Fault-Tolerant Computing from work presented at FTCS-20.

Interest is increasing in transputers. The Commission for European Communities supports 55 universities in Europe to pursue research on parallel computers based on transputers. Also, INMOS has announced an new powerful transputer --H1-- that eliminates some of the idiosyncracies of the previous product. Dr. Malek discusses these facts and other transputer-related topics presented at the Second International Conference on Applications of Transputers.

ELECTRONICS

Because traditional sources of funds for research are shrinking, R.S.R.E. may need to reassess their work in crystal growth. Mr. Lessoff discusses R.S.R.E.'s history and alternatives in this area.

The author discusses the work on atomic layer epitaxy as presented in this first symposium, which was held in the country where the ALE process was first patented--Finland. The Office of Naval Research has been at the forefront of support for ALE research in the U.S.

MATERIALS

Dr. Koczak discusses BRITE/EURAM programs in diamond-film technology as presented in this recent conference, and provides references to program partners.

This conference and workshop focused on the key issues in intelligent processing techniques and addressed the critical issues relating to the future development of basic research themes and their eventual industrial applications.

Dr. Koczak presents information about BRITE/EURAM joint research efforts in metal matrix composites, composite processing, ceramic composites, and polymer matrix composites.

This conference emphasized the need for innovative as well as hybrid techniques that treat materials at the micromechanical level where related micromechanical or finite-element structural analysis can be incorporated.

PHYSICS

This workshop revealed exciting new developments on new accelerator concepts. The second in the Erice series, the workshop was devoted to exploring accelerator concepts for the Italian equivalent of the superconducting supercollider.

REMOTE SENSING

The author discusses the history of and current research at the Institute for the Statistical Mechanics of Turbulence (IMST).

Advancement in European programs in remote sensing is apparent in the technology presented at the 10th annual EARSeL symposium.

NEWS, NOTES, AND ABSTRACTS

ACOUSTICS

Recent Investigations of Ocean Variability and Its Relationship to Acoustic Propagation

by Dr. Mel Briscoe, Director, Applied Oceanography and Acoustics Division, and Dr. Alan Brandt, Program Manager, Small Scale Physical Oceanography, Office of Naval Research, Arlington, Virginia; LCDR Larry Jendro USN, the Liaison Officer for Oceanography and Environmental Systems at the Office of Naval Research European Office; LCDR Jendro is an active duty Naval Officer from the U.S. Navy's Oceanography community; David Feit, formerly the Liaison Scientist for Acoustics and Mechanics in Europe and the Middle East for the Office of Naval Research European Office. Dr. Feit has returned to the David Taylor Research Center, Bethesda, Maryland, where he is a research scientist in the Ship Acoustics Department.

Introduction

Recent research involving Ocean Variability and Acoustic Propagation Workshop and its relation to acoustic propagation was presented in San Terenzo, Italy, June 4-8, 1990. The NATO SACLANT Undersea Research Centre (SACLANTCEN), the Office of Naval Research (ONR), and Energy Environment Research Center (ENEA) cosponsored the workshop. The venue was the Italian ENEA in San Terenzo, near Lerici (suburbs of La Spezia). The facilities are quite good with a large, fully equipped room for presentations, and a modern cafeteria-style dining room situated on park-like grounds, commanding spectacular views of the Mediterranean and the harbor at La Spezia.

Workshop Description

The workshop's objectives were to bring together recognized experts in oceanographic processes and acoustic propagation to address the middle ground of (a) how one uses acoustics to help understand oceanography (so-called acoustic oceanography), and (b) how one develops new and appropriate oceanographic descriptions to aid acoustic understanding and prediction. The implicit assumption of the workshop was that oceanic variability causes important acoustic variability, at least in some situations, and that understanding how and when this happens provides for better research and application on both sides. The workshop was really more of a symposium. No overt goals were set, no formal recommendations provided, and no working groups established. Each session had cochairs who summarized the day's deliberations in writing. However, the rather random sequencing of speakers meant many topics were addressed several times throughout the week, thus reducing the utility of a single day's summary.

The organizers, Drs. John Potter (U.K.) and Alex Warn-Varnas (U.S.), SACLANTCEN, solicited contributed papers throughout the NATO countries. About half the offered papers were selected for presentation at the workshop. Each paper had an extended abstract, submitted in advance. The abstracts were collected and bound into a volume available at the workshop. Each paper was presented during a 30-minute time slot, of which 10 minutes were allowed for discussion. An additional 60-minute discussion period was allowed at the end of each day. This format was extremely useful. Usually, a very interesting (although sometimes tangential) workshop-like discussion resulted from each talk on detailed scientific topics and from the day's group of talks. Such a meeting format (allowing ample time for discussion), which requires a strong session chair and the willing involvement of the participants, should be considered for future meetings of this type.

A complete collection of the papers presented will appear as a book edited by Potter and Warn-Varnas later this year. For further information, contact John Potter or Alex Warn-Varnas, SACLANTCEN, Viale S. Bartoloteo 400, 19026 La Spezia, Italy.

The mingling of the junior professionals and some really worldclass senior oceanographers and acousticians was delightful. Such mingling of cultures (oceanographers and acousticians) and experience levels should be encouraged.

Throughout the 4 days of the conference, 46 papers were presented. Five very interesting papers are outlined

below. A repeated theme of these talks was the deterministic versus stochastic nature of ocean variability. Even within apparently great complexity, one can find understandable and useful physics, description, and understanding.

U.S. Navy-Sponsored Participation

Papers were presented by

- M. Briscoe - Applied Oceanography and Acoustics Division, ONR
- LCDR L. Jendro USN - Office of Naval Research Europe (ONREUR)
- R. Field, P. Jackson, G. Kerr, and K. Saunders - Naval Oceanographic Atmospheric Research Laboratory (NORAL)
- M. Collins, W. Kuperman, B. McDonald - Naval Research Laboratory (NRL)
- L. Dozier, B. Dushaw, T. Ewart, D. Farmer, S. Flatté, G. Frisk, J. McCoy, W. Munk, R. Pinkel, R. Pollard, A. Robinson, D. Rubenstein, R. Samelson, K. Smith, and D.-P. Wang - the Office of Chief of Naval Research-supported scientists from universities, non-Navy laboratories, and industry.

Outstanding Presentations

Robert Pinkel, Scripps Institute of Oceanography, San Diego, California, presented "Internal Wave Induced Fluctuations in the Oceanic Density and Sound Speed Fields" that suggested that much or all of the few-minute acoustic variability (for example, transmission loss) is caused by a nonlinear effect of internal waves in which small-scale internal waves are advected by larger-scale internal waves. A sensor sitting stationary sees more apparent internal wave variability than does one moving with the waves. Acoustic propagation, unfortunately, sees the more complicated picture. This was a satisfying result that nicely helped explain why transmission loss can vary in a few minutes even though the oceanic processes causing the fluctuations have longer time scales.

In "Impulse Response Analysis of Ocean Acoustic Propagation," Stan Flatté, University of California, Santa Cruz, concentrated on the propagation of wavefronts from pulses. He argued strongly for working in the time domain if one wished to achieve understanding of the relationship between propagation and oceanic variability. Since his focus throughout the week was on inferring oceanography from acoustic measurements, especially internal-wave oceanography, he also advocated the idea of higher-frequency, shorter-range acoustic experiments, and of statistics rather than determinism. Additionally, he argued that knowledge of the oceanographic process causing the variability was essential to experiment design and data analysis.

Hans Schneider's (Forschungsanstalt der Bundeswehr fuer' Wasserschall und Geophysik [FWG], Federal Republic of Germany) presentation, "Average Sound Intensities, in Randomly Varying Sound Speed Structure," was in stark contrast to Flatté's talk.

He looked at shallow-water acoustic propagation in a Baltic Sea environment that had a layer of relatively constant temperature over a layer of extreme temperature variability not likely to be described by any simple (or known) oceanography. Rather than giving up, he developed an *ad hoc* diffusion theory to account for acoustic energy leaked out of the surface duct and into the layer below, or vice versa, depending on source depths. His point was that sufficient complexity lets you move to a statistical, probabilistic regime and actually get some useful answers.

Bill Kuperman, NRL, in "Three Dimensional Oceanography and Acoustics," and Michael Collins, NRL, in "Environmental Focusing and Source Localization in the Deep Ocean," discussed aspects of essentially the same problem: matched field processing (or equivalent) when the "target" is just distributed ambient noise and the ocean is not given but rather is highly dimensioned in the optimization search space. In effect, they assume that the ocean is an unknown lens through which the noise propagates, and then determine the properties of the lens.

Items of Interest to the Navy

The Interpolation of Oceanographic Parameters in Acoustic Models. Range-dependent acoustic propagation models are an important technological first step in supporting naval tactics by acknowledging the importance of oceanic variability and its effects on sound propagation in naval tactics. These models require Sound Speed Profiles (SSP), from the surface to the bottom, sampled at individual points along the track of sound propagation, to be input. This allows the modeling of acoustic propagation through an oceanic front separating different water masses. Questions of immediate interest are:

- What spacing of SSPs is required when using a range-dependent acoustic propagation models to resolve an oceanic mesoscale feature?
- What should be done if sampling at this spacing is not possible?

The question of how to interpolate between SSPs was raised during the conference. Different approaches to this problem (no interpolation, linear interpolation, empirical interpolation, and feature models) were used in several papers presented. This indicated that no definitive method is now available. Walter Munk initiated a discussion in which the importance of this issue

was underscored. He said, "Years of experience have shown that the method of interpolation between samples in a range-dependent acoustic propagation model is as important as the model used." He also said, "This is a problem for the men and women of oceanography, not for the boys and girls." The general consensus at the workshop was that some method of smart interpolation should be used and that care must be taken not to average out frontal features.

From an operational standpoint, the design and documentation of tactical range-dependent acoustic models need to insure that either (a) sufficient oceanographic data is input to resolve the features across which propagation loss is computed, or (b) a realistic interpolation between widely spaced SSPs is accomplished. The importance to the operational Navy of properly designed and applied acoustic propagation models is significant. Erroneous modeling of mesoscale features could provide bad data in a tactical situation.

Acoustic Reflection Profiling of Ocean Acoustic Structure. J.D. Phillips, University of Texas at Austin, presented a new approach to measuring the acoustic structure of the ocean. His paper, "Multichannel Acoustic Reflection Profiling of Ocean Watermass Temperature and Salinity Interfaces," describes the unveiling of oceanic acoustic features through the directed processing of multichannel acoustic reflection data. Comparison of the velocity depth profiles generated from reflection profiling with *in situ* XBT samples indicate that this analysis technique successfully imaged:

- Base of a warm seasonal duct
- Thin layer of Labrador Sea water overlaying the Gulfstream
- Top of the main thermocline
- Interface just above the deep sound channel.

There are several features of this ocean sampling method that could provide advantages over currently used systems.

- Provides a direct measurement of acoustic properties
- Samples a greater area more quickly
- Supported by the development of equipment and processing software used in seismic surveys
- Presents the possibility of active towed-array systems sampling the environment in which they are operating.

Operationally Interesting Non-U.S.-Sponsored Presentations

Hubert Bouxin, Delegation Generale pour l'Armement (DGA), France, presented "Radar Altimetry and Acoustic Prediction." He described an experiment that took place in the Northeastern Atlantic in which altimetry data from GEOSAT was used to map eddy positions using objective analysis techniques, and acoustic propagation loss was based on SSPs developed from surface dynamic eight and vertical empirical modes. Propagation loss computed with SSPs derived by this method is compared with propagation loss derived from *in situ* data. In 51 cases out of 80, the propagation loss computed using the GEOSAT altimetry data described the acoustic environment (as defined by sound speed profiles taken along the track of GEOSAT at about 20-km intervals) better than did a single sound speed profile taken at the point of the emitter.

Anthony Heathershaw, Admiralty Research Establishment (ARE), U.K., in "The Use of Coupled Ocean Acoustic Models in the Design of Naval Ocean Forecast Systems," described an interesting approach to the design of ocean forecast models. He coupled a range-dependent acoustic propagation model with a three-dimensional eddy-resolving ocean model and monitored the effect of changing ocean parameters on the acoustic propagation. This work has shown that the ray paths and calculated propagation loss values may be sensitive to the choice of ocean model parameters in particular, to the horizonal eddy viscosity coefficient.

Basic Ideas of Continuing Interest

Determinism Versus Stochastics. The discussions during the workshop returned repeatedly to the problem of determinism versus stochastics. Clearly, those interested in oceanographic descriptions to put into acoustic propagation models simply wanted to know the deterministic sound speed field. Some seemed willing to try to treat the variable part of the ocean as some kind of error bar to place on the deterministic acoustic result. There was strong agreement, however, that one could not, in general, determine the "mean" acoustic result by propagating through the "mean" ocean. This is an extremely important result that says the concept of averaged databases is flawed in the vicinity of fronts, eddies, and strong internal waves.

Internal Waves. A theme addressed repeatedly in the meeting, and one important to us, is the variability of the interval wave field as sensed acoustically, and the complementary problem of acoustic variability caused by internal waves. However, essentially all the discussion was on past efforts with few suggestions made as to how one should proceed in the future. The only consensus seemed to be that direct acoustic paths (fairly short ranges), highly oversampled oceanography, and very stable geometries are important.

Future Directions. To foster future studies of ocean-acoustic interactions, a brief meeting was held outside the structure of the workshop by representatives

from ONR, SACLANTCEN, ARE, and FWG. Representatives from ONR expressed its interest in encouraging work in this area. All agreed they would be very willing to direct the resources of their agencies toward a joint experiment, particularly if it were in the Greenland-Iceland-Norwegian Sea area. As a result of the paramount importance and need for further coordinated internal wave/acoustic propagation studies, as expressed at this workshop, the ONR Small-Scale Physical Oceanography Program (A. Brandt) is actively encouraging future work in this area. Theoretical and field studies will be undertaken in cooperation with the ONR Applied Oceanography and Acoustics Division (M. Briscoe) and the Ocean Acoustics Program (M. Orr). Toward this end, the theoretical basis for advanced ocean internal wave modeling will be reviewed at the January 1991 'Aha Huliko'a in Hawaii. An international, interdisciplinary (oceanography and acoustics) field experiment planning meeting will be convened in spring 1991.

BIOTECHNOLOGY

Immobilized Cell Research

by Keith E.Cooksey, the Liaison Scientist for Biochemistry, Microbiology, and Marine Biology in Europe and the Middle East. Dr. Cooksey is on leave from Department of Microbiology, Montana State University, Bozeman, Montana, where is he Professor of Microbiology.

Preface

The following is based on two meetings held in Europe in December 1989, and April 1990, as well as my own observations. Specifically the meetings were: (a) "Physiology of Immobilized Cells" held in Wageningen, the Netherlands, and organized by the European Federation of Biotechnology and the Agricultural University at Wageningen; (b) "Immobilized Cell Processes" organized by the Society for General Microbiology of the United Kingdom at Warwick University. Proceedings of the first conference will be available in late 1990 from Elsevier. The second conference will not be published.

Introduction

The general interest in biotechnological production systems using fixed-cell reactors is increasing. Two similar meetings being held in less than 6 months is a strong indication of the interest. Although these meetings dealt specifically with the biotechnological side of cellular immobilization, there are aspects of this research that have importance in other fields. Such systems have been proposed as simple mimics of natural biofilms. All the physical and chemical analytical problems associated with research on biofilms of natural origin are also seen in systems where cells have been immobilized intentionally for biotechnological reasons. Thus, cells immobilized in films can be used as models for processes in biofilms. They offer the possibility of investigating cell-cell interactions and other consortial processes in a defined system--investigations that are not really possible in films produced in nature.

There are several perceived advantages to the use of fixed biocatalysts in production systems, the most important of which is touted as economy of operation. However, from the papers presented, it seems there is not yet universal agreement about the scientific reasoning behind this statement. Nevertheless, the overall impression I gained was that immobilized cells are genetically more stable, are protected from hydraulic shear stresses and higher densities of biocatalysts (cells) can be achieved. As a result, this leads to shorter contact times in the reactor. When reporting on conferences such as these, generalizing can create problems. Causes can be the diversity of techniques used to immobilize cells, the extremely different types of organisms, and the many techniques used to compare cellular physiologies. Undoubtedly, any technique used to define the physiology of an immobilized cell must not change the environment in which the cell is living. The same, of course, applies to biofilm research. Intuitively obvious? Unfortunately not, and many investigations in the past have used homogenization of the fixed film of cells as a preliminary step to making measurements. The reasons for this are clear; it is difficult to sample reproducibly a film of cells or cells imbedded in a matrix. The conferences therefore stressed noninvasive techniques in assessing immobilized cell physiology. These techniques are just as relevant to the study of natural biofilms as they are to the systems described here.

Why Use Immobilized Cells in Biotechnology

Performance. In general, there appear to be no compelling biological reasons for the adoption of an immobilized cell system to carry out a biological transformation over a process based on suspended cells. Immobilization of cells in a matrix is an additional step in the biotechnological process. Moreover, in most cases this step has to be carried out aseptically. Thus, immobilized cell processes are only potentially useful if they offer some considerable procedural advantage, such as in the recovery of product; i.e., downstream processing. In each case therefore, the procedural advantages must be weighed against the investments to obtain them.

In a process where immobilized cells produce material that must be removed from the growth medium, it is obvious that a reactor effluent stream free of cells enables

an easier, and hopefully cheaper, product recovery. There are instances where cells immobilized in a continuous-flow reactor can offer a further procedural advantage over suspended cells. Where there is considerable preparation time before cells begin forming the required product, a system where the biological process is poised at the production stage is obviously advantageous.

Michael Dempsey, Manchester Polytechnic Institute, England, made this point rather clearly using as an example *Zymomonas mobilis* immobilized naturally on coke; i.e. no matrix was used to keep the cells in place. In this system, run as a fluidized bed reactor, Dempsey's group achieved flow rates equivalent to 11.5 times μ_{max} with a biomass concentration 15 times that for suspension cultures in conventional stirred reactors. Even so, the concentration of continuously prepared ethanol in the effluent medium was only 7 percent (cf batch fermented ethanol about 12 percent). As was pointed out by a questioner (Nicholas Emery, University of Birmingham, England), a continuous process such as this one is unlikely to be very cost effective unless all the substrate (glucose in this case) is used up on a single pass through the fluidized bed. In Dempsey's experiments 90 percent of the glucose was used.

Ethanol is a primary cellular metabolite; i.e., one that is produced as a result of growth. Since growth in cells that are immobilized is somewhat restricted, it is more reasonable to consider secondary metabolites for production by such systems. In this context, B. Hahn-Hägerdal, University of Lund, Sweden, showed that the production of penicillin G was slower in immobilized *Penicillium chrysogenum* than in washed freely suspended mycelium. In contrast, there was a 1,000-fold increase in capsaicin production in immobilized cultures of a plant cell line from *Capsicum frutescens* (V. Bringi and M.L. Shaler, Cornell University, Ithaca, New York). Similarly, alkaloids are retained at an enhanced level in the medium by the ergot fungus *Claviceps purpurea* when it is entrapped in a calcium alginate gel compared to the situation where the cells are freely suspended. Production of alkaloids was, however, slower in entrapped cells (M. Lohmeyer et al., University of Münster, FRG).

Plasmid Stability. The loss of plasmid recombinant-DNA from commercially used genetically engineered cells is a problem inherent in its nongenomic location. There appears to be general agreement that immobilized plasmid-bearing cells are genetically more stable than their freely suspended counterparts. Several groups substantiated that this effect is an indirect result of immobilization. For instance, Barbotin et al., University of Compiégne, France, showed that when *Escherichia coli* containing the plasmid p TG201 is immobilized in K-carrageenan beads, the plasmid is twice as stable as in cells grown in continuous culture over 200 generations.

In the same laboratory, it was further shown there was more rapid decline in plasmid number in cells at the surface of a carrageenan slab than in the interior. The process of loss of plasmids is not restricted to bacteria. Yeast containing a plasmid encoding for a *Bacillus subtilis* ß-glucanase also loses its extra-chromosomal DNA when allowed to grow in suspension. This process is much retarded when the yeast is immobilized in Ca-alginate beads, a situation that has been exploited biotechnologically. Immobilized yeast in continuous reactors secrete 20 times more ß-glucanase (an extracellular enzyme) than cells grown in batch fermentation. Again, plasmid stability was greater in the core of the beads than at the periphery.

The consensus is that cells that have been immobilized do not grow as well as cells in free suspension. This alone causes them to retain plasmids. To this end it is better therefore, to immobilize cells at very high densities; i.e., 10^{10}/ml, to minimize growth in the immobilization matrix (Hahn-Hägerdal, University of Lund).

In the general area of stability, it has been suggested that immobilized cells are more resistant to bacteriophage attack than free-living cells (Morin, Agricultural Institute of Canada, Ottawa).

Methods of Immobilization of Cells

Matrices. Before describing such methods, we must distinguish between passive and active immobilization. That is, between cells that become fixed in place because they colonize inert particles (glass, carbon, and celite), or microporous organic polymers (polyurethane foams) and cells that are purposely immobilized in a thermosetting, (agarose, K-carrageenan) or chemically cross-linked, organic polymer (Ca-alginate, polyacrylamide, and glutaraldehyde/protein). No fundamentally new methods were described at these meetings nor did I find any in making personal enquiries. However, it is instructive to review some aspects of the papers presented which describe advances in existing methods, effects of matrices themselves and to provide a few typical examples of success. We will not consider here the types of microcarrier beads used to grow anchorage-dependent mammalian cells.

Methods. For the purpose of this report, we will consider methods as standard which involve Ca-alginate, K-carrageenan, polyurethane and polyvinyl foams, agar, and polyacrylamide matrices. I will not describe the many papers that used these techniques in a standard manner.

Usually, matrices of these materials are formed into beads of several millimeters in diameter by allowing the mixture to drop from a needle orifice into a curing solution; e.g., cold liquid, Ca^{2+} solution, and K^{+}

solution). Bead size cannot be lowered much below 1 mm using current technology, and their mass production for commercial utilization is difficult. The attraction of small beads is that the cells near their center suffer less from nutrient limitation than those of larger diameter (but see later remarks concerning the positive effects of physiologically stressing cells by immobilization in beads).

Siemann et al., Technical University of Braunschweig, FRG, described an apparatus for the reproducible mass production of beads as small as 0.25 mm. Cells and liquid matrix are fed through a spinning ring with more than 5,000 nozzles. The ring is immersed in a Ca^{2+} solution. Bead size is inversely proportional to spinning speed and not the size of the holes (nozzles) in the ring. Up to 2.8 Kg/hr of Ca-alginate beads could be made with only 5 percent of them being deformed. Since bead size could so easily be controlled, it allows this to be investigated as a variable in immobilization experiments--something that is not easily achieved with beads formed by extrusion from needles. No results of cellular activity within these beads was mentioned.

Britelaar et al., Agricultural University at Wageningen, described a second method to control bead formation. Here, thermosetting gels (carrageenan, and agar) were used with three types of cells--yeast, bacteria, and plant cells. The system was based on using membrane pump which was controlled from a sine-wave generator; i.e., the membrane resonated at the frequency produced by the generator. Results of varying the frequency were not presented, but for a given (unspecified) frequency, respiration of cells in beads in all matrices tried was considerably reduced when compared to those produced by the more usual extrusion technique. The only advantage to this resonant nozzle technique appears to be the speed of production of the beads. Although not mentioned by the authors, it should be possible to control bead size with this apparatus.

Polyacrylamide gel (PAG) is generally considered too toxic to cells to be used in immobilization experiments (acrylamide itself is also toxic to people!). However, some work still goes on with this polymer, probably because of the ease with which the pore size of the gel can be controlled and because of its chemical stability. Thus, Lusta et al., U.S.S.R. Academy of Science, Moscow, reported that a series of eucaryotes and procaryotes lost viability in PAG but that resistant clones could be isolated. On the other hand, Balakrishnan, Jawaharlal Nehru University, Jabalpur, India, found that *Bacillus thermoalkanophilus* immobilized in PAG produced satisfactory amounts of endoglucanase but a little less total enzyme than free cells over the period of the experiment. However, the immobilized cells continued to produce the enzyme until the end of the experiment (10 days), whereas the freely suspended cells stopped after 6 days. If the experiment had continued for a longer time, the immobilized cells would have outstripped the suspended cells in enzyme production. These results emphasize the need to consider all matrices when choosing to immobilize cells and not to dismiss any merely because they have been found to be toxic in other systems.

Working with the ergot fungus *Claviceps purpurea*, Kren, Czechoslovak Academy of Sciences, overcame adverse effects of PAG, chitosan, and K-carrageenan as immobilizing matrices. He used a low-temperature carrageenan, and modified its gel strength with locust bean gum to produce alkaloids from immobilized fungal hyphae.

A further innovative suggestion by this worker was using immobilized catalase in the presence of low concentration of hydrogen peroxide in the medium. Oxygen would be generated *in situ*, thus preventing the interior of the bead from becoming O_2- depleted because of mass transfer limitations. In my opinion, this procedure would have to be carefully regulated or the toxic effects of H_2O_2 would easily overcome any benefits gained. The inclusion in beads of microalgae as sources of photosynthetically derived oxygen has been suggested, but then light must be provided to the reactor interior. This is not a trivial task in a large industrial fermenter.

Problem solving was also the approach taken in a paper by Kawakami et al., Kyushu, University, Japan. These workers wished to make the conversion of 1-octene to 1,2 epoxyoctane a continuous process. The approach they chose was to immobilize the biocatalyst, *Nocardia coralline*. There is often a mass transport limitation of microbial activity in matrices used to immobilize cells. In this case, the situation is compounded because the substrate for the bioconversion, 1-octene, is barely soluble in the aqueous phase. Accordingly, Kawakami and coworkers immobilized *Nocardia* in a two-phase matrix containing a hydrophilic and a hydrophobic component. To achieve this, they used polydimethylsiloxane and Ca-alginate as well as including an aqueous component that consisted of the normal growth medium (30 percent by volume). Strictly speaking, these are three-phase beads; i.e., hydrophilic structural phase, hydrophobic structural phase, and an aqueous phase. The immobilized catalyst thus formed could be operated as a continuous multiphase bioreactor with the bathing fluid consisting of n-hexadecane and substrate. This paper is interesting to those scientists involved in operating biocatalysts in nonaqueous environments since it describes ways to overcome one of the problems inherent in this type of work; i.e., the instability of the catalyst in nonpolar solvents.

Kniebusch et al., Technical University of Hamburg, FRG, also used an unusual matrix in their bioremediation work. Here, they achieved catalysis of the chemical reactions with cells adhered to the surface in addition to

those inside the support, rather than the by more usual method of active immobilization in a gel. They used a gas-permeable polyetherimide macroporous membrane to separate the gas and liquid streams in a flow bioreactor. Colonization of the membrane pits by bacteria exposed them on one side therefore to oxygen, and on the other to the aqueous milieu containing compounds to be broken down or bioremediated. The membrane has the oxygen permeability advantage of silicones, but is much more easily colonized by bacteria. The aim of these workers is to design small instream bioreactors to treat pollutant streams at source with highly specific biocatalysts. Such bioreactors could possibly be designed for shipboard use, especially for the treatment of oil-laden bilgewater.

Early attempts to immobilize cells often used proteinaceous materials denatured and cross-linked with small aldehydes such as formaldehyde or glutaraldehyde--compounds that are universally toxic. Alterlis et al., University of Naples, Italy, overcame this aldehyde toxicity by using the nontoxic oxidized carbohydrate starch as a cross-linking agent for gelatine. Cells could be recovered from the matrix by digesting with trypsin.

At these meetings, there was only one paper presented on a new immobilization support (rather than matrix). Dempsey described using coke as a porous, nontoxic support for immobilizing yeast in a continuous fluidized bed reactor. (Coke is the end-product of coal distillation in the formation of coal-gas and tar). Advantages to using coke over other equally cheap alternatives (sand and granite chips) are its comparatively low density and its highly porous nature. The density aids in the flotation of the colonized particles and the porosity in the protection of the adherent yeast cells. Dempsey has also used the same system to immobilize sugar beet cells. Coke seems to be a promising nontoxic and inexpensive substratum for immobilized biocatalyst fluidized bed reactors.

Matrix Effects. Throughout the conferences, quite naturally the theme of many papers was the inherent advantages for bioconversion of immobilized cells over cells in suspension. However, often no real reasons were advanced concerning why the performance of immobilized cells should be physiologically distinct. Three papers addressed this question in particular.

Brits et al., Instituto Superior Técnico, Lisbon, Portugal, showed that freely suspended cells of yeast-producing ethanol and *Pseudomonas aeruginosa*-producing alginates were as active as immobilized cells if aqueous extracts of the matrix compound K-carrageenan were added to the medium. Although they had not yet identified the active fraction(s), it was suggested that Ca^{++}, Mg^{++}, or Zn^{++} were strong candidates.

Similarly, Thomasset et al., University of Compiègne, showed that the gelling ions Ca^{++} and K^{+} increased the alkaloid production of freely suspended *Coffea* and *Datura* plant cells. Further, they suggested that the immobilization process provided better cell/cell contact and allowed the establishment of the cell-generated chemical gradients that were involved in promoting secondary plant metabolism.

Although not strictly a matrix-effect, the paper by Schneider et al., National Research Council of Canada, is highly relevant to anyone working on biofilms. This group investigated the production of extracellular polymeric substances (EPS or slime) by *Pseudomonas aeruginosa* growing on surface of ultrafiltration membranes placed on nutrient agar. If the U/F membrane used allowed the diffusion of compounds of MW30-50,000 or higher, no slime was formed; i.e., EPS formation required the presence of some material of this size produced by the cell. The workers suggest that such molecules may be a component of the slime or a signal required for slime production. In this context, I suggest that this material may act as a transducer indicating that the bacterial cell is on a surface and maybe therefore, an example of surface-induced change in metabolism.

Reactor Types for Immobilized Cells

Considering the number of papers presented (120) at these meetings, few of the reactor types described could be considered innovative. This may have been because most of the authors were microbiologists rather than biochemical engineers. In fact, most studies seem to have been carried out using the simplest possible equipment; i.e., a packed bed or stirred reactor, rather than other, perhaps more appropriate systems. Few papers mentioned the reason for the choice of equipment, yet this is possibly one of the most significant variables in a process. Reactor design has profound effects on mass transfer in discontinuous systems. Exceptions to these generalizations were seen in the papers of Wilderer, Technical University, Hamburg, and Dempsey. Dempsey described the reasons for his use of yeast immobilized in the matrices of coke particles in a fluidized bed reactor. Notable in this paper were the large flow rates able to be used, the rate of product formation (ethanol) and high glucose consumption efficiencies at the high flow rates used. Wilderer's approach was quite different. His group is engaged in designing small *in situ* bioreactors for use in treating industrial effluent streams at source. In effect, these workers have produced a large hollow fiber reactor where there is only one growth tube. The tube is a semipermeable membrane that allows gas transfer but not liquid movement. Although not strictly relevant to this report, the approach this group has taken to bioremediation of effluent streams is worth mentioning. They maintain that the practice of trying to remediate the

bulked discharge from many sources is far harder than removing toxic materials from the waste of a series of single-product effluent streams. Thus their emphasis is on small, instream, fixed-biofilm treatment devices. (The matrix used here is described more fully in the section entitled Methods of Immobilization of Cells.)

Two studies were presented where choice of reactor was central to the investigation. Looby et al., Center for Applied Microbiology and Research, Porton Down, England, found that yields of Chinese hamster ovary cells (CHO) were higher in fixed-bed than fluidized-bed reactors. The reason for this, they speculate, is particle abrasion leading to a lower cell density in the fluidized-bed reactor. Hybridoma mouse cell yield in a fixed-bed culture system was higher than in systems where the cells were freely suspended. Antibody concentration per volume of medium was also increased. Moreover, antibody production continued for 100 hours longer in the fixed bed system than the suspended-cell system.

Baron and Van Capellen, Free University, Brussels, described a new type of bioreactor that allows good mixing at the level of the individual cell-containing bead, but with very low shear at the bead surface. The reactor, which depends on the principle of Couette-Taylor flow, consists of two horizontal concentric cylinders with the inner one rotating so the annular space between them that contains the medium is mixed. The horizontal flow of the medium and the mixing caused by the rotation of the internal cylinder sets up local eddies. These eddies promote mixing. Beads containing immobilized cells are therefore subject to mixing while entrained in the eddy. This system is not similar to the annular reactor described by Siebel and Characklis, Montana State University, Bozeman, because here the width of the annulus is 10 cm. In the reactor described by Siebel and Characklis, it is less than 1 mm.

Products From Immobilized Cells

Two kinds of products can be obtained as a result of microbial activity--growth associated primary metabolites and products of secondary metabolism. The product desired has considerable influence on the cellular immobilization method, the type of reactor chosen, as well as any process variables. To list the many products mentioned in these meetings is beyond the scope of this report. However, some general rules are emerging. If a growth-associated product is desired, it is undesirable to use cells immobilized in beads. Cellular growth leads eventually to the destruction of the bead. A system that is better for this type of product is where cells are attached to a surface of a carrier such as glass or a plastic foam. Secondary metabolite production is sometimes favored by immobilization because in some cells, crowding along with restricted diffusion, promotes this type of metabolism.

Bringi and Shuler, Cornell, University provided a striking example. In this paper, it was reported that cells of tobacco, when immobilized in Ca-alginate beads, underwent cellular differentiation to produce tracheary elements. Differentiation in plant cells is considered to be a visible example of secondary metabolism. The greatest degree of differentiation took place in the center of the bead. This implies that the signal to differentiate could be related to the relatively lower concentrations of nutrients such as phosphate and O_2 in the center of the bead. Differentiation is not seen in cultures of suspended plant cells, except when aggregates form.

A paper from Syldatk's laboratory, Technical University of Braunschweig, FRG, was unusual on several accounts. These workers used cells of *Chlorella* or *Synecchococcus* immobilized in alginate to reduce acetyldimethyl phenylsilane to hydroxyethyl dimethylphenylsilane enantiometrically. Both free and immobilized cells produced the chiral alcohol in high yield, but the immobilized cells remained active over 14 cycles without significant loss of activity. However, the free cells lost activity after one, and had no activity after seven such cycles. No other paper surveyed potential matrices to the extent this one did or used algae in enantiometric transformations. Further, the use of immobilized biocatalysts to transform silicoorganic materials was unique.

Physiology of Immobilized Cells

Is the physiology of immobilized cells different from that of freely suspended cells? Before examining the evidence on this question, it is pertinent to consider if there are reasons why immobilized cells and their freely living counterparts could be physiologically distinct.

Karel, University of California, Berkeley put this quite succinctly! "Do cells know they are immobilized?" The most obvious difference between the environments in which these groups of cells find themselves is the degree to which free diffusion can take place. Cells entrapped in a matrix or even in a natural biofilm are subject to diffusion limitation; i.e., the transfer of substrates to and metabolites from them is reduced because the diffusion pathways are lengthened. Free diffusion for small molecules in the gel matrices themselves is only a little slowed from that in water. Nevertheless, substrate limitation of O_2 will lead to a situation where anaerobic or at least microaerophilic conditions will exist inside a bead containing aerobic organisms. Quite obviously, this will lead to either death of cells in the center of a bead or, if the organism is facultatively anaerobic (e.g., yeast), anaerobic metabolism. Similarly, lack of combined nitrogen without carbon limitation will lead to conditions

where the composition of the immobilized cell will change towards the synthesis carbohydrate or neutral lipid/triglyercide; e.g., ß -polyhydoxybutyrate.

Of course, given the same nutritional stresses, well-mixed, free-living cells will react similarly. The exaggerated physiological response of immobilized cells therefore, may be more a product of geometry rather a physiological change *per se*. More specific responses of restricted diffusion are possible, however, especially where metabolic activity is controlled by feedback regulation by extracellular products. This behavior can be considered as a response to crowding of the population, making cell-cell interaction more likely. Such responses are more common among eukaryotes than procaryotes.

Evidence For and Against the Question. One of the problems in assembling evidence of this kind is that the techniques used to decide whether various populations of cells are different physiologically from others are rarely the same from paper to paper. For instance, measurements on suspended cells are made usually when they are in the logarithmic phase, yet immobilized cells are in what is often referred to as a pseudo-resting state; i.e., they are not growing logarithmically. In the two symposia, I counted the papers and posters where a definite decision was made; i.e., whether cells were more active, less active, or there were no physiological changes detectable. Ten authors reported greater activity and five reported no change. There were no reports of cells that were less active on immobilization. In judging this result, one must bear in mind the bias of the authors. In general, they were at the meeting to promote immobilization of cells for biotechnological purposes! Below are some of the papers exemplifying perceived differences between entrapped and free cells.

In free-living cells of the cyanobacterial genus *Anabaena*, the interheterocystous distance along the filament measured in numbers of vegetative cells is constant. When filaments of *Anabaena azollae* are immobilized in polyurethane foam, heterocysts are found more frequently. Furthermore, as one might expect, nitrogen fixation on a chlorophyll basis is also increased to the extent that NH_4+ is secreted from the foam-entrapped cells. Mucilage secretion also appears to be involved in this physiological response by Browers et al., University of Liege, Belgium.

Bisping et al., University of Münster, showed that cells of *Pichia* (yeast) in alginate beads behaved as though they were osmotically stressed; i.e. they converted a large fraction of the growth substrate glucose to glycerol. Moreover, they underwent a morphological change from ovoid cells to a pseudomycelium. Papers on mammalian cells were not common at these two conferences, but one described a phenomenon of great practical importance and very relevant under the present heading. The CHO cells adapted to growth in serum-free medium when immobilized in collagen microspheres, whereas free living cells did not (Venkat, The Heinz Co., Pittsburgh). This has considerable impact for animal cell biotechnology. No biochemical or physiological reasons were advanced to explain this ability of CHO cells to adapt to the removal of serum from the medium. However, it was speculated that it was because of differences in microenvironment.

Similarly, Bunch et al., University of Kent, U.K., showed that *Streptococcus faecalis* undergoes the same aerobic/anaerobic change in metabolic patterns when immobilized that it does when O_2 is withheld. Karel made this point earlier more generally; i.e., immobilized cells that do not suffer mass transfer limitation will not behave differently from suspended cells. Evidence in favor of this explanation came from Smith et al., Agricultural University at Wageningen. When they immobilized cells of *Mycobacterium* at very low cell densities in alginate, no differences were observed between these and free cells. Reduced pyridine nucleotide generation and utilization was measured with 1,2-propene as substrate, as well as the energy status of the cells.

Again Kuenen, Delft University, the Netherlands, using O_2-microelectrodes, showed that immobilized cells (agarose) of the mixotroph *Thiosphaera pantropha* were similar to chemostat-grown cells with respect to their growth kinetic parameters (i.e., μmax, qo2 and Kacetate). In most cases therefore, immobilization or entrapment of cells causes a stress response, a phenomenon quite familiar to the microbial biochemist.

Stouthamer, Free University of Amsterdam, the Netherlands, made this the subject of a biochemically detailed talk--the only one in the two symposia. Stouthamer began his talk with a discussion of the rationale for the use of chemostats in studying slow growing cells. Maintenance energy is one of the parameters used in dealing with the stoichiometry of substrate utilization in a chemostat. This energy is derived from substrate metabolism that does not give rise to growth, but merely maintains the physiological status of the cell. The concept has been well accepted for the last 25 years. Whether the amount of substrate utilized for maintenance is independent of growth rate remains controversial. This is largely because it is extremely difficult to grow cells at very low growth rates. Where estimates of maintenance energy at low growth have been made, they are often extrapolations to zero growth rate of curves prepared by plotting growth rate (x-axis) versus substrate concentration (y). The intercept on the y-axis at zero growth rate is the maintenance energy, provided the equation relating these parameters is linear. Stouthamer explained that it is not a linear relationship and the reasons for excluding classical chemostat experiments from this type of work.

First, the composition of slowly growing cells is different from that of fast growing cells. The former contain more protein, but this protein is turning over faster. There is also less efficient use of messenger RNA (m RNA) and less RNA synthesis in general. Stouthamer maintains that cells growing very slowly are really starving and therefore exhibit *alarmone* response. *Alarmone*, or "stringent response" is triggered by amino acid or energy limitation and involves guanosine tetraphosphate (ppGpp) and guanosine pentaphosphate (pppGpp). Protein turnover in bacteria is proportional to the ppGpp content of the cells. Thus slowly or barely growing cells; i.e., the types found frequently in immobilized cell reactors, are not merely biochemically less active forms of fast growing cells, but are very different indeed. Stouthamer went as far as to say that Pirt's growth equations do not apply at low growth rates. The maintenance coefficient is not a constant parameter, but one which decreases at lower growth rates. Cells relatively rich in ppGpp have lower glucose uptake rates, but synthesize more glycogen than normal cells.

Stouthamer's paper provided a fresh approach to examining the physiological changes that may occur when cells are immobilized. He proposed the use of a fed-batch reactor with a medium recycle loop to study this phenomenon rather than a classical chemostat. Supporting the idea that cells in immobilized matrices exhibit "stringent responses" is suggested by the observation of their loss in biocatalytic activity under nongrowing conditions and its prevention by the occasional addition of low levels of growth substrates.

Noninvasive Techniques to Study Immobilized Cells. At Warwick University, there was little mention of the means by which one can study immobilized cells, *in situ*. At the Agricultural University at Wageningen, this extremely important topic was covered well. However, older studies of fixed cells suffered from our inability to take relevant samples for analysis. Often the three-dimensional structure of the film was destroyed by these methods and subsequent physiological measurements were invalid. Consequently, noninvasive techniques are needed. This is not to say, however, that a technique that does not depend on a homogenization step is noninvasive.

Take the case of the microelectrode to measure oxygen or other chemical profiles. The electrodes, although small at the tip (1-2μm.), are still large enough to disrupt a redox gradient in a thin film. Therefore, it is important, to use these electrodes with care. The redox profile measured while moving gradually in towards the substratum and through the film should be duplicated when the electrode is moved in the opposite direction (the electrode withdrawal profile). The thinner the biofilm, the more important this is.

DeBeer et al., University of Amsterdam, described how two new electrodes could be used in conjunction with a classical Clark-type-O_2-electrode to measure all the major reactants and products in natural aggregates of nitrifying bacteria; i.e., gradients of NH_4+, NO_3-, and O_2. From their results they concluded that biofilms of more than 100μm were inefficient at oxidizing ammonia. These new types of electrodes will be useful in microbial ecology but are not sufficiently selective to use in marine systems. The work of the Delft group (G. Kuenen et al.) on the use of O_2 microsensors has been mentioned earlier.

Most of the other techniques mentioned at the symposia were physical and relied on some type of spectroscopy. In these techniques, the only invasion of the biological films is by the electromagnetic radiation used for the spectroscopy; but, in almost every case, the fixed cells have to be situated in the optical system of the spectrometer. This means that analysis of films in nature is not possible unless they are formed in a device such as an nuclear magnetic resonance cuvette (for NMR spectroscopy) or on a germanium prism (for Fourier transform infra-red spectroscopy). Both of these techniques, as well as others, were covered at the Wageningen meeting.

Clark, University of California at Berkeley, reviewed most of the methods currently in use in immobilized cell investigations. From his presentation and those of Lohmeier-Vogel et al., Calgary, Canada, and Angela-Taipa, Centro de Technologica, Lisbon, Portugal, it was evident that NMR holds the most promise for future studies of the biochemistry of immobilized cells.

Further, the advent of NMR-imaging holds even greater promise. Imaging depends on proton resonating nuclei rather than those of the more usual ^{31}P or ^{13}C. Potentially, imaging NMR could be combined with the spectroscopic version so that it is possible to assign specific biochemical reactions to particular cells or horizons in a biofilm. There appears to be far less potential for Fourier transform infrared spectroscopy (FTIR) since it is not selective at the level of the small molecule. The FTIR has some use as a monitoring system for instream biofilm studies, for instance. As an example, Clark cited the increase in the amide-stretching signals gathered using the attenuated internal reflectance technique during the time that a culture of CHO cells grew to confluence on the surface of a germanium prism.

Clark also reviewed electron spin resonance spectroscopy. He gave no examples of its use with immobilized cells, nor did anyone else. I do not see this technique as being very useful to study cells in a matrix since it is dependent on the presence of spin-probes that must diffuse uniformly through the immobilization matrix for results to be valid.

An as yet unproved mass-spectroscopic system was described by Willaerts et al., Free University, Brussels. The apparatus is similar to that pioneered by Bessel Kok in his work on photosynthetically produced chemical transients. An immobilized cell system is separated from the mass-spectrometry inlet by a membrane, the permeability of which specifies the type of molecule detected in the mass spectrometer. Willaerts and colleagues used a quadropole mass spectrometer and only volatile compounds were measured. At the same time, there is considerable potential for this to be developed. These workers also mentioned a second type of reactor. In this apparatus, the membrane supporting the immobilized cells was washed continuously on its reverse side, and the washings analyzed by an appropriate technique (electrochemistry, chromatography, mass spectrometry). I have proposed a similar reactor to study volatile acid production by microbial films involved in corrosion before, but the addition of MS-analysis would greatly improve this suggestion.

Malinski et al., Oakland University, Michigan, described a further unique method to measure cellular activity on surfaces. These workers allowed cells of baby hamster kidney (BHK) to adhere to the surface of indium oxide coated glass electrodes. They then measured the impedance and resistance of the cells. When insulin or vanadate was added to the liquid bathing the cells, their resistance fell to a plateau of about half that of the untreated controls. Both compounds are known to modify ion-flux in mammalian cells. This technique could be used to measure the physiological status of cells in films as a function of the external concentration of some other plasma membrane perturbants of interest to the antifouling industry. There seems the possibility of using regimes of successive molecules as well as to measure biofilm penetration rates. Only mammalian cells have been investigated so far.

Most of the systems I have described are expensive. Scheper et al., University of Hannover, FRG, described a system that promises to be relatively inexpensive. Reduced pyridine nucleotides are intimately involved in metabolism and they are fluorescent at 460nm when excited at shorter wavelengths. Thus, they form ideal reporters of cellular activity. If whole cells are excited and the emission collected using *in situ* fiber optics, the system becomes a monitor of cellular health. This idea is not new, but seems to have been used little in biofilm research so far. The idea could also be used with cells that contain the lux-genes as reporters of gene expression.

Other Methods. Some forms of microscopy can be regarded as noninvasive, but most forms of the technique require some kind of sample preparation and these must therefore be regarded as invasive. Several workers mentioned the use of microscopy in their studies. I will not describe results obtained with internal reflectance microscopy, image analysis, or the various forms of electron microscopy, since these techniques are well known. Less known, especially in the field of the study of immobilized cells, is the use of the microscope as a microfluorimeter.

Ollis et al., North Carolina State University, Raleigh, measured the relative RNA and DNA contents of alginate beads at various distances from the center of bead. The lateral resolution of the analysis was about 10μm. The results showed that specific RNA content of the beads, which is related to RNA/cell, is twice as great at the periphery of the bead as in the interior.

Again, this technique could be used in conjunction with the biofilm slicing technique described by Bryers and Banks, Duke University, Durham, North Carolina, for estimates of relative cellular growth rates in fouling films. I believe this technique is sufficiently novel to bear more detailed description. The goal of this laboratory is to understand the processes controlling the population dynamics during the formation of a biofilm. As pointed out by these workers, films in nature are always of the mixed variety, yet most investigators, because of the complexity of modeling mixed films, work with monospecific films. Completely natural films are almost useless as systems for study at this stage of our knowledge since we cannot yet even assess quantitatively the types of organism in a film. Bryers and Banks described two types of system.

The first, a natural enrichment of acetate-oxidizing organisms was mixed with an autotrophic enrichment of nitrifying bacteria. A second series of experiments was carried out with a biofilm containing the heterotroph *Pseudomonas putida* and a *Hyphomicrobium* species. These organisms were metabolically distinct in that the *Pseudomonas* metabolized only glucose and the *Hyphomicrobium*, methanol in the mixed glucose/methanol reactor feed. The reactor was a small duct 2.5-cm wide by 0.1-cm deep and 7.6-cm long, which allowed the placement of standard microscope slides on its base. Removing a slide gave a more or less undisturbed section of the biofilm in the duct as a sample. To enumerate the organisms in a film, a sample of the biomass was removed as described above and incubated with labelled substrates ($NaH^{14}CO_3$ and ^{3}H-acetate for the autotroph/heterotroph biofilm and $^{14}CH_3OH$ and ^{3}H-glucose for the mixed heterotrophs). After incubation, the labeled films were washed, fixed, and embedded in electron microscopy sectioning resin. Slices of the embedded film (20m) were placed in appropriate cocktail in a liquid scintillation counter set for double-label counting. Previous calibration experiments allowed the results to be expressed as biomass (dry weight) of cells per slice thus making it possible to determine spatial variation of cells with time.

Using these techniques, Bryers and Banks showed that microscopical examination of the effluent from a reactor does not give the species composition of the film (unless the film is uniform and all species of cells slough at exactly the same rate). The system can be adapted to use immunofluorescence as the detection system rather than radioactivity. In this case, dead as well as live cells would be counted. These workers have coupled image analysis to the examination of unfixed cells. This technique also could be used to assess radioactivity in individual cells after autoradiography of the biofilm slices.

In this work, no account appeared to be taken of inter-species metabolite transfer or anaplerotic CO_2-fixation by heterotrophs. This could be quite significant in cells growing on 1- or 2-carbon substrates. In spite of these reservations, this technique to measure species dynamics in a mixed film is very useful and can be adapted to assess inter-species carbon transfer.

Modeling the Metabolic Activities of Immobilized Cells

The lesson to be learned from the two symposia was that so far, most modeling effort have been "naive" and "glib",(Hamer, ETH, Zurich) or perhaps based on "fantasy" (Karel et al., Princeton University, New Jersey)! The most critical of the two is Hamer. His basic complaint rests largely with the engineering community and their slowness to appreciate the fact that linear models of biological phenomena rarely fit completely, usually because the biological process is not linear! Furthermore, just because a linear model appears to fit a process well does not mean it is biologically predictive. He believes that the universal application of material balance equations that assume that cells have constant composition irrespective of their growth rate is too simplistic (see earlier remarks in Physiology of Immobilized Cells).

Other problems that Hamer sees concern the general lack of appreciation of the influence of microenvironments. This is compounded by the fact that modelers usually base their equations on measurements made in the macroenvironment. Developing this further, Hamer believes there are no true steady states since there are gradients everywhere. Although it might be argued that diffusion patterns at least in a laminar flow situation, are uniform, it is more than likely that they are not, because of the existence of microturbulence or eddies. The influence of such eddies on mass transfer to cells from media undergoing laminar flow is hard to predict.

An example of the concerns as expressed by Hamer is demonstrated in a paper given at the same symposium. Siebel and Characklis, Montana State University, modeled a mixed biofilm of *Klebsiella pneumonia*, and *P.aeruginosa*. The organisms are treated as aerobic heterotrophs, which under conditions of oxygen excess, they are. However, in conditions other than this, *Klebsiella* is facultatively anaerobic. Thus, specific glucose consumption rate will not be related linearly to the oxygen consumption rate--a fact shown by their experimental data but not by the model presented.

Karel and his coauthors at Merck, Sharp, and Dohme, and Stanford University, Stanford, California, echoed some of Hamer's thoughts concerning microenvironments and their influence on cellular activity in films and matrices. Neither the other papers presented nor my previous experience in the field convinced me that the reservations expressed by Hamer and Karel were unfounded or exaggerated.

Geographic Distribution of Papers and National Emphasis

One should not predict the location of centers of research activity based on a small number of papers presented at one geographic site In this case, there were two sites involved and 120 papers, so I feel comfortable in doing so.

The major European centers of activity in immobilized cell research are in the Netherlands, the U.K., and the FRG. This distribution agrees with my perception of the relative scale of biotechnological research in Europe. The leaders in Europe are followed closely by France, Belgium, and Spain. Seventeen other countries were represented at these conferences. Notable centers of research in Europe are the University College of London, U.K.; University of Compiégne, France; the Center for Biotechnology, Sofia, Bulgaria; and Agricultural University at Wageningen, the Netherlands. The expertise in immobilized cell research is not concentrated in a particular center in Germany, but the Technical University of Braunschweig has an active group. The use of particular techniques is randomly distributed, but there is a greater emphasis on sophisticated, and thus expensive, physical instrumentation in the U.S. than in Europe.

Research Needs

The techniques used to immobilize cells for biotechnological purposes are not new, nor are the matrices that are used. As this sphere of activity progresses and begins to encompass organisms from other areas of biotechnology, better means of immobilizing cells will be needed. For instance, no papers at either of these meetings concerned the biotechnological uses of thermophilic microorganisms. Yet there is a large research effort aimed at using organisms at elevated temperatures. Few of the matrices used now are useful at higher temperatures, and those

that would be stable may well be toxic. There is a need to find a replacements for Ca-alginate. Calcium is a regulatory ion, especially in eukaryotes, and to immobilize a cell in a high Ca environment seems counter productive to achieving catalytic stability. Greater stability of the biocatalytic activity is a need even at mesophilic temperatures. Organisms immobilized in a nongrowing state lose activity after a few cycles in the reactor. They can be reactivated by allowing a short period of growth to take place. To understand this phenomenon is important. What is the mechanism of inactivation and reactivation of immobilized cells? Possibly, mutants could be exploited that can metabolize at some basic low maintenance level, but cannot divide. They should be catalytically more stable than wild-type cells.

Those interested in the activities of natural biofilms may well be able to exploit immobilized cell technology to form model, defined films. However, since natural films always consist of more than one organism, it will be important to understand how films of mixed species can be made and to what extent organism-organism interaction takes places. Such mixed films could be used for multi-step reactions, or one organism could be involved in generating the conditions, for the other to operate; e.g., poising of E_h.

Research with organisms in films will be facilitated if we have a greater battery of noninvasive techniques to exploit. Nuclear magnetic resonance spectrosocopy seems to be the method of choice, but this is expensive and requires a special reactor to be constructed that fits in the measurement well of the instrument. The current microelectrodes are still rather large in comparison to the size of a film of cells only a few cells thick. Smaller electrodes would be an advantage as well as electrodes with other chemical sensitivities. Better, noninvasive techniques will enhance greatly our knowledge concerning the interactions between cells in films and matrices.

Greater knowledge of the physiology of entrapped cells will allow more accurate modeling scenarios to be proposed, especially those dealing with nonlinear responses and cellular-interactions. Very few modelers have tackled the phenomenon of cellular interaction.

Finally, I believe that advances in all of these fields will allow the subject of microbially enhanced corrosion to be studied in an artificial system where corrosion rates can be obtained that are similar to those seen in nature. A correct mixture of organisms in a nontoxic matrix is necessary. The source of the metal could be colloidal iron particles included in the matrix. Further if matrix containing cells and iron were mounted on a semipermeable membrane, chemical analysis of reactions within the film could be monitored by any one of several techniques mentioned earlier.

The use of microorganisms in biotechnological endeavors is almost as old as civilized man. Their immobilization seems to offer us a means to control more closely desired catalytic processes.

COMPUTER SCIENCE

ESPRIT Basic Research Actions and Working Groups in Computer Science

by Robert D. Ryan, a mathematician currently serving as a Liaison Scientist for Mathematics and Computer Science in Europe and the Middle East for the Office of Naval Research European Office. Mr. Ryan is on leave from the Office of Naval Research Arlington, Virginia, where his is Director of the Special Programs Office.

Introduction

The purpose of this note is to provide a guide to the European Strategic Programme for Research and Development in Information Technologies (ESPRIT) Basic Research Actions and Working Groups in computer science. The motivation is my observation that colleagues in the U.S. are, in general, not familiar with the scope of research activity currently underway. As I indicated in a longer article about ESPRIT (ESNIB 90-06:41-46), all of this information is available in the ESPRIT documentation. With this in mind, my purpose is to make essential information--who, what, and where--quickly available to the readers of ESNIB who have not yet acquired the original material. I have also organized the information differently from the way it appears in the official documentation, where it appears sequentially by project number. Here I grouped projects by research area. The material for this article comes from my ESPRIT article cited above and from the original ESPRIT documentation. The first section discusses the motivation and ground rules for the ESPRIT Basic Research Actions and Working Groups.

Basic Research Actions and Working Groups

While ESPRIT I was becoming a major success in promoting cooperation on precompetitive research, there was a growing consensus within ESPRIT that supporting basic research in information technology (IT) is a solid investment with considerable payback, even if it does not come in the form of short-term industrial applications. This position is widely held in the United States, and, in fact, the level of U.S. funding for IT basic research is quoted in the European Community (EC) literature rationalizing the establishment of a basic research program within ESPRIT II.

The EC managers also realized that the ESPRIT I ground rules excluded important work being done at universities and research institutes. At the same time, public funding for basic research in national programs was decreasing because of the growing emphasis on industrially oriented research.

After considerable debate by leading European researchers, the ESPRIT management adopted these objectives for the first ESPRIT Basic Research Actions:

- To support collaborative fundamental research in selected IT areas
- To increase the involvement of leading research teams in ESPRIT.

In keeping with the ESPRIT spirit, it was agreed to not spread limited resources thinly over all possible areas of interesting, or even exciting, research, but to set up criteria to define the scope of the Basic Research Actions. Thus Basic Research Actions

- Should have the potential to produce future breakthroughs or important advances even though they might not have any immediately visible applications
- Should fall in areas where collaborative research on a European scale brings added value
- Should be clearly upstream from main precompetitive research and development.

Basic Research Actions operate under modified ground rules. Most significantly, it is not necessary to have two independent industrial partners in different member states. Two of the partners must come from different countries, but they need not be industries. They may be universities, research institutes, or industrial research laboratories.

The first call for proposals came on March 25, 1988. By the deadline, about 300 proposals were received, representing requests for 485 million European Currency

Units (ECU) for a total research effort exceeding 1 billion ECUs. This response was much greater than expected. The proposals were of generally high quality and involved most European teams working in the forefront of basic IT research.

After evaluation by the European Commission (Commission) and recommendations by the ESPRIT Management Committee and the ESPRIT Advisory Board, 61 proposals involving 285 different organizations were funded. In addition, 13 proposals were joined in working groups and given limited support to facilitate cooperation through travel and workshops. This latter action underlines the importance the ESPRIT management places on cooperative efforts.

Future Basic Research Actions will be selected to

- Maintain dynamically coverage of key areas
- Reinforce interdisciplinary links which open new ways of looking at major problems
- Ensure that the scarce qualified manpower needed for basic research is available
- Make certain that the results of research are transferred downstream to industrial research.

The ESPRIT takes this last point seriously, and to this end requires that each action hold a workshop once a year. Invitations are issued to participants in related Basic Research Actions and to industrial researchers who can provide feedback on the suitability of the results for addressing industrial problems. Some workshops will encompass activities of several actions in related areas. They also will act as focal points for developing special training schemes on emerging topics where qualified manpower is scarce.

Funding for Basic Research Actions is only about 10 percent of the budget. However, I have been told that basic research funding is increasing.

Organization

The current ESPRIT actions and working groups fall into three areas: microelectronics, computer science, and artificial intelligence and cognitive science. This article deals only with computer science plus two actions from microelectronics that concern formal methods. The information presented here, is, for the most part, that presented in the ESPRIT documentation. In turn, this was clearly taken from the proposals to ESPRIT. Thus, the research descriptions sound somewhat ambitious and are often written in a "selling" mode. I have edited these in places, and I have grouped similar research actions and working groups together. This taxonomy is not unambiguous, but it should help to identify related work.

Logic and Algebra

Categorical Logic in Computer Science (CLICS) Action Number 3003

This action is motivated by the belief that recent developments in category theory and the categorical approach to logic are ripe for application in a number of important areas in computer science. The goals of the action are:

- Deeper understanding of type structures for programming languages
- Systematic accounts of denotational, operational, and axiomatic semantics for programming languages, with emphasis on the connections between these kinds of semantics and the possibilities of automatic derivation of one from another
- Development of logics for computable functions, which exploit constructivity and the powerful machinery of categorical logic to provide a better match between the logics and the computational concepts being modeled
- Development of a framework for logics and models of parallel computation and the theories of specification in which the highly diverse and superficially disparate work in these fields can be unified and integrated with work in other areas. This is essential if different programming and specification paradigms are to be successfully united, and if the fundamental and enduring concepts are to emerge from the current babel of competing formalisms.

An important aspect of this action is to produce a supply of research workers in computer science who have a thorough grounding in categorical methods.

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Computational Logic (COMPULOG)
Action Number 3012

The ultimate objective of this action is to develop the foundations for an integrated, logic-based software environment. The environment would extend existing logic programming languages by using related techniques developed in computer algebra, deductive databases, and artificial intelligence. Also included are logic-based tools for incremental development of knowledge bases and programs, for transforming programs, and for programming-in-the-large.

The immediate objective will be tackled by investigating related developments of computational logic in the three areas of artificial intelligence, deductive databases, and logic programming.

Computational logic is understood here as the use of logic to represent "knowledge" and the use of deduction to solve problems. The main technologies to be developed are language extensions, knowledge assimilation, and meta-level reasoning.

Language extensions include constraint logic programming and object-oriented structured types. Work on knowledge assimilation will develop techniques for integrity checking, belief revision, incremental program development, and hypothetical reasoning. Work on meta-level reasoning will develop metalogical language constructs, metalogical techniques for knowledge representation, programming-in-the-large, and program transformation.

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The Semantics and Pragmatics of Generalized Graph Rewriting (SEMAGRAPH)
Action Number 3074

The principal objective of this action is to develop knowledge relevant to the semantics and pragmatics of generalized graph rewriting. In this context, the notion of graph rewriting theory extends the term to include sharing, nonroot rewriting, and explicit control of reduction order. These can be used for optimized reduction, side effects, process communication, and synchronization. Taken together, these extensions provide a potentially unifying framework for a variety of models of computation including:

- Functional languages
- Logical languages
- Object-oriented languages
- Parallel generalizations of imperative languages.

A number of computational models have been considered as a possible basis for a "common virtual machine" to support work on various symbolic and other languages. While no common model is presently known, one based on graph rewriting might succeed. An important aspect of the action is that it brings together participants from various European information technology programs in a united attempt to develop further basic knowledge about graph rewriting.

This action is a program of investigation into the foundations of graph rewriting, which will bring together and extend knowledge on the following areas of generalized graph rewriting systems (GGRS):

- Formal descriptions and abstract models
- Relating other models to GGRS
- Controlling reduction order and typing
- Static analysis
- Efficiency of normalizing lambda graph reducers.

Significant progress is expected on identifying those results that carry over from the term rewriting to graph rewriting. The project will lead to a better understanding of the constraints on a rule system necessary for efficient implementation. Such results will be interesting to some of the larger ESPRIT II projects, particularly those concerned with the general- and special-purpose rewriting formulations of both symbolic and numeric problems for parallel machines.

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Algebraic and Syntactic Methods in Computer Science (ASMICS)
Working Group Number 3166

The aim of this working group is to bring together a collection of researchers from various parts of Europe to collaborate on problems of mutual interest in algebraic and syntactic methods in computer science. The research is divided into four subareas:

1. Combinatorics on words and the theory of codes

- String-matching algorithms and problems linked with data transmission, including data compression, structure of codes, equations in words, and similar issues
- Modeling of parallelism by "partially commutative" words
- Words also allow the encoding of a large variety of problems: algorithms, data structures, counting problems, tiling problems, planar maps, generation of combinatorial objects.

2. Formal language and grammar theory

- Decision problems related to rational expressions. Properties of grammars and rewrite systems: presentation of structures by confluent rewriting systems. Extension of the standard theory of languages and grammars on words to trees and graphs
- Validation of distributed systems and algorithms via subsets of the free partially commutative monoid
- Syntax mappings and syntax-directed translations.

3. Theory of automata

- Mathematical tools of automata theory: semigroups, formal power series, dynamical systems and discrete iteration theory, combinatorics and graph theory, formal logic (model theory, games)
- Automata on words, on infinite words, on trees and graphs, automata with output, automata with multiple inputs, alternating automata, connections with logic and circuit complexity
- Modeling of parallel and distributed systems by automata networks and cellular automata: performance analysis, synthesis, and optimization of networks.

4. Process algebras, infinite behaviors of parallel programs and systems

- Algebraic, topological, and algorithmic properties of sets of infinite behaviors of processes and of automata, temporal gic, and automata proof techniques
- Axiomatic definitions of process algebras, traces, and event structures. Study of standard calculi like CSP and CCS.
- Efficiency measurements of synchronization mechanisms.

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Logical Frameworks: Design, Implementation, and Experiment (LF)
Action Number 3245

Recently, there has been a steady increase in research towards systems that can provide assistance with reasoning about a variety of problems, particularly systems for the development of hardware and software. Such systems must be usable by programmers and hardware designers who are not experts in logic, and so must provide a comfortable, problem-specific environment for developing formal proofs.

A wide variety of formal systems is interesting to system designers (such as operational semantics, lambda calculi, sequent calculi, type theories, and first - and higher-order logics). The task of implementing a proof development environment for a given logic is daunting, and there is considerable duplication among implementations of different logics. Therefore, it is desirable to develop unifying theory of formal systems that allows one to give a concise specification of a given logic. The proof development environment can then be logic-independent, accepting a specification of the logic to be used. A "logic framework" is such a unifying theory of formal systems; it provides a notation and calculus for specifying logics.

The partners in this action have been experimenting with various AUTOMATH-related type theories, with variants of Church's higher-order logic, and with a general system of operational semantics as frameworks in which to conduct formal proofs. One aspect of the joint action is to understand the relationships among these systems. Apparently, based on present evidence, that some form of typed lambda calculus is a basic component of the desired framework.

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A Comprehensive Algebraic Approach to System Specification and Development (COMPASS)
Working Group Number 3264

The main focus of this working group is on formal methods for system specification and development. A major emphasis on software technology is currently on methods and development environments for the construction of generic, reusable software. The state of the art in this area allows specifying and checking of the syntactic aspects of interfaces of system components. A major breakthrough can be expected through the algebraic approach that supports precise specification of the semantic aspects of interfaces and their formal verification. The algebraic approach also provides a conceptual basis and practical tools for the stepwise formal development of correct system components from their specifications, and this covers the whole software development process from the specification to the finished system. These methods are potentially applicable to the development of correct hardware systems as well.

Originally the algebraic approach was most suited to the development of first-order applicative programs. Recently, new programming paradigms such as object-oriented, logic, and higher-order functional programming, corresponding theoretical concepts, and new application areas such as VLSI verification, net theory, concurrency, and distributed systems, have all merged. An important aim of the working group is to generalize the foundations and applications of algebraic methods in a comprehensive way, so that they accommodate modern programming methodologies and meet requirements of the aforementioned application areas.

The intention is to provide a comprehensive algebraic approach to system specification and development, to consolidate the theoretical background, to increase the power of support tools, and to encompass new programming paradigms and application areas. This will be a guideline for subsequent technology transfer, and could be the basis for a uniform European language and environment for system specification and development.

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Computing by Graph Transformations (COMPUGRAPH)
Working Group Number 3299

This working group is bringing together members of the most important schools for graph grammars and graph transformations on the international scene to make scientific contributions towards the following aim: the use of graph transformations to improve the efficiency, reliability, and correctness of computing at all levels from hardware to software, where computing includes specification, programming, and implementation by graph transformations as well as computational models and computer architectures for graph transformations.

The group intends to improve the state of the art in the following areas:

- Foundations
- Concurrent computing
- Ability to execute algebraic specifications and graph transformations in other areas
- Algorithmic and implementational aspects.

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Concurrency

Theories of Concurrency: Unification and Extension (CONCUR)
Action Number 3006

Formal verification of software programs, protocols, and chip design is becoming increasingly important as systems become more complex, as production becomes more expensive, and as testing is recognized as an insufficient guard against malfunction. Verification of concurrent or distributed systems has been undertaken only on a very small scale, haphazardly, and with a multitude of techniques and formal theories. Among the many formal approaches existing for concurrent communicating systems, the important algebraic approaches are represented in this action. The principal aims of the action are to explore the relationships among these different approaches, and to develop a formalism applicable to a wide range of case studies. The possibilities for integration are being investigated. The relationships and relevant roles for the algebraic theories and model-based theories are being studied. A list of open problems is being compiled. Methods pioneered in one group are applied to problems originating in another, and the results are compared. In addition to collaboration at the theoretical level, there is collaboration through the developing, using, and comparing software reasoning tools.

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Compositional Distributed Systems (CEDISYS)
Action Number 3011

The overall aim of the action is to develop a fundamental understanding of the nature of concurrency and to provide a formal framework useful for describing concurrent and distributed systems. This formal framework should support specifying and developing such systems and should lead to methodologies for proving systems correct and, more generally, for deriving their properties.

Many behavioral views of concurrent systems have been suggested. The most successful ones have one major drawback: they all interpret concurrency or parallelism as a linguistic shorthand for nondeterminism. Instead, this action will choose a framework that more correctly reflects the inherent concurrent and distributed nature of processes. This framework is sometimes known in the literature as the true concurrency approach. The action investigates various proposed formalisms for distributed systems and compositional proof methods for deriving their properties. The action will design new languages for these systems, elucidate new semantic models that emphasize nonsequentiality, and use their models as foundations for new logical frameworks. Prototype implementation of these new formalisms will be considered.

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Formal Methods and Tools for the Development of Distributed Real-Time Systems (SPEC)
Action Number 3096

The aim of this action is to obtain a framework for the development of distributed real-time systems that is both practically adequate and theoretically sound.

Recent research has produced specification formalisms and associated developing and verifying tools that have been successfully applied to small systems. For instance, temporal logic, automata, process algebras, and assertional methods have all been used with some success. The main insight is that existing formalisms are mainly complementary and that combining these formalisms can be very effective. For this reason, the problem of building bridges between different theories or applying them in combination to moderately large systems will be studied.

Besides combining formalisms, the research proceeds in two major directions: broadening the scope of existing formalisms and narrowing the gap between formal specifications and executable code. The focus of the former is on handling real time. The work on narrowing the gap between specifications and executable code involves methods for deriving implementations from specifications and the study of executable subsets of declarative specification languages, especially of executable temporal logics.

The action emphasizes development and verification tools. A main motivation is to test the applicability of formal methods to the development of reactive systems. Applications include hardware, communication protocols, and real-time systems.

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Provable Correct Systems (PROCOS)
Action Number 3104

The objectives of this action are to advance the state of the art of systematic design of complex heterogeneous systems, including both hardware and software, in particular to reduce the risk of error in the specification, design, and implementation of embedded safety-critical systems. The approach is to develop a concrete system consisting of the following five major components:

- Specification language
- Programming language
- Definition of a hardware machine

- Compiler from the programming language to the instructions of the machine
- Kernel supporting the execution of compiled programs on that machine.

The syntax and semantics of these components will be formalized, and their formal interrelationships will be established. The work will be based on the CSP/occam/transputer tradition. First, a simple occam subset and a simple transputer-like RISC machine will be selected and formalized as far as possible. Next, the employed methods will be generalized and improved, and the system design reiterated. The work will be supported by:

- Case studies of requirements for, and development of, safety-critical systems
- Experiments in computerized verification support
- Liaison with a number of related projects.

An early product will be a book on principles of constructing provably correct systems using the development system as a special case.

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Design Methods Based on Nets (DEMON)
Action Number 3148

The general objectives of this action are to explore a spectrum of important theoretical issues involved in formal reasoning about concurrent systems, and to develop a formal framework supporting the specification, design, and verification of large, sophisticated concurrent, and possibly decentralized, systems. This is approached through the Petri-net model, which benefits from a graphical representation that is intuitively appealing for informal use, and through a supporting formal theory, which captures the essential characteristics of concurrency and locality of state and action, and which is general enough to subsume all other formal models of concurrent systems. The focus is to enhance Petri-net theory, laying the foundations needed for a complete and effective design calculus for concurrent systems, including:

- Composition, refinement and abstraction techniques
- Algebras and proof rules
- Appropriate notions of equivalence and implementation
- Associated formal analysis techniques.

From a practical viewpoint, the essential contribution of the theoretical enhancements will be support for modular system construction and refinement of high level designs. In this way, the current frequent use of Petri nets as a graphical and analytic tool in the early stages of the design of individual parts of concurrent systems can be extended to include and integrate formal methods for all stages and aspects of the specification, construction, and analysis of entire systems.

The work is organized into two closely interrelated parts. The central part provides a few carefully chosen and thoroughly developed classes of nets with modularity and other properties required for the envisaged design calculus. The second part involves general theoretical work, case studies, and other input to the development of the required net classes and to the understanding of their relationship to other approaches. Latter work includes the construction of prototype design tools, including a textual Petri-net programming language.

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Programming

Integration
Action Number 3020

The aim of this action is to integrate the foundations of functional, logic, and object-oriented programming. Functional programming has its mathematical foundations in the fields of lambda calculus and term rewriting. Logic programming is rooted in predicate logic and automatic theorem proving. The integration of these two programming styles has been pursued vigorously for several years. For object-oriented programming, it is generally felt there is a strong need for a better understanding of its mathematical nature. There is evidence that one may profit here from insights from functional programming, for example, concerning notions of typing and inheritance, and from logic programming, for example, regarding the interplay between actions and deductions. These insights motivate this effort to integrate the three programming paradigms, which effort proceeds along three directions:

1. Integrating functional and logic programming
2. Integrating functional and object-oriented programming
3. Integrating logic and object-oriented programming.

Within each area, the work is organized into tasks, selected so that common problems and techniques may be identified. There are nine tasks. In each of the three areas, tasks dealing with semantic issues have been defined. These deal with extensions of the customary declarative semantics for logic programming, with subtyping for logic programming, and with parallelism for object-oriented programming.

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Semantics-Based Program Manipulation Techniques (SEMANTIQUE)
Action Number 3124

This action concerns software engineering. The aim is to emulate the industrial revolution by developing technology for manufacturing software under human guidance, but with much less detailed human involvement. There are three interrelated approaches.

The first thrust is to further develop methods for automatic program transformation. This is motivated by the success in manufacturing prototype compilers and compiler generators. The action will improve the power and applicability of automatic program transformation, investigate binding-time transformation, and use it to manufacture parts of highly optimized compilers.

The second thrust concerns semantic analysis, since automatic program manipulation depends on the automated "understanding" of programs. The plan is to extend the scope of abstract interpretation to new semantic frameworks and new problems, for example, to analyze parallel and logic programs.

The third thrust is the application of these techniques to the efficient implementation of declarative languages. This will focus on the incorporation of program manipulation methods into a prototype compiler for Haskell, the newly defined standard functional language.

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Hierarchical Integration of Logic and Functional Paradigms: Specification, Refinement, and Implementation (PHOENIX)
Action Number 3147

This action aims to develop the technologies necessary to make a practical declarative programming language that combines and extends current logic and functional languages. The research takes place not just at the language level, but at all levels in the hierarchy necessary to provide a practical method of mapping high-level system descriptions into efficient executions on a range of target machines, including parallel machines. Thus, as well as investigating and integrating language concepts and their semantic models, the action compares and

develops transformation and refinement techniques aimed at converting high-level specifications into efficiently executable forms, and develops abstract machines capable of supporting efficiently the transformed and compiled programs. These are some aspects of declarative languages being investigated:

- Semantic models for integrating logic and functional concepts
- Role of unification techniques in a combined logic and functional language
- Support for programming-in-the-large
- Declarative ways to provide descriptive features currently provided nondeclaratively
- Source-to-source transformation techniques including partial evaluation and algebraic techniques necessary to convert high-level descriptions into efficiently executable forms
- Intelligent analysis and compilation techniques
- Comparison of logic and functional abstract machines, and derivation of an abstract machine capable of supporting efficiently combined languages, as well as parallel evaluation.

The main results are expected to be:

- Hierarchy of language concepts with the full power of these languages available at the higher level, and an identified, efficiently supportable subset at the lower level
- Transformation and compilation techniques to convert between levels
- Abstract machines, allowing efficient execution of transformed and compiled programs.

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Common Foundations of Functional and Logic Programming
Working Group Number 3230

The common foundations of functional and logic programming are found in the proof theoretic results of the 1930s. The Curry-Howard isomorphism of formulae as types, and proofs as functionals, can be adopted as a common paradigm for various approaches to declarative programming. Two different activities are distinguished within this paradigm:

1. Given a type (proposition), find a program (proof) of the given type
2. Given a program (proof) of a given type, transform it to obtain another program of the same type.

Up to now, the logic programming approach has seemed more attractive, but its implementation requires control (cut, negation) that is not formulated in a purely logical way, thus losing one of the main properties of functional programming, namely modularity. What is missing at present in logic programming is the consideration of the internal logic (of execution) as opposed to the external logic (of specification). In other words, logic programming does not require new *ad hoc* solutions, but a solid mathematical theory at the level of, say, typed lambda calculi. On the other hand, the functional approach has the potential that has not, up to now, fully been exploited, namely the use of functionals. The aim of this effort is, instead, to make a deeper use of combinators in functional programming specifications, algorithms, and implementations.

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Information Systems

Information Systems-Correctness and Reusability (IS-CORE)
Working Group Number 3023

The objective of this working group is to explore the methodological foundations of information systems design, with the intention of achieving provably correct systems and higher levels of reusability through the use of formal, object-oriented design techniques. To this end, the group works on topics rarely addressed so far in information systems design, among them formal (logical, algebraic, and categorical) methods backed by a sound theory, full incorporation of dynamic aspects, static and dynamic integrity checking, as well as design-in-the-large issues like modularization and parameterization. The working group favors a formal, object-oriented approach, viewing the information system as a society of interacting objects, some passive like database records and some

active like database transactions. The group also works on the comparison with other approaches and the integration of new techniques with current information systems design practice.

The working group aims to deliver logical calculi as well as algebraic and categorical semantics for a broad spectrum language and methodology supporting the object-oriented, transformational, and modular design of information systems. The proposed object-oriented model allows the integration of "data" and "processes", opening the way to new architectures of information systems as object-bases, favoring concurrency and distribution.

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Catholic University of Tilburg	the Netherlands

Formally Integrated Data Environment (FIDE)
Action Number 3070

This action seeks advances in the technology used to support large-scale and long-lived information systems. The problem is that information systems are currently supported by a set of loosely connected, heterogeneous software components: database systems, programming languages, programming environments. Each component was designed and built using a specific technology. The inconsistencies among these components make programming difficult.

A first-level of integration is being accomplished by groups building integrated systems using existing technologies. Object-oriented database systems and deductive database systems are examples of these efforts. Ostensibly, these efforts are insufficient since separate technologies like query optimization techniques, compilation techniques, scheduling algorithms for database transactions, and operating systems processes do not mix well.

The ambitious task of this action is to build a new, integrated technology to replace these several ill-fitting ones. The consortium has a three-level solution to the problem:

1. Develop a better formal understanding of the contributing technologies so their fundamental properties may be understood and combined
2. Specify and develop a new single integrated technology
3. Evaluate and demonstrate this new technology through the design and implementation of experimental prototypes.

Because the current size of the project does not permit the addressing of all three levels exhaustively, it will concentrate on the following points:

- Type systems
- Object stores
- Design methodology
- Transactions.

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University of Paris - Sud	France
University of Pisa	Italy
University of Glasgow	United Kingdom
St. Andrews University	United Kingdom

Algorithms

Algorithms and Complexity (ALCOM)
Action Number 3075

The ALCOM action aims to advance and strengthen research on the design and analysis of efficient algorithms and on the intrinsic difficulty of computational tasks. This action focuses on the following seven areas of algorithm-oriented research:

- Data structures
- Computational geometry
- Graph algorithms
- Probabilistic methods and average case analysis
- Complexity theory
- Parallel algorithms
- Distributed algorithms and protocols.

Examples of research include:

- Design and analysis of data structures for complex objects in primary and secondary memory

- Algorithms for 3-dimensional geometric problems in computer graphics and robotics
- Algorithms for dynamic graphs and hypergraphs
- Techniques for expected-case analysis of algorithms
- Study of the theoretical limits for resource-bounded computations
- Design and analysis of efficient processor interconnection schemes and parallel algorithms
- Design and analysis of efficient techniques for control and coordination of processes or processors in a distributed system.

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EHESS, Paris	France
Institute of Computer Technology - Patras	Greece
University of Rome	Italy
University of the Saarlands	Federal Republic of Germany
University of Warwick	United Kingdom

Dependable Computing

Predictably Dependable Computing Systems (PDCS) Action Number 3092

The objective of the PDCS action is to make the process of designing and constructing dependable computing systems more predictable and cost effective than it is at present. The action will develop:

- Unifying concepts underlying dependability, which should support design decisions involving tradeoffs between different approaches to dependability and draw together technical work within both this action and other related research projects
- Means for the establishing and validating dependability requirements, including those related to the timing properties of hard real-time systems
- Stochastic techniques for assessing and predicting dependability, covering all means of attempting to prevent, remove, and tolerate all types of faults, including design faults and deliberate attacks.

The ultimate long-term objective is to produce a design support environment that is well-populated with tools and ready-made system components and that fully supports the notion of the predictably dependable design of large real-time distributed systems.

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Technical University of Vienna	Austria
University of York	United Kingdom

Geographic Database System

Basic Research Actions for a Geographic Object-Oriented Database System (Basic Goods) Working Group Number 3191

The main objective of this working group is to formulate better theoretical foundations for the representation and management of geographical information. In particular, the members will perform an extensive analysis of the object-oriented approach to the definition, representation, and management of geographical data, with special regard to the treatment of pictorial information. The main problems to be studied are:

- Definition of object-oriented data models and data definition languages for the specification of geographical data; the models should allow the representation of both the characteristics of the represented entities and the constraints defined over them
- Definition of object-oriented data manipulation languages for geographical information querying and managing
- Definition of advanced access methods for data consisting of geometric and descriptive information at the physical level. These methods should support the efficient access to geographic data during the

resolution of "hybrid" queries, that is, queries referring to both geometric and descriptive characteristics of data
- Definition of basic frameworks for the design and implementation of advanced geographical information systems. The working group expects to develop small prototypes of limited parts of a geographical object-oriented database system and an environment for the design of an object-oriented geographical database.

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University of Freiberg	Federal Republic of Germany

Hardware

Higher Order Logics-Supported Design for Complex Data-Processing Systems (CHEOPS)
Action Number 3215

The objective is to combine the efforts of the three partners on using the higher order logic (HOL) system for proving the correctness of complex data processing systems that are synthesized by the CATHEDRAL-II silicon compiler. The realization of the proof method for correctness has two goals. The first is to develop a cross check for systems synthesized using automatic methods. The second and more important goal is to extract the meta-knowledge that is required for general digital system verification, supported by a powerful theorem-proving environment like HOL.

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Correct Hardware Design Methodology: Towards Formal Design and Verification for Provably Correct VLSI Hardware (CHARME)
Action Number 3216

The objective is to develop a methodology, called design for verification, for the formal proof of the complete correctness of digital systems before manufacturing. A plan will be worked out on how this methodology must be incorporated in design activities and CAD systems in order to obtain error-free designs at low cost. The action is divided into two complementary work packages.

The first work package is about verification methodology and its integration in hardware design in order to apply appropriate formal verification techniques as early as possible in the design process. A specific effort will be made on high-level design languages suitable for formal verification and, more generally, on the effect of introducing formal verification methods into design methodologies and CAD tools. A promising approach using design constraints to facilitate the verification process will be investigated.

The second work package is related to efficient formal verification technologies. The methodology must be supported by appropriate tools for correct design and verification. Therefore, new methods will be developed and promising approaches will be elaborated further and used for experiments. Work will identify and develop the techniques best suited for the formal proof of hardware, starting form existing ones developed by the participants, extending them, or developing new ones as required. The participants believe that no one formal tool is able to describe and validate all the different aspects encountered in complex digital system design. Therefore, they plan to develop different complementary formal techniques.

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Comments

The stated objectives of these actions and working groups are, in general, idealizations, beyond the ability to achieve during the contract period, which is usually 30 months, but occasionally 24 months. These objectives do, however, reveal something about the ambitions and beliefs of that part of the European computer science community represented by these actions and working groups. As I read these descriptions, several major themes emerge. My analysis and condensation is slightly redundant and not comprehensive, but this is how I see it.

Major Themes

Determine the connections (understand the relationships) among

- Different semantics (denotational, operational, axiomatic)
- Different formalisms for concurrency
- Different software reasoning tools.

Unification and Integration of

- Programming languages
- Specification languages
- Models of parallel computation
- Logics
- Foundations of functional, logic, and object-oriented programming.

Develop a formal framework for

- Specifying and developing concurrent and distributed systems
- Specifying and developing distributed, real-time systems
- Proof development environment that is logic-independent and which accepts a specification (notation, calculus) of the logic to be used.

Stated slightly differently, much of the proposed work reads like this. Study two or more different logics, specification languages, tools, or similar objects until they are well enough understood to know where they overlap and where they differ. Based on this insight into the several objects (systems), build an umbrella object (system) that does everything the individuals do, incorporating the best of all worlds. These ambitious plans reminded me of the encyclopaedists and the Bourbaki effort. Such things tend to be overtaken by the progress of science, they fall under their own weight, or both. This is not to say that good work is not produced, for much good work is being done. I just do not believe we will see too many umbrellas.

What I do believe will happen is this. As two or more different objects/systems become well understood by the same group, features will migrate from system to system, and, in fact, this more realistic goal is the stated objective of some of the actions.

Some of the other themes briefly stated are:

- Develop a practical (declarative) programming language that combines and extends logic and functional programming paradigms
- Object-oriented information systems, including the database and the transactions
- Logic for computable functions
- Formal reasoning (specification, verification) for concurrent systems based on Petri nets
- Graph rewriting as a unifying framework for functional, logical, and object-oriented languages
- Algorithms, complexity.

Added in proof

I have recently received the September 1990 edition of the ESPRIT Synopses. The Synopses of Basic Research Actions and Working Groups, Volume 8 (of 8) has been expanded and reformatted. The telephone numbers and some other details in this have been updated to correspond to those in the new synopses. Anyone wishing more information on the Basic Research Actions can obtain the ESPRIT Synopses by contacting the ESPLRIT Information Desk at the Commission of the European Communities, BREY 10/178, 200 Rue de la Loi, B-1049 Brussels. Telephone: +32/2-235-1603; FAX: +32/2-235-3821, E-mail: esprit_information_desk@eurokom.ie.

Swedish Institute of Computer Science

by Robert D. Ryan

Introduction

This report is based on a visit to the Swedish Institute of Computer Science (SICS) early in June 1990. Sources include my notes from that visit, the SICS annual report for 1989, and several SICS research reports.

My host was Mr. Janusz Launberg, the information and planning manager. He organized the visit which began with a general introduction to SICS and its origins. This was followed by presentations on the activities of the three SICS laboratories: Distributed Systems Laboratory, Logic Programming and Parallel Systems Laboratory, and Knowledge-Based Systems Laboratory. They also provided a demonstration of their Muse Or-Parallel Prolog System.

Background

The SICS was established in October 1985 to conduct research in computer science and artificial intelligence. It is a nonprofit organization sponsored by the Swedish National Board for Technical Development (a government agency commonly known as STU) and by an industrial association of five Swedish companies. These are Asea Brown Boveri AB, Bofors Electronics AB (formerly Philips Electronikindustrier AB), Telefonaktiebolaget LM Ericsson, IBM Svenska AB, and Televerket (Swedish Telecom). Each of the five companies has one representative on the SICS Board of Directors. The STU appoints four members to the board. The SICS is located in the Electrum research and education center in the town of Kista, about 11 kilometers northwest of Stockholm.

My first impression was that SICS is to Sweden as the European Strategic Programme for Research and Development in Information Technologies (ESPRIT) is to the European Community (EC). This is an oversimplification, but parallels exist. Computer science is young in Sweden. My hosts estimate that Swedish education in computer science was about 10 years behind the U.S. and U.K. in 1985. Up to 1980, there was only one professor of computer science in Sweden. The STU created computer science research in Sweden. From 1980 to 1985, they supported the buildup of computer science to where there were more than 200 people engaged in research, including several new chairs. (This was when the U.S. was producing about 250 computer science Ph.D.s a year.) Some Swedish groups, like the one led by Professor Erik Sandewall at Linköping, received international recognition. (The rate at which Sweden came up to speed in computer science contrasts with their strong reputation in numerical analysis. For example, Professor H.O. Kreiss established his reputation while at Uppsala University.) In spite of pockets of excellence, problems persisted as late as 1985. There continued to be a lack of university positions. The Ph.D. students received relatively low wages and often left university to work in industry, where there the demand for computer scientists was growing. Professors of computer science became discouraged because of the difficulty in recruiting and retaining students. The productivity of the existing students was low. With teaching and other jobs on the side to make a living, they did little research. The university professors approached STU requesting better wages for the students. At the same time, industry was disappointed in the students--mostly undergraduate--that they were receiving. Industry also began putting pressure on STU and the educational system to produce more and better-prepared people. At one level, Sweden needed more computer science educators. There was money but not enough qualified people. Chairs in computer science went unfilled for lack of qualified applicants.

As the importance of information technology for maintaining a competitive edge increased, so did industry's discomfort. They felt that they did not have the work force to take advantage of new scientific developments. They needed more and better-trained people to bring the latest technologies into Swedish industry. Industry approached the government with this challenge: Either we get trained people or we must leave Sweden. The government's response reflected the Swedish political situation in the mid 1980s: If industry thinks something important needs to be done, they should pay for it. The result was a compromise in which both industry and STU joined to establish SICS in 1985.

The SICS charter states that the institute should increase the competitive strength of Swedish industry through research. The SICS also fulfills an important educational role. Namely, it provides a good salary for graduate students; it provides a home for research professors who can afford to teach part time in the universities; and it is a source of well-qualified Ph.D.s to fill computer science positions in Swedish universities.

The SICS is Sweden's strategic response to the problems of the mid 1980s in computer science research and education in much the same way that ESPRIT was the EC's response to structural and research issues in the

European information technology industry of the same period.

Personnel and Funding

At the end of fiscal year 1988/89, SICS employed about 50 researchers, and another 25 people were employed temporarily. About 15 researchers are at the postdoctoral level. The majority of the others are studying toward doctoral degrees.

The SICS research program consists of two parts. The first part, the Frame Program, is directed toward building and maintaining competence and high research standards, and generating new, industrially relevant, scientific results. This work forms the basis for communication within the national and international research community. In addition, it is the source of new knowledge and technology for industry.

The second part is performed under a collection of research contracts, and is responsible for transferring knowledge and disseminating results. This part of the program also provides a vehicle for valuable feedback from industry to the Frame Program. Readers familiar with the Office of Naval Research programs can roughly equate the Frame Program with Core and the contract-supported part with Accelerated Research Initiatives.

The Swedish government represented by STU and the industrial association agree upon the goals, content, volume, and funding of the Frame Program every third year. The Frame Program is based on discussions between industry and SICS researchers to ensure its industrial and scientific relevance. The activities in the Frame Program are long-term, goal-oriented projects. These projects are defined by the SICS researchers and approved by the board of directors. The projects typically last 3 years, but the plans are updated each year.

Work done under contract is closely related to projects in the Frame Program. Contracted projects last between a half year and 3 years. Each project is normally financed by one or more companies within or outside the five sponsors, or by the national funding agencies. Projects are defined in cooperation with the contracting company or companies, and the work, in most cases, involves the participation of company personnel. This is in line with the SICS motivation to facilitate technology transfer and to gain experience by applying research results to practical industrial problems.

Industry finances the major part of the Frame Program, each company paying equal shares of 12 million Swedish Krona (MSEK). The STU contribution is 10 MSEK for a total funding in 1988/89 of 22 MSEK. Contract research amounted to 14 MSEK during the same period. The total SICS funding for 1988/89 was 36 MSEK compared to 27 MSEK for 1987/88. Projected funding for 1989/90 is 41 MSEK. (One U.S. dollar is worth about 5.7 Swedish Krona.)

Knowledge Transfer

As indicated above, knowledge and technology transfer are key SICS activities. Swedish industry expects a return on investment, as does the government. Although there is an underlying long-term view, it is important to have a flow of current results. The contract research provides an important vehicle for the transfer of results and knowledge, and the level of contract work has been increasing. An equally important pathway for knowledge transfer is the transfer of people. In fact, the movement of people being the most efficient way of transferring new ideas and technology, SICS encourages employees to migrate to industry. During the 1988/89 period, 13 SICS employees moved to other jobs, 11 of them to Swedish industry. In return, SICS has recruited new personnel with valuable industrial experience, young and promising graduate students, and experienced researchers from abroad. All of this is in keeping with the SICS charter.

Research Programs

Research at SICS is done under the three organizational units referred to by SICS as laboratories: Distributed Systems Laboratory, Logic Programming and Parallel Systems Laboratory, and Knowledge-Based Systems Laboratory. I will describe the main projects and recent results of these groups. This will be done project by project for ease of organization and exposition. Notably, however, the research at SICS is well coordinated and forms a coherent program focused on the goals expressed in their charter.

Distributed Systems Laboratory

The laboratory manager is Dr. Björn Pherson; he is also adjunct professor at the Royal Institute of Technology, Stockholm, in the Department of Telecommunication and Computer Science. The research is organized into four projects: Formal Design Techniques for Distributed Systems, Experimental Design Environments, Design of Communication Systems, and Computer Networking and Distributed Applications. The overall goal is to advance the state of the art in the design of distributed systems and to transfer products to Swedish industry.

The goals of the Formal Design Techniques project are to increase and articulate the understanding of fundamental concepts related to distributed systems, to identify and refine semantics and methods relevant for the design process, and to develop prototype

computer-aided design (CAD) systems based on these methods. Because of the lack of consensus on what constitutes the best type of semantics, methods, or languages, the group is studying and working on different candidates and different aspects of formal design techniques. They conduct comparative studies of different techniques, and they participate in the international development and standardization of formal methods. In this regard, the group is involved in two ESPRIT Basic Research Actions: Action Number 3006, Theories of Concurrency: Unification and Extension (CONCUR), and Action Number 3096, Formal Methods and Tools for the Development of Distributed Real-Time Systems (SPEC). The group develops prototypes of CAD systems to help the designer of distributed systems deal with routine tasks. An example is the Concurrency Workbench, a prototype tool for the analysis of synchronously communicating finite-state processes. The Concurrency Workbench is available for noncommercial use. Contact Joachim Parrow (joachim@sics.se).

The Experimental Design Environments projects develop techniques and tools for rapid prototyping of design environments which support the design of distributed systems based on formal design techniques. Along with others, the people at SICS believe that, although formal techniques form a necessary basis for design environments, designers need not be theoreticians to use them. Indeed, there is widespread feeling that it is impractical to expect all but a small percent of designers to be knowledgeable in formal methods. The formal semantics, and their interpretation in real applications, must be embedded in languages that provide comprehensible presentations and offer intuitive interaction for creating and editing design specifications. Prototype products incorporating these ideas include:

- LOROS - An extension of the Xerox Artificial Intelligence (AI) Environment/LOOPS programming environment and a knowledge-based management system including a syntax-oriented rule-editor
- YAFFY - A user interface design toolkit, facilitating the design of interaction elements like palette, buttons, and menus
- LOGGIE - A Language-Oriented Generator of Graphic Interactive Environments. Programming environments are generated from formal specifications of languages with graphic syntax using attribute grammars and constraints. Programs are either derived (synthesized) or parsed
- GWC - A LOGGIE application implementing a graphical editor and simulator connected as an interactive front end to the Concurrency Workbench
- G-LOTOS - Another LOGGIE application, a graphic interactive editor for a subset of the proposed graphic syntax for the LOTOS protocol specification language. The G-LOTOS prototype was developed to experiment with the current proposal for standardization to assess it, and to gain a better understanding of possible future graphic LOTOS tools.

The goals of the Design of Communication Systems projects are to develop methods and support systems for implementing layered communication systems and to develop a protocol machine architecture. This is based on the beliefs that the implementation of communication protocols is the bottleneck in distributed systems, that in future systems all layers in the protocol stacks will be implemented in a dedicated computer system, and that protocol specifications will be translated directly into machine code. The implementation of these ideas is the 6pm project. The goal of the 6pm project is to design and implement a protocol machine that can meet the high bandwidth and low latency requirements of distributed multimedia applications. The project is intended for protocols at the transport layer and below, but it is not limited to these layers. The 6pm protocol machine will not be tailored to a specific protocol stack. Instead, SICS plans to develop a platform for efficient implementation of several types of protocols. The machine will be based on a multiprocessor card which consists of 4 Motorola 88000 family processors, M-bus, cache, memory, and the distributed operating system, Mach. This card and Mach are also used in the Data Diffusion Machine (DDM). (See the next section for more about the DDM.) When DDM is the host, 6pm will be a fully integrated node on DDM. Previous accomplishments of this group include SPIMS, a tool for performance measurements of layered protocols. The SPIMS prototype is available for noncommercial use from SICS. Contact Per Gunningberg (per@sics.se).

The fourth area under Distributed Systems is Computer Networking and Distributed Applications. Here the goals are to develop techniques and tools for the design of computer networks and distributed applications and to deploy the results for use in available computer networks. Research activities for the next 3 years will focus on establishing a run-time environment for distributed applications (the REDA project). Subprojects under REDA include investigating different interprocess communication mechanisms, specifying and prototyping and object-oriented programming environment, and providing a distributed file system for a multigigabit network of heterogeneous hosts. Much of this work is oriented toward multimedia applications using a multigigabit network. I note that SICS will be using the ISIS Distributed Programming Toolkit (Cornell University) to provide distributed correctness for several of the planned applications.

Logic Programming Systems Laboratory

Dr. Seif Haridi is the laboratory manager for Logic Programming Systems. The research is organized under 6 projects: Industrialization of SICStus Prolog (ISP), DDM, Declarative Programming, Programming of Large-Scale Open Systems, Or-Parallel Systems, and Andorra Prolog. The laboratory's long-term goal is to design efficient computer systems for general applications that require intensive symbolic processing with a focus on parallel and distributed processing. Envisaged applications include software development environments, databases, real-time systems, as well as applications with automated reasoning abilities like natural language understanding and knowledge-based systems. Research is focused on hardware architecture and software technology for these applications.

The first project, ISP, is a technology transfer project to transform a successful research prototype, SICStus Prolog, into an industrial quality system. An initial effort at the laboratory was to demonstrate the feasibility of logic programming as an effective formalism and tool for programming parallel computers. To do this, they needed an efficient, portable sequential Prolog system that could be distributed to their research partners. Since they could not acquire such a system meeting their needs, they developed their own, SICStus Prolog. SICStus Prolog version 0.6 is now installed and used at over 180 university and industrial research sites around the world as a vehicle for research on parallel logic programming. Version 0.7 should be available in the summer of 1990. Information about SICStus Prolog version 0.7 can be obtained by contacting sicstus_request@sics.se.

The ISP project deals with important extensions of SICStus Prolog with the overall objective of introducing logic programming into Swedish industry. This work is being done in cooperation with major Swedish companies at SICS, and involves personnel from SICS and industry. The industrial version, called ISP for Industrial SICStus Prolog, will include the following additional functionalities:

- Library - This provides a variety of routines for graphics, mathematics, graph processing, list, set, and queue operations, array manipulation, random number generation, and tools for debugging and program analysis
- Modules - This gives ISP the ability to divide large programs into modules with separate name spaces
- Graphical Profiling Tool - This is a tool to analyze programs run-time behaviors
- Native Code - This provides compilation for Sun-3 and Sun-4 workstations
- Processes - This will give the user an opportunity to create remote (parallel) processes and to set up communication channels between them
- Persistent Prolog Data - This is to support external storage of Prolog data. This database will be just like any Prolog database from the user's point of view
- Embedda bility - This will make it possible to compile a Prolog program into a standard ob ject file that can be linked as part of a larger application development in an oDher language
- Enhanced Programming and User Environment - This will give the user an enFironment, with support for all aspects of program development
- Constraint Solvers (reals, integers, finite domains, Boolian algebra).

The first releases of ISP are in use within the involved companies. Some of the additional functionalities are still under development. The second project is the DDM. The DDM is a type of multiprocessor architecture where a shared-memory view can be achieved without any physically shared memory. From a hardware point of view the system looks somewhat like a message-passing architecture in that all processors have their own private memories; no physically shared memory exists. Hence the DDM is expected to provide the scalability of a message-passing architecture in combination with the programming paradigm of a shared-memory architecture.

The memory of one DDM processor is organized like a large cache, residing at the tip of a hierarchical bus structure. The processor sees a big shared address space. Most of the processors's accesses will be local to its cache. Upon access to a datum not in the cache, a protocol, hidden from the processor, will retrieve data from another memory in the hierarchical bus system. The protocol makes the remote accesses to the closest possible copy of the data. Also, it handles the data coherency and replacement. All communication is kept as local as possible.

This work is related to the ESPRIT project, Parallel Execution of Prolog on Multiprocessor Architectures (PEPMA). In the context of PEPMA, the short-term goal is to design the system and verify it by simulation. The long-term goal of the DDM project is to develop a prototype multiprocessor based on the DDM idea. The SICS has selected the Motorola 88K processor and the Mach operating system for the prototype. More information about the DDM can be found in (Hagersten et al., 1989).

The Declarative Programming project aims to make work simpler for the programmer by removing many of the cumbersome procedural aspects of programming. One would like to make Prolog more declarative without being prohibitively inefficient. A current goal is to devise a set of efficient algorithms for constraint solving together with techniques to handle constraints within Prolog.

The goal of the project called Programming of Large-Scale Open Systems is to develop a practical,

integrated programming system to support the development and maintenance of large-scale programs for distributed open systems. The idea is to develop a higher level logic programming language that integrates a kernel language for programming-in-the-small with the required mechanisms to support the design of individual encapsulated and reliable program components. The language must also provide mechanisms to support the interconnection and integration of large-scale systems from existing components that can reliably communicate and share information. The work focuses on a concurrent logic programming language called Sandra. Some work from this project is reported in (Elshiewy, 1990).

The Or-Parallel Prolog Systems project is a major effort toward realizing the promise that logic programming languages are suitable for programming multiprocessor systems. Two subprojects, Aurora and Muse, are devoted to this goal. Before I describe these, some background is appropriate.

At the Third International Conference on Logic Programming in London in 1986[1], a group interested in various aspects of parallelism in logic programming established an informal collaboration that came to be known as the Gigalips Project. In 1987, the core group within the project, consisting of Argon National Laboratory, Manchester University, U.K., and SICS, decided to develop an Or-parallel Prolog System for shared memory multiprocessors. This became the Aurora project. Subsequently, the Manchester group, headed by Professor David H.D. Warren, moved to Bristol University, U.K. Ewing Lusk heads the effort at Argonne National Laboratory, Illinois, and Seif Haridi heads the work at SICS. I note that in all of this work on parallel logic programming, the ideas of David Warren, in particular the Warren Abstract Machine (WAM) (Warren, 1983), play a central role.

The motivation for Aurora is the belief that or-parallel Prolog is an excellent vehicle for exploiting the processing power of multiprocessors, and that many applications contain exploitable parallelism. The goal from the outset was to let the system itself decide where and when to exploit the inherent parallelism in a Prolog program. The system also had to run existing applications programs with correct results. Thus, there was the rather strong requirement on the implementation that the semantics of an application program remain unchanged when it runs in parallel.

The basic structure of Aurora is that several processes cooperate in exploring a Prolog search tree. Each process has two components: an engine, which executes Prolog code, and a scheduler, which distributes the available work to the processes. A semiformal interface defines the communication between the scheduler and the engine, making it possible to interchange schedulers. Each of the participants has produced schedulers. The Aurora project is now rather mature, and in April 1989, the first prototype system, running on the Sequent Symmetry and the Encore Multimax, was released. The prototype has also been ported to the BBN Butterfly by a team at Brandeis University, Waltham, Massachusetts. There is no doubt that the technology works. However, the people at SICS point out that Aurora, being a portable implementation written in C and not being well tuned, is not now commercially competitive with Quintus Prolog, which is implemented in a low-level language. For more information see (Lusk, E. et al., 1990).

Muse (Muti-sequential Prolog engine) is one of SICS' latest approaches to or-parallel execution of Prolog on shared memory and a class of distributed memory multiprocessor machines. In 1986, a research project at SICS, called BC-machine, was started with the goal of finding a suitable approach to or-parallel execution of Prolog on distributed memory multiprocessor machines. The BC-machine is based on having multiple sequential Prolog engines. This allows keeping all the advantages of the sequential Prolog technology. On the other hand, one is always faced with the overhead problems: copying an engine state and load balancing. The BC-machine attacks load balancing by using some shared memory. The copying overhead is reduced by using a special broadcast network for parallel copying. Early results on prototypes showed that copying overhead was much lower than expected, ranging from 0.10 percent to 25 percent of processors' time depending on the programs. Muse currently runs on a 16-processor commercial shared-memory machine, Sequent Symmetry, and a 7-processor distributed-memory machine developed at SICS. The sequential SICStus Prolog has been adapted to or-parallel implementation on both systems. Extra overhead associated with this parallel adaptation in around 5 percent. The speed-up factor is close to the number of processors, ranging from factors of 11.85 to 14.98 on a set of test problems run on the Sequent Symmetry using 15 processors.

The last project in the Logic Programming Systems laboratory is called Andorra. This is an ambitious, long-term project in logic programming with the goals of combining or- and and-parallel processing and supporting constraint programming. The Andorra project is the latest vehicle for continued cooperation with David Warren's group, University of Bristol. The project is also part of the ESPRIT Project 2471, PEPMA, whose objective is to produce an efficient parallel execution model of Prolog for industrial use on available parallel machines.

[1]The Eighth International Conference on Logic Programming (ICPL '91) will be held in Paris, June 25-28, 1991.

The goal of the project is to design and implement a language that combines the advantages of languages usually implemented in or-parallel (like Prolog) and in and-parallel (like GHC). The language is to be expressed as a language framework, called Kernel Andorra Prolog, in which several sublanguages having desirable properties may be specified. Here are some of the design goals for the Kernel Andorra Prolog framework:

- Formal Specification - Kernel Andorra Prolog and its computation model should be formally specified.
- Subsumption - The languages Prolog, GHC, Parlog, and Atomic Herbrand, should all be subsumed by Kernel Andorra Prolog. There should be a single general instance of Kernel Andorra Prolog into which the majority of programs written in these languages are easily and automatically translatable. Such a language will be called the Andorra Prolog User Language. This will allow most existing logic programming software to be run in the User Language implementation with little or no change to the original code.
- Efficient Implementation - The User Language should allow efficient implementation on both single- and multi-processor architectures. In the latter case in a way so that the major forms of parallelism are exploitable.
- Constraints - Kernel Andorra Prolog should be based on a constraint framework. Future projects will implement constraint solvers for the usual domains.

See (Haridi, S.) for further information about Andorra.

Knowledged-Based Systems

The laboratory manager for Knowledge-Based Systems (KBS) is Rune Gustavsson. He was not at SICS the day I visited, and another member of the laboratory, Olle Olsson, briefed me. The overall goals of the KBS laboratory are to advance the state of the art in selected areas of KBS technology and to facilitate the understanding and use of the KBS technology in Swedish industry. In response to my question as to why SICS had gone into KBS, I was told that it was because there was a need in Swedish industry. Industry wanted to use the technology, they were not familiar with the technology, and they did not have people trained in the technology. Work in the KBS laboratory is done under 5 projects: Natural Language Processing, Foundations of Programming for KBS, Large Knowledge Bases and Complex Structures, Temporal and Modal Structures, and Experimental Knowledge-Based Systems. The last project consists of a collection of contracts to apply KBS in several areas of interest to the SICS sponsors.

Work under the Natural Language Processing project focuses on the development of tools and methods for the construction of flexible broad-coverage natural language interfaces like, for example, database frontends. The work is oriented towards using the logic programming paradigm both for building the processing systems and for representing the syntax and semantics of natural language expressions. One of their products is the platform, SNACK-85, which is used for experiments with natural language processing. The platform is also used in work on the syntax and semantics of comparative constructions and on explanation-based learning. This is reported in (Rayner, M., 1989). The work on platform development is continuing with work on a Swedish version of the Core Language Engine developed by Stanford Research Institute (SRI). This platform is an extension of the present day SNACK-85 platform; it will support the development of interface systems, translation systems, and tutoring systems. This latter work is being done in cooperation with SRI International, Cambridge, U.K.

The Foundations of Programming for KBS project's long-term goal is to provide a uniform formalism for programming for KBS. Most of the recent work has been on the language, GCLA (Generalized Horn Clause LAnguage). The GCLA is a logic programming language that is based on a generalization of Prolog. Moreover, GCLA incorporates a generalization of the concept of inductive definitions, called partial inductive definitions, a formalism developed by Lars Hallnäs. The authors claim that GCLA, as a logic programming language, takes a much more "definitional" view rather the traditional logic view, as in Prolog. Since GCLA allows for hypothetical and nonmonotonic reasoning, it makes implementation of reasoning in knowledge-based systems more direct than in Prolog. The GCLA is also general enough to incorporate functional programming as a special case. Considerable work has been done on this language. A complete interpreter has been designed and implemented. The interpreter is implemented in SICStus Prolog and is available as a prototype from SICS. A users manual has been published. So it can achieve more efficient execution, an abstract machine based on the Warren machine for Prolog has been designed and implemented. Work is near completion on a compiler from GCLA to the machine language of this abstract machine. The usefulness of GCLA for practical programming has been tested in implementing an expert system for building construction planning. For more information, see the references under Aronsson.

The goal for the project called Large Knowledge Bases and Complex Structures is to formulate and validate new theories for organization of systems in which the interaction between constituent elements creates some kind of structure. Specific activities include the

development of algorithms for learning and developing methodologies to reveal "embedded" knowledge in large relational databases, including an implemented prototype called LFREYR. Philippe Mathieu, who is now at the Thompson research laboratory in Paris, has introduced a new idea for constraint logic programming called calculable rings (Mathieu, 1989). The calculable ring concept has been implemented in a constraint solver prototype, which can incorporate most of the constraint models that are found in existing constraint logic programming systems.

The Temporal and Modal Structures project is concerned with the formal treatment of knowledge communication. The long-term goal is to develop methodologies and tools for reasoning about the interplay between knowledge, perception, planning, and actions. Recent work has focused on the development of the Pragma-Communicating Intelligent Agents platform. The Pragma platform will provide and environment in which several kinds of reasoning are integrated: reasoning about time, action, knowledge, probabilities, and cooperative action between intelligent agents. The Pragma platform will also be a testbed for experiments with natural language processing.

The Experimental Knowledge-Based Systems project consists of a collection of research contracts. These have been undertaken to meet the needs of SICS' sponsors and to gain experience in developing knowledge-based systems. I will briefly describe four of these projects.

A Knowledge-Based System for Testability Check. This project was initiated and sponsored by Mekanförbundet, an association of Swedish manufacturing industry, to investigate if, and to what extent, low-priced KBS technology offers a viable way to solve problems in electronics design. The goal was to demonstrate the applicability of knowledge-based techniques available on the market (personal computer [PC] shells) to a specific problem in electronics, namely checking circuits for testability. A testability checker was constructed using an off-the-shelf expert system shell. Despite performance problems, mostly because of mechanisms in the expert system shell and the system being isolated from the CAD system in use, the system has been used successfully for checking several electronics designs of moderate complexity.

An Experimental Knowledge-Based Environment for Design. This project builds on the project described above, which in principal demonstrated the potential of KBS technology in electronics design. The goal is to demonstrate applicability of knowledge-based techniques to enhance the utility of existing CAD systems used by industry. An important requirement is the ability to integrate KBS solutions into different design environments. The first completed application is a design rule checker which by analysis detects design errors on the electrical level in circuits. The project is financed by the Swedish Information Technology Program --IT4--, Ericsson Telecom, and Infologics. This Swedish industry involvement assures appropriate technology transfer.

Computer-Aided Construction Planning and Site Management. This project is part of a research program, Humans - Computers - Working Life, sponsored by STU and Arbetsmiljöfonden. The SICS participates in the subproject dealing with different aspects of planning at a building construction site. This effort is coordinated with activities of other researchers and practitioners in the fields of cognitive science, sociology, architecture, construction, and organization, as well as construction workers representatives. The goal of the project was to study the problems and to specify and implement prototype tool supporting the planning process. It was discovered that this type of planning is very complex, that replanning (or adjustment) of plans occur frequently, and that this latter activity results from issues that are most difficult to know *a priori*. With this in mind, efforts turned toward an automated "assistant" rather than a fully automatic planning tool. Several demonstration systems have been implemented, one of them using the language GCLA.

Knowledge-Based Techniques in the Food Industry. This is part of a research program sponsored by STU addressing the needs of the process control industry. A case study at Felix AB, a Swedish food processor, was made. The report describes a possible KBS support for operators in the food industry.

Summary

The SICS is a young organization, being in business for only 4 years. It sits at the interface between research in computer science and applications in Swedish industry. The SICS is called upon to produce world-class research, educate students, and contribute directly to the competitive position of Swedish industry.

I have the impression that the research is going well. The planners have focused on a reasonable scope and set of topics for the size of the organization. The research productivity is high (through 1989, SICS had published over 80 research and technical reports). In my view, some of this research is world class, particularly in distributed systems and logic programming.

My perception about the quality of interaction with Swedish industry is less well informed. There is clearly a transfer of knowledge through the movement of people from SICS into industry and through the direct participation of guest researchers from Swedish industry. The question I cannot answer is to what extent computer science (and AI) is improving the competitive position of Swedish industry. I have the impression, based on the increasing budget for SICS and my visit, that both STU

and the industrial partners are currently pleased with their investment.

Finally, I note that the first two doctorates based on research done at SICS were recently awarded by the Royal Institute of Technology, Department of Telecommunication and Computer Science, to Mats Carlsson (Carlsson, 1990) and Bogumil Hausman (Hausman, 1990).

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Fault-Tolerant Computing in Europe - an Update

by Miroslaw Malek, the Liaison Scientist for Computer Science and Computer Engineering at the Office of Naval Research European Office. He is on leave from the University of Texas at Austin, where he holds the Bettie Margaret Smith Professorship in Engineering in the Department of Electrical and Computer Engineering.

Introduction

The Twentieth Fault-Tolerant Computing Symposium (FTCS-20), was superbly organized by Professor Brian Randell, University of Newcastle-upon-Tyne, U.K. Held on June 26-28, 1990, FTCS-20 brought together over 230 researchers, mainly from academia, and some from government and industry. This symposium gave an excellent update on the latest fault-tolerant computing research in Europe, Japan, and the U.S.

Steady progress is being made in this increasingly important area where the range of effects caused by computer system downtime varies from minor inconveniences to a loss of human lives. Computer applications continue to proliferate from research laboratories to commercial use and have become a part of our lives. For example, ever-growing applications of electronics in automobiles are expected to create a $40 billion market within 5 years. High dependability[1] is crucial in this type of system as well as many others.

[1]Dependability is an umbrella term for reliability, availability, survivability, mean-time-to failure, safety, security, and other concepts and measures. It is formally defined as a reliance that is placed on computer service.

Keynote Addresses

The symposium featured three keynote addresses and 58 technical papers selected from 229 submissions. More than half of the presented papers originated from the U.S. and others came mainly from Europe. In this report, I will focus on keynote addresses, and most promising European contributions. Symposium proceedings may be obtained from The Institute for Electrical and Electronics Engineers (IEEE) Computer Society (Order Number 2051, ISSN 0731-2071). Send orders to IEEE Computer Society Press, 10662, Los Vaqueros Circle, P.O. Box 3014, Los Alamitos, California 90720-1264.

The keynote speeches were a highlight of the symposium. M.N. Meyers, AT&T, gave the anatomy of the disastrous breakdown in telephone communication in mainly the Northwestern U.S. on January 15, 1990. Apparently, at the core of the problem was system diagnosis because the system did not correctly identify its status. This is equivalent to the processor membership problem where the objective is to establish which computers operate correctly and which have failed.

Incidentally, the same problem was a main concept of the third keynote address. Flaviu Cristian, IBM

Research, California, introduced the key fault-tolerance and real-time issues in IBM's Advanced Automation System, which is a next-generation, air-traffic control project supported by the Federal Aviation Administration. He described simple, yet powerful, service-server concepts which, combined with server failure semantics, provides a comprehensive framework for fault-tolerant system design. The complete article is in the proceedings and is a must for anyone who is interested in the design and development of fault-tolerant distributed systems. The article elaborates on failure classes that should be included, which of them should be masked, and which require delayed recovery. Cristian outlined the major mechanisms for redundancy management, methods and requirements for dependable communication. Furthermore, he gave the protocol for reaching an agreement on which equipment is faulty in the group of processors--a crucial function. He also described how to add new processors or eliminate faulty processors from a group.

In the second keynote speech, Reeves and Birks, the Association for Payment Clearing Services, explained the operation of a check clearing system, called CHAPS. The system is based on Tandem computers hardware and clears 10 million checks a day for major British banks which are distributed over 16,000 branches. The key requirement is high dependability and the ability to keep the system operational during software upgrades, changes, repair, and replacement. The system's availability is 99.1 percent, which amounts to about 8 hours of downtime per year, which for safety critical applications would have been unacceptable.

Papers on modeling and empirical results in distributed computing systems dominated the conference. Also software fault tolerance begins to overshadow the hardware issues. Many hardware platforms have a lot of built-in, fault-tolerant hardware mechanisms making them highly dependable. Alas, don't we all know it--software faults seem to be part of our major problems.

European Contributions

I will concentrate on some, in my opinion, main contributions from European scientists.

A substantial experiment on software fault tolerance was jointly carried over the last 2 years by the French agency, Centre National d'Etudes Spatiales (National Center for Space Studies), and three French aerospace companies: Matra Espace, Cisi Ingenierie, and Aerospatiale. After the development of three-version software, written in Ada, for spacecraft orbit and altitude control system, the usefulness of the N-version programming approach was evaluated. The following advantages have been reported:

- Refinement of specification by information exchange between three development teams and the project manager
- High level of diversity with respect to architecture and interface levels
- Improvement in test coverage because of back-to-back testing (three variants of programs were executed using the same test sets which were concatenation of the tests developed for each version; back-to-back testing was especially useful in the timing error detection).

The obvious drawback of this approach is a high development cost. It was pointed out that it costs about 2.5 times more to develop a three-version program with voting than to write a single fault-tolerant program. The decision software took about 30 percent of the total effort. This work will continue with development of a generic voter and on-board microprocessors. The further efforts will concentrate on evaluation of real-time aspects in the conventional and N-version approaches to fault-tolerant software.

The related paper, presented by Eric Pilaud, Merlin-Gerin, Grenoble, France, gave an excellent overview of the software development for a nuclear reactor control which has extremely high safety requirements. The software took about 5,600 hours to develop and 4,220 hours to verify a 10,800 line long program, written in C, whose main function is to shut down a nuclear reactor in case of emergency. This program is very well documented. The documentation is 3,882 pages long which means that on the average, one page of documentation was written for every three lines of code!

European efforts in software safety are significant with a strong drive towards standardization. For further information on this timely topic, see the Proceedings of the Safecomp '90 Conference, London, October 30 - November 2, 1990.

The next three papers from Europe focused on system modeling ranging from workload-dependent memory faults to dependability growth.

The paper by J. Dunkel, University of Dortmund, Federal Republic of Germany, entitled "On the Modeling of Workload-Dependent Memory Faults," presents the impact of memory faults on performance of a given computer system. Based on the queuing model and the number of tasks, the impact of memory faults is quantified by the average rollback time, the paging-induced faults, the fault-induced paging rates, and the relative task delay. Relative task delay and rollback time may increase by as high as 14 percent on a busy system, while, during a light workload, the potential performance degradation may vary from almost 2 to 10 percent.

The next paper "On the Modelling and Testing of Recovery Block Structures" by Geppino Pucci, who, after

graduating at the University of Newcastle-upon-Tyne, will spend 1 year at Berkeley, presents a new approach to reliability modeling of recovery block structures. The model is based on error events that can be observed and distinguished during testing. This model can be used in deciding what are the best options for recovery techniques during the software development cycle.

The paper by Jean-Claude Laprie and his associates, Laboratory for Analysis of Applied Systems, Toulouse, France, addresses a timely topic on reliability and availability growth modeling. Studies by Wallace and Barnes, AT&T, indicate that unavailability may decrease by more than two orders of magnitude during 3.5 years of system operation. This phenomenon is attributed to removal of software errors and hardware design faults during the operational life of the system. Laprie and his colleagues provide a hyperexponential model for the reliability and availability growth which correlates well with experimental studies on Electronic Switching Systems reported by AT&T. The main potential usefulness of such models is in prediction of dependability growth for future family-compatible systems and that is what the group from Toulouse plans to pursue in the future.

The paper by J.A. Carrasco applies an accelerated simulation method, originally developed by Goyal et al. at IBM Research, to large Markovian reliability/availability models of repairable fault-tolerant computer systems. The main contribution of the paper is an extension of the accelerated simulation method to evaluation of reliability and instantaneous availability.

In the area of systems, there were three interesting papers from Europe. First, by Saucier and her associates from the Institute National Polytechnique de Grenoble, France, entitled "Design of Microprocessors with Built-in On-line Test." The paper describes an effective method of concurrent checking of a microprocessor at two different levels: control flow checking in the application program and verification of the sequencing control flow in the controller. Using signature analyzers the method was implemented in a 32-bit 1.5 micron complementary metal oxide semiconductor (CMOS) technology microprocessor and resulted in 6.5-12.6 percent overhead and an error detection latency of only four clock cycles. This practically reduces the aliasing probability; i.e., the probability of getting the same signature, to zero.

Kopetz and his group from the Technical University of Vienna demonstrated techniques for tolerating transient faults in their MAintainable Real-time System (MARS) which is a fault-tolerant distributed architecture for real-time applications. Transient faults are of utter importance. Depending on the source of data, the estimates say that the transient faults are 30 to 1,000 times more frequent than the permanent ones. In the proposed approach, error detection takes place at three levels: hardware, operating system, and application software. At the hardware level, extensive checking by watchdog timers, power supply and temperature monitoring, and other standard mechanisms is provided. Based on some experimental data, it is assumed that 99 percent fault coverage is achieved. The remaining 1 percent should be detected by special mechanisms in operating system and application software. These mechanisms include robust data structures, massive use of assertions; e.g., checking bounds on functions or variables, timing checks, and temporal redundancy by executing a task twice and comparing signatures. To meet the real-time requirements, an extra 50 percent of spare capacity is provided. For error handling, the mechanisms ranging from system diagnosis to get a consistent view of a system to a restart are incorporated. Obviously, a standard feature such as an automatic restart is usually very effective for transient faults. The key contribution of this paper is that several approaches to fault tolerance have been implemented and evaluated. Notably, fault-tolerant implementation of critical tasks increases the mean-time-to-failure by a factor of 10 provided that the maintenance intervals are less than 4 hours. If shadow (redundant) components are used, the maintenance intervals can be extended to 30 days.

The paper by a group from Philips Research Laboratories, Eindhoven, the Netherlands, entitled "The Error-Resistant Interactively-Consistent Architecture (ERICA)" is one of the most interesting fault-tolerant architectures that will very likely become a standard for the next generation of this type of systems. The system is based on the (4,2)-concept, introduced by Theis Krol (Philips). The (4,2)-concept is an architecture comprised of four processors, two memories, a special encoder/decoder, and a Byzantine chip that ensures protection against Byzantine faults and maintains consistent view of the system. The system is implemented on MC68010 processors distributed over two modules that have 6 Mbytes of memory each. The beauty of the proposed approach is that any nonredundant, well-defined single processor system can be elegantly transformed into a fault-tolerant system based on the (4,2)-concept. The hardware overhead is small and, except for the encoder/decoder and Byzantine chip (approximately 4,000 gates total), the design is not more complex than the design of a single processor system. With progress in the processor technology, it should be trivial to incorporate the extra logic on a processor chip if someone like Motorola, Intel, or Inmos decided to do so.

The (4,2)-concept compares favorably with duplex and triple modular redundancy systems (TMR) and delivers about 80 percent performance of a single processor chip. It is expected that optimization of the extra hardware could stretch it to 90 percent. The (4,2)-concept is

successfully used in the Philips business communication switch SOPHO S-2500 and in a broadband H1-switch. The current version described here will probably be used as a controller in an electronic switching system, an on-line transaction system, as well as a general purpose, fault-tolerant system.

The paper on Delta-4 system, which is a European Strategic Programme for Research and Development in Information Technologies effort to define an open fault-tolerant distributed computing architecture, focuses on throughput and response time in a system based on replication of software components on distinct host computers. Various replication strategies are proposed and implemented. It might be interesting to see a full implementation of this system because it could serve as a testbed for evaluation of a variety of fault tolerance and real-time techniques.

With parallel sessions and multiplicity of interests, it was difficult to get the consensus on what were the most important contributions presented at this conference.

Conference Highlights

After discussions with friends and colleagues and attending several sessions, it seems that the highlights of the conference should include (but by no means be limited to):

Consensus Problems. Processor membership/system diagnosis problems, F. Cristian - IBM (see earlier remarks about his keynote address); R. Bianchini et al., Carnegie Mellon University (CMU), Pittsburgh, Pennsylvania, who implemented distributed system diagnosis based on the concept by Kuhl and Reddy; it works and users are happy, they find quickly if something is wrong on the network; the code can be directly obtained from R. Bianchini; P. Berman (Penn State) and A. Pelc (University of Quebec at Hull) generalized the original Preparata-Metze-Chien model and modified it for the use in practice.

Modeling. Several works were described earlier in this article, others to be mentioned is the work by Wang and Fortes from Purdue University, West Lafayette, Indiana, on optimization of the number of spares for achieving a particular meantime to failure (MTTF); recovery time modeling by Geist et al., from Clemson University, South Carolina; accelerated simulation methods by Nicola et al., from IBM Research, and, as mentioned earlier, by Carrasco from University of Catalonia, Spain.

Experiments and Fault Injection. Anomaly detection for diagnosis by R. Maxion from CMU holds a promise and could be also incorporated in Group 1, failure analysis for VAX-cluster by Iyer and his group from Illinois, and effects of transient gate-level faults on program behavior by Check and Siewiorek from CMU.

Fault-tolerant Architectures. A (4,2)-concept from Philips deserves an uttermost attention; there is incremental progress in several fault-tolerant distributed systems that are in various stages of design or implementation.

Other topics included testing, checkpointing and recovery, algorithm-based fault tolerance, yield enhancement methods, distributed algorithms, and software fault tolerance.

At the conference banquet held in beautiful Wynyard Hall, Brian Randell read a letter from H.M. Queen Elizabeth II who hoped the participants had a productive meeting. I certify that they did.

Transputers Applications '90

by Miroslaw Malek

After a tremendous success of the First International Conference on Applications of Transputers, held in August 1989, at the University of Liverpool, the second event in this series took place at the University of Southampton on July 11-13, 1990. The conference brought together over 450 delegates, mostly from Europe, who listened to 75 papers presented in 5 parallel streams. There were also interesting presentations by nine invited speakers and a keynote address by Professor Tony Hoare from Oxford University. A quite extensive exhibition provided an impressive review of transputer-based products.

An increased interest in transputers stems from two facts. (1) The Commission for European Communities (Commission) supports 55 universities in Europe to pursue research on parallel computing based on transputers. (2) INMOS (manufacturer of transputers) has announced a new powerful transputer, H1, that eliminates some of the idiosyncracies of the previous product and stands a fair chance to compete with Intel, Motorola, Sparc, and MIPS processors.

The conference began with a keynote speech by Professor Tony Hoare entitled "The Transputer - The Last 20 Years and the Next 20 Years." Professor Hoare

is a Director of the Oxford Programming Research Centre and a pioneer in parallel programming techniques. His Communicating Sequential Processes (CSP) model gained him world recognition and it is well-known that his concepts are at the core of the first parallel programming language, called occam. Hoare reminisced about his years at Elliot, a British computer company, where in the 60s a parallel computer idea was alive and well, but there was one catch: nobody knew how to program a machine connecting many processors together even if one were to be built. At about the same time, in 1965, a programming centre was founded at Oxford, and it was 12 years before Hoare joined it from the University of Belfast. In 1977, he was also a consultant to INMOS. That is when his ideas related to the CSP were becoming real, after tossing them around for years with distinguished colleagues such as Dijkstra and others. Dijkstra initially did not like the idea. Over the years, he began to accept it and indeed grew fond of it.

Hoare rejected UNIX (referring to a follow-up version of AT&T's UNIX) "as a creation of some Berkeley hacker at four o'clock in the morning" (similarly, Dijkstra calls UNIX a fraud) and supports scientific formal methods. The CSP model stems from marrying concurrency with input and output; it is based on two fundamental concepts: processes and communication. Hoare stated that the name of the game is matching the time of computation and communication; the key to a successful system is that a computer waits for the environment and not that the environment waits for a computer. This observation results in an apparent paradox, and demands "to increase a speed of waiting" by clever programming or additional resources. Hoare stated that nondeterminism is not necessarily bad. In fact, nondeterminism is accepted to improve the efficiency of waiting. Understanding it, controlling it, and making it harmless are crucial in embedded real-time systems development.

Next, Hoare explained basic concepts in the CSP and occam. Designed for embedded parallel/distributed real-time systems, both CSP and occam support processes and communication. The process distribution is extremely simple. Logical clarity and high responsiveness to interrupts are obvious advantages of this approach but programming in occam still seems to be cumbersome. With over 100 independent laws, it is feasible to prove logical equality of two programs, but without timing verification.

With occam, transputers, and a good compiler, embedded real-time computing became a reality. The success of transputer architecture can be measured by the fact that over 300,000 transputers have been sold. It took 10 years from a concept to implementation and a pretty complete understanding of the underlying issues, but the results are very encouraging. Transputers are still the only processors that explicitly support parallelism. This unique capability will ensure a steady growth in demand for transputers in parallel architectures.

UNIX and C will continue to swamp the world, whether we like it or not. However, mathematically sound techniques, despite their inherent complexity, will ultimately dominate, based on the promise of program correctness, higher dependability, and performance.

The next 20 years will bring 10,000-fold increase in performance for the same price. Highly reliable programs, independent of hardware platform, will become a reality, and heterogeneous architectures will be commonplace. Transputers will grow in power and the size of on-chip caches will continue to increase. Supernetworks (mainly optical) will be developed capable of connecting a plethora of heterogeneous systems. By synchronization and program optimization, interprocessor traffic will be further reduced. According to Hoare, occam constructs will be good for the next 25 years.

Hoare was asked a question about a relation between Unity by Chandy and Misra and his CSP. He answered that Unity is geared towards distributed systems and protocol support, while CSP is focused on parallelism. He said that both can coexist, and combining them would be conceivable. I see it more as a hierarchy where Unity provides a global framework, while the CSP is more specific and provides useful constructs to support parallelism.

Next, Dennis Shea, IBM Research in Yorktown Heights, described transputer-based systems developed at IBM. In a short 3 years, several multiprocessor systems with 16-, 32-, 64-, and 256-transputer systems have been implemented with several applications ranging from modeling of oceanic wind currents to fault simulation and superconductivity. The goal of this project is to provide the researchers with a platform for experimentation in message-passing MIMD parallel processors with distributed memory. The Victor V256 is a 16 x 16 mesh of transputers which delivers almost linear speedup for several applications. The Victor V256 performs especially well for computation-intensive Monte Carlo codes.

David Talbot, Commission, head of Directorate General XIII, gave a superb talk outlining the goals and plans of the European Strategic Programme for Research and Development in Information Technologies (ESPRIT) project regarding parallel computing and software engineering. The previous phase of the ESPRIT program resulted in the capability to develop a 1,024 processor system known as a "supernode." The system spawned several companies. At present, several companies can deliver multiprocessor systems. A new parallel processing initiative, with a budget of $120 million, began with deployment of 55 systems supporting over 200 researchers. It is expected that about 300

students will graduate each year to support the growing multiprocessor industry. Continuing development, training, competitiveness, tenacity, persistence, and imagination are what will be supported and required to win in the supercomputing race. The ESPRIT already has several programs in place.

- Parallel Universal Message-passing Architecture (PUMA) that focuses on architectures
- Novel Parallel Algorithms for New Real-Time VLSI Architectures (NANA) on algorithm development
- Research and Education in Concurrent Systems (REX) on education, development, and management of parallel and distributed systems.

In the post-RISC Supernode-2, microprocessor initiative, Meiko and INMOS will be involved in the $120-million development to create the next generation of supercomputers.

Ian Pearson, Technical Director, INMOS, in his invited talk, described the company's plans for this decade, and revealed several interesting details about present and future INMOS products.

A new transputer, called H1, will run at 150-MIPS peak and 100 MIPS sustained rate, in addition to, more than 20-MFLOPS peak and 15-MFLOPS sustained performance. New bidirectional communication links will be able to deliver 80 Mbytes/s by multiplexing logical channels on physical links. The H1 will support conventional operating systems' features such as multiple priority levels, memory protection, and virtual memory. An enhanced process model will support real-time kernels and operating systems. A major change is in the support for interprocessor communication. New protocols will ensure high rates and low latency because of multiplexing and automatic routing. Binary compatibility with the present transputer family will be maintained. Also, INMOS will support mixed Tx/Hx series (Tx series indicates the current members of transputer family of products such as T400, T800, and others; Hx series are H1, H2, and others to be introduced in 1991 or later). Improved performance for multiprocessor assemblies will come together with the ease of use. The new chip will include a pipelined, superscalar processor, floating-point unit, 16-K cache, communication processor, and programmable memory interface manufactured in advanced CMOS technology. Up to 16 Mbytes of RAM can be attached to each processor without any additional components, and up to 4 Gbytes can be added in total.

In the future, INMOS will continue with the T-series, but the emphasis will be on application-specific transputers (ASIC T-series; ASIC Application-Specific Integrated Circuit). In the H-series there will be mainline products such as H1 and H2. At the same time, there will be several ASIC H-series that will be designed with specific functions as requested by the system houses and large users. The migration of software into hardware will continue. In like manner, the post-H generation of transputers (to be introduced in 1993), the E-series, is geared to meet the requirements of the European MicroInitiative (EMI), whose aim is to define and support a wide range of open systems. INMOS already claims the lowest cost per MIP (less than $2). With new infusion of capital, after being bought by SGS-Thomsom in 1989, it will become one of the main forces in the microprocessor industry in the world.

Another interesting development is the INMOS commitment to the design and implementation of a variety of communication ASIC chips. The C10x-series will be capable of connecting transputer products to any busses. The C100 chip, a converter, will support communication between Tx-series and Hx-series transputers, which will have a new generation of links. The C004, 32-way crossbar switch, will be replaced by the new C104 chip with improved protocols and the latest technology. Hx-series links for several products will also be developed.

The links for the H1 processor will enable communication between processes on the same chip, via memory, as well as support communication between processes on different chips. The bidirectional, self-synchronizing, virtual communication channels use send-ack protocols with an up to 32-byte packet format with an end-of-message (EOM) byte. Splitting messages into packets is automatic and wormhole routing is used. The communication is deadlock free and addressing is provided by a special interval numbering scheme. The new routing chips will provide communication capability for any number of heterogeneous devices and networks, such as ethernet and token-passing rings.

The companies manufacturing the transputer-based systems are rapidly growing in size and number. For example, Meiko, Parsys, Parsytec, and Telmat developed powerful "supernodes," which contain up to 16 transputers on a single board. "Meganodes" may have, according to manufacturers, as many as 1,024 transputers, but to my knowledge the largest existing systems do not have more than 500 processors. EE International Computer Corporation, Pasadena, California, delivers up to 16-transputer workstations. The transputers are connected over a superswitch, developed by the Jet Propulsion Laboratories in Pasadena, and the systems performance exceeds 100 MIPS and 20 MFLOPS at a low price, starting at $13,000.

Transputer Applications at Volkswagen (VW) Research was the title of a talk presented by P. Zimmermann. He described a 43-transputer system developed at VW for a driving simulator that can simulate the behavior of brakes, steering, and suspension systems. Although the performance of 600 polygons at 25 frames/s

is still far behind state-of-the-art simulators from Evans and Sutherland, but the price is orders of magnitude lower, which makes the transputer system an attractive alternative.

Ian Browning, Royal Signal and Radar Establishment, England, concentrated on military applications of transputers. The British Ministry of Defence (MOD) started the parallel processing program in the early 80s. Hence, the first parallel machines were based on transputers, because of their cost effectiveness, extensibility, and reconfigurability. Application areas include: embedded real-time control systems, image processing, speech recognition, battlefield simulation, missile system, and terrain line-of-sight modeling. Three levels of parallel systems are distinguished based on the application: low-level with 2-8 transputers, medium-level with 9-32 transputers, and high-level with more than 32 processors. The medium-size systems are most popular within the MOD. The mousetrap is a miniaturized version of a supernode with 16 transputers within a package the size of a shoebox. The mousetrap can be battery powered (less than 40 watts is needed), and delivers impressive performance of 180 MIPS and 20-40 MFLOPS.

Christian Tricot, Archipel, France, showed several commercials and a short, humorous movie developed on a nine-transputer system for image synthesis called VOLVOX. This application demonstrates that direct parallel programming is a viable approach in special-purpose system design. The architecture is tailored to video synthesis applications and there is no need to form a reconfigurable network. The fixed-topology architecture gives the optimum performance at an affordable price. The VOLVOX system can easily be attached to a personal computer or a standard workstation such as SUN or Apollo.

Wiggers and Vermeulen, NIKHEF-H, Amsterdam, have developed a data acquisition and processing system, called ZEUS, with over 500 transputers for high-energy physics experiments. The system is mainly used for data acquisition, data compression, event selection, and data monitoring. The high-energy physics experiments aim at identifying elementary particles, determining their properties, and analyzing their interactions. ZEUS will be used in spring 1991 at HERA, an electron-proton collider, located at DESY in Hamburg, Federal Republic of Germany (FRG). ZEUS is a special-purpose architecture where transputers are connected in various configurations: VME bus, 16-way crossbar, and a tree. To realize the complexity of the entire system, bear in mind that the transputer-based system is only a front end to a processor farm of MIPS R-3000 microprocessors that analyzes the entire data collected and preprocessed by the transputer system. The reasons for choosing transputers at the front end were:

- Direct memory access communication capability on all four links
- Simplicity of communication by using transputer and communication chip-set
- Efficient multitasking (task switching takes a few microseconds)
- Acceptable processing power at low cost
- Support in occam for parallel processing, interprocess communication, and synchronization, eliminating the need for an operating system.

All in all, ZEUS is the largest transputer-based system built to date for physics applications.

The last invited talk was by A. Eppinger, Bosch Company, Stuttgart, FRG, entitled "Object Oriented Simulations in Mechatronics." Eppinger described an object-oriented approach to analysis and simulation of a mechatronic (mechanical and electronic) system. A typical example of a state-of-the-art mechatronic device is an Anti-blocking Braking System (ABS), which is a complex combination of sensors, microprocessor-based controllers, electromagnetic actuators, as well as mechanical and hydraulic components. Several examples have demonstrated how hierarchical decomposition and modularity can help in model development that is then directly mapped onto a physical multitransputer system. This approach proved to be effective for interactive simulations. The software tool that was developed for simulation support is based on two concepts: "baseblocks" and "structureblocks." "Baseblocks" correspond to objects and can be fully characterized using, for example, algebraic and differential equations. "Structureblocks" provide "a glue" to connect all the modules together into one coherent system. The eight-transputer system, with a powerful workstation front end, has been implemented at Bosch and serves as an interactive simulator for several applications.

The contributed papers were presented in parallel tracks (see Table 1).

I was amazed by the large number and diversity of special-purpose, transputer-based systems that have been implemented and operate at a variety of European universities and laboratories. These systems have workstations, or powerful PCs, as front ends and typically use up to ten transputers interconnected in customized fashion, or up to a hundred connected in a two-dimensional array.

The range of applications is quite spectacular: pneumatics and hydraulics systems modeling, particle-flow measurement, Kalman filters, several real-time control systems (examples include automatic-flight control, vibration suppression, turbines control and robotics), image reconstruction, radiological visualization (for medicine, oceanography, and meteorology), real-time traffic monitoring, spectral-elements methods for computational-fluid

Table 1. Contributed Papers

Specific-Session Titles	No. Papers
Instrumentation	4
Real-Time Control	6
Tools for Real-Time Control	2
Simulation	1
Image Processing	15
Molecular and Particle Modelling	4
Operating Systems	2
Networking	1
Programming Environments	3
Parallel Programming Tools	3
Applied Signal Processing	4
Signal Processing Enabling Technologies	2
Graphics	1
Hardware Emulation	1
Music Synthesis	1
Industrial Inspection	1
Commercial Applications	2
Computer-Aided Design	2
Continuous Simulation	5
Classical Algorithms	6
Discrete Simulation	4

dynamics, real-time image analysis, graph isomorphism, textural analysis, protein-structures prediction, gate-level timing simulation, radiation engineering, and product-label inspection.

As an aside, I found it interesting that, according to Dunford from University of Sheffield, the 16-bit transputers are radiation hard and can withstand 20-30 Krad (1 Krad is lethal to a human) and are, in this respect, better than Intel's chips. This is partially a reason why they are being used in the Digital Wave Processor for the European Space Agency Cluster (Cluster) mission. The Cluster mission is intended to study the wave and plasma environment of the Earth's magnetosphere.

A complete conference proceedings entitled "Applications of Transputers 2" (ISBN 90 5199 035 9) can be obtained from IOS Press, Postal Drawer 10558, Burke, Virginia 22009-0558.

The next conference will take place in Glasgow, Scotland on August 28-30, 1991. In 1992, the conference will move to Barcelona, Spain.

ELECTRONICS

Revisiting Electronic Materials at the Royal Signals and Radar Establishment

by Howard Lessoff and Eirug Davies. Dr. Lessoff is a physicist serving as Liaison Scientist for solid-state chemistry and physics at the Office of Naval Research European Office. Specializing in crystal-growth, and material sciences dealing with electronics and opto-electronics, he was formerly Head of the Electronic Materials Branch, Naval Research Laboratory, Washington, D.C. Dr. Davies is Chief of Microelectronics and Semiconductors Physics at the European Office of Aerospace Research and Development (EOARD), London. Before joining EOARD, he worked on thin-film silicon technologies and has published over 50 papers on various aspects of semiconductor doping by implantation.

Introduction

The Royal Signals and Radar Establishment (R.S.R.E.) has an extensive and notable history in the growth of semiconductor crystals. It is very unusual to read a technical review article on crystal growth, not having references to R.S.R.E. or its predecessor, the Royal Radar Establishment. There are many examples of R.S.R.E. being the first or major contributor to solid-state material sciences.

Much of the original effort developing the Liquid Encapsulated Czochralski (LEC) growth of compound semiconductors was done at R.S.R.E. High-pressure crystal puller designs owe much to R.S.R.E. The laboratory played a major roll in establishing the theoretical foundations of the gallium arsenide (GaAs) and indium phosphide (InP) Czochralski growth and the phase relationships. The R.S.R.E. had major impacts in the epitaxial growth of III-V and II-VI compounds. Major advances in mercury cadmium telluride (CdTe) materials were made by the Electronic Material Division. Although the list of investigators is quite long, special mention should be made of the works of W. Bardsley, S.J. Bass, B. Cockayne, D.T.J. Hurle, S.J.C. Irvine, and J.B. Mullin. The Queen's Award for Technical Achievement was given to the Electronic Materials Division for:

- 1979 - Malvern Crystal Growth Equipment (high pressure Czochralski furnace technology)
- 1983 - High-Resolution X-ray Detector Crystals
- 1990 - Metalorganic Precursors for Semiconductor Materials.

Thus to visit the laboratory was to bring back memories of the dynamism of a major electronics materials center.

Nearly all efforts in bulk crystal growth are terminated. The remaining bulk activities are

- Growth of oxides and fluorides for solid-state and tuneable lasers
- Automatic LEC growth of InP and GaAs, in cooperation with MR Semicon, Ltd.
- Use of magnetic field to stabilize Czochralski growth.

The latter program will soon stop.

During LEC growth, the portion of the growth cycle that is most susceptible to twinning is segmented between "seed on" to maximum diameter. This segment of growth is characterized by a continuously changing interface shape. D.T.J. Hurle has developed a theoretical basis to predict when twinning will occur in the Czochralski growth of crystals. Hurle's work is based on the hypothesis that twinning will occur when an edge facet is present at the three-phase boundary. The energy for twin formation at the boundary condition is dependent on the specific material being grown. By proper control of the boundary conditions, especially temperature variations, twinning should be reduced.

Dr. Hurle is now developing a computer program that will automatically increase the diameter of a crystal from the seed on point to the full growth diameter. The angle of the outgrowth from the seed to the full diameter should be controllable and thus reduce twinning. The program, when developed, will be digital and will use the familiar weighing cell with a feed-back loop for the thermal control. The main change from the earlier analog program is the use of the surface tension component in the calculation, along with the liquid solid thermal interface. The surface tension takes into account the interface between the encapsulant and the melt. The change in surface tension is essential during the seed on

and cone out. If the surface tension is not used then, the weighing cell will show no change in weight (related to change in diameter) during the cone-out phase of growth. After reaching full diameter, the surface-tension component is no longer used for the control of the diameter. If successful, this effort will lead to fully automatic LEC growth for GaAs and InP. The program will also reduce the potential of twinning of large-diameter crystals. The twinning problem has prevented high yields of crystals with diameters more than 4 inches.

During Czochralski crystal growth, the advantage of using magnetic fields for thermal damping has been demonstrated by several laboratories. The magnetic fields are normally either set perpendicular to, or parallel to, growth direction. The use of the field reduces the temperature fluctuations. The magnetic field can also decrease interfacial stability of the melt leading to increase the impurity inhomogeneities. Using two orthogonal magnets for the growth of single-crystal silicon (Si), R.S.R.E. has shown that the uniformity of an impurity or dopant across the diameter of a wafer is improved. The orthogonal magnetic field also reduces the thermal fluctuations in the melt, and especially near the edge of the crucible and increasing crystalline uniformity.

The efforts in thin-film growth of semiconductors under Dr. Cockayne are still very active. The R.S.R.E. scientists are using traditional vapor-phase epitaxial growth, metal-organic chemical-phase deposition (MOCVD), and molecular beam epitaxy (MBE). The materials under investigation include: the zinc sulfides/selenides for potential blue emitters, cadmium selenide/sulfide for visible opto-electronics, gallium indium arsenide phosphide ($Ga_xIn_{1-x}As_yP_{1-y}$), the antinomides, and other related alloys. Much of the II-VI growths use new adduct precursors. The precursors were developed cooperatively at R.S.R.E. and Epichem Ltd. Using the precursors, Zn-based layers are grown having low-residual carrier concentrations, and high mobility. The ZnS alloys have no deep centers at the room temperature, as seen by photoluminescence. An interesting effort is heterostructures of wide bandgap materials, such as CdTe or aluminum antinomide with narrow-bandgap indium antinomide. The method, if successful, will take advantage of the very high-electron mobilities of the narrow-bandgap semiconductor for room-temperature device applications. The molecular beam epitaxy activity includes the use of an eximer laser to lower the deposition temperature of materials. The laser growth should increase control on impurity concentration and thickness. The method also lends itself to *in situ* characterization. This program is part of a larger European Community (EC) program in optical processing.

Interesting ferromagnetic materials have recently been discovered by Dr. Cockayne and his group. The materials are alloys of iron gallium arsenic ($Fe_3Ga_{2-x}As_x$) where x varies between 0.21 to 1.25. As the gallium content increases, the Curie temperature and the saturation magnetization also increase. Curie temperatures as high as 644K are measured, and room-temperature saturation values as high as 95 emu/g. Although the materials are still in the research stage, they offer potential for replacing the currently used magnetic materials.

The silicon division at R.S.R.E. is involved in several research efforts, in addition to running a fabrication facility. The fabrication is used primarily to customize gate arrays using direct write electron-beam lithography. Research activities include various aspects of plasma processing, low-temperature epitaxial growth, and quantum-size effects. The latter effort has yielded visible luminescence out of Si.

The luminescence work utilizes porous Si that has been developed over many years at R.S.R.E. as a potential replacement for Si on sapphire. Micro pores are formed in p-type Si on anodizing in HF solutions. This was first discovered at Bell Laboratories in the early years of the semiconductor industry. Later, it was adapted as an SOS replacement by Nippon Telephone and Telegraph who oxidized subsurface porous material to provide dielectric isolation. Development at R.S.R.E has shown that it can be a viable process, and 5-inch wafers can be processed in minutes without requiring excessively expensive equipment.

The material used for oxidation has a porosity of 55 percent. This leads to complete oxidation. No oxidation is undertaken for luminescence, and the material is given a very slow, wet etch until the porosity reaches 80 percent. This leaves isolated columns of Si suspended between enlarged pores. The resulting photoluminescence peak is enhanced and shifts further into the red as the etching is extended. The room-temperature peak is at around 1.6 eV with f.w.h.m. .1 eV. This is appreciably narrower than that observed in the red with amorphous hydrogenated Si. The wafer appears bright red when illuminated with an argon laser at room temperature.

A U.K. multi-chip consortium is also based at R.S.R.E. The hybrid approach is viewed as an alternative to wafer-scale integration which requires appreciable redundancy. Comparable packing density may be achieved by using wafer technology for the off-chip interconnecting metallization. Screen printing, for example, is replaced by photolithography.

This consortium is an outgrowth of an earlier government program referred to as RISH--Research Initiative on Silicon Hybrids. The present program was initiated in October 1989 and is scheduled to run through October 1991. The program is jointly funded by the

participants who assign their own personnel to R.S.R.E. General Electric Co., British Aerospace, Smith Instruments (Microcircuit Engineering), and R.S.R.E. appear to be the organizations with the most interest in applying the technology. The director of the program is Dr. Rob Nayler of GEC Marconi, and the present staff of 8 is soon to be increased to 12, or possibly 14.

The technology pursued is based on a substrate Si wafer which is overlaid with four levels of metallization. One provides the ground plane, one the power, and the remaining two are for signal. Polyamide is used as the intermediate isolating dielectric. For the metal, photolithographic techniques are used to define 50-m tracks in evaporated aluminum. Plasma etch, via holes, provides access to the different metal planes.

One example of a fabricated hybrid circuit included four memory chips and four ceramic capacitors mounted in conjunction with an Inmos transputer on an approximately 1-inch square substrate. Another example had an active memory substrate with a transputer mounted over the 32-K DRAM. Present concern centers around moisture effects on the polyamide and other polymers are under consideration. Stress testing is also a significant part of the program.

In spite of the illustrious past, there is a bit of concern over the future of electronic materials activities. Among the challenges R.S.R.E. will face, one is gaining research funds. The laboratory's primary source of funds was the Ministry of Defence. The current plans, are to cost share activities with other sources such as the EC, commercial enterprises, and other government agencies. Making the proper contacts, and developing adequate proposals is a learning process. The traditional sources of funding research are shrinking, in a manner very similar to that in the U.S. Thus, not only are the methods of funding changing but the availability of research funds is decreasing. Additionally, there are pressures for short-term research efforts, with actual application to systems of the results of research and development in 5 years or less. Such a policy is not suitable for materials research. The time needed for the basic conception of a new material to the device, is normally more than 5 years. It took nearly 25 years for the development of GaAs to go from a laboratory curiosity to actual usage in commercial devices. Even today the GaAs wafers are not fully ready for insertion into a pilot production plants without expensive testing.

First International Symposium on Atomic Layer Epitaxy

by Max N. Yoder, Electronics Division, Office of Naval Research, Arlington, Virginia

Introduction

The First International Symposium on Atomic Layer Epitaxy (ALE) was held in Helsinki, Finland, on June 13-15, 1990, with 99 people attending (11 Americans). I will provide several summaries here of the 33 presented papers. The ALE publications are currently growing at an exponential rate and, appropriately, the first symposium was convened in its country of origin. The second symposium will be in the U.S. in 1992.

T. Suntola and J. Antson first conceived of the Atomic Layer Epitaxy (ALE) and it was first disclosed by a Finnish patent in 1974 (Suntola et al., 1974). Not long after, ALE was patented in the U.S. (Suntola et al., 1977) but remained generally unknown there until I described it in European Science Notes (Yoder, 1982). Until recently, ONR exclusively supported ALE technology in the U.S. While Strategic Defense Initiative Organization (SDIO), via the Office of Naval Research (ONR), supports the bulk of ALE work in the U.S, other governmental and industrial funding continues to grow. Japan has most of the organizations engaged in ALE research and development. Indeed, there were more Japanese attendees at the symposium (38) than Finnish (35). The fourth largest ALE group is in the Soviet Union; various European Community countries have token efforts.

Background

The ALE technique was originally conceived as a method of compound; e.g., consisting of two of more elements of the periodic table, crystal growth wherein the growth surface was alternately exposed to reagent gases or radicals containing first the anion species and then the cation species. The technique was originally demonstrated on II-VI compounds and later on various III-V compounds. At this meeting, it was also disclosed to be efficacious for the synthesis of elemental; e.g., group IV semiconductors, and compounds of group IV elements.

The ALE method has several advantages over competing (traditional) methods of crystal growth:

- Absolute uniformity of the growth layer thickness over an arbitrary area
- Wide range of variation of gas flow rate and growth temperature
- Inherent ability to prevent unwanted impurity incorporation
- Delta impurity doping capability
- Generally much lower permissible growth temperature (particularly attractive as semiconductor device sizes are shrinking to the submircometer region and diffusion [enhanced by higher temperatures] is unacceptable.).

The ALE method is not without its drawbacks: (1) more complex, (expensive) growth apparatus and (2) slower growth rates.

Presentation Summaries

The following summaries are representative of the presentations at the symposium.

Molecular Layer Epitaxy in Gallium Arsenide, J. Nishizawa and T. Kurabayashi, Research Institute of Electrical Communication, Tohoku University, Sendai, Japan. Dr. Nishizawa is widely known for his invention of the static induction transistor in silicon. Until 1984, it was widely thought that most of the III-V compounds may not be amenable to ALE synthesis as there was no substrate temperature at which cation-cation bonds would thermally break without also breaking the desired cation-anion bonds. Using alternating molecular rather than atomic beams, he showed that surface catalysis could be used to deposit selectively single atomic layers (Nishizawa et al., 1984). Later, he showed that by an adaptation of the method, elemental silicon could also be synthesized by ALE (Nishizawa et al., 1989) although the technique was not isothermal. In his plenary presentation, he described these pioneering advances, then described more recent work. Most important among these were his descriptions about how the ALE technique could be used to control the site location; e.g., cation or anion, of the normally amphoteric silicon impurity dopant in gallium arsenide (GaAs) and related III-V compounds. The cyclic positional sequence of the silicon impurity introduction and the subsequent anion reagent pressure and exposure time determined the site placement procedure.

Atomic Layer Epitaxy of Semiconductor Thin Films, S.M. Bedair, North Carolina State University, Raleigh, North Carolina. Professor Bedair described his pioneering ALE synthesized growth of GaAs and related III-V materials. His method differed from Professor Nishizawa's in that the Bedair approach physically and cyclically moves the substrate under differing reagent gas streams; whereas, the Nishizawa method relies on purging the chamber of residual gases between exposures. Highlights of the Bedair presentation were the vertical sidewall ALE growth, and the use of ALE to create delta-doped ohmic contact regions. Thus, he eliminated the need for alloyed ohmic contacts, and the efficacy of the laser beam enabled ALE to grow III-V materials with all of the attributes of conventional ALE. The delta-doped ohmic contacts were made using H_2Se gas instead of the arsine cycle, thus ensuring that the Se impurities were located on anion sites. Donor concentration exceeded $10^{18}/cm^3$. This technique significantly improved field effect transistor source and drain conductance. The SDIO funded most of this work via ONR.

Atmospheric Pressure Atomic Layer Epitaxy: Mechanisms and Applications, P.D. Dapkus, B.Y. Maa, W.G. Jeong, and S.P. denBaars, Departments of Electrical Engineering and Materials Science, University of Southern California, Los Angeles. In this primarily ONR-funded work, the mechanisms of III-V ALE growth were explored. The mechanism by which self-limiting (saturated) growth occurs in the near atmospheric region (e.g., 10 - 760 Torr) is controlled by the formation of decomposed organometallics in the gas phase at high temperature and by slow surface reactions at low temperature. For trimethylgallium (TMG), this limits the useful ALE growth temperature to a region of 30° C. Using a 40 micrometer diameter 514.5 nanometer laser with a 150-200 $Watt/cm^2$ excitation, however, the temperature range over which the self-limiting growth will accrue is increased to 100° C. Experiments were described in which both thermally driven and optically excited ALE growth were used to fabricate quantum well lasers. Lasers grown in this manner exhibit threshold current densities as low as 650 A/cm^2-- about three times that of similar lasers fabricated by conventional means. The investigators used reflection difference spectroscopy to determine that steric hindrance may be present in TMG reagents suggesting that other reagents may be more efficacious in III-V ALE synthesis.

Beam-Assisted Layer-by-layer Processes and the Mechanism in III-V Compounds, Y. Aoyagi, T. Meguro, and S. Iwai, Institute of Physical and Chemical Research, Saitama, Japan. This work sought to determine the exact nature of the efficacy of the light wave in selectively stimulating the ALE growth of III-V compounds. They investigated two basic suppositions. The first was that the optical beam created electron-hole pairs just beneath the growth surface and the diffusion of theses charges to the surface were responsible for catalyzing the decomposition of the reactant gases at temperatures much below their normal pyrolization level. The second supposition was that the optical phonons acted by direct bond breaking at the surface. Using a series of growths

involving hyperabrupt P-N junctions, the investigators showed that the second supposition was the correct one. This paper also described the first atomic layer etching of the GaAs surface. Although such techniques had previously been described for diamond (Yoder, 1989), this was the first for a III-V material. The technique cyclically exposes the GaAs surface to atomic chlorine and electrons. The author described how a combination of the etching and growth techniques could be used to correct a vicinal surface.

ZnSe-ZnTe and ZnS-ZnSe Strained Layer Superlattices Grown by Atomic Layer Epitaxy, M. Konagai, Y. Takemura, R. Kimura, N. Teraguchi, H. Nakanishi, and K. Takahashi, Department of Electrical and Electronic Engineering, Tokyo Institute of Technology. This work sought to compare ALE and metalorganic molecular beam epitaxy (MBE) approaches to the growth of type II heterojunctions of ZnTe:ZnSe. In contradistinction to most ALE growths, they found that the ideal ALE growth of ZnSe was between 250 to 350° C, whereas that of ZnSe MBE growth was between 225 and 300° C. Delta-doped Cl donors were found to be efficacious. $ZnCl_2$ was used as the dopant source and impurity concentrations between 5 x 10^{17} and 3 x 10^{18} / cm^3 were demonstrated. Type II superlattices were made of ZnSe:ZnTe. Yellow-green luminescence was observed and found from thermal cycling to be associated with the recombination of excitons trapped by Te atoms. The self-limiting mechanisms of ZnSe were found to be independent of diethylselenium flow rates and exposure times, very limited by Zn cell temperature (10° C window), and reasonable tolerant of Zn cycle exposure time.

Development Challenges of Atomic Layer Epitaxy, T. Suntola, Microchemistry Ltd, P.O. Box 45, SF-02151 Espoo, Finland. The inventor of ALE traced its development and illustrated several current applications including giant and long-lived electroluminescent yellow displays in airports and very thin; e.g., 2.5- inch thick, monochrome high contrast computer monitor displays. He illustrated how most favorable surface chemistries must be found for each compound to be grown and the need for developing reagents specially formulated for ALE use. Also discussed was the importance of properly cleaning the starting surface, the general criteria of choosing reagents with high chemical reactivity, of high ratios of absorption and nondesirable desorption, the elimination of gas phase reactions, and well-designed reactor flow dynamics.

Investigation of Growth Processes in Flow-Rate Modulation Epitaxy and Atomic Layer Epitaxy by New *In Situ* Optical Monitoring Method, N. Kobayashi, T. Makimoto, Y. Yamauchi, and Y. Horikoshi, NTT Basic Research Laboratories, Tokyo. In a modification of the basic electro-reflectance spectroscopy pioneered by Aspnes (Aspnes et al., 1988), this work illustrates the efficacy of the approach to investigate in situ the nucleation of the ALE surface. By impinging the interrogating laser beam on the nucleating surface at the Brewster angle, the surface- to bulk-generated electro-reflectance could be maximized. In so doing, and by rotating the optical polarization, the electro-reflectance provided a temporal indication of the surface resident species in synchrony with the ALE cycle. In this manner, the individual exposure time constants could be optimized and the surface resident species determined. An alkyl Ga surface was found to exhibit different reflectivity than did a metal Ga surface. A 325 nanometer He-Cd laser was used. The Ga organometallic molecule adsorbs to the arsenic surface, but not to the alkyl metal surface.

Principles of the Precise Synthesis of Supermolecular Objects: Atomic Layer Epitaxy, Molecular Layering, Chemical Buildup, V. Aleskovskii and V. Drozd, Department of Chemistry, Leningrad University, Leningrad, U.S.S.R. This paper was interesting from several aspects. First, in the oral presentation, the author said he is from St. Petersburg, Russia. Second, he presented a technique of growing diamond at 600° C by simply alternately exposing the surface--first to methane and then to carbon tetrachloride. In his oral discussion, he stated that he first grew diamond by this ALE method in the late 1960s. Unlike most other techniques for growing diamond at low pressures, this technique requires neither a plasma nor a hot filament and it does not require dilution in molecular hydrogen. He chose to not concentrate on diamond, however, and most of the paper was devoted to the growth of insulators by ALE. Among the insulators grown were Cr_2O_3, V_2O_5, TiO_2, ZrO_2, HfO_2, WO_3, and Nb_2O_5. Cr_2O_3 was used in conjunction with a thin, thermally grown oxide on silicon to improve metal-insulator-silicon devices by reducing the pinhole porosity of the insulator. Several of the oxides were effectively synthesized at room temperature (although the effective temperature of the growth surface during exothermic chemical reactions of the ALE process may have been much higher).

ALE of Group IV Compounds, M. Yoder, Electronics Division, ONR, Arlington, Virginia. I introduced the concept of the extraction-exchange approach to ALE, thus enabling the growth of elemental semiconductors and compound semiconductors of the group IV elements. The process is based on the chemical binding energy of hydrogen to a halogen element being much stronger than the chemical bonds of the semiconductor-being-synthesized to either hydrogen or the halogen being used. Using this approach, two differing molecular gases of the element of the semiconductor being synthesized are used. One gas is hydrogen based while the other is halogen based--similar

to Drozd's paper described above. Using the rationale developed in this paper, however, the Drozd method, to be most effective, must employ fluorine rather than chlorine. The paper further explains how superlattices and heterojunctions of the various group IV elements may be ALE synthesized.

Surface Reaction in Alpha Al_2O_3 Layer Growth, G. Oya, Utsunomiya University, Japan, and Y. Sawada, Research Institute of Electrical Communication, Tohoku University, Sendai, Japan. By alternating between $AlCl_3$ vapor and a gas of 15 percent oxygen diluted in helium, single crystalline layers of Al_2O_3 were grown on sapphire. A self-limiting growth was experienced over a broad range of temperature (650-800° C) and pressure. $AlCl_3$ molecules were found to disassociate upon reaction with an oxygenated surface. Apparently, $AlCl_2$ radicals chemisorb to the surface and are further decomposed upon subsequent exposure to oxygen. Both basal plane and other crystallographic orientations were employed.

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MATERIALS

Diamond and Diamond-like Coatings - Conference Summary and Potential

by Michael J. Koczak, the Liaison Scientist for Materials for the Office of Naval Research European Office. Dr. Koczak is on sabbatical leave from Drexel University, Philadelphia, Pennsylvania, where he is a Professor of Materials Engineering.

Diamond Potential

The recent interest in diamond and diamond-like coating has galvanized researchers throughout the world to seek the production of diamond films. The question is not can it be done, but rather, it moves to a question of cost-effective production, scaling, and film quality. The application of diamond films span a range of applications to include optical and x-ray windows, abrasive, free-standing films, infrared, cathode luminescence, wear, electronic, heat sinks, chemically stable surfaces, low friction, and acoustic applications. The enabling technology of the diamond film properties can drive many critical technology areas as detailed in Table 1.

Table 1. Motivations For Diamond Films

Enabling Property	Application
High modulus	Free-standing structures
High hardness	Bearing and wear applications
Low friction	Wear application
Transparency	X-ray and laser windows
High thermal conductivity	Heat sinks
Electrical properties	Sensors
High-power density	High-power semiconductors
High refractive index	Lens
Diffusion barriers	Hydrogen barriers
High radiation hardness	Electronic, windows, mirrors
Corrosion resistance	Containment vessels

Beyond the natural interest in these applications is a fundamental chemistry and structural issue; i.e., what is the character of the diamond, and namely the degree of diamond bonding; e.g., sp^3 type versus graphitic or sp^2. Apart from chemistry characterization, can the electrical, mechanical, and physical properties be scaled and consistently reproduced for cost-effective applications.

First European Conference on Diamond and Diamond-like Carbon Coatings - Crans Montana, Switzerland

The First European Conference on Diamond and Diamond-like Carbon coating was held in Crans Montana, Switzerland, with over 500 attendees. The sessions were appropriately held in the Crystal and Amorphous Rooms and involved the following topics:

- Preparation of Diamond Films
- Preparation of Diamond-like Films
- Characterization of Diamond Films
- Characterization of Diamond-like Films
- Application of Diamond Films
- Optical Electronic Application of Diamond-like Films
- Mechanical Applications of Diamond-like Films

The international interest in diamond technology is demonstrated by the spectrum of industry, academic and governmental participants, and invited lecturers to include:

- Diamond and Diamond-like Films: Growth Mechanisms and Structure - Professor J.C. Angus, Case Western Reserve University, Cleveland, Ohio
- Characterization and Applications of CVD Diamond Films - Dr. P.K. Bachmann, Phillips Research Laboratories, Aachen, Federal Republic of Germany (FRG)
- Diamond in Perspective: A Review of Mechanical Properties of Natural Diamond - Professor C.A. Brookes, University of Hull, U.K.
- Analysis of the Quality of Diamond Films Deposited from the Vapor Phase - Professor J.T. Glass, University of North Carolina, Chapel Hill

- The Combustion Flame Method for Diamond Deposition - Dr. Y. Hirose, Nippon Institute of Technology, Saitama, Japan
- Applications of Synthesized Diamond in the Aerospace Industry - Dr. S. Holly, Rockwell International Corp., Canoga Park, California
- Characterization of Diamond and Carbon-Based Material by Raman and Micro-Raman Spectroscopy, Dr. P.V. Huong, University of Bordeaux, France
- Recent Work on CVD Diamond in Japan, Dr. M. Kamo, National Institute for Research for Inorganic Materials, Ibaraki, Japan
- Nucleation and Growth of Diamond Films, Professor B. Lux, Technical University of Austria, Vienna, Austria
- Structure and Properties of Vacuum Arc-Deposited Amorphous-Diamond Films, Dr. D.R. McKenzie, University of Sydney, Australia
- CVD Diamond Coatings for Cutting Tool Applications - Current Status of the Technology, Dr. S. Söderberg, AB Sandvik Coromant, Sweden
- CVD Diamond-Layered Structures, Dr. B.V. Spitsyn, Institute of Physical Chemistry, Moscow, U.S.S.R.
- Gas-Phase Diamond Crystallization: Past, Present, and Perspectives, Dr. V.P. Varnin, Institute of Physical Chemistry, Moscow.

The Question of Diamond versus Diamond-like

The technology of diamond film formation has attracted interest in carbon chemistry and the development of several synthesis procedures. The difficulty is the need for reproducible diamond and diamond-like films that have reliable electrical, optical, and mechanical properties. The need to produce a 100-percent diamond coating may not be absolutely necessary since many diamond-like films have interesting and apparently tailorable wear, electronic, and optical characteristics. A comparison of diamond and diamond-like coatings is shown in Table 2. The goal should be to develop consistency in diamond synthesis and couple it with a low-cost manufacturing approach.

The keys tests in assessing the diamond-like features of the synthesis process have been Raman spectroscopy coupled with luminescence, electrical, and thermal conductivity. Diamond is the best thermal conductor at ambient temperatures and has excellent insulating properties. In addition, doping permits alteration of the electrical conductivity. As a result, the ability to utilize diamonds for electronic applications resides in an electrical stable film with no porosity; i.e., dielectric-breakdown potential coupled with a consistent electrical performance over a range of temperatures.

Table 2. A Comparison of Properties of Diamond and DLC

Property	Diamond	DLC
Physical		
Hardness (kg mm^{-2})	> 10,000	2000-9000
Coefficient of friction	0.1 air	0.02(vac)-0.7(air)
Lattice constant (A)	3.567	amorphous
Density (g cm^{-3})	3.51	2.0-2.8
Youngs modulus ($N m^{-2}$)	10.5×10^{11}	1.2×10^{11}
Chemical		
Bonding	Covalent sp^3	mixed sp^2,sp^3 and C-H
Impurities	N,B (substitutional)	H
Reactivity	Inert in acids, solvents, salt, water.	generally inert
Thermal		
Conductivity ($W mK^{-1}$)	2200	1100
Electricity		
Resistivity (ohm cm)	$> 10^{16}$	10^{6}-10^{16}
Dielectric constant	11	5-9.5
Dopants	B,N,P,Li	P,B
Optical		
Band gap (eV)	5.45	0.8-2.0
Refractive index	2.42 (at 589.3 μm)	1.8-2.3
Optical transparency	0.225 to > 80 μm	2.5- > 50 μm

Thermal Conductivity - Carbon 12 Diamonds

A measure of the quality of the diamond synthesis has been thermal conductivity measurements. Recently, General Electric Research and Development Center has grown gem-quality diamond via a combination of chemical vapor deposition (CVD) combined with high-pressure techniques. The high-thermal conductivity is achieved via the utilization of carbon-12 versus carbon-13 using 99.9 percent carbon-12 methane as a feed stock for diamond production. The production is reportedly carried out at 55,000 atmospheres and utilizes a liquid catalyst that permits carbon-atom migration to the diamond surface. A comparison of the ambient-temperature thermal diffusivity and thermal conductivity is shown in Table 3 for the isotopically carbon-12 diamond as well as other materials. In addition to the improvement in thermal properties, the isotopically-pure diamond can resist high-power laser damage versus natural diamonds. The speculation for the performance enhancement is based on the improved thermal diffusivity and conductivity coupled with a

Table 3. Diamond Characteristics at Ambient Temperature

Material	Thermal Diffusivity (cm^2/sec)	Thermal Conductivity (w/cm-K)
GE - Diamond C-12 99.93 %	18.5	33.2
Synthetic Diamond	12.4	22.3
Natural Diamond	12.2	21.9
Copper	1.25	4.0

perceived narrower phonon-absorption spectrum which reduces energy absorption and permits faster heat dissipation.

It should be noted that diamond's thermal properties are very temperature dependent. Also, the diamond thermal conductivities peak at 100 W/cm-K at 100K and are superior to other materials above 30K, below which copper has superior thermal conductivity. An obvious intriguing question is the ability to produce diamonds in bulk quantities for commercial electronic and wear applications based on carbon-12 technology. The cost of carbon-12 is estimated at $3.00 per gram. However, the lengthy processing times may limit the cost effectiveness of the production process.

Conference Summary

A range of researchers demonstrated capabilities in diamond syntheses techniques. Several papers in the conference that were of specific interest in the areas of synthesis, characterization, and applications include:

Synthesis

- Low-Temperature Growth of Highly Purified Diamond Films Using Microwave Plasma-Assisted CVD (Chemical Vapor Deposition) - Y. Muranaka et al., Hitachi Research, Ibaraki, Japan
- Investigation of Diamond Growth in a New Planar-Microwave Plasma Source - A. Ohl et al., The Academy of Sciences of the German Democratic Republic, Greitswald, FRG
- Deposition of Diamond and Diamond-Like Carbon Films Using an ECR Microwave Source - B.D. Sartwell et al., Naval Research Laboratory, Washington, D.C.
- Diamond Growth from the Gas Phase: Multiple Techniques to Obtain the Same Material? - G. Janssen et al., University of Nijmegen, the Netherlands
- Nickel-Assisted Metastable-Diamond Formation (Surface Recrystallization) in a Dissolution Medium at Atmospheric Pressure - K.A. Cherian, Sardar Patel University, Kaira, Gujarat, India
- The Reaction of Atomic Hydrogen with a C:H and Diamond Films - E. Vietzke et al., Fraunhofer Institute, Juelich, FRG
- The Structure of Acetylene Flame for Diamond Synthesis - Y. Matsui et al., Nippon Institute of Technology, Saitama, Japan.

Diamond Film Synthesis

The development of diamond films has been accomplished by several deposition techniques that can produce films at a range of deposition rates and temperatures. Rates of deposition of 930 μm/hours have been reported, however typical ranges are in the 10 - 100-μm/hour range. Diamond films from Sumitomo have been deposited at 450C at a rate of 90 μm/hour and over an area of 500 cm^2. The goals are naturally higher deposition rates over larger areas and curved surfaces.

A "breakthrough" synthesis paper was presented by G. Janssen from the University of Nijmegen, the Netherlands, (1) that reported the rapid formation of single-crystal diamonds via acetylene oxygen-flame deposition. Although other investigators have reported single-crystal formation (2,3), this approach demonstrates the epitaxial growth of diamond films on a diamond substrate at a reasonably rapid rate. The technique deposited films on (110) diamond substrates at a deposition rate of 50 μm/ hour. The single-crystal quality of the film was confirmed by Raman spectroscopy and photoluminescence techniques. Infrared absorption approaches revealed the presence of hydrogen impurities. The research is sponsored by the Netherlands Technology Foundation and Drukker International B.V. The economical viability of the research is to be established with potential applications for heat sinks, knives, and wear-resistant tools. The presentation only discussed one 150-μm thick film on a 70-μm diamond substrate and the question of consistent reproducibility was not addressed.

The conference's program interest centered upon the characterization and quality of the films. Raman spectroscopy coupled with the substrate temperatures, rates of deposition, and thermal conductivities were measures of the successful processing of diamond films. The processing windows for diamond versus graphite formation are restricted; e.g., at high carbon levels, graphitic formation occurs while at elevated oxygen levels, oxidation initiates. For diamond formation at low temperatures, an oxygen/carbon ratio of 1.6 - 1.7 was required for various hydrocarbon gas mixtures. At higher temperatures, the chemistry window of diamond

formation narrows, although the rate of production can increase.

A summary of the various deposition approaches and corresponding temperatures are shown in Table 4 (4,5).

Table 4. Production Routes for Diamond Films

Deposition Rate (μ/hr.)	Processing Route	Temperature (K)
0.01 - 0.1	Thermal decomposition	1000 K
0.1	Glow pressure discharge Radio frequency	1500 K
0.5 - 10	Low pressure microwave plasma hot filament	2500 K
10 - 100	Combustion flame diamond CVD	3200 K
900	Hot radio frequency DC plasma arc discharge plasma jet	5000 K

Applications

The near-term applications for diamond films are in the area of abrasive and tools with optical and electronic applications having large potential markets. Demonstration of transitions of diamond-film technology has been, again demonstrated in Japan with the following products and the associated companies (see Table 5).

Table 5. Application Of Diamond Films Into Products

Product	Manufacturer
Speaker membranes	JVC/Sumitomo Electric
Diamond films on crucibles	Showa Denka
Diamond coatings	Asahi Glass
Diamond cutting tools	Toshiba Tungaloy
Thermistors	Sumitomo Electric
Abrasive	Sumitomo Metals

With regard to cutting tool applications, the utility of diamond coating is in the nonferrous; e.g., aluminum-cutting, area. At high-cutting temperatures; e.g., 900C, the diamond films become unstable and dissolve or decompose when the matrix has carbon solubility. Papers of manufacturing interest included:

- Microfabrication of Diamond Films: Selective Deposition and Etching - S. Miyauchi et al., Kobe Steel Ltd., Kobe, Japan
- Improvements in the Adhesion Strength and the Cutting Performance of Diamond-Coated Tools - K. Saijo et al., Toshiba Tungaloy Co., Kawasaki, Japan
- Diamond-Like Carbon Applied to Bio-Engineering Materials - J. Franks, Ion Tech Ltd., Teddington, U.K.
- Abrasion Resistance of Diamond-Like Carbon Coatings on Thick Film-Resistor Material - H. Krokoszinski, ASEA Brown Boveri, Heidelberg, FRG.

The electronic application of free-standing films, which are excellent insulators and thermal conductors, may permit the development of three-dimensional, electronic-design arrays. The needs for computational thermal-management systems coupled with proper design of microelectronic devices go beyond the manufacture of the films. The films must also address the film/circuit interconnections and substrate mechanical and thermal strain compatibility. The efforts at Harwell, Didcot, U.K., and Jet Propulsion Laboratory, Pasadena, California, address the strain compatibility issue and elevated temperature resistivity.

- Evaluation of Internal Stresses Present in CVD Diamond Films-I.M. Buckley-Golder, et al., Harwell
- High-Temperature Electrical-Conductivity Measurements of Natural Diamond and Diamond Films - J.W. Vandersande, Jet Propulsion Laboratory.

The conference proceedings can be obtained from:

Elsevier Sequoia
P.O. Box 564
1001 Lausanne 1 Switzerland

The Second international Symposium on Diamond Materials will be held May 5-10, 1991, in Washington, D.C., as part of the 179th Meeting of the Electrochemical Society. For information, contact:

The Electrochemical Society
10 South Main Street
Pennington, New Jersey 08354-2896

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Appendix

BRITE/EURAM Programs in Diamond-film Technology

Apart from the individual corporate and university efforts, two major efforts are underway under a European Community (EC) Basic Research in Industrial Technologies in Europe/European Research in Advanced Materials (BRITE/EURAM) initiative in diamond technology for optical fibers and diamond and silicon-carbide sensors for microelectronic devices. The leaders of the two efforts are Ceram Optic GMBH and the Microelectronics Group at Harwell. The objectives of their efforts from the Synopses of Current Projects 1989-1990 (1) are detailed below with their research partners.

From: BRITE/EURAM Programme, Synopses of Current Projects 1989 -1990, Commission of European Communities, Pub. No. Eur 12600, (1990)

Diamond and Silicon-Carbide Sensors (DISCS)

Starting Date: 1990 Duration: 36 months

Objectives

The DISCS will develop deposition- and downstream-manufacturing technologies to exploit diamond and silicon-carbide materials in several market sectors including aerospace, automotive, medical, energy, materials supply, and instrument development. By bringing together pockets of EC and European Free Trade Association (EFTA) expertise in four countries based in industrial conglomerates, Small Manufacturing Entities (SME), universities and research institutes, the aim will be to integrate the manufacturing technologies so that new industrial processes and prototype products in diamond and silicon carbide can be demonstrated. Thus, CVD, plasma processing, ion-beam modification and laser-processing techniques will be developed, and advanced sensors and environmentally-resistant layers will be demonstrated.

Prime Partner

Harwell Laboratory
Microelectronics Materials Centre
B.552, Didcot Oxon, England
UK-0X11 0ra Oxon

Other Partners

Program Partners	Country
MBB	FRG
Technical University Berlin	FRG
IMEC	Belgium
CSEM	Switzerland
British Aerospace	U.K.
Centronics	U.K.
EPICHEM	U.K.
Thermal Controls	U.K.

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The Development of Diamond-film Technology and Its Application to Improve the Quality and Durability of Optical Fibres

Starting Date: January 1990 Duration: 48 months

Objectives

Low-pressure, diamond-film deposition is an important emerging technology still at the precommercial stage worldwide, which has many important potential applications. To date, there has been little serious European research on this topic. Furthermore, we intend to develop an application for the technology by focusing specifically on the coating of optical fibres to improve their long-term reliability. This will be a major innovation. The main quantified targets are to produce diamond film-coated optical fibres with stress corrosion susceptibility factors > 200 at fibre drawing speeds up to 10 m/s. The successful achievement of these targets would result in world leadership in fibre optic technology for European industry. The project will also lay the foundations for other commercial applications of diamond technology in various engineering and electronics markets.

Prime Partner

Ceram Optec GMBH
Optical Fibre
Siemensstrasse 12
D-5300 Bonn, FRG

Other Partners

Program Partners	Country
Standard Elektrik Lorenz AG	FRG
General Signal Thinfilm Company	the Netherlands
Eolas-The Irish Science & Technology Agency	Republic of Ireland

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The Intelligent Processing of Materials Workshop Summary

by Michael J. Koczak

Introduction

The Katholieke University, Leuven, and Drexel University conducted a two-day international conference and workshop on Intelligent Processing of Materials (IPM) on June 22-23, 1990, concluding with a satellite invited specialist workshop on June 23rd. Supported by the Office of Naval Research European Office (ONREUR), speakers were invited from France, the Federal Republic of Germany, the U.S., Sweden, and the U.K. The conference and subsequent workshop focused on the key issues in intelligent-processing techniques and addressed the critical issues relating to the future development of basic research themes and their eventual industrial applications. The conference and workshop proceedings provide an insight into the status of materials modeling, sensor and control systems, and artificial intelligence as applied to materials processing.

The question of intelligent processing of materials concerns a diverse group of technologies and fields of expertise. The goal of this workshop was to provide a venue that would bring together the demanding requirements of materials producers, the highly developed capabilities of sensor technologies, and the enabling efforts of control systems to define the past and seek future contributions. It is foreseen that the major areas of definition are

- Process modeling which incorporates the theories of deformation and solidification processing as well as the newer processing technologies; e.g., spray deposition and chemical vapor deposition
- Sensor systems where under the influence of a chemical or physical change, a signal is generated, conditioned, amplified, and displayed to operate a control system
- Advanced control systems that permit the important linkage from the sensors to materials process-control systems
- Artificial intelligence that allows knowledge-based controllers and process simulations to enhance the productivity of materials processing.

Workshop Organization

The 1-day workshop following an IPM conference was divided into three task groups; i.e., process modeling, sensor, and control systems, to develop an interdisciplinary perspective on the needs of intelligent processing of materials. Following a deliberation period, the reports of each task group were presented to the combined-workshop panel and a consensus summary were sought. Each of the three working groups could formulate separate, and possibly conflicting, responses to a research agenda for the development of IPM. Some of the key questions in the workshop involved issues regarding basic research and the goal of defining new directions and research. The contributions from the three task groups sought to address the following themes and questions:

Background

A. What have been the four most significant research and development contributions to intelligent processing of materials in the last 5 years in (1) process modeling, (2) novel sensor systems, (3) advanced control strategies, and (4) artificial intelligence?

Current Research Activity

A. Which are the leading research areas of IPM research activities; i.e, with the areas of process modeling, novel sensor systems, advanced control strategies, and artificial intelligence?

B. What do you see as the most dynamic areas of research activity with regard to theoretical and experimental control approaches?

Research Road Blocks And New Directions

A. What are the limiting theories, instrumentation, and processing approaches which hinder the development and understanding of IPM?

B. Once these areas are identified, what efforts should be undertaken to overcome these roadblocks, and promote the scientific understanding and development of IPM? What are the constraints?

Research Agenda For The Future

A. What should be the new directions and research themes that will enable the development of IPM?

B. Are the current approaches adequate or should an interdisciplinary and/or international approach be sought?

Workshop Summary

The conference and workshop proceedings focused on and addressed issues and agenda items to define new research directions in materials processing. Following the task groups' reports in materials modeling, sensor, and control systems, the workshop participants met in plenary session to discuss the general overall barriers, required initiatives, demonstration areas, and the role of international cooperation. The discussion endeavored to combine an industrial and academic view of intelligent materials processing with a focus on:

- Overall barriers to intelligent materials processing
- Required initiatives.

From an industrial and academic viewpoint, a summary will focus on the areas of materials processing where IPM is actively integrated, and the areas where it should be considered for future applications.

Differing Views Of Materials Processing

There are important linkages between the groups representing product interests; i.e., the industrial sector; material and process modeling; i.e., the academic side, sensor, and control systems. The strength of these interrelations in materials processing can be partially quantified and depicted in Figure 1. For instance, utilization of control systems in automatic welding and positioning operations is well advanced at the microwelding level to large-scale welding and cutting operations in heavy industries. However, for solidification processing, progress has not been as rapid. In this case, the timescale for microstructural development is lengthy and process control during the solidification process may be impossible. Consequently, the application of intelligent processing is a function of the material and manufacturing process and is coupled to the timeframe of the process; e.g., 10^{-4} seconds for rapid solidification versus 1-10 seconds for sand casting.

In addition, there is the structure/property/processing linkage that should also connect to the manufactured product (see Figure 2). There are several views that can be considered in this structure/property/processing/product linkage. For the industrial manufacturing sector, the view starts with the requirements for the fabricated product (see Figure 2) which includes microstructural, material property, and dimensional control restrictions. As a result, the manufacturer's view is, naturally, centered upon the product, and the strength of the linkages from the product requirements drives the properties, processing, and microstructure. The manufacturer sees a strong link between the product shape and processing, and good linkages to structure and processing. The secondary linkage between processing and property in this case is weak and may not be seen as a direct product

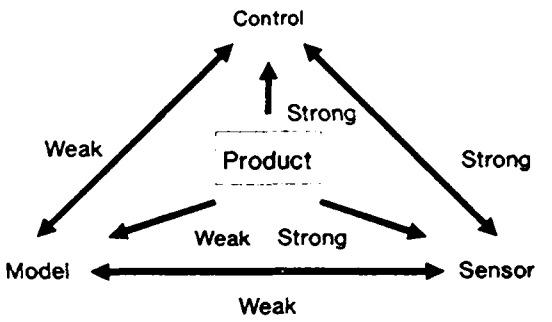
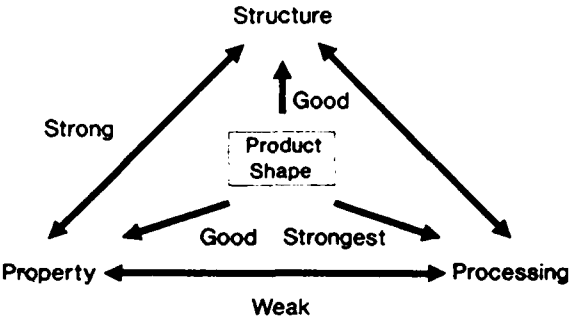


Figure 1. Linkages between sensor, control system, process model and manufactured product.



INDUSTRIAL VIEW → CENTERS ON PRODUCT

Figure 2. The manufacturer's view of the relationship between product - properties - structures and processing.

concern by the manufacturers, as long as the individual connections and control from the product are strong.

Similar comparisons can be drawn on the design engineer's view with specific interest in properties and materials performance, as well as the process model view. A designer's view is focused on the property requirements of the material, while an academic's is more concerned with the processing model (see Figures 3 and 4, respectively). The views of the product, designers, and modeler must be appreciated and harmonized into a total product and process understanding. The academic community claims to have a reasonable understanding of the process model and the relation to microstructure and properties. Consequently, the academic, design engineer, and industrial groups have different starting viewpoints in their integration of the process model, microstructure, mechanical and physical properties, and finished manufactured product.

Intelligent Processing Of Materials - An Industrial Viewpoint

The manufacturer's many requirements for intelligent processing include the needs for real-time, cost-effective control, total-quality management, a more complete sensor link, and communication of process interactions,

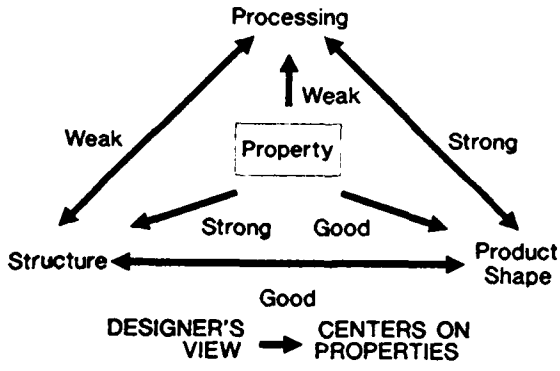


Figure 3. Design engineer's view of the relationship of property - structure - processing and product shape.

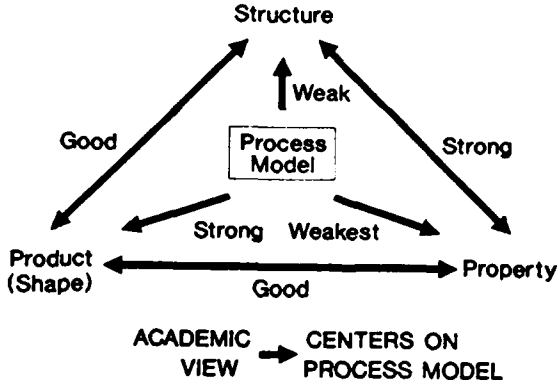


Figure 4. An academic's view of interests in the process model.

upstream to downstream in terms of sensor and control feedback. The logical extension of these events may suggest complete plant integration and control for all materials-processing operations. Although these goals are admirable, there are cultural and financial barriers in terms of industrial workers and technicians who must comprehend and control the process. Using computer terminals and programming language may not be appropriate for a noncomputer-literate steel worker or foundryman; the requirements of user-friendly controls and voice recognition systems would enable a more successful transition.

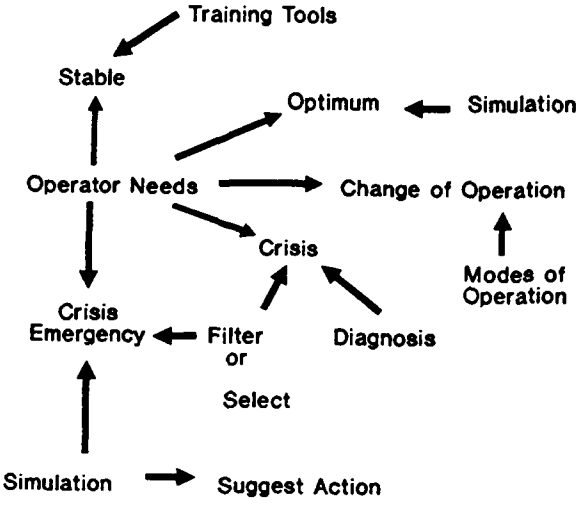


Figure 5. Operator's interaction with a manufacturing process and a control program.

One example of the role of the operator in a manufacturing operation is depicted in Figure 5. The process may be stable, at an optimum, change of operation or production mode, at a crisis or a crisis emergency. In each of these instances, a control system can assist, diagnose, filter the inputs, and suggest an appropriate course of action. At a large scale control program, the flow of information and control is depicted in a manufacturing trials operation at a University of Birmingham program (see Figure 6). The goals of the program include reduced leadtimes, quality assurance with microstructural, and dimensional control. Operational windows and control strategies are defined for the manufacturing process. The transition from human to a systems control can improve productivity, but may be fraught with difficulties in the return on investment and payoff, particularly for small to medium enterprises with limited production runs.

One view is that the implementation sensor and process control will be an effective insurance policy for quality and reproducible manufactured products in terms of geometry and physical performance. The linkage between the sensor developers, the control, and manufacturing systems must be enhanced and cost effectively presented to the materials processing community. The linkage between product, sensor, control system, and processing model must be strengthened. The strongest linkage is seen between the sensor and control system. Weaknesses are seen with the relationship to the process model and the sensors and control systems.

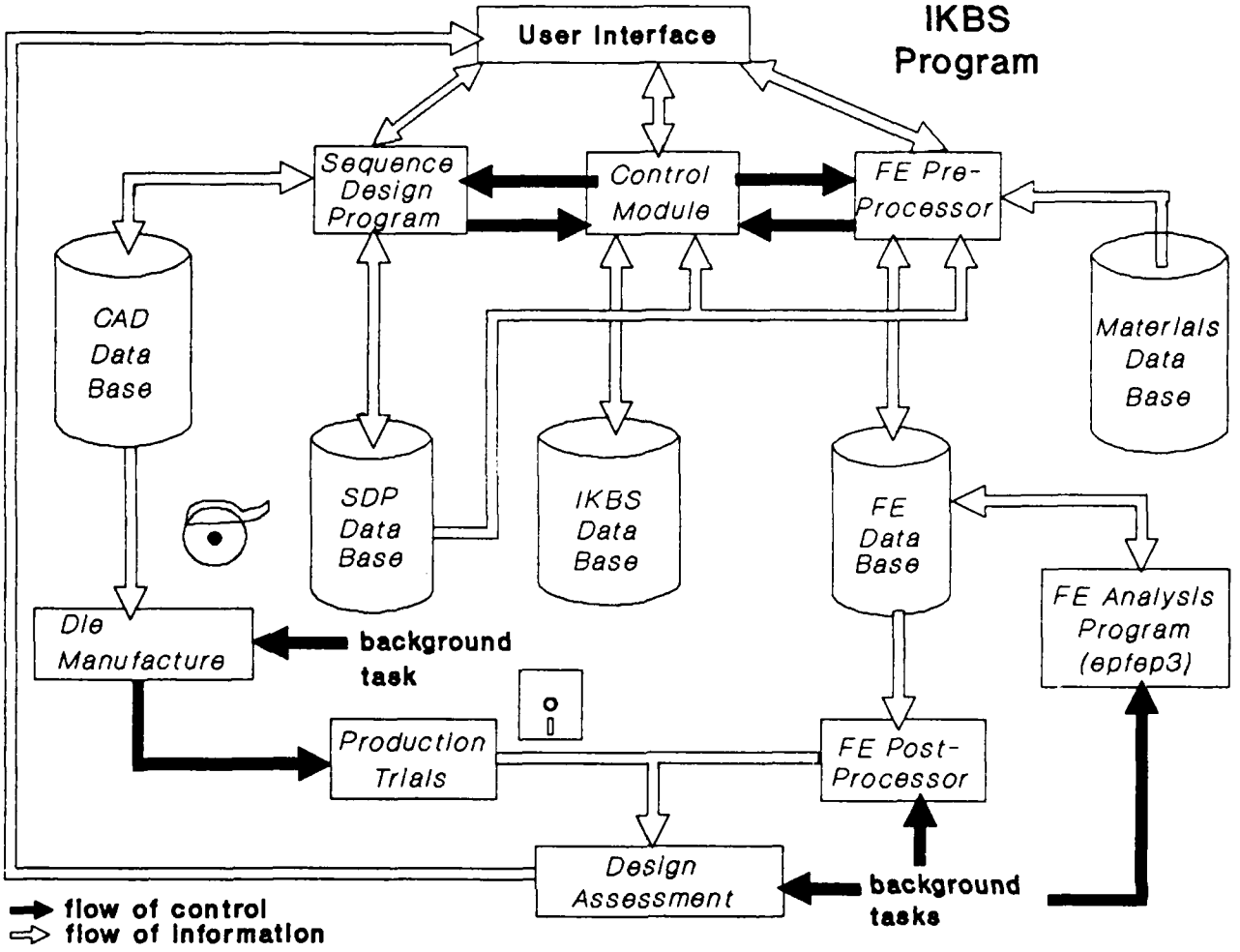


Figure 6. The flow of information and control for manufacturing trials (courtesy of the University of Birmingham).

Initiatives in IPM

The initiatives IPM suggested were a combination of educational activities, coupled with the needs for processing demonstrations of the benefits provided by integrated manufacturing programs. The view of the sensor and control community relates to the promotion and education of the industrial and manufacturing engineers to the needs and benefits of intelligent processing control systems. The needs include selecting the appropriate sensors and the correct simulation of operational parameters. These should define correctly appropriate process conditions, and recognize and control deviations.

It was emphasized that the application of IPM can best be applied when a materials production process is converted from a batch to continuous process. In this case, a financial and time investment is required to select the models, sensor, and control system for the process. The candidate industries for the application of IPM are large mass production with a uniform product line include automotive, aerospace, and ferrous industry.

The education process for the manufacturing sector detailed the needs for the development of process automation for optimal control models, fuzzy logic control, learning control, neural networks, and wavelet theories. The human factors for process control requires the education of engineers and the development of reliable software that can be incorporated on the manufacturing floor. An example of the education theme was the sensor selection process generated by American Iron and Steel Institute (AISI) and the European Community Action Scheme for Mobility of University Students (ERASMUS) exchange programs of the European Community. In general, the education of industrial engineers is a prime factor. In many cases, the manufacturing engineers take a less scientific, product-related view that hopefully requires a real-time control of the product. The materials engineers take a more academic view with regard to the understanding and modeling of the process. These views must be effectively communicated and integrated into an overall approach for effective materials processing.

At this time, the credibility of self-learning systems must be clarified and in many cases the outputs are too

slow for rapid fabrication processes; i.e., sheet stamping, wire drawing. In the cases where the manufacturing occurs rapidly; e.g., metal forming, spray deposition, the sensor process-control, feed-back loop may not be sufficiently fast to control the process. The need was expressed for generic process models, general purpose codes, faster, and more cost-effective workstations. Object-oriented computer codes, higher resolution graphics, and voice-recognition systems were cited. In sensor technology, the needs involve smart sensors; i.e., the combination of a sensor with a control interface, which is linked into the process control. There are several manufacturing areas in the metal productions, namely, extrusion, sheet forming, solidification, rolling, and powder consolidation process where sensor and control systems technologies have not made effective inroads. Other areas are more advanced; i.e., machining, welding, surface hardening, autoclave processing, and injection molding. The networks for effective technology transfer into the manufacturing sector should be established and the connections between these technologies must be reinforced.

The Future Agenda

The process control for materials has been demonstrated with partial success in several manufacturing technologies; i.e., metal forging, welding, autoclave composite processing, integrated circuit manufacturing. One of the current difficulties involves the wide varieties of processes with myriads of materials. In this case, a key question is, can the concept of intelligent processing be effectively translated to the various sectors of manufacturing?

Accepting, assimilating, and integrating into the manufacturing cycle are the difficult steps that involve education, cultural, and financial questions. Demonstration projects can highlight the capability of process integration where sensor and controls systems are desirable. In addition, the education of manufacturing engineers appears essential with regard to the capabilities and range of cost-effective sensors and control systems.

Utilization of control techniques should focus on more productive applications in the automotive, aerospace, and primary materials-processing sectors. In many ways, the inhouse efforts of many industries lead the academic sectors in the demonstration and application of process control. However, many small enterprises do not benefit from this base of knowledge and are often excluded or do not realize the opportunities they can derive. As a consequence, the application of sensor and process control is an emerging field that requires encouragement. The needs are therefore essential for communication and education for sensor development, control, and process-modeling capabilities to the manufacturing engineers. The issues of cost-effective, reliable monitoring and controls systems must be jointly addressed by the industrial sector and the control systems sector. The role of the academic community is to provide the training and process models that can realistically relate to the materials-processing quality management.

The proceedings from the IPM conference and workshop can be obtained from:

Dr. Jeff Roos
Katholieke Universiteit
Departement Metallunde en Toegepaste
Materiaalkunde
de Croylaan 2
B - 3030 Heverlee, Belgium

Metal and Ceramic Matrix Composites Activities in Europe

by Michael J. Koczak, the Liaison Scientist for Materials for the Office of Naval Research European Office. Dr. Koczak is on sabbatical leave from Drexel University, Philadelphia, Pennsylvania, where he is a Professor of Materials Engineering.

Introduction

The European Community (EC) has orchestrated a major research effort directed at several materials areas. Of particular interest to the composites community is the Basic Research in Industrial Technologies for Europe/European Research on Advanced Materials (BRITE/EURAM) efforts which have several joint research efforts in

- Metal matrix composites
- Composite processing
- Ceramic composites
- Polymer matrix composites.

In summary, the BRITE/EURAM programs are supporting 445 projects under two Framework budgets (see Tables 1 and 2). Although the level of funding may be considered small with regard to major industrial or defense research, funding the process of program integration and cooperation is a precursor to a more united European research effort.

The establishment of the joint programs provides a valuable linkage into cooperation on large-scale efforts. Particularly in the materials community where very few companies can vertically integrate from raw material to the final product, the mechanism for cooperation has been established based upon a German cooperative model, and the stage has been set for future interactions. There may be difficulties with the smaller, less-industrialized EC countries in the cooperative ventures. Nevertheless, their role raises the level of their individual technology, and the funding serves as a precursor for a future generation and growth of cooperative research.

The process of technology transfer and cooperation between competitive allies in a new environment of cooperation may be difficult to comprehend for old hands. Nevertheless, the new European scientist has developed linkages, and within Europe the artificial political and geographic barriers, which hampered cooperative efforts, are being eliminated. It would be naive to say that the major companies are being completely candid concerning their front-line research efforts. However, it would be correct to say that a formal mechanism of cooperation has been established at a research level in the BRITE/EURAM programs and at a

Table 1. Current Framework Program Budgets (1987-91)

		MILLION ECU	%
A	Quality of Life		
	1. Health	80	
	2. Radiation protection	34	
	3. Environment	261	
	TOTAL	375	6.9
B	Towards a Large Market and as Information and Communications Society		
	1. Information technologies	1,600	
	2. Telecommunications	500	
	3. New services of common interest (including transport)	125	
	TOTAL	2,275	42.3
C	Modernization of Industrial Sectors		
	1. S&T for manufacturing industry	400	
	2. S&T of advanced materials	220	
	3. Raw materials and recycling	45	
	4. Technical standards, measurement methods, and reference materials	180	
	TOTAL	845	15.6
D	Exploitation and Optimum Use of Biological Resources		
	1. Biotechnology	120	
	2. Agro-industrial technologies	105	
	3. Competitiveness of agriculture and management of agricultural resources	55	
	TOTAL	280	5.2
E	Energy		
	1. Fission: nuclear safety	440	
	2. Controlled thermonuclear fusion	611	
	3. Non-nuclear energies and rational use of energy	122	
	TOTAL	1,173	21.7
F	S&T for Development	80	1.5
G	Exploitation of the Seabed and Use of Marine Resources		
	1. Marine science and technology	50	
	2. Fisheries	30	
	TOTAL	80	1.5
H	Improvement of European S&T Cooperation		
	1. Stimulation, enhancement and use of human resources	180	
	2. Use of major installations	30	
	3. Forecasting and assessment and other back-up measures (including statistics)	23	
	4. Dissemination and utilization of S&T research results	55	
	TOTAL	288	5.3
	GRAND TOTAL	5,396	100

Table 2. New Framework Program Budgets (1990-94)

	MILLION ECU	%
A Enabling Technologies		
1. Information and communications technologies		
- Information technologies	1,352	
- Communications technologies	489	
- Development of technological systems of general interest	380	
TOTAL	2,221	39
2. Industrial and materials technologies		
- Industrial and materials technologies	748	
- Measurement and testing	140	
TOTAL	888	16
B. Management of natural Resources		
1. Environment		
- Environment	414	
- Marine science and technology	104	
TOTAL	518	9
2. Life sciences and technology		
- Biotechnology	164	
- Agricultural and agro-industrial research, including Fisheries	333	
- Biomedical and health research	133	
- Life sciences and technologies for developing contries	111	
TOTAL	741	14
3. Energy		
- Non-nuclear energies	157	
- Nuclear fission safety	199	
- Controlled nuclear fusion	458	
TOTAL	814	13
C. Management of intellectrual Resources		
1. Human capital and mobility		
- Human capital and mobility	518	
TOTAL	518	9
GRAND TOTAL	5700[1]	100

[1] Including ECU 60 million for the dissemination and exploitation and ECU 550 million for the Joint Research Center.

more market- oriented level in the European Research Organization Agency (EUREKA) programs. Skeptics regard the EC research efforts as layered with administrative paperwork. However, the EC has learned from the previous BRITE programs, and some of the recommendations include the following changes in the new Framework programs. The overall programs are to be market oriented and driven by the market forces rather than being pushed by the researchers. As a result, the strategic market implications of the programs should be considered with a greater participation of the industrial community. In an effort to involve smaller to medium enterprises, special consideration is provided to these companies.

The major activities of composites research are centered in the aeronautic, space, and automobile and transport sectors. Additional areas of interest include petrochemical, biomedical, general manufacturing, sports, leisure, building, furniture, rotating machinery, and marine. A summary of the programs in metal and ceramic matrix composites is provided.

Further information of the BRITE/EURAM programs can be obtained at no cost from the EC offices in:

2100 M Street, NW (Suite 707), Washington, D.C. 20037
Telephone (202) 862-9500, telex 64 215
EUROCOM NW, telefax 429-1768

Suboffice of the Washington Office
3 Dag Hammarskjöld Plaza
305 East 47th Street, New York, NY 10017
Telephone (212) 371-3804, telex 012 396
EUROCOM NY, telefax 758-2718

Programme Manager: Willem van der Eijk
Production and Materials Technology
Telephone Brussels, Belgium, 235.59.60

Joseph Wurm
Materials Research
Telephone Brussels, Belgium, 235.40.55.

Commission of The European Communities
Directorate General for Sciences
BRITE/EURAM Program, Research and Development
XII/C, 200 Rue de la Loi
B-1049 Brussels, Belgium
Telephone 32-2-235-1111.

Metal Matrix Composites

The metal matrix composites program is involved in several aspects of materials processing with the support of major fiber producers in Europe; i.e., Imperial Chemical Industries - oxide fibers, British Petroleum (BP) - silicon carbide filaments and particulates, and Rhone Poulenc - Silicon carbide fibers. As detailed below, several efforts are examining particulate composites based upon a powder metallurgy or Osprey spray deposition approach. The study of the interfacial reactions between SiC filaments and titanium matrix systems is also being addressed. The programs stressing applications involve the utilization of long-oxide fiber systems for helicopter gearbox and diesel piston applications. The processing routes of squeeze casting and low-cost composites produced by spray deposition are commercially oriented. The program for the

aerospace sector involve Atomic Energy Authority (AEA)-Harwell, the French Aerospace Research Institute (ONERA), and the German Aerospace Research Establishment (DLR), with BP as the industrial partner. The largest programs involving industrial participation include the programs on spray deposition with nine participants, and the automatic piston and gear-box program with ten participants. In general, a strong commercial market driven examination of metal matrix composites is detailed below (see Table 3).

Ceramic Matrix Composites

Many of the strength-in-ceramic composites in Europe are developed from the French programs at the Society of European Propulsion (SEP) and Aeroaspatiale. The utilization of C-SiC, SiC-SiC, and C-C components for the European shuttle program has put these companies in the forefront of the ceramic-matrix composites processing and applications in the world. Applications have included C-C turbine wheels, C-SiC nose cones, and C-SiC turbo engine-thruster petals. In the Federal Republic of Germany (FRG), Maschinenfabrik Nürnberg (MAN) Technologies is utilizing chemical vapor impregnation (CVI) and silicon-infiltration techniques for carbon-carbon composites. Therefore, an important linkage is the program-combing SEP and MAN concerning the reliability and thermomechanical response of ceramic matrix composite. A second important program is the collaboration of the University of Karlsruhe and The University of Bourdeaux. The modeling of the CVI process involves a physical and chemical approach with model substrates. The third program of note is the Groupement d'Études pour la Construction (GEC) Alsthom and Saint Gobain who are optimizing processing for whisker and particulate composites. It is suggested that whisker reinforcement is processed ideally via hot pressing, while particulate composites are fabricated by pressureless sintering. Although the scale of the ceramic matrix composites efforts is smaller vis à vis metal matrix systems. The partners represent some of the best research groups in the world (see Table 4).

Table 3. Metal Matrix Composites Programs

Program	Partners	Country
Optimization of Ceramic Fibre Reinforced Aluminum Alloys	*Renault	
	Univ. of Surrey	UK
	Universidade Do Porto	P
	Senter For Industriforskning	NO
	Hydro Aluminium	NO
Prepregs & Composite Materials Made of Aluminum Alloys Reinforced with Continuous Fibres	*Deutsche Forschungsanstalt	D
	Chimie Du Solide Du CNRS	F
	Aerospatiale, Les Mureaux	F
	Universite De Bordeaux	F
Development of Fibre Reinforced Aluminium Metal Matrix Composites for Applications in Aerospace Primary Components Using Powder Metallurgy Techniques	*Agusta Spa	I
	Aluminia Spa Novara	I
	Technische Universiteit Delft	NL
	Carborundum, Sale	UK
Novel Metal Matrix Composites Based on *Hyper Eutectic* Aluminium/Silicon Alloys Ederlan Cooperative	*University of Sheffield	UK
	Lucas Automotive, Ltd.	UK
	Osprey Metals, Ltd.	UK
	Streesceit	E
		E
	Ruhr University	D
Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes From Long Fibre/Metal Matrix Composites VW AG	*ICI Advanced Materials	UK
	Didier Werke AG	D
	Kolbenschmidt AG	D
	Fraunhofer Gesellschaft	D
	Imperial College	UK
	Ricardo Consulting Eng., Ltd.	UK
		D
	Ray Advanced Mtls., Ltd.	UK
	Agusta Spa	I
	VAW AG	D
Innovative Manufacturing Design & Assessment of Aluminium Matrix Composites for High-Temperature Performance	*University of Dublin	IRL
	Ecole Centrale De Paris	F
	Politecnico Universidad Madrid	E
	Oxford University	UK
	Birmingham University	UK
Control of Fibre/Matrix Interactions in SiC/Ti Metal Matrix Composites	*AEA-Harwell	UK
	DLR	D
	ONERA	F
	BP Advanced Composites, Ltd.	UK

Program	Partners	Country
Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation	*Hi-Tech Metals R&D., Ltd.	UK
	Agusta S.P.A.	I
	National Aerospace Lab NLR	NL
	University of Southampton	UK
	Airbus Industrie	F
	Raufoss A/S	NO
Improved Aluminium Alloy Matrix Composites Through Microstructural Control of the Processing and Fabrication Routes	*University of Strathclyde	UK
	Laboratorio Nacional De Engenharia E Tecnologia Industrial (LNETI)	P
Cast Light Alloy Matrix Composites-Assessment of the Rheocasting Route	*Pechiney	F
	Instituto Nacional De Tecnica Centre De Aeroespacial, Madrid E	
Technische Universiteit, Delft		NL
Development of Advanced Carbon-Magnesium Metal Matrix Composites By Applying The Semi-Liquid Phase Infiltration	*ONERA	F
	Deutsche Forschung Und Versuchsanstalt Fur Luft Und Raumfahrt	D
	Aerospatiale, Les Mureaux	
Assessment of Semi-Solid State Forming of Aluminium Metal Matrix Composites	*Delft University of Technology	NL
	Institut National Polytechnique De Grenoble	F
Low-Cost MMC Made By Spray Deposition	*Messerschmitt-Bölkow-Blohm GMBH	FRG
	Aerospatiale	F
	British Aerospace	UK
	Alcan International	CA
	Pechiney	F
	British Alcan	UK
	Otto Fuchs Metallwerke	FRG
	Insa	F
	Lneti	P

Table 4. Ceramix Matrix Composites

Programs	Partners	Country
Comparison of Short Fibre & Particulate Method for Reinforcement of Glass-Ceramic Materials	*GEC Alsthom Ltd.	UK
	Saint Gobain Recherche, Aubervilliers	F
Ceramic-Ceramic Composite Materials-A Modelling of the CVI Process	*Universite De Bordeaux	F
	Institut Fur Chemische Technik Karlsruhe Universitat	FRG
Fabrication and Joining of Graded Cermets by a Technique of Metal Infiltration	*British Ceramic Research Ltd.	UK
	Hamburger Institut Fuer Technologiefoerderung	FRG
Metal Reinforced Ceramics	*Krupp Widia GMBH	FRG
	Johnson Matthey Techn. Centre	UK
Ceramic/Metal Bonding by HIP	*Armines/Ecole Des Mines De Paris	F
	CEA/CEN Saclay, Gif-Sur-Yvette	F
	Universite Catholique De Louvain La Neuve	B
Reliability, Thermomechanical and Fatigue Behavior of High-Temperature Structural Fibrous	*Societe Europeenne De Propulsion	F
	MAN	FRG
	Institut Nationale des Sciences Appliques-Lyon	F
Ceramic Composites	I Caen	F
	University of Manchester Institute of Science and Technology	UK
	United Nationals Economic Commission for Europe (IKE) Stuttgart	FRG
Development of Technology To Produce 2-and 3-D Carbon Reinforced Graphite Structures High-Strength and High-Temperature Application	*New Metals & Chemicals, Ltd.	UK
	Sintec Keramik GMBH	FRG
	University of Loughborough	UK

Programs	Partners	Country
Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Temperatures with Improved Creep Resistance, Chemical Stability and Reliability	*Vetrotex International	F
	Ceramiques Techniques Desmarquest	F
	Jose A. Lombia Camina SA	E
	Ceramicas Tenacess SA	E
	Instituto Ceramica Y Vidrio	E
	Institut National Des Sciences Appliquees	F
	Bundesanstalt Fur Materialforschung Und	
Organometallic Precursors for the Preparation of High-Performance Non-Oxide Ceramics and Ceramic-Matrix Composites	*Fairey Tecramics, Ltd.	UK
	ATOCHEM	F
	BROCHIER SA	F
	Max-Planck-Institut, Stuttgart	FRG
Improved High-Temperature Corrosion-Resistant Silicon Nitride, Silicon-Carbide Composites	*University of Limerick	IRL
	Newcastle-Upon-Tyne Polytechnic	UK
Industrial Production Process for Silicon-Carbide Whiskers for Composite Materials Reinforcement	*Pechiney Electrometallurgie	F
	I.N.P.G. Grenoble	F
	Universidade De Porto	P
	Mahle GMBH	FRG

*** = primary partner**

Country Codes

A - Austria
B - Belgium
CH - Switzerland
D - Denmark
E - Spain
F - France
FRG - Federal Republic of Germany
GR - Greece
I - Italy
IRL - Ireland
L - Luxembourg
NL - the Netherlands
NO - Norway
P - Portugal
S - Sweden
SF - Finland
UK - United Kingdom

9th International Conference on Experimental Mechanics - Conference Review and European Programs

by Michael J. Koczak

Introduction

Over four hundred years ago Galileo Galilei was quoted as saying:

"It is necessary to measure everything that can be measured, and to try making measurable what isn't as yet."

A second more cautionary quotation from S.W. Golomb was also cited by K.H. Laermann, Bergische University:

- "Don't believe the model to be reality
- Don't extrapolate beyond the region of fit
- Don't distort reality to fit the model
- Don't retain a discredited model
- Don't fall in love with your model."

In this spirit, a conference on experimental mechanics convened to review the experimental measurement techniques and their application to advanced materials and manufacturing processes.

The International Conference on Experimental Mechanics was held at the Technical University of Denmark in Lyngby with support from the Society of Experimental Mechanics, Japan Society of Mechanical Engineers, Imeko Technical Committee for Experimental Mechanics, Technical University of Denmark, and the Office of Naval Research European Office. The 16 sessions included:

- Experimental Contact Mechanics
- Mechanical and NDT Methods
- Instrumentation and Electrical Methods
- Experimental Techniques Used on Composite Systems
- Materials Testing
- Stress Analysis by Thermo-Elastic Techniques
- Photoelasticity
- New Developments in Residual Stress-Measuring Techniques
- Structural Testing
- Experimental Techniques for Cementitious Structures
- Grid Methods
- New Developments in Residual Stress Measurements Techniques
- Holographic and Laser Interferometry
- Hybrid Methods/Data Processing
- Experimental Mechanics - Past and Future
- Experimental Mechanics - What Future?

The conference proceedings can be obtained from:

Department of Structural Engineering
Technical University of Denmark
DK-2800 Lyngby, Denmark
Telephone 454 2883511
FAX 454 2882239
E-Mail expmech9@risoe.dk

The conference emphasized the need for innovative techniques as well as hybrid techniques that treat materials at the micromechanical level where related micromechanical or finite-element structural analysis can be incorporated.

A challenging example is the need to evaluate the actual stress state in the localized interior of a composite material. The requirements for *in-situ* measurements would permit the evaluations of loads, deformation, and damage assessment in these complex structures. The development of analytical and experimental methods combine and become mutually supporting. The field is further spurred by the development-improved sensors and faster computational techniques to provide for real-time assessments of loading and damage progression. From an international viewpoint, the European Community (EC) is combining resources to address cooperation within the EC to promote and combine the independent activities of various European organizations. A list of the Basic Research in Industrial Technologies for Europe/European Research for Advanced Materials (BRITE/EURAM) Programs in experimental mechanics and nondestructive evaluation (NDE) is provided in the Appendix.

Plenary Lectures

The plenary lectures examined the past, present, and future of experimental mechanics featuring speakers with contributions from the People's Republic of China (Y. Youquan and Luo Zhishan), the U.S. (A. Kobayashi), Japan (T. Kunio), and Europe (R. Royles).

Experimental Mechanics in Japan

Dr. T. Kunio, Professor Emeritus of Keio University, Tokyo, highlighted the application of strain gauge

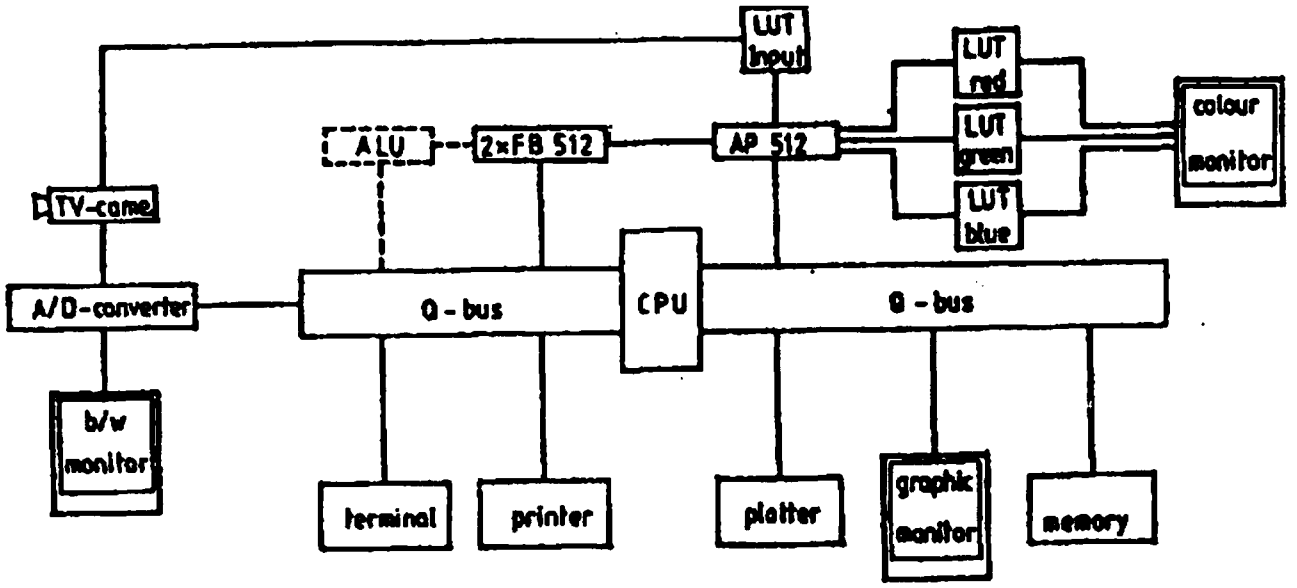


Figure 1. Signal processing and computer control of measurement systems

techniques, photoelasticity, Moire, and fine grid and dot methods. Photoelasticity techniques in Japan divide into two categories. The *fringe diagram method* and the *functional construction method* techniques are utilized to analyze quarter-scale models of turbine disc to provide for stress distributions via isochromatics frozen photoelastic-stress analysis. In the *fringe diagram method*, isoclinic and isochromatic lines are constructed to locate points of extreme brightness at the junctions of these lines. In the *functional construction method*, the photoelastic fringes are used to construct a function that describes the principal stress direction and distribution over the area. In the *photoviscoeleasticity method*, residual stress distributions in polymeric structures are evaluated based on time and temperature dependency. A third approach considered a Moire method for the analysis of strain distributions over large areas utilizing overlapping gratings termed master and model gratings. Computer-aided imaging of this technique has eliminated the tedious chore of analysis and will facilitate further implementation of the approach. Refinements of this approach include a fourier-transform inverse method and a hadamard-transform method with special television monitors being utilized to provide for the analysis. For the measurements of local strain distributions in the vicinity of crack tips, a fine grid/dot technique has been utilized with the strain distribution determined by the positional change of the dot or grid patterns. The future efforts in experimental mechanics in Japan are tied to the needs of rapid-data analysis by computer-aided techniques. A second goal is the extraction of more useful data by increasing the signal-to-noise ratio. There is also a vision to take these techniques into other fields of study where they can be applied.

Application Of Experimental Mechanics To Industry

The theme of transitioning experimental mechanics into allied fields was echoed by K.H. Laermann, Bergische Universität, Wuppertal, Federal Republic of Germany (FRG). Apart from the standard approaches of analysis of the dynamic response of structures, experimental mechanics techniques can be implemented for the supervision of operating systems; i.e., machinery in chemical plants, power generation stations, and medicine; i.e., experimental biomechanics. The input of experimental mechanics can be applied to design, expert systems, system control, optimization, and quality control. The challenge of these approaches lies in the analysis of dynamically loaded anisotropic structures.

The future developments in measurement capability is in the automated computer control of measurement systems. The hardware cost of these systems has been escalating. However, the software control is becoming increasingly important since the operational system is dependent upon the programming protocol. The imaging systems can detect images over a range of wavelength from xrays to the infrared. Also, the range of signals from interference, photoelastic holographic methods can be converted into digital signals. These signals can be analyzed versus look-up tables (LUT). The processing times can be reduced by an algebraic logical unit (ALU) as depicted in Figure 1. In this attempt for integration of techniques, computer control, and systems operations, a general technical language or communication barrier must be overcome to allow system integration.

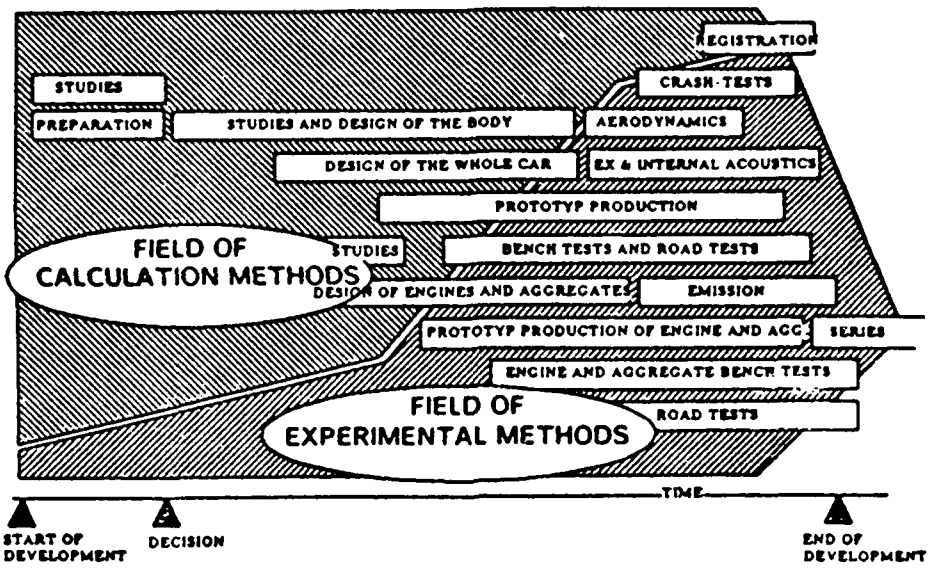


Figure 2. The different fields of experimental and theoretical methods in the development of cars

Applications For The Automotive Industry

The application of experimental mechanics to the automotive industry represents a useful example of a major manufacturing technology with the resources to apply the various approaches in the developmental and experimental methods. H. Marwitz, Mercedes Benz AG, Stuttgart, FRG, described the intense competition between the experimental and mathematical methods in an era of major advances in computational techniques (see Figure 2). The needs in experimental analysis is sought in the following areas:

- Nondestructive stress analysis of welded joints or closed sections, especially the warnings of critical load cycles
- Nondestructive stress analysis of spot-welded joints
- Analysis of stress distributions because of steady-state and transient-temperature distributions
- Critical stress analysis of components subjected to mechanical shocks.

The role of the experimental mechanician is viewed as a transient from an instrument-oriented individual to a system approach expert where the contributions will be directly related to product and system reliability rather than a monitoring and reporting role.

Contributed Papers

The following topics were selected as particularly good reviews or papers that combined novel experimental-mechanics techniques with a useful analysis and/or application.

Experimental Contact Mechanics

- Noninvasive Sensor Techniques in Contact Mechanics, M. Arcan, Tel Aviv University, Israel.

Instrumentation and Electrical Methods

- The Development of Embedded Piezoelectric Sensors to Measure Peel Stresses in Adhesive Joints, G.L. Anderson and D.A. Dillard, VPISU.

Experimental techniques Used On Composite Systems

- Embedded Sensor Development for Composite Smart Structure, T.B. Salzanano et al., Oregon State University, Corvallis
- On-Line Damage Assessment System For Composite Materials, P.L. Nielsen and L. Bjorno, Technical University of Denmark, Lyngby
- Measurements of Residual Stresses in Filament-Wound GRP Pipes by Embedded Strain Gauges, T. Tama, Technical University of Budapest, Hungary
- Characterization of Composite Materials by Means of a Reflective Moire Holographic Technique, F. Ginesu and R. Rossi, University of Caligari, Italy
- Non-destructive Control of Multilayer-Metal Composites, I. Kostin and A. L. Polyack, Moscow Civil Engineering Institute
- Strain Measurement on A Filament Winding Cylinder with Reversible Strain Gauge in a Wide Temperature Range, K. Egawa and Y. Hayashi, National Aerospace Laboratory, Tokyo.

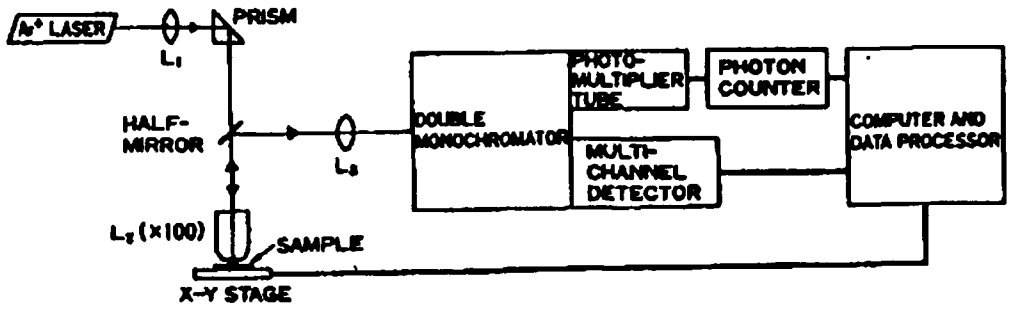


Figure 3. Schematic drawing of the Raman microprobe apparatus

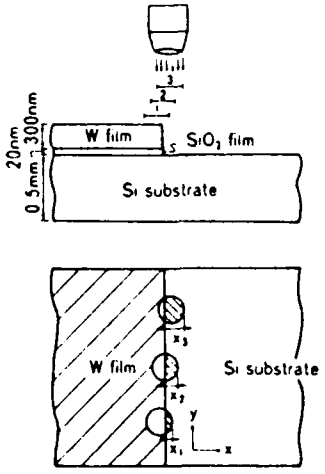


Figure 4. Sample configuration and laser spot position

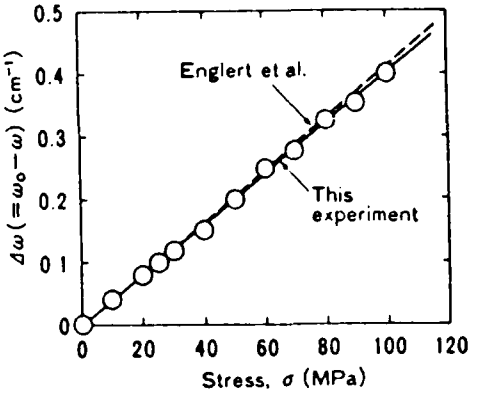


Figure 5. Plot of the shift $\Delta\omega$ vs the applied uniaxial stress δ

NDE and Combined Techniques

- Non-destructive Evaluation of GRP Using Ultrasonic Techniques, T.J. Rafiq and J.N. Ashton, University of Manchester Institute of Science and Technology, U.K.
- D-Sight - A New Optical Arrangement with Applications in Experimental Mechanics, J.P. Kowrowski, National Aeronautical Establishment, Ontario, Canada.

Photoelasticity

- Thermoelastic Stress Analysis - Progress and Prospects, P. Stanley, University of Manchester, U.K.
- New Automatic Stress Analysis System by Using Photoelasticity and Laser, T. Tsuji et al., Shizuoka University, Hamamatsu, Japan
- Automatic Whole-Field Measurement of Photelasticity using Linear Polarized-Incident Light, T. Kihara, Kinki University, Osaka, Japan.

Structural Testing

- Gas Turbine Engine Shaft Fatigue Test Rig - IHI, Tokyo, Japan.

Ultrasonic Testing and Neutron Diffraction

- AUSTRA - An Instrument for The Automated Evaluation of Stress States Using Ultrasonic Techniques, R. Herzer et al., Fraunhofer Institute, Saarbrücken, FRG
- Combination of Two Methods for Measuring The Residual Stresses Gradient in SiC Reinforced Metal Matrix Composites, J. Lu et al., CETIM, Senlis, France.

Optical and Magnetic Methods

- A New Stress Measurement Technique by Microscopic Raman Spectroscopy, H. Sakata et al., Hitachi, Ltd., Ibaraki, Japan provided for localized stress measurements.

Highlight Papers

The study of Raman Spectroscopy can be utilized to provide stress distributions in Si/W interface substrates at the submicron level. Although the utilization of Raman shifts has been well documented for various materials; e.g., silicon, graphite, the analysis of the stress state at a submicron level is a notable contribution. This can be extended to several materials systems, particularly to examine the interface region in electronics and composite structures. The schematic of the Raman microprobe apparatus is depicted in Figures 3-5 utilizing an argon

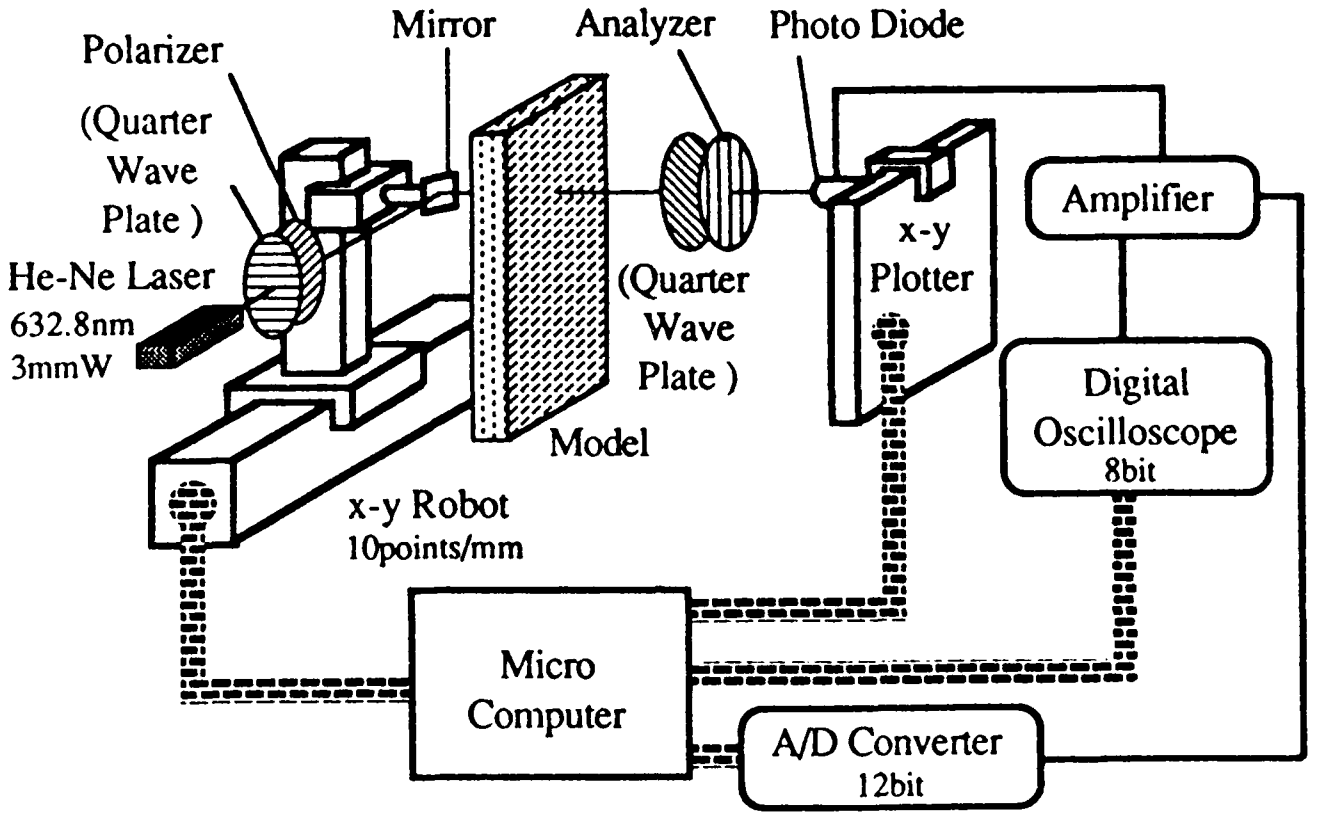


Figure 6. Automatic photoelastic system

laser with a spot size of 1 μm. The stress dependent shift of the Raman peak was assessed as a function of distance from a W-film and a Si substrate. Although the spot size was 1-μm variations of residual stresses can be evaluated at increments of 0.1 μm. Previously, the utilization of Raman spectroscopy peak shifts has been applied to interface stresses in fibrous composites as well as Si. In a related paper, the residual stress state in silica films on Si was evaluated as a function of oxidation conditions with 0.9 μm of the depth.

X-Ray Methods

Microresidual Stress, Evaluation by X-rays, Results Assessment, V. Hauk, Institut für Werkstoffkunde, Achen, FRG. The measurement of residual stresses can occur at the macro or micro level. V. Hauk's presentation reviewed the ability of x-ray and neutron approaches to interrogate the materials under vary deformation conditions; e.g., fatigue, rolling, thermal cycling.

Ultrasonic Testing and Neutron Diffraction

AUSTRA - An Instrument for The Automated Evaluation of Stress States Using Ultrasonic Techniques, R. Herze, et al., Fraunhofer Institute. The development of an automated ultrasonic evaluation; i.e., termed ERDER, of the surface and bulk properties of ferrous components was sponsored by the EC for carbon and steel. The purpose of the instrumentation is to provide for a assessment of critical defects, estimate residual lifetimes, optimize thermo-mechanical treatments for a beneficial residual stress and provide for an assurance of quality. Utilizing an acousto-elastic effect, the effects of bulk and residual stresses can be evaluated. The system provides for an in-field analysis and can be utilized to determine two- and three-dimensional stress states in components; e.g., turbine rotors, welded plates as well as two dimensional stress states in vessels, and welded plates. In an example, the surface axial and hoop stresses in a 2-meter steel roll were evaluated before and after heat treatment.

Photoelasticity

New Automatic Stress Analysis System by Using Photoelasticity and Laser, T. Tsuji, et al., Shizuoka University, Hamamatsu, Japan. An automated rapid photoelastic system was developed utilizing a high-intensity neon laser and a high-speed photo diode (see Figure 6). A comparison of the new technique,

compared to conventional video systems and strain gauge techniques, is depicted in Table 1. The performance capabilities are detailed in Table 2. The authors indicate that stress analysis in the system is possible even when the loads are too low to generate fringes. With the incorporation of the high-speed photodiode system, an x-y robot, automated data acquisition, and analysis-improved stress analysis is available for dynamic systems.

Table 1. The performance of the system.

Component	Performance
Light source	He-Ne Laser 632.8nm 3mmw
Width of measurement	185×185mm
Point resolution	10 points/mm
Intensity resolution	12 bit(static), 8 bit(dynamic)
Speed of measurement	500 kHz

Table 1. The performance of the system

NDE and Combined Techniques

D-Sight - A New Optical Arrangement with Applications in Experimental Mechanics, J.P. Komorowski, National Aeronautical Establishment, Ontario, Canada. The National Aeronautical Establishment in Ontario is examining an optical method to examine reflective aircraft structures termed Difracto-Sight or D-Sight. The optical system utilizes a retro-reflective screen and uses the reflectance to accentuate surface imperfections. The technique can be utilized to examine both aluminum and composite surfaces to detect surface imperfections and distortions (see Figure 7). The technique was shown to detect surface imperfections on composite horizontal and vertical stabilizers as well as detecting fatigue cracks around fasteners holes. The sensitivity of the D-sight technique has to be established. The technique can detect surface undulations, impact damage, edge delamination, cold work fastener holes, and fatigue cracks with an apparent low-cost approach. The total reliance on a surface technique may not be appropriate. Nevertheless, the technique does show particularly good sensitivity for the cases considered.

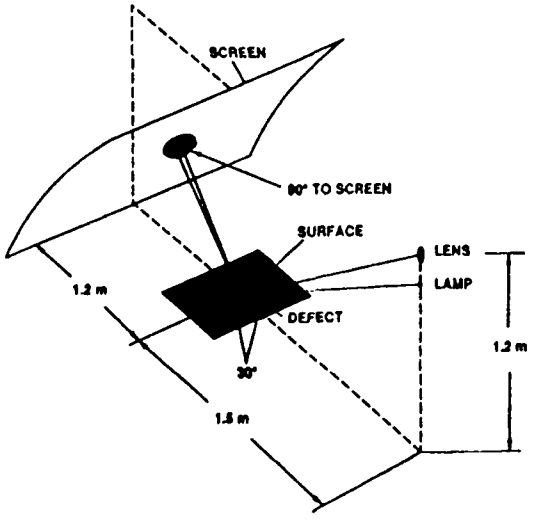


Figure 7. D-Sight experimental arrangement

	Video System	Strain Gage	Present System	Accuracy of the Present System
Use under light.	×	◎	○	-
Stress resolution.	△	○	○	12 bit
Point resolution.	△	△	○	10 points/mm
Size of the system.	Large	Small	Small	-
Cutoff frequency [kHz].	(10)	50	500	Depend on Amp.
Cutoff frequency [kHz]. (Theoretical)	?	1×10^3	500×10^3	Depend on the light wavelength.
Dynamic problems.	△	○	○	-
Measurement of plane.	◎	△	○	-

◎: Excellent, ○: Good, △: Fair, ×: Poor

Table 2. Comparison among a video system, a strain gage and the present system

Experimental Techniques Used On Composite Systems

Embedded Sensor Development for Composite Smart Structure, T.B. Salzanano, et al., Oregon State University. The application of constantum wires with an insulating polyamide coating in a graphite-epoxy composite structure was utilized to provide static strain information during loading cycles. The advantage of a constantum sensor includes low cost, durability, ease of installation, no significant degradation to composite properties, immunity to EMI, and EMP. The constantum wires at 0.025 and 0.15 mm were placed in a graphite-epoxy beam and tube structures.

Instrumentation and Electrical Methods

The Development of Embedded Piezoelectric Sensors to Measure Peel Stresses in Adhesive Joints, G.L. Anderson and D.A. Dillard, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. An experimental technique was utilized to examine the magnitude of peel stresses in adhesive joints. Metallized poly (vinylidene fluoride); i.e., PVDF, films were embedded into adhesively bonded joints. Adding PVDF reduces the strength of the adhesive bond. However with photoligographic techniques, a possibility exists of miniaturization of the sensors. The comparison of the stress state from the sensors and closed-form solutions from lap and butt joints show good agreement.

Summary

The 9th International Conference on Experimental Mechanics had several areas of traditional studies. However, the most interesting areas included:

- Developments of smart structures where embedded sensors; e.g., fiber optics, PVDF films, and wires were utilized to assess the health of the structure. The limitation imposed upon the structure reflects the local perturbation of the structure resulting in a property degradation. There appears to be a real need for the reduction or miniaturization of the sensors where the influence upon composite structural response can be minimized.
- Development of combined laser and Raman approaches shows promise in structural evaluation of structures. The Raman approach allows for the assessment of surface stress states at an interface when combined with fine focus laser techniques.
- Combination of high-speed sensing of laser holographic combined with image analysis allows for sensitive surface studies.

In general, advances appear to utilize combined approaches and incorporate computational techniques which allow for rapid-data analysis.

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Appendix

A summary of the BRITE/EURAM Programs in sensors, NDE and optical techniques is provided below with the various European partners.

Titles	Partners	Country
Process and Product Assurance		
High Temperature Measurement of Strain in Steel Using Novel Thin-Film Gauges	*ERA Technology, Ltd.	UK
	ENEL - CRTN	I
	CEGB	UK
Innovative Transducers for Advanced Signal Processing	*SIEMENS AG	D
	Fulmer Research, Ltd.	UK
	CISE	I
	University of Strathclyde	UK
	IZPF-Fraunhofer Institut	D
	University of Bochum	D
Development of Fabrication Technologies for the Production of Metal-Oxide Based Sensors	*IMEC	B
	NTUA	GR
	Armines	F
	Coreci	F
	Elltec	GR
	Vynckier	B
Non-Destructive Evaluation		
Control of Flocculation of Cellulose Fibre and Mineral Solids in Papermaking Stocks	*PIRA	UK
	TNO	NL
	Inst. Papelero Espanol	E
	University of Madrid	E
Laser Mass Spectrometry for In-Line Industrial Microanalysis	*ELLTEC SA	GR
	GEC Mechanical Handling, Ltd.	UK
	Inst. Of Electronic Structure and Laser	GR
	Max-Planck Inst. Für Quantenoptik	D
	University Of Edinburgh	UK
In-Process Monitoring of Element Composition and Derived Properties of Polymeric Materials by Remote Laser Microanalysis (Relma)	*Fried, Krupp Forschungsinstitut GMBH	D
	King's College London	UK
	Pirelli Coordinamentio Pneumatici SPA	I
Nondestructive Characterization of Damage in Paricle-Reinforced Aluminium Matrix Composites	*Billiton Research BV	NL
	Biosonic Sarl, Famars	F
	Fraunhofer Institut, Saarbrucken	D
	Katholieke Universiteit, Leuven	B
	University Of Surrey, Guildford	UK
Development of Microwave Techniques for Nondestructive Evaluation of Advanced Ceramics	*Societe Francaise De Ceramique	F
	ONERA-CERT	F
	British Ceramic Research, Ltd.	UK
	SCK/CEN	B
	Ceramiques Techniques Desmarquest	F

Titles	Partners	Country
X-Ray Voludensitometry Application to the Testing of Technical Ceramics and Advanced Materials	*INTERCONTROLE	F
	DLETI	F
	Cualicontrol	E
	Milano Ricerche	I
	Regienov	F
	Fairey Tecramics, Ltd.	UK
Development of Noninvasive Methods for Measurement of Stress in Welded Steel Structures	*Harwell Laboratory	UK
	CISE	I
	Industrial Sponsors	
Microstructure and Residual Stress Analysis of Metallic Materials	*GKN Technology, Ltd.	UK
	Equipos Nucelares SA	E
	ARMINES	F
	SGM	NL
	ECN	NL
	Thyssen Stahl AG	D
	University Of Twente	NL
	Fraunhofer Gesellschaft	D
High Resolution Nondestructive X-Ray Equipment for Industrial Production Line Monitoring with Online Computer Evaluation	*Heimann GMBH	D
	EURORAD	F
	CNRS Strasbourg	F
	Rutherford A. Laboratories	UK
	Technical University Darmstadt	D
The Development of a New NMR Microscope for Structural and Dynamic Studies of Chemical and Biological Processes	*Surrey Medical Imaging Systems, Ltd.	UK
	University Of Antwerp RUCA	B
	Plant Genetic Systems (PGS)	B
SUB Angstrom Structure Characterization	*Philips	NL
	Tietz Video And Image Processing GMBH	D
	University Of Antwerp	B
	Delft University Of Technology	NL
	University Of Tubingen	D
Nondestructive Evaluation for the Preinstallation Assessment and *In Situ* Inspection of Wooden Transmission Poles	*Timber Research And Development Association	UK
	Eastern Electricity	UK
	Universität Danmarks Tekniska Hojskole	DK
	Calders & Grandidge, Ltd.	UK
	British Telecom PLC	UK
Development of a Nondestructive Test Method Based on Acoustic	*Ansaldo Trasporti SAP	I
	Bertin & Cie	F
Microscopy for Process Monitoring of Power Semiconductor Device	Dibe-Universita Di Genova	I
	Lmam - Universite De Montpellier	F
	Marconi Elec. Dev., Ltd.	UK

Titles	Partners	Country
Optimization of Noise Control Measures in Complex Lightweight Sheetmetal Structures by Using Energy Flow Analysis	*Porsche AG	D
	Jaguar Cars PLC	UK
	University Of Southampton	UK
Optical Methods		
Development of Nondestructive High Precision Test Method for Aspheric Components and Tools in Optics	*Phillips Research Lab. Wag	NL
	University Of Stuttgart	D
	CERCO	F
Optical Sensors and Fibre Optic Wavelength Division Multiplexing Systems for Process Control	*FRAMATOME	F
	Thorn EMI CRL	UK
	Degussa	D
Hybrid Optical/Electronic Multichannel System for Industrial Inspection	*British Aerospace	UK
	ONERA	F
	Universita Di Genova	I
	University Of Glasgow	UK
Project "Ophelia"-Optical Fibres for Electrical Industry Applications'- Development of Passive Opto-Electronic Sensors for Measurements and Diagnostics in Electrical Power Systems	*CESI	I
	Cavi Pirelli Spa	I
	Fecsa	E
	Sistemas E Instrumentacion SA	E
	Univ. Politecnica Catalunya	E
Intelligent Composites Containing Measuring Fibre Optic Networks for Continuous Self-Diagnosis	*BERTIN	F
	Harwell Laboratories	UK
	GKN	UK
	University Of Strathclyde	UK
	EDE	F
	CISE	I
	AERITALIA	I
Optical Inprocess Inspection of Electroplated Contact Surfaces	*Siemens AG	D
	Trinity College, University Of Dublin	IRL
	Zenon SA, Athens	GR
Project Demos - Distributed Environmental Monitoring with Optical Fibre Sensors	*SCK/GEN	B
	VUB	B
	ATEA	B
	Gloetzl	D
	Photonetics	F
Computer Vision Based Inprocess Quality Control (Brightvision)	*Hitec S.A.	GR
	BIKIT	B
	Dansk IT	DK
	V.T.T.	SF
	Rautaruukki Oy	SF
	FIRA	UK
	Scanmicro	DK

Titles	Partners	Country
Fast-Motion-Colour Television Camera System for Failure Detection and Analysis on Fast-Moving Production Steps	*Proxitronic Funk GMBH & Co KG	D
	Sofretec SA	F
Development of Advanced Noncontact Methods for Nondestructive Detection of Defects and Damage in Aeronautical Structures	*AERITALIA G.A.T.	I
	CASA	E
	Fokker Aircraft BV	NL
	MBB GMBH	D
	SABCA	B
	TNO	NL
	Universita Di Napoli	I
	University Of Delft	NL
	IEI/CNR	I
Optical Sensor Systems for Monitoring and Control of Physico-Chemical Variables in Process Industries	*BICC Technologies, Ltd.	UK
	Degussa AG	D
	City University	UK
	Wessex Business Services, Ltd.	UK
Integration of Noncontact Inspection with Modelling of Engineering Components	*Rolls-Royce PLC	UK
	Athens T :hnology Centre	GR
	Imperial College	UK
	Marposs SPA	I
	RDP Technology, Ltd.	UK
Interferometric Cineholography for Nondestructive Testing and Quantitative Inspection	*Labor DR. Steinbichler	D
	QUANTEL	F
	SOPRA	F
	Holo3	F
	University Madrid	E
	ISL	F/D
Holographic Interferometric Analysis of Vibrational Acoustical Behaviour of Structures by Determination of the Displacement Vector	*PEUGEOT SA	F
	Mercedes Benz	D
	Laboratory Dr. Steinbichler	D

*** = primary partner**

Country legend

A - Austria
B - Belgium
CH - Switzerland
D - Federal Republic of Germany
DK - Denmark
E - Spain
F - France
GR - Greece
I - Italy
IRL - Ireland
L - Luxembourg
NL - the Netherlands
NO - Norway
P - Portugal
S - Sweden
SF - Finland
UK - United Kingdom

PHYSICS

The 1990 Erice Picosecond Power Optoelectronics Workshop

by Marco S. Di Capua, formerly the Liaison Scientist for Physics in the Office of Naval Research European Office. Dr. Di Capua is an experimental physicist who has now returned to the Lawrence Livermore National Laboratory of the University of California.

Introduction

Francesco Villa, Stanford Linear Accelerator Center (SLAC), convened this workshop at the Ettore Majorana Center for Scientific Culture, Erice, Sicily, April 1-7, 1990. The Accelerators of the Future workshop reviewed the last 18 months' progress in the picosecond power optoelectronics frontier applied to high-gradient, switched-power accelerators. The second in the Erice series, the workshop was devoted to explore accelerator concepts for ELOISATRON--the Istituto Nazionale di Fisica Nucleare (INFN) Euroasiatic equivalent of the Superconducting Super Collider (SSC). The Italian Ministry of Education, The Italian Ministry of Scientific Research, and the Sicilian Regional Government cosponsored the workshop under the aegis of the INFN ELOISATRON project.

The first workshop, also convened by Villa, took place in Erice in March 1988. A similar one, in Shelter Island, New York, in October 1988 (Fernow, 1988), chaired by R. Palmer, Brookhaven National Laboratory, Upton, New York (BNL), also reviewed the technical challenges arising from the application of switched power to linear accelerators.

Syllabus of the Workshop

This workshop (and speakers) covered:

- Design considerations for high gradient Switched Power Linacs (SPL) (F. Villa, SLAC)
- Picosecond photoemission of electrons from metal cathodes (J. Fisher, BNL)
- Photoemission stimulated by femtosecond laser pulses (T. Rao, BNL)
- Electro-optical field measurements in radial transmission lines and laser-triggered switching elements (W. Donaldson, Laboratory of Laer Energies [LLE], University of Rochester, New York)
- Subnanosecond photoconductive switching in GaAs (W. Hofer, Lawrence Livermore National Laboratory [LLNL], California)
- Ferroelectric electron sources for accelerators and Power Switching (H. Riege, CERN, Geneva)
- High-speed gas switching (F. Villa, SLAC)
- Lasers as SPL switch drivers (I. Bigio, Los Alamos National Laboratory, New Mexico)
- The BNL accelerator test facility (ATF) update (H. Kirk, BNL) (Pellegrini, 1989)
- The Frascati mm-wave FEL design (Sabia, ENEA, Frascati)
- Spectral analyzer detection methods for short electron bunches injected in accelerator cavities (F. Caspers, CERN)
- The electron facility for laser acceleration (ELFA) of the INFN (R. Bonifacio, University of Milano).

Switched-Power Technology

The switched-power frontier in accelerator science and technology involves:

- Production of high-voltage (tens of kV), high-speed (sub ns or ps risetime) short-duration (1 ns or less) pulses in transmission lines of low impedance (1 Ω or so)
- Sub ns or ps jitter synchronization of these pulses through laser triggering
- Synchronized production of nanocoulomb electron bunches in tens of ps at current densities of a few times 1.0E + 04 A cm^{-2}
- Coupling of the propagating pulses through transformers to accelerating gaps producing gradients of GV m^{-1}
- Acceleration of the bunches in the gaps.

Integration of these techniques for the generation of precisely timed, sequential, high-voltage, high-power

electrical pulses to charged particle accelerators could result in:

- Electron sources for high-brightness electron accelerators
- High-gradient (GV m^{-1}) compact electron accelerators that could find applications in:
  1. Industrial radiography
  2. Radiotherapy and medical diagnostics
  3. Free electron lasers (FELs)
  4. New generations of TeV colliders.
- Drivers for basic research of relaxation processes at atomic scales
- Generation and free-space launching of electromagnetic monopulses with large frequency spectra
- Generation of high-power microwaves at cm wavelengths
- Solid-state, light-weight, monopulse, air-borne radars
- Other yet undreamt applications that may arise from the accessibility to compact, efficient, cost-effective, affordable, mass-produced, solid-state, high-power, short-pulse technology.

As in other areas of physics and technology, some the ideas behind switched-power acceleration; i.e., acceleration of charged particles by a sequence of timed pulses, date from the early days of accelerator research (Willis, in [Fernow, 1988]). Other applicable ideas have also been known for quite some time: the photoelectric effect, photo-creation of electron-hole pairs in crystal lattices, pulse propagation in transmission lines of nonuniform impedance. However, the concept awaited maturation of appropriate technologies (short-pulse lasers, switching materials, instrumentation) and an economical incentive for compact, cost-effective accelerators that could reap the benefits of progress in condensed-matter physics and applied electromagnetics.

New developments in picosecond, high-power pulse lasers, high mobility and high dielectric strength semiconductor materials, GHz bandwidth single pulse data recorders, ps-resolution streak cameras, electromagnetic and particle-in-cell finite difference codes, now encourage exploration of new physics domains and application of switched-power techniques beyond the research laboratory.

Gradient Limits in Accelerating Structures

Villa explored the physical basis for limits on field gradients (V m^{-1}) in accelerating structures by reviewing data from the literature for short-pulse vacuum breakdown between electrodes. While there are difficulties in comparing data from a range of conditions, Villa concluded that for times below 1 ns: vacuum can sustain fields of 3 GV m^{-1} after conditioning of the electrodes (Juttner, 1970). After conditioning, field emission probably arises at the interface between the metal electrode and dielectric inclusions that remain on the metal surface. J. Halbritter and R. Latham proposed this idea in the mid 70s to explain breakdown in accelerator cavities at microwave frequencies.

However, present understanding of breakdown processes for short pulses is still poor now. Villa suggested that, for short pulses, the metal could undergo a process of electrostatic insulation. In this case, the presence of emitted electrons effectively suppresses the field on the surface. The effectiveness of this insulation process would depend on how far the electron cloud extends from the surface. This hypothesis requires sounder theoretical and particle-in-cell code modeling and experimental testing within the context of vacuum microelectronics.

Villa also discussed limitations on power density for pulses that propagate in transmission lines. This limitation arises from limited skin-depth penetration of current in the metal conductors. This current flow sustains the Transverse Electromagnetic (TEM) Pointing vector propagating in the gap. This power density limitation is equivalent to a field of 30 GV m^{-1}, an order of magnitude above the 3 GV m^{-1} the SPL technique requires for particle acceleration. Incidentally, 30 GV m^{-1} (3 V/Angstrom) is a field comparable to fields that exist in atomic scales.

Villa concluded his presentation by examining the beam requirements and suitability of SPLs to drive the accelerator and undulator sections of FELs.

Sources of Electrical Impulses

This workshop reviewed progress on several candidate sources for short electrical impulses:

- Vacuum photodiodes
- Semiconductor photo switches
- Ferroelectric emitters
- Synthetic pulse generators
- Gas switches.

Vacuum Photodiodes

J. Fisher, in collaboration with T. Tsang and T. Srinivasan-Rao, BNL, reported on photoemission from thin wires, flat surfaces, and a Y grainy surface with 4.66-eV, 10-ps pulse illumination. At energy densities below the Y damage threshold of 10 mJ cm^{-2}, with extraction fields close to 0.01 GV m^{-1}, Fisher measured quantum efficiencies, expressed as the product of emitted charge times photon energy divided by the incident energy as high as 1.0E-03 with a 3-eV effective work function and a maximum charge density of 1 uC cm^{-2}.

Higher surface fields can improve the quantum

efficiency and increase the charge densities through field-aided photoemission. However, vacuum breakdown places limits on the fields the surface can withstand. Fisher estimates, based upon pulsed (Mesyats, 1989) and radiofrequency data, that vacuum breakdown fields could be as large as 3 GV m^{-1}. Extrapolations of present field-aided photoemission data to 0.7 GV m^{-1} suggest a factor of 2 improvement in efficiency and extracted charge density.

Fisher then described experiments where he is planning to explore the field-aided photoemission regime and to get data on pulsed, high-voltage breakdown limits in vacuum. In the new experiment, a Marx-driven, laser-triggered, 200-kV Blumlein circuit delivers a voltage pulse to the emitting surface. Fisher is now performing preliminary tests of the diagnostics with a laser-triggered transmission line pulser that delivers a 15-kV, 2.5-ns full width at half maximum (FWHM) pulse, synchronous with the UV pulse on the cathode.

T. Srinivasan-Rao, working with the authors of the previous report, described experimental measurements of emission efficiency of metals that undergo picosecond and femtosecond laser pulse irradiation. The efficiency, the ratio of the number of electrons per incident photon, reaches 0.5E-04 for Y at 266 nm with a measured work function of 2.9 eV and a damage threshold of about 20 mJ cm^{-2} in 10 ps. For Au, the work function is 4.3 eV, the efficiencies are 10 times lower and the damage threshold is 10 times higher.

Srinivasan-Rao then discussed options to improve the efficiency of the emission process taking advantage of a strong measured dependence of electron yield on the polarization of the light incident on the surface.

Another approach, requiring illumination of the back side of the emitter, is surface plasmon mediated (SPM) emission. Since plasmon generation is a resonant wave generation process at the interface between two media, the emitted current is exceedingly sensitive to the angle of radiation incidence on the surface. For Au, with 2- eV, 80-fs pulses, SPM emission yields current densities that are two orders of magnitude higher than the current densities available through nonresonant processes. A possible disadvantage, however, is a lower damage threshold of the emitter because of the presence of the substrate.

Photoconductive Switches

Si and GaAs, which can hold fields of about 200 kV cm^{-1} for μs without breakdown and carry MA cm^{-2} current densities during conduction, are attractive candidates for high-voltage, high-speed switches. Absorption of pulsed laser light that spans the band gap of the material creates electron hole pairs in 1.0E-14 s timescales. These pairs "close" the switch in synchronism with the fastest pulses available today (ps or shorter). W. Donaldson, LLE, University of Rochester and W. Hofer, LLNL, reported on exciting new developments in GaAs switching that show promise for the practical implementation of switched-power accelerators.

Donaldson discussed a noncontact diagnostic technique, developed with Office of Naval Research sponsorship, to image electro-optically the internal fields in GaAs. The 100-ps, 10-μm, 100-V cm^{-1} resolution of this technique allows real-time measurement of the collapsing electric fields as the switch closes. Typically, Donaldson images, with a 512 x 512 pixel resolution, the changes in polarization of light passing through a 3 mm x 3 mm chip of birefringent material, proximal to the switch. The electric field in the switch penetrates the chip, locally altering the rotation of polarization. A diode array then records the intensity of a reflected polarized probe beam.

The data on electric field collapse in GaAs unexpectedly revealed, that at fields above 2 kV cm^{-1}, in the conduction phase, the GaAs retains an electric field that remains peaked near the contacts. This residual field, which would be zero in an ideal case, lowers the efficiency of the switch. A probable cause of this remanent field is the dependence of electron velocity on the applied field. In GaAs, the velocity rises, peaks at 2 kV cm^{-1} and then decreases. Therefore, upon switch illumination, the field drops initially and then settles at a lock-on level that is different from sample-to-sample of GaAs material. At fields below 2 kV cm^{-1}, the switch behaves more as expected. Hofer claims that this lock-on behavior takes place at fields above 20 kV cm^{-1}.

Donaldson also applied a simpler electro-optic diagnostic to measure the voltage; a propagating pulse develops at the center of a radial transmission line. Donaldson measured, with a KDP crystal insert, a 5-times voltage gain with a 18-ps risetime in the converging pulse that reaches the center of a 6-cm OD radial transmission line. Photoconductive switching of 500 V at the outer edge launches the inward propagating pulse. Switching takes place uniformly and, as expected, shorter pulse risetimes result in larger gains.

Hofer reported on progress in switching and pulse formation with GaAs at LLNL (Druce, 1989; White, 1989). Hofer described two configurations. In the first one, the switch shorts a 100-Ω transmission line pulse charged to 50 kV in 500 ns. The switch is a 1-mm thick, 5-mm high, 20-mm long GaAs slab clamped between electrodes that relieve the local electric field at the edges. Photoconduction in the switch launches a pulse in the transmission line. By stacking three slabs, LLNL has improved the power gain of the switch by allowing a larger absorption of the incident energy. Their results so far display a laser-limited, 135-ps risetime at a field of 70 kV cm^{-1} with switching in the linear as well as the avalanche regime.

In a second configuration, the switch is a 3-mm x 3-mm, 0.25-mm thick GaAs chip with an annulart gold contact. A laser illuminates the center of the annular contact. This geometry is appropriate for optical fiber or laser diode illumination. These triggering methods yield risetimes of 350 ps with energy gains of 1.0E+04 and lifetimes of 1.0E+04. With these switches, LLNL has succeeded in launching into free space, a 4-MW, 390-ps FWHM pulse with a 200-ps risetime.

There is large progress on GaAs switch performance and the LLNL and LLE results are sufficiently encouraging to warrant an experiment with accelerating gaps in vacuum. However, there are still issues to resolve. Among them are:

- Maximum attainable field
- Maximum allowable pulse charge duration
- Achieving theoretical risetime limits
- Failure mechanisms of material and contact interfaces
- Residual voltage during lock-on operation.

Ferroelectric Emission

H. Riege discussed ferroelectric emission research at CERN (Gundel, 1989). In this technique, application of a fast electrical pulse to a ferroelectric reverses the polarization. This reversal produces fields as high as 1.0E+07 - 1.0E+09 V m^{-1} that expel the screening electrons that compensated the surface charges arising from the original polarization.

The most important properties of ferroelectric emission are:

- The surface expels electrons, hence, an extraction field is unnecessary
- Emission can take place in modest vacuums
- Ferroelectric materials are rugged
- The inherent conductivity resets the charge allowing repetitive operation at MHz frequencies
- The beam cross-section can take arbitrary shapes.

The total charge density per emission cycle is equal to the spontaneous polarization (0.5 C m^{-1} for PbTiO3, 1.0E+15 electrons cm^{-1}, for example). The emitted current density is equal to the ratio of charge density to the duration of the current pulse that neutralizes the surface charge arising from the initial polarization. The current (charge) the pulser can deliver limits the total current (charge) emission. Therefore, the impedance of the pulser and the dielectric relaxation time (product of dielectric constant and conductivity) of the ferroelectric limit the emission current. The limitation on applied voltage, on the other hand, arises from the breakdown strength of the ferroelectric material. Excitation with a low-impedance transistor pulser (4 X 120 A @ 5 kV) could deliver 480 A from about 0.5 cm^2.

According to Riege, the application prospects for ferroelectric emitters are very bright since emission at room temperature could produce normalized emittances of 2.5E-05 mrad and brightnesses of 1.6E+11 A $mrad^{-2}$. Designs for transient hollow cathode discharge switches (THCD) (ESNIB 90-06:53-56; Riege, 1989) already incorporate such emitters. So far, Riege has measured currents up to 100 A with current densities ranging from 10 A cm^{-2} in a vacuum to 1.0E+3 A cm^{-2} into a plasma.

Among the potential applications of ferroelectric emission sources, Riege (1989) counts: accelerators, microwave frequency oscillators (Bizek, 1988), vacuum microelectronics (Grandke, 1989; nn, 1989), electron beam lithography, and ultra flat cathode ray color television displays. A commercially successful application, such as the TV display pursued by Hitachi in Japan, would assure the future of vacuum microelectronics.

Synthetic Pulse Generation

Synthetic pulse generation involves superposition of several high-Q modes in a cavity to produce short, high-field pulses along the cavity axis. Synthetic pulse production may bypass limitations on the superconductive cavity-quenching fields resulting from the maximum radio frequency (RF) power during continuous wave (CW) operation. Pulsed operation may allow higher fields when the pulse length is shorter than the time required to form conductive domains in the cavity wall.

G. Muller, at the University of Wuppertal, in collaboration with F. Caspers from CERN, succeeded in superimposing pairs of modes in a cavity within free oscillation and with phase-locked-loop (PLL) control. Narrow bad pass filters and precise phase shifters in the feedback loop would suffice for successful cavity operation in the self-oscillating mode. This approach would avoid the expense and complications imposed by PLLs. However, weakly coupled modes may still require seed signals of the correct frequency to activate oscillation in the presence of stronger modes with a lower Q.

Gas Switches

Avalanche breakdown in gas switches could also generate fast electrical pulses. Cassell, SLAC, presented calculations of avalanche growth in vacuum at previous workshops (Fernow, 1988). At this workshop, Villa displayed breakdown data from a preliminary experiment he performed at SLAC, in collaboration with W. Hofer's group from LLNL. A 250-μm gap in air at 22 bar, pulse charged to 46-kV (E p^{-1} = 110 kV cm^{-1} $Torr^{-1}$) with a 2.5-ns FWHM pulse broke down, after holding voltage

for 1.5 ns, with a 35-ps current risetime. A diagnostic shortage (a Tektronix 7250 on loan for 2 days) limited the duration of the experimental run. Avalanche calculations agreed with this data.

The self-breakdown was the easiest way to test the avalanche calculations. Synchronization for SPL applications requires triggering so future experiments will have to test avalanching in a range of pressures and fields as well as breakdown by laser illumination. Since the GaAs switching approach appears to offer so much promise, it is likely that it will delay further development and testing of gas switches.

Accelerating Microstructures

A discussion on accelerator microstructures complements the discussion of new acceleration techniques. One idea underlying the use of microstructures is to extend the radiofrequency acceleration concept to optical frequencies, replacing microwave tubes by lasers and cavities by grating-like open structures. The acceleration mechanism is the inverse Smith-Purcell effect (Smith, 1953). The expectation is that shorter wavelengths may allow higher accelerating gradients. Moreover, smaller structures require smaller amounts of electromagnetic energy to fill. A detailed discussion of the microstructure approach to particle acceleration is beyond the scope of this report. However, for completeness, I mention the approaches outlined at this workshop.

Laser Acceleration of Electrons in Micrograting Structures at the BNL Accelerator Test Facility. In this presentation, J. Warren, BNL, described the BNL program and displayed grating structures available at this moment. These structures are a double row of 4.5-μ tall columns with a 5-μ period. Improvements in fabrication techniques and quality control can deliver uniform structures that fall within manufacturing tolerances. There are limits, however, to the aspect ratios that conventional etching techniques produce. Etching in preferred crystallographic directions may improve the aspect ratios.

In a companion presentation, H. Kirk, BNL, described the capabilities of the BNL accelerator test facility (ATF). Even though the drive for the ATF is RF, ATF could produce the beam to test novel accelerator concepts. Since the ATF RF drive synchronizes with a laser pulse, testing of laser-driven SPL or micrograting concepts is possible.

Dielectric Resonators and Dielectric Waveguides for Particle Acceleration. F. Caspers, CERN, discussed some ideas for small, tunable, stable high-Q dielectric resonators on a substrate that couple to a microstrip line. Dielectric materials with F * Q products of 2.0E+05 GHz and dielectric constants equal to 20 are available today. These allow 3-cm diameter, 1-cm long resonators to operate at 3-Ghz frequencies. Dielectric resonators, in contrast with metallic structures, will not radiate in certain modes. Testing of these dielectric structures could take place at microwave frequencies. Dimensional scaling would allow operation at optical frequencies where one would expect lower losses than in metallic structures. Another advantage is that implementation of accelerator structure could exploit recent advances in integrated optics.

Caspers considers a colonnade structure built on a substrate fed by optical waveguides that couple to the substrate. Caspers even imagines two intersecting colonnades with the focusing properties of RF quadrupoles. At this moment, these ideas require more detailed exploration. This exploration could warrant a BNL-LLE-CERN collaboration to determine feasibility of this concept.

Laser Discussions

The attendants also heard presentations from I. Bigio, LANL, on laser drivers for SPL concepts as well as a thorough discussion, by R. Bonifacio, P. Pierini, and L. de Salvo Souza on the INFN-funded effort on mm-wave FELs at the University of Milano. A future report will describe in detail FEL research in Milano program and its connection to the European heavy ion fusion program.

Conclusions

This workshop revealed exciting new developments on new accelerator concepts. Enthusiasts perform this research on a part-time basis with restricted funding. An underlying theme of the workshop is that lasers, condensed matter electronics, and microfabrication may have the same or larger impact on accelerators of the 21st century as developments in microwaves and vacuum electronics had on the present generation of accelerators. International collaboration and increased funding of this field could yield large dividends.

In the mind of many of the workshop participants, successful implementation of a few sections of an SPL could aid the case for further development of this technique. Success would point the way to significant reductions on the size and cost of electron accelerators of the future.

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REMOTE SENSING

The Institute for the Statistical Mechanics of Turbulence Marseille

by Hans Dolezalek, a physicist serving as Liaison Scientist at the Office of Naval Research European Office, London. He is currently specializing in remote sensing (with emphasis on the ocean), and questions about applications of atmospheric electricity for global change. Before this assignment, he acted as a Scientific Officer of the Remote Sensing Program in the Ocean Sciences Directorate, Office of Naval Research Headquarters, Washington, D.C.

Introduction

Theodore von Kármán was born 1881 in Budapest and died 1963 in Aachen. He and other researchers created for Hungary, their home country, the reputation of a highly esteemed source for scientific excellence. John von Neumann was a Hungarian (b. 1891 Budapest, d. 1957 Washington), and so were Georges Charles de Hevesy (b. 1885 Budapest, d. 1966 Freiburg), and Leo Szilard (b. 1898 Budapest, d. 1964 La Jolla). As stated by Frank Joseph Malina, v.Kármán "pioneered the use of mathematics and the basic sciences in aeronautics and astronautics, as well as in other fields of technology in which, until then, progress had been achieved mainly empirically." During his time in Göttingen, this attitude was supported by Ludwig Prandtl, the father of modern fluid mechanics (1875-1953), and Felix Klein (1849-1925) stressing the fullest use of mathematics in engineering. In 1944, v. Kármán became a cofounder of the Jet Propulsion Laboratory (JPL) of the California Institute of Technology in Pasadena.

By the early 1960s, v.Kármán was a member of the Academy of Sciences in Paris and famous as the father of the "Kármán Vortex Street," a central problem of turbulence in fluids. At that time, he initiated the founding of the Institut de la Mécanique Statistique de la Turbulence (IMST) in Marseille, France.

Independent of each other, both JPL and IMST became interested in a very modern application of mathematics and basic sciences to a particular domain within the v. Kármán field of interest, that is fluid mechanics in which, until then, progress had been achieved mainly empirically: the remote sensing of the ocean by a special type of radar that provides very fine geometric resolutions (3 m or better) of the ocean surface from satellites and aircraft, day and night, through clouds.

After theoretical studies, scientists in both institutions were confronted with the fact that an understanding of the governing processes is possible only by direct measurement of the involved parameters of the lowest atmospheric and the uppermost oceanic layers. The number of these parameters is large; they are interconnected by physical processes. As many of these interconnections are of a nonlinear nature, it often is impossible to derive one of the parameters from the measurement of another one. This is making it necessary to measure them all as directly as possible, at the same time and place. In doing this, JPL (and later other groups) concentrated on measurements in the open ocean, while IMST emphasized investigations in the special wind/wave tunnel which they operate in Marseille-Luminy.

In the following, I discuss the work at IMST. I describe briefly their wind/wave channel and indicate the desirability of future developments involving both the JPL succession and IMST (and potentially another institution in the Netherlands that began efforts toward the same general goals).

History of IMST

According to Favre (1971), research related to the often turbulent mechanics of fluids and gases had already been pursued at the Faculté des Sciences de Marseille since 1932. This has been supported and applied by many institutions:

- Direction Technique et Industrielle de l'Aéronautique
- Météorologie Nationale
- Office National d'Études et de Recherches Aérospatiales
- Centre National de la Recherche Scientifique
- Commissariat à l'Énergie Atomique

- Direction des Recherches, Études et Techniques
- Institut Français de Recherche pour L'Exploitation de la Mer
- Laboratoire d'Océanographie Physique du Muséum National d'Histoire Naturelle
- Électricité de France
- Chambre de Commerce et d'Industrie de Marseille
- Centre National d'Études Spatiales.

After discussions with v. Kármán, A. Favre inaugurated the Institut de Mécanique Statistique de la Turbulence, in the frame of the Faculté des Sciences. In 1961, it was established in Marseille-St.Charles. In 1971, still under the directorship of Professor A. Favre, IMST was divided into two branches: one remaining in Marseille-St.Charles, the other one was established in Marseille-Luminy. At that time, IMST had about 50 employees.

At present, Professor M. Coantic (IMST Luminy Laboratory head from 1971 to 1981) is both the Director of IMST and of the branch at St. Charles. The Luminy Campus is situated about 15 km south of Marseille. It is a large assembly of university buildings.

Administrative Information

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This report will deal only with IMST at Luminy.

Organization-Personnel

There are five departments (students or guests mentioned in parentheses):

1. Interactions vent vagues = Wind/Wave Interaction; J.P. Giovanangeli, Guillemette Caulliez (O. Le Calvé, N. Ricci, R. Dupont)

2. Instabilités et phénomènes de transition = Wave Instabilities, Transitions (Breaking); Chris Kharif, A. Ramamonjiarisoa, Pierre Bonmarin (M.Ioualalen, Joel Poitevin)

3. Interaction vagues courant = Wave/Current Interaction; A. Ramamonjiarisoa, C. Kharif, P. Bonmarin (Bernd Jähne)

4. Interaction ondes électromagnétiques vagues = Remote Sensing:

a. Scatterométrie = Scatterometry; J.P. Giovanangeli, C.Kharif (J. Poitevin, L. Bliven)

b. Altimétrie = Altimetry; A. Ramamonjiarisoa, Hubert Branger (J. Poitevin, L. Bliven)

5. Developpements d'équipements spécifiques = Development of Special Instrumentation:

a. Mesure de pression (p') = Measurement of Pressure p', J.P. Giovanangeli

b. Mesure de vitesse du vent à la surface des vagues = Measurement of the Wind Velocity close to the Surface of the Waves; J.P. Giovanangeli

c. Spectres d'amplitude des vagues en vecteur d'ondes = Wave-number Amplitude Spectrum; A. Ramamonjiarisoa, (B.Jähne)

d. Visualisation = Vizualization; P. Bonmarin.

Financing

In broad terms, about one-half of the costs are carried by the university, the other half by the Centre National de la Recherche Scientifique (CNRS). The CNRS pays for the salaries. The costs for other items; e.g., housing, are shared by both. The specific costs for research are mostly covered by contracts. In other words, the salaries do not depend on contracts; i.e., they are "hard money." (At present, there does not seem to be a provision for employing "soft money" scientists.) Yet arrangement of additional working space seems to be possible; if not now, then for the future. Because of this fact, emloyees can continue doing theoretical research even when there are no contracts available. Thus, everybody is fully engaged all the time. A potential disadvantage of this system is that it is difficult (or sometimes impossible) to accept new work even if it could be funded from the outside.

Overview of Work-Some Results[1]

For the last 15 years, IMST's major contributions have been made to the dynamics of the atmosphere and of the surface of the ocean as they are related to air-sea interactions. More recently, first results obtained on the microwave reflection by water surfaces are important for ocean remote sensing.

[1]Based on a contribution by A. Ramamonjiarisoa, head Luminy Laboratory 1981-1989.

Experimentally, the Miles-Phillips model of wave generation was carefully checked by an original arrangement (i.e., generation of rows of vortices in the air flow) and by applying a highly sophisticated technique to estimate all terms that contribute to the wind stress at the surface. (IMST has developed a miniaturized pressure sensor and a hot-wire device that rapidly traverses the water surface.) From a conceptual viewpoint, the model appeared to be basically sound, but the experiments revealed unexpected phenomena such as the generation of nonresonant waves with significant amplitudes. The experimental rates of growth by the instability mechanism are generally higher than the theoretically predicted values. The dispersion of wind waves was found (experimentally) to differ, by a lack of dispersion, from the classical linear law adopted in theoretical models.

For several years, this had been a cause of controversy among specialists. Several models of wave motion (ranging from strictly linear to strongly nonlinear) were proposed to explain this "anomalous dispersion." Based on similar experimental results, a new wind-wave model was developed at TRW, Redondo Beach, California. Recently, a numerical work done by the La Jolla Institute, California, shows that this dispersion may result from strong long wave/short wave interactions. The influence this might have on oceanic microwave remote sensing was recently discussed by Barrick and by Leblond.

The investigations mentioned above emphasized the importance of nonlinearity in water surface wave evolution, including wind waves. The numerical work performed at IMST significantly contributes to the understanding of the nonlinear evolution. At first, this work was concerned with the stability of Stokes waves to linear two-dimensional (2-D) or three-dimensional (3-D) perturbations. Computations were made for a large steepness, very close to the maximum value. A specific numerical technique has been developed on supercomputers. The computations revealed new domains of instability and gave more precise information on relative strength of instability of different classes. Recently, the computations have been extended to nonlinear perturbations, including surface tension and viscous dissipation. One of its striking features is a strong distortion of the wave profile. No recurrent state is observed. Instead, clear subharmonic transition occurs. This may be related with the so-called "frequency-downshift," a well known, but not yet explained, fundamental feature of wind/wave fields.

Other important results gained at IMST deal with the deformation of the deep-water gravity wave to breaking and the associated process of bubble generation and dispersion inside of the water mass. For bubbles of small size (60 to 3000 μm), an optical device combined with a sophisticated data processing yielded a complete set of results concerning the bubble size spectrum, speed, and time of residence. These results are of fundamental interest for various fields, especially for the air-sea gas exchange and the scattering of sound or of microwaves by breaking waves.

The extension of experimental work to the capillary-gravity range by using a laser Doppler current meter, yielded (possibly for the first time) a complete and detailed set of data on the motions of the air and the water surface and on the water drift current. These data will greatly help to understand the dynamics of wind generated capillary-gravity waves, as involved in ocean microwave remote sensing. In collaboration with the University of Heidelberg, Federal Republic of Germany, this has recently resulted in the first set of wave number spectra of short waves (wave length approximately in the range 1 mm to 10 cm). The technique used represents a complicated combination of optical recording of 3-D wave images (done with an original system) with digital processing.

In 1984, research directly aiming at problems of ocean remote sensing started at IMST, prompted mostly by the need for a better understanding of the physical mechanisms involved in the backscattering of electromagnetic microwaves from the ocean. It was believed that this understanding required a thorough knowledge of surface wave dynamics and associated processes. In this regard, the work was expected to benefit from previous results obtained by IMST itself as well as from other investigations. A first collaborative experimental work with the Centre National d'Études Spatiales (CNES), France, led to a clear identification of the phases of water wave motions, of various types, which predominantly contribute to the microwave reflection (near-vertical incidence). The critical effect of the wave breaking on the microwave reflected signal was striking. This research has been recently completed using numerical models. The numerical computation of water waves cited previously was combined with a high order (in water wave slope and curvature) model of microwave reflection. This model shows a dependence of the reflected microwave cross section on the microwave frequency. The phenomena has been observed in recent field experiments with altimeters but no explanation has been found. Another investigation done with NASA, Wallops Island, Maryland, dealt with azimuthal response of scatterometers. A new expression relating the backscattering cross section to the wind friction velocity was proposed. An original aspect of the work concerned the effect of rain on backscattering.

The IMST took part in the large international cooperative program Humidity Exchange Over the Sea (HEXOS). The laboratory was mostly involved in problems of the effects of bubbles produced by breaking waves and sprays on the air-sea humidity exchange. Experiments conducted with a group at Commisariat à

l'Énergie Atomique (CEA), France, on the gas exchange (carbon dioxide) at the air-water interface, were also directly related to air-sea interaction. A formula connecting the exchange rate to the wind friction-velocity was established. After refinement at the Laboratoire d'Océanographique Dynamique et Climatologie (LODYC), France, the formula recently served for a first estimate of the carbon dioxide cycle over the world ocean.

The IMST's scientific program for the near future includes a continuation of experimental and numerical work on the nonlinear evolution of water waves. Specific aspects will concern the nonlinear dynamic of wind waves in relation to the so-called electromagnetic bias in altimetry. A large part of the program will deal with wave-current interactions in relation to the synthetic aperture radar (SAR) imaging of current, underwater topography, and internal waves. In addition, fundamental work on wind/waves interactions will be pursued that could include the case of nonhomogenous water-surface motion. The work will be combined with investigations on scatterometry.

Present Research Tasks (Selection)

Wind/Wave Interaction, Generation of Short Waves by Wind, Scatterometry (Giovanangeli, Caulliez). The goal of this research is to understand the processes in the immediate neighborhood of the water surface. These processes demonstrate different behavior depending on whether they occur at the crest or in the trough of the longer waves or on the slope. In defining the term "immediate neighborhood of the surface," one must take into account the opportunities to measure. Extrapolation of data obtained in some distance from the surface to the surface itself must, a priori, be considered as undesirable because we do not know whether linearity will be maintained. Indeed, we have good reasons to assume that it will not be so. The IMST scientists are considering the first 2 mm above and below the water surface as accessible to direct measurement (to be done in their wind/wave tank). This is a specific and typical task for laboratory experiments preceding open-ocean measurements where most scientists would consider it impossible to obtain such a fine resolution.

Measurement objectives actively pursued at IMST: atmospheric pressure, wind, wind profile (within the 2 mm!), and form drag just above, and current within 2 mm under the water surface. They found a method to measure the pressure and are obtaining methods for wind and wind profile, while a Danish laser-doppler instrument provides for the current measurement. The Staunton/Thornton 3-D current meter within a 1-mm cube was obviously not yet known to them.

Similar tasks involve, for example, the variation of energy transfer from air to water as it depends on the fetch length. Here, three regimes are defined--laminar flow, instable flow, and turbulence. In each, the energy-transfer gradients are different. Earlier work by Gaspar Valenzuela (1976) and Klaartje van Gastel et al. (1985) is being quoted, while the Deardorff theory of 1967 serves as a broader basis for the whole task.

In this regime, the nonlinear character makes itself felt by the fact that simple relation of the slope as being the time derivative of elevation times the inverse of the phase velocity does not hold anymore. This brings up the question of the definition of phase velocity in this scope. Here, the measurement of pressure in the thin layer becomes essential for the derivation of the stress. Obviously, it is not permissible to simply assume these relationships. They should be assessed by a validated theory based on measurements in this regime.

As long as we believe that the radar return signal depends on the characteristics of the small waves, and that they respond in some way to the wind (scatterometry), the solution of the problems indicated here becomes a necessity. Only then can we determine the accuracy and reliability of scatterometry data. The reliability will indeed also depend on validated knowledge about the behavior of environmental and radar limitations.

Wave Instabilities[2]. Phenomena such as breaking, frequency downshift, wave number modulations, and the radar response are investigated by numerical models and numerical simulations in three groups of tasks:

1. **Linear Stability** (C.Kharif). Studies on instabilities of deep-water gravity waves cover almost the full range of admissible steepness. Instabilities (2-D and 3-D) of McLean's class I and II for basic wave steepness larger than 0.41 were investigated. New 2-D superharmonic instabilities were predicted, confirming the recent contribution of Mackay and Saffman (1986). The linear stability of 3-D progressive deep-water, short-crested gravity waves are studied with a modified Galerkin method (which is more efficient than the collocation one), based on the theory of linear stability of a finite-amplitude wave to infinitesimal perturbations. Extending the calculations of Hsu, Tsuchiya, and Sylvester (1979), and using a perturbation expansion method up to the fifth order and an algebraic algorithm, the basic wave is analytically calculated. Harmonic resonances, analyzed by Roberts (1983), may be identified as superharmonic instabilities of class I; their growth is estimated.

2. **Nonlinear Evolution, and Short-Wave/Long-Wave Interactions** (C.Kharif, A. Ramamonjiarisoa). To investigate the still unexplained frequency downshift (Lake et al, 1977), the high-order spectral method

[2]Condensed from a contribution by C. Kharif who could not be interviewed during the visit to IMST.

developed by Dommermuth and Yue (1987) allows the treatment of the nonlinear long-time evolution of a uniform wave train that is initially subject to modulation instabilities, taking into account effects of viscosity and surface tension. When exact boundary conditions are applied, the frequency downshift is observed. Confirming the analysis by Trulsen and Dysthe (1990), this phenomenon is observed by high-frequency localization over the steepest crests of the wave train where dissipation is important. Radar response from nonlinear wave fields has been computed using a deterministic model. Poitevin et al. reported some results related to scatterometry and altimetry (1990 a,b). The wave profiles exhibit rapidly a very strong asymmetry even for an initially moderate value of the amplitude of the basic Stokes wave. This also makes the radar response asymmetric, more so than predicted by the weakly nonlinear wave theory that is also valid for the number of specular points. The electromagnetic bias in altimetry is influenced by this. For scatterometry, the intense amplification of short-wave groups on the crests of the long waves may produce significant amounts of backscatter. Kharif (1990) has shown that when the nonlinearity of the longer wave is taken into account, together with the capillary effects of the short waves, the action conservation principle (Bretherton and Garrett 1969) remains applicable for studies of the modulation of wave-number and amplitude of the short waves as they ride on long, deep-water gravity waves.

3. **Evolution to Breaking**, (P. Bonmarin). Near the breaking region, the wave profile becomes more or less asymmetric, requiring more and more parameters for description. Crest asymmetry, highly marked for plunging breakers, has been measured in the wave tank of IMST with a frame analysis process, resulting in some agreement with numerical predictions. The profile evolution near the breaking region was observed to display a significant evolution of geometric parameters that reach maximum values at the breaking point. This demonstrates the transient nature of the process.

Additional Tasks. Three groups of additional tasks are related to altimetry, scatterometry, and to the visualization of surface developments:

1. **Special Problems Inherent to Altimetry**, (Ramamonjiarisoa, Branger). Explanation of the electromagnetic (EM) altimeter bias is desirable for basic reasons, but also for the upcoming Topex-Poseidon satellite. This bias (measured in terms of the power of the return signal) amounts to about 5 percent of the $H_{1/3}$. Returns from the nadir-looking radar signal show spikes when the radar spot is in a wave trough. That can, in part, be explained by multiple reflections, in part by the fact that there will be more horizontal facets in the trough of long waves than on their slopes and even their crests.

The goal of this research is not the development of algorithms or empirical formulae but the understanding of the processes involved. This approach is based on ideas of Ramamonjiarisoa.

Experiments conducted in September 1990 in the wind/wave tank employed the large optical lens developed by Chester Parsons at NASA Wallops, which was shipped to Marseille. Used with a bistatic radar arrangement, a 3-cm diameter radar spot is produced on the water surface near the wave gauge.

The CNES intends to fly a special altimeter on the satellite TOPEX-POSEIDON. If results from IMST can be included in this effort, comparisons with Hasselmann's wave model may become desirable.

Kharif investigated other special problems related to altimetry, specifically on the relationship between surface currents and short waves. B. Jähne invetigated which short waves are mostly influenced by the long ones.

2. **Additional Activity on Scatterometry**, (J.P, Giovanangeli, C.Kharif, Poitevin). Experimental and numerical studies are conducted on interactions between electromagnetic microwave and windwave fields. The experiments are carried out in cooperation with L. Bliven, NASA/Goddard Space Flight Center, Greenbelt, Maryland, and Wallops Island, Virginia. For the experiments at Luminy, the wind/wave tank ("La Grande Soufflerie" described later in this article) has been equipped with a 36-GHz, 30-degree incidence angle scatterometer, hot-wire anemometers, a pressure fluctuation probe, and gauges for wave amplitude and slope. A pure wind-wave field is generated and the response of the scatterometer to wind velocity is measured. First results show that (a) with increasing wind velocity, the difference between upwind and downwind cross section decreases; (b) azimuthal dependence of radar cross section is linked to the directional properties of the short wind waves; and (c) radar response depends more on friction velocity than on wind velocity. Other experiments demonstrate that rain strongly increases the radar cross section but reduces the directional sensitivity to wind direction.

The numerical studies consider the interaction between a Stokes wave and rain-produced capillary waves, and develop a model of the radar response. They demonstrate strong modulations of the radar return signal in phase with nonlinear interactions between large and short waves.

3. **Visualization**, (P. Bonmarin). Bonmarin has developed a method by which the camera follows the movement of an individual wave as it propagates down the wave tank until it brakes. The camera looks into an inclined mirror that is half under and half above the water. The mirror sees the cross section of the wave in the direction of its propagation; i.e., perpendicular to its

crest, while the whole system moves on rails under the roof of the tank. The scene is illuminated by a vertical "sheet of light" inside the tank, which can be varied as to intensity and width. The data obtained are digital and allow the actual measurement of slope development.

Several other visualization methods are in the speculative stage. Others, in this case with Bernd Jähne, are more advanced. The latter uses two Fresnel lenses--one above, the other below the water. A diffused light is under and a camera is above the water.

Position of IMST in Ocean Radar Remote Sensing

Three Approaches to Radar Remote Sensing of the Ocean (an introductory discussion). Products of radar remote sensing of the ocean frequently have been of an ad-hoc nature. The products demonstrated that remote sensing can do useful things, but rarely gave a satisfactory presentation of the true potential. This does not come as a surprise because such a presentation would require a large effort. The effort should include a well-planned, systematic approach toward a complete theory by hypotheses, models, laboratory trials, and field experiments with a selective mixture of remote sensing and surface truth acquisition. Such an effort could not be started before enough ad-hoc experiments producing landmarks and hypotheses were available as a pool of information to be evaluated for a more systematic approach. Seen in this light, three groups of approaches may be distinguished. Essentially, the groups are characterized by the degree to which they differ in emphasizing the direct measurement of some or all the hydrodynamic parameters involved (in addition to radar measurements):

1. The "Phenomenological Approach." This approach was the only one used during the first years of ocean remote sensing by radar. The approach produced a host of new general oceanographic insights and fresh information on many oceanic parameters. Many of these have found application in oceanographic research and also directly for practical purposes. As a most welcome side product, this approach produced and still produces data needed for the construction and continuous improvement of the more systematic approach indicated above and described below. Many efforts in this group emphasized radar measurements over oceanographic measurements, sometimes without any surface truth. More often, there was a relatively small surface-truth effort aiming only at the direct measurement of the oceanic parameter to be assessed by SAR.

2. The "Detailed Physical Approach." This approach investigates in depth the physics of individual parameters of the SAR process, including error sources or model evaluations. This had turned out to be necessary because our previous understanding of these parameters was not good enough to understand their role in the SAR process.

3. The "Comprehensive Physical Approach." This approach is the systematic attempt, starting from available ad-hoc data, then speculating about their physical importance, recognizing data gaps, providing the experimental material to fill these gaps, and finally formulating hypotheses for a complete theory of this remote-sensing method. This approach includes the experimental testing of these hypotheses. The approach includes the determination of accuracy potentials and of the validity range of the tested theories, as they depend on meteorologic, oceanologic, and radar parameters. Recognizing information gaps includes an assessment of the relations between the data to be measured. When linear relations between, and Gaussian distributions of, the data measured cannot be taken for granted, the true nature of these relations and distributions can often be derived only by the direct measurement of any intermediate links and/or of the full spectrum. Recognizing information gaps also includes an assessment of the need to measure the multitude of influences which are not dependent or are only loosely dependent on each other but act on the SAR process. Obviously, this approach requires broadly based long-term planning, dedicated scientific personnel, and enough financial means. But evidently only such a comprehensive physical approach can create a scientifically acceptable basis for utilizing the full potential of radar remote sensing of the ocean.

Survey of the Comprehensive Physical Approach

Looking back over the past 2 to 3 decades, we can distinguish two scientific starting points for this approach. They are linked to O.H. Shemdin (then University of Florida; later JPL) and A. Ramamonjiarisoa (University Marseille-Aix II). While developed independently of each other, they arrived at similar and complimentary procedures. Both efforts distinguished themselves from many others of their time. They started from the oceanographic features as the essential elements for ocean sensing by radar, while most other researchers approached these problems from the radar side. Both also realized early that an understanding of what the Office of Naval Research (ONR) later called the *Intermediate Link* (essentially the hydrodynamics) was needed. In addition, both realized that this could be acquired only by direct experimental measurements of the relations between the ocean features of interest and the radar image. Remember, there was no lack of scientific hypotheses or of models, and discussions about

their validity were abundant. Often these discussions were in vain because the experimental data did not exist that were needed for a decision between conflicting hypotheses or for verifying models. At that time, the most urgent need was for new and better data--not for more theoretical efforts before the essential data would be available.

About 1983, Shemdin's initiative, as well as the provision of sufficient *ad hoc data*, had sufficiently matured to lead to ONR's Ocean-SAR Program. The Ocean-SAR Program is an effort based on coordinating theory with field experiments in the ocean (called TOWARD and SAXON), and supporting them by laboratory measurements when required. Ramamonjiarisoa's initiative resulted in IMST's present program, which is the object of this report. This program represents a coordination of theory and experiments in the 40-meter wind/wave tunnel at IMST.

Both approaches deal with the fine structure of the ocean surface and near surface. During the TOWARD and SAXON experiments, measurements aimed at an assessment of these layers with spatial resolutions of less than a centimeter. At the same time, the wind/wave tunnel measurements emphasized the lowest 2 mm of the atmosphere and the uppermost 2 mm of the ocean. The ONR work is broader. The work includes SAR and real aperture radar (RAR) airplane overflights and a set of measurements of all other parameters as they occur in and over the open ocean. The work at IMST is more detailed and takes advantage of the fact that the water, air, and radar conditions in the wind/wave channel can be deliberately adjusted to closely approach whatever is desirable. Thus, both approaches complement each other in an almost ideal way.

In recent years, similar programs have been started elsewhere, with the "VIERS" Program of the Fysisch en Elektronisch Laboratorium TNO, The Hague, the Netherlands, being the most comprehensive.

After having achieved the first series of field experiments, the ONR program has been enlarged in various directions. Most importantly, the investigation of the small-scale hydrodynamics of the water surface and subsurface regions is even more emphasized, together with a more detailed investigation of the atmosphere in the lowest meters and dekameters. The investigation includes the assessment of the biological-chemical layer in the uppermost micrometers of water. At the same time, hypotheses come under consideration of the application of the newly gained insights for larger scale oceanography. The basis was enlarged by including more and more results from investigations listed above under the first two groups (the "phenomenological" and the "detailed-physical" ones).

Considering all this, a conflux is logical of mutually supporting efforts including the ONR, IMST, and VIERS programs. Efforts undertaken elsewhere; e.g., Shirshov Institute of Oceanology, U.S.S.R. Academy of Sciences (Professor V. Zakharov), are to be included. Below, I present some ideas on achieving this.

The Fort-Meter Wind/Wave Channel

This unique facility was conceived as a combination of a micrometeorological windtunnel with a wind/wave channel underneath. The air part has a cross section of 3.2-m width and 1.5-m height, while the water part is 2.6-m wide and 1-m deep; the test length is 40 m. The flow of the water can be regulated from 0.01 to 0.1 m/s, the velocity of the air from 0.3 to 14 m/s. The water can be heated and cooled for a range of 10 to 25° C; temperature and humidity of the incoming airflow are regulated by heating and cooling and vapor injection in ranges of 1- to 20°-wet-bulb and 10- to 35°- dry-bulb temperature. The temperature of the ceiling above the wind tunnel can be regulated between 5 and 35°, producing a quantitative heating effect by radiation. A submerged wavemaker generates waves from capillary ones to waves of 1-m wave length, including the possibility of breaking.

The most important measuring equipment varies, of course, with the specific investigation under way and could not be described comprehensively. In recent years, much effort has been spent in developing instruments measuring atmospheric or oceanic parameters in microscale. Such special equipment also must be supported by a set of more or less standard instruments, among which we find pitot tubes, hot-wire and hot-film probes (single or multiple), constantan thermo-couples, thermistors, miniature psychrometers, dew-point sensors, microwave refractometers, and capacitance wave gauges. With these standard instruments, investigations of turbulent velocity and temperature fluctuations in water, mean values and turbulent fluctuations of humidity, and surface motions of the water had been carried out in this channel 20 years ago (Coantic and Bonmarin, 1975).

Future Combination of Efforts

Frequent discussions take place about the three programs described above; I know of one scientist who is considered an active member in all three programs. Direct cooperation has been proposed; e.g., using the pressure sensor with 1-mm resolution developed at IMST in an ONR field experiment. This did not materialize because the work in progress at IMST did not allow them to provide the necessary scientific manpower and time. This situation prevails. Also, it exists in connection with the present ONR program.

A discus ion of future work by all three programs will certainly be necessary after ONR conducts and initially

evaluates the two recent field experiments (SAXON-FPN and SAXON-CLT II), and after IMST concludes some of its present experiments, and VIERS also arrives at a threshold to a new step. The conduct of a small conference entitled Ocean Surface Hydrodynamics and Microwave Remote Sensing hosted by IMST was discussed between the IMST scientists and me during my visit. This conference would cover

- The hydrodynamics of the ocean surface, including the atmospheric dynamics of the lowest dekameters, the air/sea interaction effects as related to microwave remote sensing with emphasis on the layer along the actual water surface or the immediate hydrodynamics of the air-water interface, including the microlayer, and the hydrodynamics of the uppermost dekameters of the ocean.
- Altimetry, scatterometry, and real and synthetic aperture imaging radar.

The following objectives are recommended:

- Defining the desired theory of ocean active microwave remote sensing as it has developed after the experiments mentioned above
- Listing and defining unproven assumptions still existing in this theory or these hypotheses
- Listing the expected consequences because these assumptions are not proven
- Determining the environmental parameters and their upper and/or lower magnitudes that set limits for the theory, under due consideration of the importance of the radar variables
- Determining the probability that a satisfactory theory can be developed
- Agreeing on work by the participants toward this goal to be performed within the next 2-3 years.

A second, potentially effective, form of cooperation could be the exchange of some coworkers for about a year but that might be difficult. The easiest form of a French-American cooperation could probably be to get a postdoc from IMST to work within ORE in Pasadena, or with the La Jolla Institute in San Diego. In the opposite direction, we learn that, in principle, IMST can get funds for foreign postdocs from CNRS.

The communication between the groups could probably be improved. If IMST had access to the OMNET electronic mail system, they would automatically be immersed into the inter-U.S. exchange of oceanic and atmospheric information. Although much of this information is not interesting to people working in Europe, that can easily be eliminated. The possibility of almost instantaneously addressing practically the whole U.S. oceanographic community (individually or collectively) might be useful for the colleagues in IMST. The situation could improve if OMNET is successful in realizing their European system, and if an intelligent method can be found to separate that flood of information that is of no interest to the other continent. This presupposes that the European governments will allow an increasing degree of freedom to their electronic mail systems, also reducing costs.

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10th Symposium of the European Association of Remote-Sensing Laboratories, Toulouse, France

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Introduction

On June 5-8, 1990, the European Association of Remote-sensing Laboratories (EARSeL) held their 10th annual symposium in Toulouse, France. This organization, relatively little known in the U.S. remote-sensing community, sponsored a well-organized and technically impressive meeting. The symposium demonstrated how far the Europeans and their scientific associates from Asia and the developing countries have progressed in the last few years. This report will summarize the technical results of this meeting and plans of the broadly defined European Remote-Sensing Community, as reflected by the EARSeL participants in their presentations. Through informal discussions, a broad cross section of participants developed observations further. In this article, I will attempt to summarize technical aspects of the meeting potentially bearing on naval applications (see Table 1), and hopefully lend insight into an emerging source of remote-sensing technology, a field once belonging exclusively to the superpowers.

In the early 1970s, EARSeL was organized as a result of European interest in the U.S. Landsat program. The establishment of EARSeL was an attempt to coordinate research activities among former independently operating remote-sensing groups in Europe. The formal association was founded in 1976 by six European laboratories that recognized the potential of remote-sensing technology and set about to exploit them. Membership is open to "all groups or individuals having a professional interest in ... research and applications of remote-sensing techniques" nominally having a common link to the EC Council of Research Ministers, the European Community, or associated members of the European Space Agency (ESA). The membership categories include an observer status (nonvoting) which enables well-known, non-European laboratories; e.g., Environmental Research Institute of Michigan (ERIM) Ann Arbor, to participate and contribute. The EARSeL presently consists of 240 members and 10 observer laboratories, who have recently approved an ambitious multiyear program in preparation for the International Space Year 1992. Funding realities will likely temper the scope of the plan, but the momentum and enthusiasm displayed should see much of it accomplished.

The conference had 167 preregistrants, only three of whom represented the U.S. and of these, two represented ONREUR; the other represented a university remote-sensing center. Of interest was the participation of scientists from Eastern European countries who, surprisingly to many, have been actively carrying out remote-sensing programs since the mid 1970s. Other non-European participants were from Canada (3) and Japan (1). Several participants, while not preregistered, were from underdeveloped countries. Attendance throughout the individual sessions averaged 50-60, suggesting that a significant number of those preregistered either did not actually attend or only stayed for part of the symposium.

The ESA will direct European programs in space and cooperate with other space-capable nations such as Japan and the U.S. G. Duchossois, ESA, described some of the major programs, including:

- Earth Resources Satellite ERS-1, probably a Spring 1991 launch, carrying both optical and SAR sensors and is stereo capable. This satellite has an expected 3-year life, which will carry into ERS-2. Funds for ERS-2 are still being negotiated, but approval is expected and a 1994 launch is anticipated. There have been 200 principal investigators selected to evaluate ERS-1 data, and ESA must decide how much of this data will be given away at the expense of future commercial markets.

Table 1. Summary of Naval Applications, EARSeL/CNES Symposium

Naval Applications	Source	Sensor/Technique	Comments
Coastal Mapping Port facilities Logistics mapping	K.J. Murray, Ordnance Survey, U.K.	Stereo SPOT Imagery	Stereoscopic high-resolution (10m) SPOT imagery can often replace aerial photos for coastal mapping at small scales (to 1:100,000). Techniques are being developed to automate mapping from SPOT.
Sea Surface Imaging	L. Krul, Delft University of Technology	DUTSCAT - multiband airborne scatterometer	Airborne measurement of radar backscatter used to simulate images useful for calibrating spaceborne imaging radars.
Measurement of Directional Ocean Wave Spectra	D. Hauser et al., CNES/CNET	Airborne FM-CW C-band radar "RESSAC"	ERS-1 will carry advanced C-band SAR to observe ocean wave fields on a global basis. Airborne C-band radar-RESSAC-will be used in the ERS-1 wind/wave validation experiments (90-91) to measure the modulation of the backscattering cross section caused by geometrical tilting, 2-D ocean wave spectra as a function of wavelength and propagation direction. Wind and buoy data will be used for "sea truth."
Detailed Imaging of Sea Surface	R. Horn, DLR	E-SAR experimental airborne SAR	Very high-resolution SAR operates at L, C, and X-band frequencies on a small, low-flying aircraft. Single look azimuth processor used for onboard real-time SAR processing.
Detailed Imaging of Sea Surface, Sea Ice, Oil-Slick Detection	N. Skou et al., Technical University of Denmark	C-band SAR & imaging radiometer	Airborne C-band SAR developed to provide underflight calibration for ERS-1 passes. 2m x 2m resolution. Imaging radiometer with 50m resolution is pallet mounted on a C-130, has been successfully used for sea ice measurement and classification and oil slick detection.
Sea Surface Imaging	P. Hoogeboom et al., FEL-TNO, the Hague	C-band Airborne SAR "Pharus"	Phased array universal SAR developed to image 7-km strip, forerunner to "Pharus" high resolution polarimetric system.
Improved SAR Processing, Oil-Spill Detection	A. Moreira, DLR	E-SAR (see Horn)	On board, low-resolution (10 x 25 m), quick look SAR processor developed to monitor oil spills at sea in real time. High-resolution (3M), real-time, multi-look SAR processor under development at DLR.
Measurement of Sea Ice, Snow Cover	M. Hallikainen et al., Helsinki University of Technology	Helicoptor-borne scatterometer, radiometer and radar polarmeter Airborne SLAR	Instruments used to measure sea ice and snow thickness; 30-m airborne SLAR (side looking airborne radar) under construction.
Measurement of Marine Environment, Ocean Color	B. Sturm et al., JRC, Ispra	Nimbus-7 Coastal Zone Color Scanner	Proposal to catalog worldwide CZCS data to establish global ocean color database.
Water Quality	G. Ferrari and S. Tassan, JRC, Ispra	Combined beam transmission, induced flourescence *in situ* measurements, submerged spectrometer.	Measurements of yellow substance absorption were used to contour water quality/pollution maps in the Gulf of Naples. Important parameters included chlorophyll concentration and sediment load.
Global Earth Observations, Estuary/Ocean Boundary Definition	A. Goetz, University of Colorado	High-resolution imaging spectrometer (HIRIS)	HIRIS contains 192 narrow spectral bands from .4 to 2.5 nm with 30-m spatial resolution to be part of late 90's earth observing systems payload.
Oceanographic Data Collection	J. Bodechtel and S. Sommer, University of Munich	Fluorescence Line Imager, GER 63 Channel Multi-Spectral Scanner	Airborne sensors were flown over oceanographic test sites in the North Sea and Venice Lagoon to collect airborne and sea truth data to identify and model ideal combinations of spectral bands for oceanographic applications. Part of European Imaging Spectroscopy Aircraft Campaign (EISAC).
Sea Surface Temperature Measurement	M. Al-Tace and A.P. Cracknell, University of Dundee	NOAA-7 AVHRR	Multilook approach used to select atmospheric corrections to AVHRR sea surface temperature data.
Weather Forecasting, Global Weather Modeling	D. Vangasse, British AeroSpace	Advanced Microwave Sounding Unit (AMSU-B)	5-channel microwave radiometer used to collect temperature and humidity data from different layers within the atmosphere.
Ocean Current Monitoring	K. Wakker et al., Delft University of Technology	GEOSAT Altimeter	GEOSAT altimeter data compared to sea surface measurements from Seasat altimeter to measure relative dynamic topography and large-scale eddies.

- Meteosat-4, Europe's first operational weather satellite, is operated by EUMETSAT, a European consortium established to commercialize Meteosat data. Morning and evening weather broadcasts are available from geostationary orbit to commercial subscribers.
- Polar Orbiting Earth Observation Mission (POEMS) will be flown in 1997 as part of ESA's Columbus platform. This satellite is part of a cooperative program with National Aeronautics and Space Administrtion (NASA) and Japan to create a comprehensive global earth observation system, and will be twice as large as the current Landsat/SPOT generation of earth-observing platforms.

Technical Presentations

The majority of the sessions emphasized land applications, global studies, and technology development, loosely arranged into eight half-day sessions. I will provide brief descriptions of each session.

Applications in Agriculture

An area of critical importance to developing countries, this session covered advances in crop monitoring and identification, yield estimates, biomass assessment, and disease detection. Techniques presented were fairly noninnovative, emphasizing the computer-based geographic information system (GIS). This approach uses the synergistic effect of multiple registered data sets to solve whatever resource assessment, detection, or monitoring problem is at hand. Some of these data-merging techniques could have marine applications in oceanographic or weather prediction efforts.

Cartographic Applications of Earth Observation Test System Imagery

A technically strong session demonstrating successes to date and innovative approaches to utilizing data from what has become Europe's (if not the world's) most advanced and widely used commercial satellite system. Earth Observation Test System (SPOT)-1 has flown since 1986, followed by SPOT-2 in 1989. These satellites are rapidly surpassing NASA's Landsat program in commercial acceptance and widespread practical impact. The SPOT Image, the commercial marketing arm of the organization, put on a major effort, both in the technical sessions and in the exhibit halls (SPOT Image headquarters is in Toulouse). This is a clear attempt to impress the Eastern European, Asian, and developing country markets represented at this conference. The SPOT Image announced several advanced products and services (timed closely to an across-the-board price increase) aimed at both the novice and sophisticated user. As another phase of their marketing strategy, SPOT has undertaken a major training effort aimed at educating teachers and scientists from developing countries, seen as a major but largely untapped market for their products. Topics in this session included automated terrain extraction, innovative three-dimensional modeling and classification techniques, stereo manipulation, and "geocoding," by which a standard SPOT satellite image can be digitally registered to virtually any selected map projection or X-Y coordinate data set. As part of an aggressive marketing strategy, SPOT Image announced an ambitious "Global Topography Project," undoubtedly planned to take advantage of the "global change" interests. The aim is to map the earth's land surface in stereo geocoded (precisely registered) imagery, which can be delivered in digital or hard copy image format. This effort would cost nearly $.5 billion and take 8 years to complete, a task probably beyond the budgets of most members.

European Intermediate Platforms and Sensors

This session concentrated on airborne microwave sensors, with applications ranging from measuring directional ocean wave spectra, to mapping soil moisture and crop types based on their unique spectral and textural characteristics. Innovative approaches included multifrequency radars that can be registered and processed much like multispectral images. These approaches combine the radiometric advantages of discrete radar wavelength bands into a single image display. They can be color coded and filtered to produce an enhanced radar digital image.

The German Aerospace Research Establishment (DLR) described their synthetic aperture radar (E-SAR) system, which combines L, C, and X-band SAR into a system designed to operate on board a low flying aircraft. Of further interest was DLR's development of a high resolution, real time, multilook processor which displays the SAR image on a cathode ray tube (CRT) monitor as it is being acquired. The display can be downlinked to a groundstation or stored onboard for further, more sophisticated processing after the mission. These efforts are preparation for the early 1991 launch of ESA's first earth resources satellite--ERS-1.

Potentially interesting to marine operations is a C-band phased array SAR sensor developed in the Netherlands by the Central Organization for Applied Scientific Research (TNO) Physics and Electronics Laboratory, to be ready by 1994. This sensor will provide high-resolution imagery of the sea surface in coordination with ERS-1 overpasses.

Global Change

This topic has captured the imagination of the world community and as such is seen as a way to attract funds

for the required very large commitments. The session concludes that we can only make environmentally sound decisions if adequate knowledge exists on a global scale. Indeed, satellite remote sensing provides the most efficient way to collect this information. Several speakers proposed programs to collect comprehensive data over the earth's land surface, oceans, and atmosphere (including the highly publicized Antarctic ozone hole). The data can be collected using existing Landsat, SPOT, coastal zone color scanner (CZCS), the very high-resolution radiometer (AVHRR), and new, next-generation sensors slated for advanced earth observation platforms.

A minimum 200 x 200-km data grid was suggested as the minimum required to collect data for global models that could adequately predict both near- and long-term global change. Existing global databases are incomplete and record only very short intervals (weather satellites from the 1960s, earth resources satellites from the 1970s). Therefore, events that appear potentially catastrophic; e.g., global warming or ozone depletion may actually represent parts of long-term natural cycles that have not been inadequately measured. While everyone agreed that global monitoring (as part of the green movement) is a worthy goal, the massive costs associated with the enormous data collection, digital processing, data distribution, and archiving efforts have found no clear sponsor. Funds will become more likely if the developed countries capable of making the required commitments become convinced that their standard of living is jeopardized through some proven degeneration in natural systems. This proof may already have been presented at the conference in papers. For example, some papers described regional eradication of Amazonian rain forests, acid rain, increasingly barren deserts in Northern Africa, and the progressive degeneration of large natural water bodies.

Imaging Spectroscopy

This session described a new generation of imaging spectrometers useful for ground, airborne, or satellite measurements. Dr. A.F.H. Goetz, Director, Center of the Study of Earth from Space, University of Colorado, Boulder, described the state of the art and future directions of the technology. Goetz provided a technical overview of a high-resolution imaging spectrometer (HIRIS) that will be part of the advanced American earth observation systems (EOS) program on the EOS-A platform. This instrument consists of 192 spectral channels distributed within the visible near- and mid-infrared parts of the electromagnetic spectrum. Hence, it will bridge the gap between *human* and *global* scales, to facilitate comparisons between single point and global measurements. Goetz provided an interesting illustration to emphasize the magnitude of the data-handling problem with HIRIS: if all 192 channels were operating simultaneous, the digital data stream generated would fill one standard 6250 bpi tape every second (obviously the instrument will not normally be operated in this mode).

Examples of applications presented at this session were mainly agricultural or land use (some geology) with little emphasis on marine or climatic studies.

Poster Sessions

There were 29 posters scheduled, but only about 70 percent were actually set up. Of those, only 6-8 were accompanied by the authors willing to discuss their work. Of potential naval interest were posters describing

- Advanced microwave sounding unit developed by British Aerospace
- Synthetic Aperture Radar processing facility at DLR (see *MASB* 45-86)
- Charged-coupled device airborne experimental scanner called *CAESAR* used for intermediate level spectral calibration
- Multilook technique for retrieving sea surface temperatures from very high-resolution radiometer data.

These are described in Table 1.

Other displays were oriented toward earth hazards, mineral exploration, and land-use activities.

General Observations and Summary Comments

While not oriented toward naval activities, this meeting lent insight into the goals of the European remote-sensing community and their rising confidence in this field. The French are among the leaders in the worldwide remote-sensing community through their highly successful SPOT program. They have provided both a focus and a source of funds and technical expertise which provides a model and encouragement for the less technologically advanced nations. This is not to ignore the significant but lesser contributions of others; e.g., U.K., Federal Republic of Germany (FRG), the Netherlands, and Scandinavia.

Disturbingly, there appears to be a real shift in momentum from U.S.-initiated, remote-sensing efforts to those suggested by foreign (especially European) nations. This is partially the result of a perceived lack of support and coordination from U.S. funding agencies and the rapid growth of expertise and facilities available to foreign remote-sensing scientists. Of the 9 or 10 remote-sensing satellites routinely providing data to the international user community, all but 2 (SPOTs 1 and 2) are American. While most of the presenters used data from these American sources, the role of the U.S. in

pioneering this technology was largely ignored. The contributions of American workers, or parallel research presently underway in the U.S., was acknowledged only in response to specific questions from the audience. Obviously, the U.S. is no longer considered to be the dominant leader in this field. Consequently, the situation is likely to worsen with the impending launch of the next generation of remote-sensing satellites in the mid nineties. No NASA representative was present at this symposium, and the U.S. remote-sensing community was only minimally represented.

The French and the Japanese have taken over the role of training remote-sensing specialists. They actively seek, fund, and train students in this field. In addition to the SPOT Image training programs mentioned before, GDTA (Association for the Development of Remote Sensing, Toulouse, France), one of several training operations, has trained nearly 1,000 students from over 60 countries. The Japanese have similarly ambitious programs, also recognizing the potential foreign relations and marketing benefits of the underdeveloped countries. The DLR is developing similar programs. Remote-sensing techniques stand to benefit most those countries that have little infrastructure, are poorly mapped, and have poorly developed agricultural or mineral resources. These countries are anxious to gain this expertise, and are able to do so through funds provided by the World Bank, the United Nations, and others.

There has been a significant growth in the number of international remote-sensing organizations founded within the last few years, usually with very little U.S. representation. These groups promote their own self-interests, organize broad-scoped meetings and conferences, and rely very little upon U.S.-based organizations like ERIM that have organized international remote-sensing symposia for many years. Organizations like EARSeL, the French Space Agency (CNES), and the Asian Remote-Sensing Society (heavily supported by the Japanese) feel that they are now able to conduct the business of international remote sensing with or without the participation of the U.S. The Japanese, in particular, announced that they expect to overtake U.S. efforts in remote-sensing research and development within the next 10 or 20 years, and have allocated a budget of 160 billion yen (over $1.5 billion) for space development for 1990 alone.

By the end of the 1990s, the present suite of (largely U.S.) remote-sensing satellites will be joined by sophisticated platforms from Canada, France, Japan, the ESA, and the Soviets. Each of these carries sensors that far exceed the capabilities of present systems and each will ompete for a share of the worldwide commercial market. The U.S. programs are underfunded and apparently have lost the national prestige associated with earlier space initiatives. In order to be competitive, the U.S. must recognize, as other nations do, the importance of a civilian presence in space. Also, it must revitalize the programs that now attract little monetary support.

There appears to be no clear sense of cooperation between European and U.S. space initiatives as reported at the conference. Often, lines of research appear to be conducted in parallel without an exchange of data or ideas, which could make the efforts of each more efficient. This cooperation exists, but is not advertised. The reason is probably the result of international rivalry, national pride, or the competition for funds or facilities. Even the superficial agreement on global issues and critical programs such as the ozone layer, global warming, or deforestation find wide agreement but little commitment to fund. Evidently, more pressing social issues and the task of national survival have a more urgent call on the budget.

Conclusions

The opinions expressed are those of the author based on limited exposure to very complicated issues. Apparently, the U.S. is rapidly losing its leadership in the remote-sensing arena as indicated by the level of technical expertise and initiative demonstrated at this meeting. The U.S. organizations involved in remote sensing should realize the rapid advances being made by other groups. Consequently, the results of these efforts are often not published in the general remote-sensing literature. The EARSeL and similar groups will play an increasingly larger role in the development of this important technology which cannot be ignored.

References

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NEWS, NOTES, AND ABSTRACTS

Future Trends In Computing

by Miroslaw Malek

This report is a slightly modified excerpt from an article by Geoff Manning which recently appeared in JFIT News, No. 16, September 1990. The JFIT News is the official newsletter of Joint Framework for Information Technology, and is published by the Institution of Electrical Engineers, a British equivalent of IEEE. The Joint Framework for Information Technology is a collaborative effort between the Department of Trade and Industry and the Science and Engineering Research Council in the U.K.

Geoff Manning, who has been a physicist for 40 years, a computer user for 35 years, and a businessman at Active Memory Technology for the last 4 years, has the following observations on future trends in computing:

- Future high-performance computer systems will use large numbers of processors (up to a million can be seriously contemplated) working efficiently on a single problem.
- Development of state-of-the art computer hardware is dominated by two technologies--VLSI and packaging. (I also believe that the feasibility of wafer-scale integration technologies for massively parallel systems will be demonstrated in this decade.)
- VLSI's great strength is the replication of simple units in large numbers at low cost and high reliability.
- Packaging developments will decrease the volume of computer systems by one or two orders of magnitude. Progress in multichip module packaging and CMOS technologies will soon result in the following remarkable figures: 30 MFLOPS per cubic inch or 2 GFLOPS per liter, 7 MFLOPS per watt, $350 per MFLOP (32 bit), $10 per MIP (8 bit) (the last figure is already lower according to my estimates).
- A high range of tasks needs the highest possible compute power, but the systems used must be deployable and affordable.
- Most compute-intensive problems are inherently parallel, and a large subset is data parallel.
- Dominant problem in the use of parallel systems is the production of software; ease of use will determine which systems sell. (I might add a modifier: production of reliable software.)
- Development of algorithms and application techniques for parallel systems is a crucial research task. We must undo 35 years of forcing parallel problems onto serial hardware.
- Future general-purpose computer systems will be heteroarchitectures with specialist units for different tasks.

I tend to agree with most of Manning's statements and might add that correctness and precision in a GFLOP environment will become a challenge. Also, parallel computers will continue to be multi-purpose rather than general purpose systems. Though many of his points represent current conventional wisdom, I think it is useful to recapitulate and ponder over even the simplest of truths.

In a nutshell, hardware will progress and technology-driven advances will continue. The world needs a breakthrough in software. Some credible efforts are underway.

ADA Returns to France on Ariane-5

by Robert D. Ryan

When Ariane-5 flies in 1995, it will be under the control of software written in ADA. The Centre National d'Etudes Spatiales (CNES), manager of the Ariane-5 project for the European Space Agency (ESA), has chosen ADA as the language to develop the software for the future European launcher.

The CNES has ordered several ADA development tools from Alsys, an international French company with headquarters in Versailles. This order, which amounts to about 3 million francs (about $550,000), includes compilers for Vax and Microvax machines, as well as compilers targeted at computers based on the Motorola 68020 processor. With these tools, Matra Espace (France) will produce programs for testing the different stages of the Ariane-5 launch vehicle. They will also develop software for the launch control in Guyana and for the computers onboard the vehicle. These latter computers are based on the Motorola 68020. Matra Espace plans to use the specification tool, ASA, from Verilog (France) and the design tools, Hood and ADA Nice, from the Italian firm, Intecs.

ADA, which is perhaps best known as the language adopted by the U.S. Department of Defense (DOD) (and recently by NASA), was conceived in 1979 by a research team led by Jean Ichbiah, who is now president of Alsys. Alsys realized 100 million francs (about $18 million) in business with ADA in 1989. In this regard, the French firm's most important recent contracts are American. One involves the development of the U.S. Army's Command and Control System, and another is to supply compilers for software development for NASA's space station Freedom.

The CNES selected ADA in part because of DOD's efforts toward standardization, which facilitates the design, development, and maintenance of the resulting software, with emphasis on the latter. Another consideration was that ADA allows modular program development. Alain Savary, of the electrical systems department, CNES, indicated that the durability of the language based on long experience was one of the fundamental criteria for the choice of ADA.

Two sites have been established for the Ariane-5 development--at Toulouse and at Charleroi. The final assembly will be done at Aerospatiale's Mureaux location near Paris and at the launch site in Guyana.

The use of ADA for the Ariane-5 program represents a new direction in software for the European space program.

Philip Hughes Stepping Down as Chairman of Logica

by Robert D. Ryan

In November 1990, Philip Hughes stepped down as the chairman of Logica, the successful British software house he cofounded in 1969. In a recent interview with *The Independent* (London), he made some observations and predictions about the software industry.

He warned that Japan may soon become the main world player in computer software, as it has come to dominate the hardware business. He argued that Japan is well placed to succeed and that this would be a logical and consistent step. Regarding the idea that Japan may be good at producing hardware but lacked the creativity to write good software, he said, "The Western world fools itself if it says that. We have a lot to learn from them. Japan is the nation that has developed the idea of rigorous quality and quality control in an engineering environment, which is exactly what software now needs."

Mr. Hughes believes that software and systems will soon dominate the computing business. The big hardware producers are dominant now, but software will be the driving force in the next century, as the open systems movement advances and hardware becomes more standard.

Looking at the history of software in the U.K., Mr. Hughes spoke of the "golden era when the government thought the software industry was important." The Labor government's efforts in the 1970s to stimulate U.K. software exports was a failure, but the National Enterprise Board's investment in software companies was critical. Then the Alvey program under the Tories stimulated software engineering and other information technology research. (Mr. Hughes was a member of the Alvey committee which recommended the program and was responsible for drafting the software engineering proposals.)

Mr. Hughes noted that the Alvey program required interaction between the government and the software industry, which was valuable to the industry and the nation. He said, "Now there is no real interaction between the government and the industry." He argued that even more important than interaction on research is the interaction on projects, particularly in key infrastructure areas such as transport, communications, and energy. He is quoted in *The Independent* as saying, "The software industry in the U.K. finds itself at a testing moment because there are so few big infrastructure projects, in comparison with France, for example. I worry when I visit France and see what is going on there." Mr. Hughes was referring to the fact that France expects to have, by the end of this year, a complete integrated systems digital network in operation. Every telephone subscriber will have access, via the telephone lines, to on-line computer communications, fast FAX and telex transmissions, all transmitted over digital routes. Britain is still stuck in the era of analogue copper telephone cables installed in the 1930s and 1940s, which are fine for voice communication but are not suitable for high-speed digital data transmission.

I find a couple of things interesting about this interview. First, I should mention for U.S. readers that Philip Hughes is probably as well known in Britain as an artist as he is for being a hero of the British software industry. In fact, at 54, he has decided to devote full time to his art, working in London and in southern France.

Regarding his comments about the possibility of Japan becoming a major software power, I have seen this idea expressed at least twice in the British press. Concerning the government's involvement in software, it is true that the direct support for computer science research is less than during Alvey, and there may not be large government-funded projects to boost activity in the software houses, but the government is still very much involved in software. For example, the Ministry of Defence in its Interim Defence Standard 00-55, advocates the use of formal methods in the development of software for safety-critical systems. This is influencing how military software is built. The recent government initiative to support research in safety-critical systems will

also tend to keep a focus on formal methods for software development. This is a 4-year, £27 million program with £13 million coming from the government. The decrease in direct government funding for computer science is, in part at least, balanced by research support from the European Community under European Strategic Programme for Research and Development in Information Technologies.

Finally, the telecommunications example cited, is yet one more example of the British unwillingness--perhaps inability--to make investments in the infrastructure. As another often-noted example, the British government decided not to fund a high-speed rail link from the Channel tunnel to London. This was announced the same day the French announced the decision to make large new investments in their rail system, which already contends as one of the best in Europe.

Second International Congress of Neuroendocrinology

by Louis D. Van de Kar, Ph.D., Associate Professor of Pharmacology, Stritch School of Medicine, Loyola University, Chicago, Illinois.

Introduction

The International Society for Neuroendocrinology (Society) held its second meeting in Bordeaux, France, June 24-29, 1990. The Society held its first international congress in San Francisco, California, in 1986. The Society was founded in 1972 and meets every 4 years. The goal is to promote the development of research in basic and clinical neuroendocrinology and to disseminate information in neuroendocrinology and related fields.

The meeting consisted of 2 honorary lectures, 4 plenary lectures, and 64 symposium lectures which were grouped in 16 symposia. There were 532 poster presentations.

Plenary Lectures

Nerve Growth Factor: From Molecule to Memory, E.M. Shooter, Stanford University. Nerve growth factor (NGF) is a protein that regulates cell death in peripheral sympathetic and sensory neurons during development. The underlying and controlling physiological process is the establishment of a retrograde flow of NGF from the target fields of these neurons, across their nerve terminals, up their axons to the cell bodies. Those neurons, which in development establish this now, are the ones that survive, those that fail to do so, die. Once established, the retrograde flow must continue for the lifetime of the neuron to regulate the developing and maintaining its differentiated functioning state. The ability of NGF to up-regulate its own receptor adds and increased level of sensitivity to the ability of NGF to rescue responsive neurons after injury.

The Role of Calcium in Intracellular Signaling in the Central Nervous System, M.B. Kennedy, Division of Biology, California Institute of Technology, Pasadena. The calcium ion is an important second messenger in most cells. The basal concentration is tightly regulated through the action of pumps that sequester it into intracellular compartments or move it out of the cell. The concentration can be increased, locally and transiently, by several mechanisms. In neurons, a relatively rapid influx of calcium can be produced by opening of voltage- or ligand-gated calcium channels. In addition, slower increases in concentration can occur when inositol triphosphate is produced by hydrolysis of phosphatidylinositol bisphosphate. Inositol triphosphate releases calcium from intracellular stores through its action on a specific intracellular membrane receptor. A large number of neurotransmitters and neurohormones cause depolarization, activate receptors that open a calcium channel, or activate receptors that are linked to the production of inositol triphosphate. For all of these agents, the calcium ion may be a significant second messenger. In a particular neuron, the local response to an increase in calcium ions will depend on the arrangement of calcium-responsive proteins at the site of the calcium transient. Several classes of calcium-responsive proteins have been identified. In the brain, they include calpain (a calcium-sensitive protease), calcineurin (a calcium-activated protein phosphatase), calcium-activated lipases (the C-kinase), and three calcium/calmodulin-dependent protein kinases.

Steroid Control of Neuronal Interactions and Function, G. Fink, R. Rosie, E. Thomson, and H. Wilson, University Department of Pharmacology, Edinburgh, Scotland. The action of steroids on the brain can be categorized as (1) fast (msec-sec), (2) intermediate (hours), (3) long-term reversible (weeks-months), and (4) long-term irreversible. Categories (1) and (4) are exemplified, respectively, by steroid-induced anaesthesia and steroid-induced sexual differentiation of the brain. Attention was focused on molecular biological studies of category (2) which is exemplified by the positive feedback effect of estrogen on the hypothalamic pituitary gonadotropin and prolactin systems. Also, attention was given to category (3) which is exemplified by sex steroid control of arginine vasopressin biosynthesis in neurons of the bed nucleus of the stria terminalis. Possible ways were discussed in which steroids affect membrane activity, determine neural connectivity, and modulate neuropeptide biosynthesis and release.

Diversity in the Gene Expression of Neuropeptides, M. Chretien, Clinical Research Institute of Montreal, Canada. There are many possible peptides that can be generated from the cleavage of a precursor molecule. There is a need to be able to predict which of these amino-acid chains are realistic products. The characterization of the cleavage enzymatic system that is responsible is important and will be a subject for future research.

Symposia

Molecular biological and developmental aspects of neuroendocrine research were heavily emphasized in this meeting. This is in keeping with the general trend that is currently sweeping pharmacological and neuroendocrine research (see Table 1).

Table 1. Symposia Topics

Development - growth factors
Hormones and adaptive behavior
Neuropeptides and the immune system
Comparative neuroendocrinology
Ionic channels and regulation of secretion
Hormones and reproductive behavior
Intracellular signalling
Neuroendocrinology and biological rhythms
Hormonal control of neuroendocrine gene expression
Neuroendocrinology of growth
Cell to cell communication
Aging
Neuropeptides from genes to pathology
Gene expression of neuroendocrine receptors
Transcription factors, oncogenes and neuroendocrine gene promoters
Recent advances on pituitary tumors.

Poster Sessions

Clearly, the poster sessions had a better balance of subjects (see Table 2). Perhaps the session on neurotransmitters and neuropeptides should have been divided into two separate sessions to facilitate and assimilate the information.

Comments

This meeting was well organized and was conducted in a very good atmosphere. The symposium rooms and poster sessions were easy to reach and there was little conflict in choice between sessions. The informal parts; i.e., opening party, beach party, and official dinner, were very well planned and executed, and were very pleasant. The next meeting of the Society will be held in Budapest, Hungary, in 1994.

Workshop on Applications of Quantum-Coupled Devices to Cellular Automata

by Dean L. Mitchell, formerly the Liaison Scientist for Solid-State Physics in Europe and the Middle East for the Office of Naval Research European Office.

Introduction

The workshop on Cellular Automata/Quantum-Coupled Devices was held June 7-8, 1990, at the Office of Naval Research European Office (ONREUR) in London. The intent of the workshop was to initiate a dialogue between scientists who are working on new architectures and modes for parallel computation using cellular automata, and their counterparts in the physics community interested in basic studies of the two-dimensional electron gas, laterally confined to form quantum-dot arrays, and other quantum-coupled devices.

Table 2. Posters

Topics	Posters per Session
Regulation of ACTH	27
Integrative neuroendocrinology	25
Comparative neuroendocrinology	18
Peripheral neuroendocrinology	15
Psycho-neuroendocrinology	19
Hormones and behavior	28
Neurotransmitters and neuropeptides	72
Regulation of LH/FSH and TSH	39
Pineal gland	14
Hormone rhythmicity	12
Expression and processing of neuroendocrine peptides	24
Posterior pituitary hormones	23
Regulation of GH	35
Mechanism of action of neuropeptides	21
Development and aging	29
Clinical neuroendocrinology	21
Pituitary adenomas	20
Molecular neuroendocrinology	33
Regulation of Prolactin	26
Actions of hypothalamic hormones	17

To simplify the discussion, the scope was limited to exploring the potential for nanoscale, quantum-coupled device arrays for application in computational cellular automata. Applications to other parallel computational networks, such as neural networks, were covered in some of the introductory talks but were excluded from the in-depth discussions. The result of the discussions was to identify directions for future research and likely areas for cross-disciplinary interaction.

The workshop was organized by D. Mitchell, ONREUR, and L. Cooper, Office of Naval Research, Arlington, Virginia. D. Ferry, Arizona State University, Tempe, and A. Ogielski, Bell Communication Laboratories, Red Bank, New Jersey, assisted on program content, participants, and travel arrangements. Attendance at the workshop was limited to 20 participants to allow everyone to be actively involved in the presentations and discussions. The participants included:

- United Kingdom - J. Barker and L. Eaves
- the Netherlands - B. van Wees and L. Geerligs
- Federal Republic of Germany - E. Gornik, J. Kotthaus, D. Heitmann, and G. Mahler
- U.S. - R. Bate, L. Biafore, D. Ferry, G. Frazier, B. Hasslacher, T. McGill, N. Margolus, M. Reed, T. Toffoli, and H. Wittmann.

The presentations and discussions during the workshop were lively and, at times, spirited. In part, this was because of the different languages and approaches used by the two disciplines. A significant success was that at the end of the 2 days there were several one-on-one sessions between the condensed matter experimentalists and the computational theorists with on-going collaborations a likely result.

Workshop Summary

Workshop participants prepared a summary of the workshop following the 2 days of presentations and discussions:

The purpose of the workshop was to bring together a select group of physicists and computer scientists to discuss methods of domesticating quantum dots for computational purposes. There are a variety of ways of constructing, with modern lithography, two-dimensional arrays of these quantum dots, in which the individual dots can range from simple quantum wells to sophisticated resonant tunneling devices. In each case, the arrays to date have been limited to two dimensions, or planar technology. Cellular automata provide a computing paradigm where uniform arrays with local interconnections can be made to yield general-purpose computation in a reasonably compact way.

One of the main technological challenges is that we are abandoning the security of the law of large numbers (say 1,000,000 electrons per bit) and we are not yet capable of controlling fabrication at the level of one or a few atoms. As a consequence, structures today are being made in the so-called mesoscopic regime and future fabrication technology must traverse a high dispersion regime, in which fluctuations in device parameters are bound to affect architectural policies significantly.

Cellular automata provide a variety of different schemes, some of which may be suitable for certain implementations of quantum dot arrays. However, insufficient cross-fertilization of the two fields has occurred to date for any significant recognition of the prospective applications or the proper routes to technological development of systems. Consequently, it is not clear whether the most promising routes are those yielding general-purpose architectures or alternatives oriented at special purpose, massive computation engines for more unique applications.

On the other hand, both disciplines seem to be sufficiently mature and to offer a significantly wide range of concepts and tools so that a match between some concepts and tolls of the two seem feasible. This was brought forth from the many remarks and the discussions. The workshop was successful in achieving cross-fertilization between the two fields. Many promising routes for future research were discussed, and several significant issues were identified. In addition, valuable contacts between various individuals and laboratories were established.

Major Issues

- If this field is to reach fruition, development of device and architectural concepts cannot continue separately, and these concepts must be merged in future work.
- Several possible modes of storage in quantum dots have been demonstrated, but modes of inter-dot coupling are still in a very primitive stage. Clearly, significant development work in this latter area is necessary, guided by the requirements of a target architecture.
- While massive throughput in quantum dot arrays seems possible, the issue of massive input/output has barely been touched. On the other hand, since many useful computations require only a modest amount of input/output, it is not vital to solve this question at once. Rather, it is possible that schemes in which information is fed from the boundaries may be quite useful and are more readily implementable in the near term.
- Most current efforts in the study of quantum dots have focused on near-equilibrium properties to reach a basic understanding; e.g., low temperatures and small applied potentials. For more realistic computational usage, these structures will need to be used in a far-from-equilibrium mode, at high temperatures. This means that considerable work must be done to understand the properties of these arrays under these conditions.

- Present studies of quantum dots have centered on material systems in which the quantum effects are more easily seen. It is unclear whether these materials are suitable to volume production of quantum dot computational arrays operating at room temperature. More understanding of the materials properties required is needed.
- Nanostructure technology must also be advanced, so size scales may be reduced to achieve quantum confinement energies suitable for room-temperature operation.
- Cross-fertilization between computational science and quantum do physics, begun with this workshop, needs to be continued.

For more information, contact Dean Mitchell, Mitchell Associates, PO Box 2337, Reston, Virginia 22090, or Larry Cooper, Office of the Chief of Naval Research, 800 North Quincy Street, Arlington, Virginia 22217-5000.

THE EMBASSIES: TECHNOLOGY ROUNDUP

Federal Republic of Germany

For further information on FRG items, contact Mr. Edward M. Malloy, Science Conselor, American Embassy, Bonn, APO New York 09080-7400.

Agreement on Soviet-German Space Cooperation

The Federal Republic of Germany (FRG) and the U.S.S.R. have signed an agreement confirming their planned 5-year space research cooperation program. The FRG Space Agency Deutsche Agentur Fuer Raumfahrt - Angelegenheiten (DARA) officials are currently in the U.S.S.R. discussing the scientific experiments expected to be performed on the joint mission. The only remaining question is which German astronaut is to participate in the 8-day flight scheduled for 1992.

An exchange of letters of confirmation between the President of the Academy of Sciences of the U.S.S.R., Professor Martschuk, and Federal Minister of Research and Technology, Heinz Riesenhuber, has confirmed the agreement on October 1988 on scientific and technological cooperation in space research. The agreement is expected to be in effect until 1995. This first Soviet-German space cooperation venture is considered by both sides to be a step toward joint utilization of resources, capabilities, and experiences. Both parties hope that the agreement will lead to a new level of international cooperation in the fields of manned space flight, extraterrestrial research, and earth research from space.

Most important is that for the first time a German astronaut can participate in an 8-day space flight to the Soviet manned space station scheduled for 1992. In May 1990, the German Aerospace Research Establishment concluded negotiations with the Soviet firms responsible for commercialization of Soviet space technology, "Licensintorg" and "Energia," with regard to German participation in the Soviet space flight. Presently, five German astronauts are acquainting themselves with the Soviet Gagarin Kosmonaut Training Center facilities near Moscow. Within the next 2 months, DLR is expected to announce which of the five FRG astronauts will participate in the mission.

A delegation from the DARA is presently visiting the Gagarin Kosmonaut Training Center to discuss the scientific experiments scheduled for the mission. The German experimental payload is limited to 100 kg, with life science research being given priority. Mission medical experiments will observe changes in blood circulation and biological rhythms in microgravity conditions.

Extraterrestrial research will include follow-up projects of scientific cooperation among the German Research Society (Deutsche Forschungsgemeinschaft [DFG]), various institutes of the Max-Planck-Society (Max-Planck-Gesellschaft [MGP]), and the Soviet Academy of Sciences. Previous cooperation has proven successful in joint research on Halley's comet and on high-energy x-ray experiments on the Soviet MIR Space Station.

In the future, research will pay special attention to solar-terrestrial correlations, the planetary system, comets, astronomy, and astrophysics. Joint experiments in the field of atmospheric research and earth observation from space, as well as a joint high-altitude rocket research program will increase significantly. Supplementary microgravity research, as well as research in the fields of space biology and space medicine are also planned. This will involve extensive information exchanges of the biological effects of space on both humans and plants.

FRG Promotes MITTELSTAND Through Technology Policy

Daimler-Benz, Hoechst, Bayer, Siemens, and Thyssen--these firms and others are bywords for German industry and prosperity worldwide. However, it is the MITTELSTAND, the German term used to describe its small- and medium-sized companies, that is credited by most experts as having been the driving force behind the postwar "Wirtschaftswunder" or economic miracle. Keeping this class of firms competitive is seen in the Federal Republic of Germany (FRG) as a major policy goal. The strength of these firms is their size. They are close to their customers and they can be flexible enough to respond quickly to market changes. This very advantage, though, can be a disadvantage when it comes to financing the research and development (R&D) costs involved in much of today's increasingly complex and sophisticated technology.

According to Federal Ministry of Research and Technology (BMFT) statistics, small- and medium-sized companies provide about two-thirds of all jobs in the private sector, or about 12 million jobs. They offer more than 80 percent of all training positions resulting in places for roughly 1.4 million trainees. These companies produce about one half of the gross national product and account for nearly 40 percent of gross investment. Given the importance of this sector, the government feels that it cannot afford to let its competitiveness deteriorate.

Small- and medium-sized firms pay a particularly large proportion of their income on R&D. Yet, for this large proportion, they are likely to get less for their money as the total sums that they can spend are comparatively small. In fields where development is either slow or expensive, R&D costs are prohibitive.

Government Support

A recurring theme in many of the BMFT's statements and literature is the idea that the FRG is being outspent in terms of government-supported R&D by both the U.S. and Japan. A recent BMFT paper explains: "In Japan, for instance, the expenditures on R&D, most of which are carried out by industry itself, are more than twice that of the FRG and in the U.S. (including a very high proportion of military research expenditure by the government) more than five times as high as the FRG."

The government funding of R&D is based on the principle of "help for self-help." As only about one-third of all research projects lead to commercial successes, many small firms, and their banks, prefer not to take the risk of financing R&D projects. In light of this, the Federal government has tried to create a general financial climate favorable to research investment by small- and medium-sized firms. Perhaps more importantly, the government ha also created several programs designed to stimulate R&D in this sector.

To create a suitable climate for R&D investment, the three-stage tax reform of 1986-88-90 will lead to a net tax relief of DM 49 billion. The reform also includes more favorable provisions regarding the depreciation of industrial buildings. According to the government, these lower taxes make exemptions superfluous. This reform is expected to increase the scope of activity and freedom of action for many of the firms in the MITTELSTAND sector.

In-Plant Technology Development

One of the most important aspects of the program is the BMFT's support of in-plant technology development. This is accomplished by several different methods. For example, the BMFT supports various individual projects. Financial support is offered for R&D projects and concentrates on production engineering, information technology, materials research, biotechnology, environmental technology, and physical science/laser technology. Another method of supporting projects concentrates on collaborative research in which several companies and research institutes work together. The advantage of the system is that it can make better use of scarce research resources through economies of scale. It is also meant to ensure better cooperation between industry and academia, long thought to be a weakness in the German system. Although cooperation between several firms in the same field on the same project would seem to stifle rather than promote competition, the BMFT claims that "this approach to funding has a broad effect and is essentially neutral in terms of competition."

Specific support for small firms will be carried out in three ways. First on larger, technologically-advanced projects, smaller firms ar to act as subcontractors whenever possible. Small firms have played, and will continue to play, an important role in the German portion of the airbus program, as well as in space research projects like Columbus.

Second, there will be indirect specific funding for promotion R&D projects in certain sectors of technology that are considered important from an overall economic point of view. Fields considered most important are microperipherals, biotechnology, and computer-integrated manufacturing.

Finally, the BMFT supports the formation of new technology-oriented companies. The BMFT-sponsored pilot project Formation of Technology-Oriented Enterprises indicated that "private venture capital investors do not yet participate to a sufficient extent in the financing of newly established companies. This applies in particular to the R&D phase during which the risk is high, consultancy and management services are particularly costly, and no income can yet be expected."

Venture capital companies usually prefer to commit themselves to young companies only after market introduction.

In order to promote the creation of new high-technology companies, the BMFT, along with the Economics Ministry, seeks to facilitate the exchange of information and technology between the academic sector and the industrial sector as well as between smaller companies. This is done by developing information centers, usually centered at universities or research institutes that specialize in a given field, as well as by the exchange of technical information.

To facilitate and increase the cooperation between small firms and universities, the BMFT will also, for example, provide a subsidy to a firm that sends a junior scientist to a research establishment for a 3-year maximum. The purpose is to make such exchanges more attractive and to quicken the transfer of know-how between the often sequestered worlds of academia and business. Thus far, most of the exchanges have occurred in automated manufacturing, biotechnology, data processing, sensory analysis, and materials science.

Federal Republic of Germany Funds Clean Coal Technology

Background

Fossil energies have been and will continue to be the primary source of energy for the Federal Republic of Germany (FRG). Recognizing that, the federal government has continuously and intensively funded research and development (R&D) projects relating to fossil energy utilization. Given the abundance of Germany's coal resources, priority in these government initiatives has been given to the promotion of clean coal technology.

A total of DM 5.0 billion ($2.85 billion) has been allocated for the FRG's Third Energy Research Program over the next 4 years. Since the first governmental energy R&D program was launched, considerable advances have been made in German coal technology. New mining technologies have resulted in higher shift outputs and thus in constant production costs despite general increasing labor and equipment costs and less favorable mining conditions. The development of coal liquefaction and gasification technologies has reached the stage of large-scale industrial applicability, although the present energy prices in the world market do not yet allow their economic utilization.

The main objective of the R&D priority project promoting fossil energy technologies is the development of environmentally sound combustion technologies, especially for new large coal-, gas-, and oil-fired powerplants. Such technologies will be required to meet environmental protection requirements from the very beginning of their design and construction phase.

Priority Projects

Approximately 150 clean coal technology projects have received and will continue to receive medium- and long-term funds through the research ministry's second and third energy research programs. Of these 150 projects, 105 have been carried out as single research projects at university institutes, large-scale national research centers, or by industrial firms. Major research areas covered by the third energy program are

- Conventional coal powerplant technology
- Advanced coal powerplant technologies
- Combustion technologies for industrial application and potential spinoffs to small consumers
- Coal liquefaction
- Coal gasification technologies
- R&D on esoteric fossil energy technology concepts.

Collaborative Joint Projects

Four projects, covering a broad spectrum of research activities in the field of advanced coal powerplant technologies, are currently underway and are referred to as Collaborative Joint Projects. These four collaborative joint research projects are:

- TECFLAM - two-phase, DM 30.5 million ($17.5 million) research project aiming to develop mathematical models for calculating stationary and mobile combustion processes and to develop laser measurement technologies
- Combined gas and steam coal powerplants - Combined gas/steam powerplant technologies focuses on pressurized fluidized-bed, pressurized coal gasification, and pressurized coal dust combustion technology
- High-temperature gas turbines - Subprojects dealing with: aerodynamic and thermal problems of charged turbine blades; development of compact pressurized and reduced-emission combustion chambers for gas and oil combustion; and the construction and test of HTGT components
- Pressurized coal gasification - Centers on practical application of powerplant technologies and promotes the development of a specific coal gasification process, the pressurized entrained-flow (PRENFLO) coal gasification process.

Basic Research on Combustion Processes

Advancements in laser measurement technology, as well as the availability of large computer capacities, have provided the means for precise research into the fundamentals of combustion processes. Optimizing such processes allows for the design of optimized burners and

combustion chambers. The TECFLAM project's focus on combustion processes is particularly important. Phase one, launched in 1984, and fully funded by the BMFT, resulted in a remarkable increase in knowledge about combustion processes and an improvement in laser measurement technology. Phase two, which commenced in 1988 with a greater share of private industry funding, focuses more on application-oriented projects.

Coal Powerplant Technologies

The R&D efforts in conventional coal powerplant technology concentrate on replacing coal powerplant stand-by capacities, on reducing emissions of nitrogen oxides and on developing catalytic processes. The stand-by capacity research focuses primarily on utilizing hydrogen/oxygen (H_2/O_2) immediate reserve facilities and a system of redundant heat exchangers to capture more of the potential energy of superheated steam.

By retrofitting existing powerplants with H_2/O_2 immediate reserve facilities, it is possible to eliminate the need for construction of additional powerplants simply to provide stand-by and peak-period capacity. Increased combustion efficiencies achieved through the installation of H_2/O_2-facilities would increase the power output of existing plants, thereby avoid construction of additional powerplant capacity, which will otherwise be required in the mid-90s. A study has confirmed the feasibility of constructing and retrofitting conventional powerplants with such facilities. Moreover, the technology is financially so attractive that it has gained the attention of some utility companies that have decided to test H_2/O_2 steam generators under actual powerplant conditions.

Combined Gas and Steam Turbine Coal Powerplants

In the future, priority will be given to the development of combined gas and steam turbine (G/S-T) coal powerplants. Presently, R&D initiatives are concentrating on two types of combined G/S-T coal powerplants:

- A combined G/S-T coal powerplant applying pressurized fluidized-bed combustion technology
- A combined G/S-T coal powerplant, based on coal gasification technology.

A third technology is under discussion for further development: a combined G/S-T coal powerplant based on pressurized coal dust combustion technology.

Such powerplants of advanced technologies have several advantages over conventional coal powerplants. The most important advantage of the combined G/S-T coal powerplants is that they produce electricity cheaper with fewer emissions than conventional coal powerplants equipped with flue gas purification facilities.

An essential prerequisite for raising the thermal efficiency ratio of future combined G/S-T coal powerplants applying coal gasification technology, is the technological enhancement of large stationary gas turbines. Such gas turbines must operate at high turbine entry temperatures. At present, stationary gas turbines have capacities of up to 140 MW (electrical) and turbine entry temperatures of about 1,150°C. R&D objectives, however, foresee turbines with capacities of 200 MW and entry temperatures of up to 1,250°. To reach these objectives, intensive R&D work is still required in the areas of development of new heat- and stress-resistant materials and development and construction of specific stress-charged turbine components, such as combustion chambers and turbine blades.

These R&D projects are carried out in the framework of the high-temperature gas turbine collaborative joint project in which about 20 industrial firms and university research institutes participate. The project is split into three subprojects: Turbotherm, Turboflam, and Turbotech. Turbotherm will be running through 1992 and aims to improve the cooling of hot gas turbine parts, as well as to extend the life endurance of turbine blades through utilizing new materials and improved production processes. The Turboflam and Turbotech projects were launched in 1988. They focus on developing reduced-emission combustion chambers, especially for coal gas combustion, and research on the reduction of flow losses from compressor and turbine blades.

Hot coal/gas purification is another prerequisite to commercial deployment of combined G/S-T coal powerplant technologies. In combined G/S-T coal powerplants, the removal of sulfur, dust, halogenes, and other pollutants from the hot coal gas is required. To date, hot coal/gas purification relies on cold washing technology, but hot and dry coal gas purification technology promises higher thermal efficiency ratios for powerplants and does not have the disadvantage of generating wastewater. Therefore, hot and dry coal/gas purification will be another subject of augmented research efforts in the future. Research activities in this field are focusing on developing filters consisting of high-temperature resistant fibers or ceramic materials.

Dual-Cycle Steam Process

In addition to the development of combined gas and steam turbine coal powerplant technologies, research is being conducted into the dual-cycle steam process. In this process, combustion energy is used to generate superheated (850°C) steam. In the first cycle, the steam passes through a potassium process that drives an electric generator. In the second (water/steam) cycle, the still overheated steam passes through a two-stage high- and low-pressure rankine working process to drive a second generator. The benefit of this technology is an essential

increase in the process efficiency ratio, compared to current power generation processes with minimal ash and flue gas generation. The potassium process, however, still suffers from severe material problems as well as problems of a technological and economic nature. Therefore, in addition to the normal pyrolytic processes based on low-temperature carbonization and coking, there are two other basic petrochemical conversion processes for generating liquid products from coal: direct hydration by the bergius-pier-process and goal gasification into carbon monozide and hydrogen followed by liquification into a hydrogen based liquid fuel. This process can produce gasoline and diesel fuel from synthetic coal gas via an intermediate production step of methanol. The catalysts required have been developed for fixed-bed and fluidized-bed technology. In addition, catalysts have been developed that are suitable for the direct conversion of synthetic gas into liquid hydrocarbon fuels. Pilot facilities will be constructed for continued research work on coprocessing, a technology of mixed hydration of coal and mineral oil tailings, or on multi-stage concepts of coal hydration. German companies are participating in certain selected international projects on coal liquefaction and coprocessing in the U.S. and in Great Britain, which have reached a promising stage of development and which provide improvements in chemical conversion processes. In the future, k hydration technology will be applied predominantly in heavy oil processing, waste oil reprocessing, and coprocessing.

Coal Gasification

The operation of two demonstration facilities, a synthetic g..s facility and a high-temperature Winkler facility, as well as of an iron-reduction facility, have successfully demonstrated the practical application of gasification technology. Because coal gas generating technologies are believed to be unable to progress further, current R&D efforts aim to apply these technologies to gas and steam turbine powerplants. For that purpose, two demonstration facilities, the PRENFLO facility of a capacity of 2 tons/hour, and a facility for partial gasification have started operation.

The pressurized entrained-flow (PRENFLO) coal gasification process is an entrained-flow process carried out under pressure at about 25 bar and high gasification temperatures of more than 2,000°C in the flame core and between 1,350 and 1,600°C at the gasification reactor outlet. The PRENFLO reactor is suitable for gasification of many kinds of dry fuels, including lignite, bituminous coal, anthracite, or petroleum coke with a carbon conversion rate of 98 percent, even with less reactive fuels. The PRENFLO gasification facility is linked to a combined gas and steam turbine power cycle in which the cleaned coal gas generated at the PRENFLO facility is burned in the combustion chambers of the stationary gas turbine. As a special feature of this process, the hot exhaust gases leaving the gas turbine combustion chambers are fed to a heat recovery steam generator to produce high-pressure steam for the steam turbine cycle. The combination of the PRENFLO coal gasification facility with the gas and steam turbine sets, which simultaneously generate electricity, is known as the integrated gasification combined cycle (IGCC) powerplant, which causes lower environmental impact and achieves higher overall plant efficiency ratios than conventional coal-fired powerplants.

In addition, R&D on circulating fluidized-bed of conventional technology, powerplants of the advanced technologies can considerably reduce pollutant emissions as well as the generation and management of wastes. These factors will generate ecological benefits, as well as reduce electricity costs.

Coke Generation

Since 40 percent of hard coal exploited in the FRG is used for coke generation, a priority for R&D activities is the improvement of the conventional coking chamber process and the development of a large-scale coking reactor. Because the development of such a rector, including the construction of a demonstration facility, exceeds the financial means of a single country, European-wide negotiations between all crude-iron producing and coking companies began in 1988 over the establishment of a European research center for coking technology. The center is to assume the leadership in developing a large-scale coking reactor demonstration facility. This project is part of the joint European Research Coordination Agency (EUREKA) Project. The principal difference in the new reactor design is a new charging system, guaranteeing completely emission-free charging and operation of the reactor, by virtue of its capture and neutralization of all emissions. In 1989, three German construction companies, experienced in the construction of coking facilities, conducted a feasibility study of the project and concluded that such a coking reactor can be realized. In 1990 for preparatory work on this project, the research ministry has budgeted about DM 1.0 million ($0.75 million).

France

For further information on France items, contact Dr. Michael Michaud, Science Conselor, American Embassy, Paris, APO New York 09777.

The French Energy Efficiency and Renewable Energy Agency

The Agence Francaise Pour la Maitrise de l'Energie (French Agency for the Control of Energy), usually referred to as AFME, is a French public sector institution with quasi-commercial features. Created by government decree in 1982, AFME has a basic mandate of promoting the efficient use of energy and raw materials. The agency was commissioned to work with government ministries to implement national energy management policies. Its roles include research, development, demonstration, and dissemination in the rational use of energy (particularly waste heat) and new or renewable energy sources (particularly solar energy, biomass, wind energy, geothermal energy, and waste). The agency's mandate also includes the conservation of raw materials and research into alternative materials.

According to Jacques Bouvet, chairman, the AFME's work focuses on three areas: using information and education programs to

(1) Motivate enterprises to make more efficient use of energy
(2) Offer professional solutions to energy use problems and, in some cases, financial subsidies to encourage change
(3) Conduct research, often on contract to government agencies or the Commission of the European Communities (Commission).

About 90 percent of AFME's budget of 414 million Francs in 1989 (about $65 million-1989 average exchange rate) comes from the government. In the case of information and education programs and professional services, the funds are from the Ministry of Industry. In research, they are from the Ministry of Research and Technology. About 60 percent of the budget goes to information programs and professional services and about 40 percent goes to research.

The AFME has a staff of about 400, divided among its Paris headquarters, a major branch in Sophia-Antipolis in Southern France, 22 regional delegations in metropolitan France, and 6 delegations in French overseas departments and territories. The agency has sectoral divisions for agriculture wood and biomass, residential and commercial buildings, geothermal energy and district heating, industry and raw materials, new technologies, and transportation. There also are departments for communication, information, documentation, professional training, and international services, as well as an economic service to assess market trends, and a management structure for research.

Research

Between 1975 and 1990, AFME's research budget was reduced as concern declined about energy. Recently, however, environmental concerns have driven a revival of interest in research. Within AFME's 1989 research budget of 171 million Francs (about $27 million), the priorities (in order) were industry, transportation, housing and tertiary energy use, solar and micro-hydro energy, primary materials, biomass, geothermal and heat networks, and agriculture. About 25 percent of AFME's research is done with universities and with the Centre Nationale de la Recherche Scientifique, and 75 percent with business firms. The AFME coordinates its research program with the Commission, notably in energy and the environment. The agency notes that the focus of its program is different from that of the European Community, as AFME concentrates more on rational utilization and less on renewables.

As noted previously, the Chairman of AFME is Jacques Bouvet; Philippe Cartier is Director of Research. The headquarters is located at 27, Rue Louis Vicat, 75737 Paris CEDEX 15; the telephone number is (33) (1) 47-69-20-00.

France Launches PREDIT, their Land Transportation Research and Development Program

Background

French Transportation Minister Michel Delebarre, French Industry Minister Roger Fauroux and French Research Minister Hubert Curien recently launched PREDIT, the Research and Development Program for Innovation and Technology in Land Transportation. The budget of the 5-year program is approximately FF 8.3 billion ($1.6 billion) from the French Research, Industry, and Transportation Ministries, the European Community, French industrialists, and universities. Program partners include companies, French government agencies, research organizations and universities active in the land transportation sector. The program remains open to other organizations wishing to join.

Program Contents

PREDIT includes three transverse and six vertical themes. The transverse themes are priorities to be integrated in the vertical themes. Vertical themes are technical subjects concerning specific areas.

Transverse Themes

- Safety
- Environment
- Energy.

Vertical Themes

- Guided transportation technologies
- Road vehicle technology
- Freight transportation
- Traffic technologies
- Organization of transportation and movement systems
- Strategic analysis and international competition.

Program Organization

The program organization is designed to improve interaction between transportation experts, equipment manufacturers, users, and the French Government. The program consists of an evaluation and planning committee, six technical committees, and an interministerial liaison team.

Research institutions specialized in research on transportation, such as INRETS, will of course participate in the research conducted within the framework of the program. Other research establishments, such as CNRS, the National Center for Scientific Research, will be encouraged to also contribute to such research.

Italy

For further information on Italian items, contact Gerald Whitman, Office of Science Conselor, American Embassy, Rome, APO New York 09794-9500.

Italian National Research Council Program on Telecommunications

The Consiglio Nazionale Delle Ricerche (CNR) has completed the first of an ambitious 5-year project directed towards the development of Broadbased Integrated Services Digital Network (B-ISDN). The CNR provided 78 billion Lira (about $69 million) to the project with additional funding coming from Italian universities and industry. According to the project manager Aldo Roveri, in the first year, 30 percent of the project staff came from national research centers (universities and public/private research laboratories) and the remainder came from private industry. Major university participation include the Universities at Florence, Pisa, Bari, Padova, and Naples.

The project's general objectives are to:

- Acquire the necessary knowledge to develop a broadband communication network and services system according to national plans and European strategic choices
- Integrate Italian national research into one advanced project
- Promote the formation of highly qualified technicians in an innovative environment.

Major areas of activity are:

- Structure of broadband communication network which includes the role of satellite system for HDTV
- Technologies for broadband optical communications concerning the experimental studies of some optical technologies in the context of B-ISDN development
- Terminals and signal processing in ATM networks
- Access and switching techniques for broadband networks to create a flexible experimentation environment
- Experimental realization of broad-based communication networks with the aim to implement some broadband integrated networks in urban areas and to experimentally employ new communication services.

According to project managers available for questioning, the entire project remains in the theoretical and early planning stages.

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