CENTRE FOR

INFORMATION SCIENCE RESEARCH

ANNUAL REPORT

1989

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Pro Vice-Chancellor

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1. INTRODUCTION

The Centre for Information Science Research (CISR) was established by the University Council in December 1986 to promote and fund original and adventurous multidisciplinary research in selected areas of the information sciences. While CISR constitutes a separate element within the Institute of Advanced Studies for all purposes including resource allocation and administration, it has a horizontal structure which links research groups across campus with an interest in the information sciences. The constituent research groups are:

- Automated Reasoning Project (RSSS);
- Department of Computer Science (Faculty of Science);
- Centre for Visual Sciences;
- Computer Sciences Laboratory (RSPhysS);
- Experimental Neurology Group, Division of Neuroscience (JCSMR);
- Department of Systems Engineering (RSPhysS);
- Mount Stromlo and Siding Springs Observatories;
- Division of Information Technology (CSIRO).

In 1989 CISR's Management Committee recommended that a further group, Electronic Materials Engineering (RSPhysS) become a constituent research group of CISR.

There are close formal links between CISR and CSIRO's Division of Information Technology. The Chief of the Division, or his nominee, is a member of CISR's Management Committee. In October 1987 the Division moved to temporary buildings on campus and in June 1989 funds were provided by CSIRO for a permanent building to be constructed in 1990 on an adjacent site.

The ANU Supercomputer Facility also co-operates with CISR where its work overlaps with the Centre's responsibilities.

The Centre has a Management Committee whose membership includes the heads of all the constituent research groups, except MSSSO, as well as some members of the academic staff conducting research within the parameters of CISR's research program. Members of the Committee serve a three year term of office. The Chairman of the Management Committee is the Pro Vice-Chancellor, Professor I.G. Ross. The Management Committee advises on policy matters relating to the Centre and its directions of development, including its research program and budgetary planning. It also advises on the selection of non-tenured academic staff to research projects which receive funding from the Centre and on policies and procedures for graduate students in information science and technology and the award of scholarships funded through the Centre.

The Executive Director of CISR is Dr M.A. McRobbie, Head of the Automated Reasoning Project, RSSS. He represents the Centre in dealings with organisations outside the University and is in charge of the Centre's administration. He is responsible to the Chairman of the Management Committee and through him, to the Management Committee, to whom he reports on the exercise of his functions. In 1989 he was nominally employed on a fractional appointment of one day per week although the amount of business generated by the Centre in fact took considerably more of his time. The Management Committee recommended to the Vice-Chancellor as part of a proposal to establish CISR on a firmer basis that the position of Executive Director should become a full-time appointment from 1990.

2. THE MANAGEMENT COMMITTEE OF CISR

The membership of the Management Committee of CISR is:

Ex Officio:

Chairman: Professor I G Ross
Pro Vice-Chancellor

Executive Director: Dr M A McRobbie
Automated Reasoning Project, RSSS

Appointed by the Vice-Chancellor:

Professor B D O Anderson, Systems Engineering, RSPhysS
Professor R P Brent, Computer Sciences Laboratory, RSPhysS
Professor D J Evans, RSC
Professor G A Horridge, Visual Sciences, RSBS
Dr R K Meyer, Automated Reasoning Project, RSSS
Professor S J Redman, Division of Neuroscience, JCSMR
Professor R B Stanton, Dept of Computer Science, The Faculties

Chief of Division of Information Technology, CSIRO:

Dr J. O'Callaghan, Centre for Spatial Information Systems

Invited as an observer:

Dr R. Erskine, Director, Computer Services Centre

The Management Committee met on five occasions in 1989. The major items of discussion were the future directions of CISR and the graduate school program in information sciences.

Future Directions of CISR After considerable discussion about the framework within which CISR might develop, a proposal was drawn up which was put to the Strategic Developments Committee of the Board of the Institute of Advanced Studies. The proposal envisaged the main functions of CISR in the near future as:

- promoting Information Science across the University and CSIRO's Division of Information Technology through grants and scholarships;
- responsibility for the graduate program in Information Science;
- responsibility for limited-term interdisciplinary projects, beyond the ambit of existing departments, including commercial contracts negotiated with CISR;
- providing the University's principal interface with the information industries.

The proposal sought to strengthen the administrative infrastructure of CISR which up to that time had been nominally administered by the Executive Director on the basis of one day per week and half-time secretarial support. The operations of CISR had, in fact, been heavily supported by resources of the Automated Reasoning Project, RSSS.

The proposal was successful in obtaining funding of $483,000 over five years to appoint a full-time Executive Director at professorial level and to provide increased secretarial support.

The Management Committee, in drawing up the requirements of the position of Executive Director, specified that the qualities sought were: high academic standing in one or more fields within the information sciences; understanding and concern for developments in the information sciences outside his or her own speciality; extensive knowledge of developments in the computer industry and experience in commercial liaison with industry; demonstrated entrepreneurial and management skills.

The position will be advertised in Australia and overseas early in 1990.

Graduate School Program As part of its mandate, the Centre has responsibility for co-ordinating graduate training in the information sciences. The Committee spent some time discussing a proposal for a graduate program in information science for inclusion in the newly established Graduate School, due to come into operation in 1990. Given the diversity of backgrounds of graduate students in the information sciences, the Committee considered it was difficult to design course work which all students would find useful. Nevertheless, it was felt that students should at least acquire some practical capability with computers and knowledge of programming.

The Committee favoured coursework which would develop students' intellectual abilities across a broad spectrum. To this end, it was proposed that groups affiliated with CISR would offer for audit short courses on topics in their particular fields. In addition, special courses and workshops on particular topics, especially programming techniques would continue to be offered in response to demand or as new equipment and software became available. Lists of staff members who were prepared to be involved in the program and graduate students who might enrol in the program were compiled.

In the final proposal, a Board of Studies, including the Executive Director of CISR and several members of the Management Committee, was charged with responsibility for the graduate program rather than the CISR Management Committee. In the field of information sciences, the graduate program in Computer Science and Technology will offer training for the degrees of PhD and MSc by research and for the Graduate Diploma in Computer Science by coursework.

3. THE CSIRO CONNECTION

The Division of Information Technology, CSIRO, has been a constituent research group of the Centre for Information Science Research since its inception. The Chief of the Division, Dr J.F. O'Callaghan, is a member of the Management Committee. He is also a co-director of the Parallel Computing Research Facility which was established by CISR in 1989.

In 1987, CSIRO provided $24,000 p.a. for three years to support scholarships for graduate students attached to CISR. The research areas in which these scholarships could be awarded were: computer vision and image processing, expert systems, geographic information systems and computer graphics. Supplementary scholarships of $5,000 p.a. have been awarded to Mr W.H. McIlhagga (Optical Sciences Centre, RSPhysS) and Mr P.A. Fletcher (Computer Sciences Laboratory, RSPhysS). A full scholarship of $14,000 p.a. has been awarded to Mr G. Vezina (Division of Information Technology, CSIRO). For reports on the work of these scholars, see the section on Scholarships.

Staff of the Division are also participating in the teaching of undergraduate and graduate students at the ANU. Dr P. Robertson has lectured in the Department of Computer Science in The Faculties and is a supervisor of three graduate students. Dr K.L. Smith and Dr H.G. McKenzie are also graduate student supervisors.

The Division is seeking to increase its collaboration with CISR in projects, focussing particularly on human-computer interaction, object-oriented techniques and environmental modelling.

The decision by CSIRO in June 1989 to provide capital funds for the permanent accommodation on campus of CSIRO's Canberra groups of the Institute of Information Science and Engineering (formerly the Institute of Information and Communications Technologies) is of highest importance. The co-operation already developed through CSIRO's membership of CISR played a large part in this decision. The Canberra groups of the Institute of Information Science and Engineering (IISE) comprise the Canberra laboratory of the Division of Information Technology, the Centre for Spatial Information Systems, CSIRO's Office of Space Science and Applications (COSSA), and a smaller number of staff from the Division of Mathematics and Statistics.

The Centre for Spatial Information Systems has 44 staff at present and will comprise 52 research staff with the expansion of research and development programs in image processing and visualization, geographic information systems and decision support systems, all of which are of interest to research groups at ANU. The intention of the new ANU-CSIRO association is active symbiosis in research and graduate work and mutual assistance in establishing industry links. A formal agreement covering collaboration and resource sharing is under discussion.

4. RESEARCH MISSION

The primary aim of the research program is to promote original and adventurous research at the cutting edge of the information sciences. The Management Committee has the responsibility of identifying research areas to be developed by the Centre. These are not to be extensions of existing research groups located in the University but discrete areas appropriate for further development by the Centre. However, this does not mean that research programs cannot build on ideas or work already in train or proposed.

The Management Committee recommended that the areas in which the Centre should be involved initially were:

- parallel computer architectures and algorithms for use in robotics, computer vision and image processing;
- artificial intelligence and its applications to scientific problems. Particular fields of research to be promoted in this area are simulation of neural networks, automated theorem proving and other applications of computers to mathematics;
- information and decision-support systems, particularly for processing spatially-referenced data;
- human computer interfaces, including those amenable to prosthetic devices;
- robotics;
- telecommunications;
- large scale scientific computation on vector processors.

A major theme linking the research interests of CISR's constituent research groups is parallel computing. In 1989 the Centre established the Parallel Computing Research Facility which will have a substantial computing resource in the three main styles of parallel computing, namely: shared memory parallel computation, local memory computation and massively parallel SIMD computation. For further details, see the section on the PCRF below.

The Management Committee funded six research projects in 1987 and a further four research projects in 1988. The funding is primarily for the employment of research staff for periods of two to three years. The areas of research supported were: advanced computation (e.g. parallel and vector processing), artificial intelligence, artificial vision, computational neuroscience, telecommunications, robotics software, and gene sequence analysis. For summaries of work undertaken in each of these projects, see the Research Projects section below.

5. INDUSTRIAL COLLABORATION: THE ANU-FUJITSU AGREEMENT

CISR's relationship with Fujitsu Japan commenced in 1987 with ANU's acquisition of its VP-100 vector processing supercomputer.

The contract for this machine specified that ANU and Fujitsu would establish a Joint Collaborative Research and Development Program with the precise details of this Program being a matter for negotiation. CISR was then given the major responsibility, together with ANUSF, for developing and establishing this Program.

Details of how this was done are complex and it does not seem necessary to describe them fully. However a brief chronology may be useful in indicating the scale of effort that went into the establishment of the Program.

July 1987	McRobbie visits Fujitsu Laboratories in Kawasaki for preliminary discussions concerning the Program.
May 1988	Stanton heads ANU team to visit Fujitsu Laboratories for more detailed discussions.
September 1988	Team from Fujitsu Japan headed by Dr Y Kosaka and Mr J Tanahashi visits ANU for site inspection and further detailed discussions. During these discussions it is decided to classify possible areas for a collaborative research and development Program under three categories: Area 1 - pure research; Area 2 - research and development primarily concerning parallel processing in the information sciences; Area 3 - software applications for supercomputers. It is agreed that McRobbie will have responsibility for Areas 1 and 2 and Faulkner responsibility for Area 3.
January 1989	ANU team headed by McRobbie visits Fujitsu Japan and presents a comprehensive proposal for collaboration under Area 2. Extensive site visits made to Fujitsu facilities. All members of ANU team present papers at various Fujitsu laboratories.
May 1989	McRobbie given responsibility by the Vice-Chancellor for all negotiations with Fujitsu Japan. Fujitsu team headed by Kosaka and Tanahashi visits ANU for further detailed discussions and negotiations on collaboration under all areas.

July 1989	McRobbie and Stanton visit Fujitsu Japan for final negotiations on the Program. It is agreed that the ANU/Fujitsu Joint Collaborative Research and Development Program will be managed by CISR and will consist of collaboration between various ANU groups, primarily CISR affiliates, and the following organizations within Fujitsu Japan: Area 1 - International Institute for Advanced Studies in the Social Information Sciences (IIAS-SIS); Area 2 - Fujitsu Laboratories; Area 3 - Fujitsu Systems Engineering.
September 1989	Mr M Ogi, President of Fujitsu Laboratories, visits ANU to sign the contract for the Area 2 part of the Program on 21 September at a public ceremony. This ceremony receives extensive press and television coverage. Contracts for Area 1 and Area 3 are signed on 18 August, 1989 and 10 September, 1989 respectively.
November 1989	ANU team headed by McRobbie visits Fujitsu Japan for further discussions concerning an extension of the Area 3 agreement.

The ANU/Fujitsu Joint Collaborative Research and Development Program is one of the largest joint ventures between an Australian University and industry. It is also one of the largest joint ventures between a computer company and a University anywhere in the world and is Fujitsu's largest joint venture with a University either in Japan or elsewhere in the world.

It is expected that total funding for the Program will rise to $10 million over a five year period. The three areas of collaboration within the Program can be summarised as follows:

Area 1 Central to this area is a collaborative agreement between CISR, initially through the Automated Reasoning Project, and Fujitsu's IIAS-SIS. It provides for collaboration on a variety of research projects, the first of which is general reasoning systems. The agreement provides for exchange visits between ANU and IIAS-SIS. The first of these commenced in September 1989 with the arrival at ANU of Mr H Sawamura, a senior researcher with IIAS-SIS, who will spend a year in the Automated Reasoning Project.

Area 2 Central to this area is a collaborative agreement between CISR, in particular the Computer Sciences Laboratory (RSPhysS), the Department of Computer Science (The Faculties), the Centre for Visual Sciences and other groups, and Fujitsu Laboratories. This agreement provides for the establishment of between three and five joint research and development projects primarily concerning parallel processing in the information sciences. Two have initially been established.

The first and largest of these joint projects is in parallel computing and involves research into the construction of software environments for parallel computers. As part of this project, Fujitsu will be locating at ANU in early 1991 the first fully engineered version of their radically new experimental supercomputer called a Cellular Array Processor (CAP-2). This machine will be around twice the peak power of the CSIRO Cray Y-MP and will have around three times the memory. This is the first time that a Japanese company has sited a prototype machine of this size and power outside of their own laboratories. Because Australia has no substantial computer hardware industry, its scientists have been denied any part in the research and development that accompanies the production of a new computer architecture. This agreement provides scientists associated with CISR an unrivalled opportunity to be involved in the development of a new computer architecture from the ground up.

The second of these joint projects is concerned with the design of artificial vision systems. The potential applications of this technology, which primarily involves object recognition, includes robot vision, security systems, machinery safety devices, vehicle guidance and remote control devices for operation in unsafe environments.

Area 3 Central to this area is a collaborative agreement between the ANU Supercomputer Facility and Fujitsu Japan's Systems Engineering Group. It is concerned with extending the software available on the VP range of supercomputers, primarily in the areas of computational chemistry and computational mathematics. An agreement has almost been completed that would make ANU a permanent supercomputer software porting site for Fujitsu Japan.

6. PARALLEL COMPUTING RESEARCH FACILITY

A major theme linking the research interests across CISR's constituent research groups is parallel computing. Parallel computers consist of a large number of individual processors connected and programmed to break a problem into parts on which all the processors work concurrently. It is widely believed that parallel computing can provide the computational resources required for the 'grand challenges' that now confront many areas of science. To give just one example: the computational resources required in the Human Genome Project, the international project to map human genetic material, are beyond current computing capacities. There is good reason to believe that the resources required can best be provided by parallel computers.

However, there is considerable debate amongst scientists as to exactly what the right kind of parallelism is for scientific applications. Some advocate large scale parallelism based on thousands of simple processors that use high performance numerical accelerators to provide very fast numerical calculation. Others advocate medium scale parallelism based on hundreds of processors of the kind now found in scientific workstations. Others still advocate small scale parallelism based on tens of very powerful processors which are sometimes themselves capable of supercomputer levels of performance. In fact, it is probable that no one parallel architecture will serve all scientific purposes and that scientific research requires a plurality of such architectures.

With the establishment in 1989 of the Parallel Computing Research Facility (PCRF), the Centre aims to provide computing resources in each of what are recognized to be the three main types of parallel computing architectures: small scale (tens of processors), medium scale (hundreds of processors) and large scale (thousands of processors). Not only will researchers within CISR and the ANU have access to these computers; they will also serve as a resource for the educational and research community in Canberra and the rest of Australia with access through the Australian Academic Research Network (AARNet). The PCRF has a Board of Management consisting of a Director (Dr McRobbie) and three Co-Directors (Professor Brent, Dr O'Callaghan and Professor Stanton). The Co-ordinator of the PCRF is John Barlow.

The Argonne Link In November 1989, an agreement was concluded making CISR the first international affiliate of the Advanced Computing Research Facility (ACRF) at Argonne National Laboratory in Chicago. Among the objectives of ACRF are to encourage experimentation on computers with innovative designs, to assess the suitability of diverse advanced computers for specific operations and to encourage collaborative research on advanced computing. The ACRF has the largest variety in the world of state-of-the-art parallel computers. These include a 16,000 processor

Connection Machine and a 32 processor BBN Butterfly 2. Experience gained by ANU scientists with computers at ACRF will be vital in helping to determine what machines will be acquired for the Parallel Computing Research Facility. The agreement with Argonne provides for a regular exchange of personnel between CISR and the ACRF.

Sequent S27 The first parallel computer to be acquired by the Facility is one having an architecture designed around small scale parallelism. This is a Symmetry parallel computer provided by the Sigma Data Corporation and manufactured by Sequent Computer Systems based in Beaverton, Oregon. The purchase of the Sequent S27 forms part of a research relationship between Sequent and ANU which designates the PCRF as one of a small number of sites responsible to Sequent for the pre-release testing of parallel programming languages such as LISP and PROLOG developed for Sequent by leading US software companies. As part of this relationship Sequent will also be providing the Facility with the MACH parallel Unix operating system developed for DARPA in the USA by Carnegie Mellon University. MACH has only been ported to a few sites outside the USA.

The Sequent S27 was installed in May 1989 and two parallel computing courses were given during the year. The PCRF was a beta test site for a parallel version of QUINTUS PROLOG. Dr John Slaney and Dr Gustav Meglicki entered the Sequent Computer Corporation public domain software competition on behalf of PCRF and their entry was shortlisted as one of the best programs in the competition (see below). The Sequent has attracted interest from users both on and off the ANU campus, due in part to the range of software that has been assembled on the machine, including parallel computer languages such as Linda, three parallel prologs, the Argonne National Laboratory's monitor MACROS, and more. It is anticipated that the addition of the X windowing interface and KAP parallel Fortran compiler will interest even more users during 1990. Reports on the main projects for which the Sequent has been used follow.

6.1 Integer Factorization Algorithms

Principal Investigator: Professor R P Brent
Computer Sciences Laboratory, RSPhysS

In many applications of mathematics it is necessary to distinguish prime numbers from composite numbers and to factor composite numbers into the product of their prime factors. For example, large composite numbers are now used to maintain the security of computers and data networks via 'public key' cryptosystems. The security depends on the difficulty of factoring a composite number which is the product of two large prime numbers. Someone who can factor large composite numbers can 'crack' the encryption system. Thus it is important to know how difficult the integer factorization problem is. No one can answer this question with certainty, but we do know how good certain approaches to the factorization problem are.

The Sequent is being used to test and improve new integer factorization algorithms, and to apply these algorithms to obtain factorizations required for various applications in mathematics.

Three algorithms have been studied - *the elliptic curve method* (ECM), the *multiple polynomial quadratic sieve* (MPQS), and recently the *number field sieve* (NFS). The basic questions addressed include: How does the time required for factorization depend on the size of the number being factored, the size of its factors, and any 'special' properties of the number (e.g. its proximity to a power of a small prime)? Can parallel computation effectively decrease the time required for factorization?

A 'second phase' developed at ANU improves the efficiency of the elliptic curve algorithm by a factor of 6 to 10, and both phases can be implemented efficiently on a parallel machine such as the Sequent (or a vector processor). Using a few minutes of computer time it is routine to find prime factors of size up to 25 decimal digits, and with more time and a certain amount of luck even larger factors can be found (the current record is 38 decimal digits).

Using the MPQS and NFS algorithms, several numbers larger than 100 decimal digits have been factored in a world-wide distributed computation (organised by A K Lenstra, University of Chicago, and M Manasse, DEC, USA). Our spare time on the Sequent has contributed to these computations. The results imply that the composite numbers used in public-key cryptosystems should be larger than 100 decimal digits.

There are several mathematical applications of integer factorization. One is the search for odd perfect numbers. In collaboration with G L Cohen (UTS, Sydney) and HJJ te Riele (Math. Centrum, Amsterdam) we have shown that there is no odd perfect number less than 300 decimal digits.

As a byproduct of testing factorization algorithms a large database of factors has been built up. Although the computation of this database required a large amount of computer time, it is now readily accessible from a personal computer.

Publications

Brent R P, Factorization of the eleventh Fermet number (preliminary report), *AMS Abstracts* **10**, 89T-11-73, (1989).

Brent R P & Cohen G L, A new lower bound for odd perfect numbers, *Mathematics of Computation* **53**, 431-437 and S7-S24(1989).

Brent R P, *Factor: an integer factorization program for the IBM PC*, Report TR-CS-89-23, Computer Sciences Laboratory, ANU, October 1989.

Brent R P, Factorizing, *Australian Mathematical Society Gazette* **16 5**, 154-155 (October 1989).

Brent R P, Parallel algorithms for integer factorization in *Number Theory and Cryptography* (ed. J H Loxton), Cambridge University Press, 1990, 26-37.

6.2 Development of Parallel Algorithms to Compare Linda and Occam

Principal Investigator: Dr N Dunstan
Computing & Information Science
Bendigo CAE

So far time has been spent on gaining familiarity with C-Linda on the Sequent and developing some algorithms in Occam on a transputer development system. Several research papers have been identified which can be used as models for comparison. They are:

Bloom, Evaluating synchronization mechanisms, *Proceedings of the 7th Symposium on Operating System Principles* (1979).

Carriero & Gelernter, How to write parallel programs: a guide to the perplexed, *ACM Computing Surveys* **21 3** (1989).

Welsh & Lister, A comparative study of task communication in ADA, *IEEE Trans-*

actions of Software Engineering, **SE-9 4** (1981).

6.3 CAP-Linda: Implementation, Performance and Debugging

Principal Investigators: Dr C W Johnson & Mr M W Zellner
Department of Computer Science
The Faculties

The Department of Computer Science, in conjunction with Fujitsu Japan, is developing software for the CAP, a distributed memory multicomputer based on the SPARC microprocessor, currently being built by Fujitsu. As part of this software development process, the parallel programming language, Linda, is being investigated as one of a number of languages and programming environments to be implemented for the CAP machine. Versions of Linda currently exist for both single processor and multiprocessor shared memory computers. One such implementation is currently being used both as a testbed for ideas about debugging and monitoring Linda programs, and is being considered as a candidate for porting to the CAP machine, should a complete new distributed memory implementation of a Linda runtime system prove infeasible.

6.4 A UNIX Utility for Parallel Program Tracing

Principal Investigator: Mr S A Mabbs
PhD student
Electrical and Electronic Engineering
University of Melbourne

As part of my research, I am investigating some performance aspects of hierarchical, shared-memory multiprocessors. In order to evaluate the potential of this architecture to support real parallel programs, I need program traces from an existing machine. It was preferable to obtain these traces from a shared-memory, symmetric machine.

I have written a program for the Sequent Symmetry called *'ptrace'*. The purpose of *ptrace* is to single-step through DYNIX applications, decoding each instruction and keeping statistics on the following: instruction usage, memory references, addressing mode used, privacy analysis (specific to my research), time of fork, exec and exit of all child processes, time spent in each system call/library routine by each child process, register usage. Simple extensions to *ptrace* allow any user to customise the information that *ptrace* generates.

I have received many expressions of interest for *ptrace* from overseas organisations, including Sequent Computers Incorporated in the USA. Once *ptrace* is completed, I will probably submit it to the gnu organisation. Hopefully, it will become the basis of a multiple-platform, general-purpose UNIX process tracing tool.

Publications

Mabbs S A, *Ptrace: a program tracing tool - user's guide.* Technical Report 85867-062-3 (4/90), Department of Electrical and Electronic Engineering, University of Melbourne, 1990.

Mabbs S A & Forward K E, A hierarchical communication architecture for a shared-memory multiprocessor, *Proceedings of the 1989 Supercomputer Conference*, Wollongong, 12-14 December, 1989.

Mabbs S A & Forward K E, *Optimising the communication architecture of a hierarchical parallel processor*, Technical Report 85867-064-X (6/90), Department of Electrical and Electronic Engineering, University of Melbourne, 1990.

Mabbs S A & Forward K E, *Performance analysis of a hierarchical communication architecture for a shared-memory multiprocessor*, Technical Report 85867-059-3 (2/90), Department of Electrical and Electronic Engineering, University of Melbourne, 1990.

6.5 Implementing ANU ML on the Sequent

Principal Investigator: Dr M C Newey
Department of Computer Science
The Faculties

The programming language ML is the premier typed applicative language in use in the world. The Principal Investigator, who was involved in its development, maintains an implementation called ANU ML on Vax, Sun and Pyramid hardware. Functional programming is argued to be an extremely important methodology for utilising parallel hardware. The aim of this project is to port ANU ML to the Sequent in such a way that a user can capitalise on the speed that comes via concurrent computation.

6.6 Parallel Computation of Artificial Neural Networks for Speech Recognition

Principal Investigator: Ms Shuping Ran
Computer Sciences Laboratory, RSPhysS

The aim of the project is to explore the multi-dimension architecture of the artificial neural networks and the ability of the shared memory parallel computation of the Sequent for speech recognition. Algorithms are being investigated that better integrate phonetic, speech, and linguistic knowledge for speech recognition. A parallel computation algorithm for Hopfield training has been developed. The relation of the speed of the training process and the number of processors used has been studied in this project.

Publications

Ran S, Parallel computation for training of Hopfield nets, paper for the *First Australian Conference on Neural Nets*, 1990.

6.7 Machine Learning in Ecology

Principal Investigators: Mr D R B Stockwell & Dr D G Green
Ecosystem Dynamics, RSBS

The project is to automate the development of 'deep knowledge' models in ecology. The concept of deep knowledge is often used to describe expert systems that contain rules based on first principles, in contrast to rules based on empirical associations (shallow knowledge). Deep knowledge is believed to produce many desirable increases in the performance of expert systems: greater robustness, more general applicability, and better explanatory capacity. Machine learning holds the promise of automating the development of deep knowledge models for simulation, explanation and prediction.

The relevance and particular needs of parallel simulations in ecological systems has been explored in the publication listed below. Typically the computational cost of ecological simulations is high as large numbers of objects such as sites or animals are processed. Similarly, in machine learning, the size of the search space in useful representational languages is large. Parallel implementations, as well as allowing more computation per unit of time, encourage the neat formulation of algorithms by enforcing the decomposition of problems into independent sub-problems. A method with a firm theoretical basis for inducing rule sets has been developed and is expected to be implemented on a parallel system soon.

Publications

Stockwell D R B & Green D G, Parallel computing in ecological simulation, *Mathematics and Computers in Simulation* **32**, 249-254 (1990).

6.8 Automatic Process and Data Partition for Multicomputers

Principal Investigator: Dr P Tang & Mr G Michael
Department of Computer Science
The Faculties

The aim of this project is to explore compiler techniques of automatic process and data partition for multicomputers. Programs to be compiled are ordinary sequential programs based on an illusionary global memory space. The parallelizing compiler, which acts on sequential programs, analyses the structures of the computations and generates the appropriate parallel programs for the target multicomputers, is responsible for partitioning the data and process space across the processors. Through comprehensive data and control dependence analysis the compiler can obtain a great deal of information about the structure of the computation. Based on this information it is possible for the compiler to produce a process and data partition in which the computation is load balanced over time and the synchronization delays and communication overheads are minimized.

This project is related to research being currently undertaken at Rice University, the Ohio State University, University of California at Irvine and the SUPRENUM project in West Germany. The work described here differs significantly from previous work in that the data partition is based on an analysis of the dependence structure of the program rather than relying upon user specifications.

6.9 Parallelising the Closure Computation

Principal Investigators: Dr J K Slaney
Automated Reasoning Project, RSSS

Professor E Lusk
Director
Advanced Computing Research Facility
Argonne National Laboratory

During the visit of Professor Lusk to the Automated Reasoning Project in November 1989 an extension was carried out of joint work begun in 1988 on efficient methods for parallel computation of the closure of a set under an operation. This is a fundamental computation having extremely important applications in many parts of mathematics, especially in algebra, and in automated reasoning where forward chaining theorem provers are computing the closure of a set of clauses under some such function as resolution or paramodulation.

A good solution to two real-life test problems was the focus of research: finding the 3088 Ackermann constants of the relevant logic R (a known example of a finite closure whose computation is moderately difficult) and generating the formulas in one variable of the related logic $E \rightarrow$ (a problem not known to be finitely solvable, though instances of it such as the result of collapsing together formulas equivalent in all four-valued models are known to be solvable though expensive to compute). The speedups obtained on the Sequent here and on the larger Sequent symmetry at Argonne National Laboratory, Chicago, were extremely good and our algorithm extends to other applications of closure such as that in theorem proving. A paper on this work was submitted to CADE (the leading conference on automated deduction) which has since been accepted and shortlisted for the award for best paper in the conference.

Publications

Slaney J K & Lusk E L, Parallelizing the Closure Computation in Automated Deduction, *Proceedings of the 10th International conference on Automated Deduction*, edited by M E Stickel, *Lecture Notes in Artificial Intelligence* series, Springer Verlag, Berlin.

6.10 MaGIC (Matrix Generator for Implication Connectives)

Principal Investigators: Dr J K Slaney & Dr Z Meglicki
Automated Reasoning Project, RSSS

During 1989 the existing program MaGIC was totally re-written in its sequential version and then parallelised. In writing the parallel version the Argonne Portable Monitor Macro Package was used. A front end was written that is intended to run under X Windows (Release 3) and to allow a user to have MaGIC itself executed on the Sequent while the user interface is on a remote machine. Both the serial and parallel versions of MaGIC version 1.0 were submitted, along with the front end xmagic, for Sequent's own User-Contributed Software competition. This software was shortlisted as one of the best programs in this competition. Work on MaGIC and on xmagic have continued into 1990.

MaGIC was applied on the Sequent not only to gain experimental results on parallelisation but also to advance object-level research into formal logic. The outcome of this research was good at the computational level, near-linear speedup being achieved with the 8 processors of the Symmetry. In terms of logic, too, there were worthwhile results including numerical theorems concerning models of propositional logics to be reported in a Technical Report and conference presentation in 1990. The program was also used in the investigation of new systems of logic. Dr Girle of the Automated Reasoning Project and vacation scholar, T Surendonk, collaborated in this work which is also to be published in 1990.

Publications

Slaney J, Surendonk T & Girle R, *Time, Truth and Logic*, Technical Report TR-ARP-11/89. Paper delivered to the Arthur Prior Memorial Conference, Christchurch, New Zealand in August 1989 and to appear in the associated memorial volume.

MaGIC 1.0: Notes and Guide, documentation (65 pp.) submitted with the programs MaGIC and xmagic in the Sequent User-Contributed Software competition.

7. RESEARCH PROJECTS

The Management Committee of CISR funded six projects in 1987 and a further four projects in 1988 which employed additional research staff. One further grant was made for equipment. Brief reports on these projects follow.

7.1 Electrophysiology of Insect Vision

Principal Investigator: Dr M V Srinivasan
Visual Sciences, RSBS

CISR-funded Investigator: Dr D R C Osorio
Visual Sciences, RSBS

In order to understand better the mechanisms of insect vision, an appointment has been made to assist Dr Srinivasan with the electrophysiology of the insect optic medulla. This is the region of the insect optic processing where the neurons carrying the most detailed spatial information from the retina suddenly end in a divergence into a large number of neurons which are arranged in columns corresponding to the visual axes. All natural visual systems have this structure; the column neurons appear to correspond to a selection of appropriate templates which detect local features in the visual scene. The only approach to these neurons is to record from them electrophysiologically. The theoretical background is provided by a new theory of vision by use of preformed templates that is being developed by Professor Horridge and others in the vision group. At the same time a patent has been taken out for an artificial vision device based on the template theory. This work is therefore part of an integrated project involving neuron circuitry, new theory and practical applications. Achievements to date include an understanding of natural visual mechanisms that is relevant to the design of an artificial system. By working in this area we have thought of a new general theory (called the gradient theory).

Publications

Coombe P F, Srinivasan M V & Guy R, Are the large monopolar cells of the insect lamina on the optomotor pathway?, *Journal of Comparative Physiology*, **A166**, 23-35 (1989).

Osorio D R C, Srinivasan M V & Pinter R B, What causes edge fixation in insect vision, *Journal of Experimental Biology*, **149**, 281-292 (1990).

Srinivasan M V & Guy R, Spectral properties of movement perception in the dronefly *Eristalis, Journal of Comparative Physiology*, **A166**, 287-295 (1990).

In Press
Srinivasan M V, Pinter R B & Osorio D R C, Matched filtering in the visual system of the fly: large monopolar cells are optimized to detect moving edges and blobs, *Proceedings of the Royal Society of London B.*

Submitted
Osorio D R C, Inhibition, spatial pooling and signal rectification in the subunits of non-directional motion-sensitive cells in the locust optic lobe, *Journal of Neuroscience.*

7.2 Artificial Vision

Principal Investigators:	Dr M V Srinivasan & Professor G A Horridge Visual Sciences, RSBS
CISR-funded Investigator:	Mr M G Nagle Visual Sciences, RSBS
Co-Investigators:	Dr P Sobey & Dr G Stange RSBS

A number of ways of copying insect vision are being put into effect. The gradient model of Srinivasan and colleagues provides a way of measuring the range to nearby objects by lateral movement of the eye. A different way to achieve the same objective by use of a linear array without movement of the eye looks more promising. These gadgets are relatively simple so that they are feasible as light weight mobile aids for the blind. The design work is based upon an invention by Dr Srinivasan and Dr Stange. The circuitry is designed and built by Mr Nagle. There is a range of related work in this research group, notably on the mechanisms of natural vision, visual behaviour of insects and other models of artificial vision which copy natural systems. Achievements to date are a real gadget that uses five facets of an eye to measure range by natural light and converts the output to a tone. We have also developed a new theory (called the gradient model) which could be the basis for a new generation of gadgets based on that patented by Srinivasan and Stange.

Publications

Horridge G A, A template theory to relate visual processing to digital circuitry,

Proceedings of the Royal Society of London B, **239**, 17-33 (1990).

Sobey P & Horridge G A, Implementation of the template model of vision, *Proceedings of the Royal Society of London B* (1990).

In Press
Fei Jin Z & Srinivasan M V, Neural gradient models for the measurement of image velocity, *Visual Neuroscience.*

Horridge G A & Sobey P, An artificial seeing system copying insect vision, *British Journal of Optoelectronics.*

Srinivasan M V, Generalized gradient schemes for the measurement of two-dimensional image motion, *Biological Cybernetics.*

Submitted
Sobey P & Srinivasan M V, Measurement of optical flow using a generalized gradient scheme, *Proceedings of the International Conference on Computer Vision*, Osaka, Japan, to be held in December 1990.

Stange G, Srinivasan M V & Dalczynski J, A rangefinder based on intensity gradient measurement, *Applied Optics.*

7.3 Receptive Field Analysis in Natural and Artificial Visual Systems

Principal Investigator: Professor W R Levick
Division of Neuroscience, JCSMR

CISR-funded Investigator: Mr G F Quinn
Division of Neuroscience, JCSMR

The project is aimed at the application of a Wiener-like Nonlinear Systems Analysis to the problem representing the repertoire of the individual elements of natural and artificial neural networks engaged on the task of visual scene analysis. The comparative analysis is expected to throw new light on the long-standing general problem of visual pattern recognition.

The initial stages of the project involved setting up an experimental white noise analysis system on local computing facilities. This involved porting the essential components of an extensive package of software and existing data originally obtained from pilot experiments carried out by the principal investigator at the California Institute of Technology, Pasadena. The main programming effort commenced on 1 August 1989. The complete suite of material was recovered from 800 bpi tapes and securely transferred to 6250 bpi tapes conveniently readable via the local network. When the project commenced the Apollo DN10000 computer for the Centre for Visual Sciences had not yet been acquired, so the first attempt at porting the code was to the CSC VAX system. An I/O subroutine library has been created to replace the original Caltech I/O system. The code for the first order kernel calculation was successfully commissioned in September 1989.

Following delivery and commissioning of the Apollo network in late 1989, there was a period of familiarization with the special computational features of this high-performance system. The opportunity was taken during the port of the suite to this system to reorganize significant sections of the code to improve efficiency. The outcome was a spectacular increase (about 20-50 fold) of speed in obtaining the computational results.

An important, but difficult step is to develop facilities for visualization of the first and particularly the second order kernels (six-dimensional arrays). In the course of debugging and testing the computational algorithms, Mr Quinn has created useful graphics routines which are now being ported to the X-Windows environment with a view to obtaining output on a newly commissioned colour laser printer in the RSBS Computer Unit.

Production work should shortly begin using extensive files of data already acquired in neurophysiological recordings from mammalian retinal ganglion cells. Mr Quinn will then be able to turn his attention to the problem of linking the front end of the analysis system to the on-line computer-controlled data collection facilities in the principal investigator's laboratory. With the greatly improved turn-round achieved by the newly developed programs on the Apollo system, there is the prospect of well-informed guidance of real-time experimentation.

7.4 Parallel Programming Environments

Principal Investigator: Professor R P Brent
Computer Sciences Laboratory, RSPhysS

CISR-funded Investigator: Dr P Lenders
Computer Sciences Laboratory, RSPhysS

Co-investigators: Dr H Schröder & Mr P Strazdins
Computer Sciences Laboratory, RSPhysS

Recent advances in parallel computer architectures have generated a growing interest in new languages for distributed systems. Languages like CSP and Occam are very good at expressing communication and synchronisation among processes. Unfortunately, they are of little help in partitioning a complex algorithm to be run on several separate processors. Dr Lenders is designing an integrated programming environment for parallel and distributed applications: a paralleliser suggests parallel programs for algorithms expressed either sequentially, or without any specified order of execution; then a compiler produces code for the message-passing type of parallel computers. Additional tools suggest mapping from the computation space into the target computer which can be a multiple-instruction multiple-data type of multiprocessor (e.g. a transputer array) or a VLSI array processor (e.g. a systolic or wavefront array). The high level language and its run-time environment have several desirable features relating to communication, synchronisation, concurrency and optimisation. Typical applications include the parallel implementation of algorithms for matrix operations, digital filters, the FFT, and shortest path problems.

The concept of the *instruction systolic array* (ISA) has been shown to be a cost efficient compromise in the trade-off between flexibility and speed. Formal semantics for ISAs and mesh-connected networks have been developed by Lenders, Strazdins and Schröder in order to support automated proofs of correctness of programs for parallel architectures.

Publications

Lenders P, A generalized message-passing mechanism for communicating sequential processes, *IEEE Transactions on Computers* **37**, 646-651 (1988).

Lenders P & Schröder H, Systolic and hypercube implementations of r-dimensional transforms, *Proceedings of the IREE Conference on Image Processing and the Impact of New Technologies*, ADFA, Canberra, December 1989.

Lenders P, Schröder H & Strazdins P, Microprogramming instruction systolic arrays, *MICRO 22*, Dublin, August 1989. Also appeared as Report TR-CS-89-17, Computer Sciences Laboratory, ANU, June 1989.

Lenders P, *Unification of IF and DO statements in GL*, Report TR-CS-89-07, Computer Sciences Laboratory, ANU, April 1989.

Lenders P, *Meta statements in CSP*, Report TR-CS-89-12, Computer Sciences Laboratory, ANU, May 1989.

Lenders P & Schröder H, *A programmable special purpose device for mathematical morphology*, Report TR-CS-89-03, Computer Sciences Laboratory, ANU, April 1989.

Lenders P & Schröder H, *A semantics for instruction systolic arrays*, Report TR-CS-89-04, Computer Sciences Laboratory, ANU, April 1989.

Lenders P & Schröder H, *2D-FFT in optimal time in a systolic array of rings*, Report TR-CS-89-16, Computer Sciences Laboratory, June 1989.

Lenders P & Schröder H, *r-dimensional transforms and their hardware implementations*, Report TR-CS-89-18, Computer Sciences Laboratory, ANU, July 1989.

Lenders P & Schröder H, Production of add-on boards with special purpose programmable arrays for workstations, *Proceedings of the International Pacific RIM Technology Transfer conference*, ANUTECH, 1989.

Millar J B, Schröder H, Lenders P & Wagner M, Real-time automatic speech recognition, *Proceedings of the Pacific Rim Technology Transfer Conference*, ANUTECH, 1989.

7.5 Telecommunications and Signal Processing

Principal Investigator:	Dr R R Bitmead Department of Systems Engineering, RSPhysS
CISR-funded Investigator:	Dr R A Kennedy Department of Systems Engineering, RSPhysS
Co-Investigators:	Professor B D O Anderson, Dr D Williamson, G W Pulford, S Crisafulli, M R Frater and B James Department of Systems Engineering, RSPhysS

The broad aims of this project are to develop advanced signal processing techniques for telecommunication problems. A range of telecommunication problems are under investigation centring on:

- digital data recovery techniques,
- adaptive and nonadaptive channel equalization,
- control theoretic reformulation of speech coding problems,
- speedup methods for the fast simulation of rare event probabilities,
- frequency tracking and estimation problems.

The key methodologies being used are the application of mathematical systems theory tools to this collection of problem areas, utilising the common aspects of their formulation.

Investigations include: developing new equalization structures based on mathematical state space block processing ideas; theoretical investigations into performance of speech encoders using abstract function spaces; non-linear filtering techniques based on Bayesian estimation techniques finding application in one and two dimensional data; theoretical investigations into blind adaptation; and advanced adaptive quantizer techniques for use in speech coding based on extended Kalman filtering ideas. The primary output at this stage is international quality journal and conference papers.

Publications

Frater M R, Bitmead R R, Kennedy R A & Anderson B D O, Rare events and reverse-time models, *Proceedings of the 28th IEEE Conference on Decision and Control, CDC '89*, Tampa, Florida, December 1989, 1180-1183.

In Press
Crisafulli S, Bitmead R R & Johnson C R Jr., An extended Kalman filtering approach to adaptive differential pulse coded modulation, *IEEE Fourth Digital Signal Processing Workshop*, New Paltz, NY, 1990.

Ding Z, Kennedy R A, Anderson B D O & Johnson C R Jr., Ill-convergence of Godard blind equalizers in data communication, *IEEE Transactions on Communications.*

Frater M R, Bitmead R R, Kennedy R A & Anderson B D O, Fast simulation using reverse-time models, *Proceedings of the ITC Specialist Seminar*, Adelaide, September 1989.

Kennedy R A, Anderson B D O, Ding Z & Johnson C R Jr., Local stable minima of the Sato recursive identification scheme, *Proceedings of the 29th IEEE Conference on Decision and Control, CDC '90*, Hawaii, December 1990.

Niedzwiecki M & Kennedy R A, Non-linear, non-causal noise rejection schemes based on competitive smoothing, *Proceedings of the 5th European Signal Processing Conference, EUSIPCO 1990*, Barcelona, Spain, September 1990.

Papers to be published in the *Proceedings of the Second International Symposium on Signal Processing and its Applications, ISSPA '90*, Gold Coast, Australia, August 1990:

Crisafulli S & Bitmead R R, Adaptive quantization: a Kalman filtering approach.

Frater M R & Bitmead R R, Escape from local equilibria in adaptive equalizers.

James B & Kennedy R A, Rejecting noise from 2-D image data by detection.

Kennedy R A, Anderson B D O, Ding Z & Johnson C R Jr., On the failure of proposed recursive identification schemes based on the Sato algorithm and its generalizations.

Kennedy R A & Johnson C R Jr., Encoder stability study for the 32kbits/s CCITT G.721 ADPCM standard based on a simplified error model.

Kennedy A, Niedzwiecki M & James B, Non-linear smoothing technique for discontinuous signals buried in noise.

Pulford G W, Kennedy R A, Williamson D & Anderson B D O, Error analysis of the block DFE using finite state markov processes.

Williamson D & Kennedy R A, Applications of IIR decision directed signal processing.

Williamson D & Kennedy R A, A new equalizer structure using vector quantization based on the decision feedback principle.

Submitted
Crisafulli S & Bitmead R R, Adaptive quantization: solution via nonadaptive linear control, *IEEE Transactions on Communications.*

Kennedy R A, Anderson B D O & Bitmead R R, Blind adaptation of decision feedback equalizers: gross convergence properties, *International Journal of Adaptive Control and Signal Processing.*

Rey G J, Bitmead R R & Johnson C R Jr., The dynamics of bursting in simple adaptive feedback systems, *IEEE Transactions on Circuits and Systems.*

Williamson D, Kennedy R A & Pulford G W, Block decision feedback equalization, *IEEE Transactions on Communications.*

7.6 A Self-organizing, Syntactic Approach to Gene Sequence Analysis

Principal Investigators: Dr A J Gibbs
Molecular Evolution and Systematics Group, RSBS

Dr D G Green
Ecosystem Dynamics Group, RSBS

CISR-funded Investigator: Dr G F Weiller
Molecular Evolution and Systematics Group, RSBS

This project aims to improve the quality and quantity of information that gene sequence analyses provide on genetic structure and function, and on evolutionary relationships. To achieve this goal, we plan to combine artificial intelligence, syntactic methods, and visualization in novel ways.

Despite international plans to sequence the entire human genome (3.3×10^9 base pairs), analytic methods have not kept pace. Databases of nucleotide and amino acid sequences are growing exponentially, but understanding of the subtleties of DNA sequence information has lagged well behind the acquisition of data.

The advantage of a syntactic approach is that it can exploit known functional features into its analyses. Self-organizing systems will make it possible to build a knowledge base of rules and the structural relationships they represent. Since the human eye is a better pattern recognizer than any system yet developed, we are exploring ways of representing sequence information visually.

An important hypothesis being explored is that evolutionary relationships between different viruses should manifest themselves in the higher-level organization (e.g. folding pattern) of gene sequences. Successful demonstration of this approach to viruses would open the way for its application to a wide range of gene and protein sequences.

Description of the project
In order to achieve the above goals, we are developing sequence analysis programs that incorporate three main features:

1. Syntactic algorithms for classifying, comparing and modelling sequences;
2. An interactive expert system for identifying, storing and applying syntactic rules about sequence structure;
3. Visual representations of sequences to highlight patterns of structure, function and relatedness;
4. The use of parallel and array processing to speed up computationally intensive operations, such as searching data-bases.

The project will focus on the analysis of selected DNA and protein sequences currently being obtained in projects in RSBS, such as the genetic and mutational analysis of the tymoviruses and their relatives and also of the Nod D genes of *Rhizobium* bacteria. One reason for this choice is that the laboratories studying these genes are able to test directly the results of the analyses by site-directed mutagenesis studies.

Equipment to be used Ultimately, most of the software will be implemented in C to run under Unix with X-Windows. To deal with computationally intensive operations, such as searches of large genetic data-bases, version of appropriate algorithms and programs will be adapted to run on the University's VP-100 vector supercomputer and parallel supercomputers available through CISR.

The main progress to date is:

1. To clarify the underlying syntactic theory and basic methods of comparing sequences. We are now preparing papers for publication to describe the method and its application to gene sequences.

2. We have written prototype software to implement the necessary screen graphics. The programs include a suite of low-level operations (e.g. applying rules) that provide the basis for scripting language. Visual displays of sequences that we have implemented include fractal images and comparison diagrams.

3. This software has been used to test the feasibility of producing valid syntactic descriptions for protein sequences. First results show that even simple rules can reveal useful structural information.

Publications

In Preparation
Green D G, Syntactic homomorphism and analogy.

Green D G & Gibbs A, A syntactic approach to the analysis of gene and protein sequences.

7.7 Computation Using Neural Networks

Principal Investigator:	Professor S J Redman Division of Neuroscience, JCSMR
CISR-funded Investigator:	Dr B P Graham Division of Neuroscience, JCSMR
Co-Investigator:	A D Coop Division of Neuroscience, JCSMR

The general aim of this project is to investigate the use of neuronal-like networks as models of real nervous systems. Though the models will necessarily be simple in comparison to the real systems, the ability to change parameters within a model should lead to an increased understanding of the real system. This can point the way to further experiments on real nervous systems, resulting in data to improve the models.

Currently two different models are under development. The first model is of the peristaltic reflex in the guinea-pig small intestine. The reflex model contains some 400 nodes representing sensory and motor neurones and interneurones. The implemented circuitry demonstrates that there is no requirement for a connection between the orally directed excitatory and anally directed inhibitory components of the reflex pathways for coordination of the reflex response to a radial stretch stimulus.

The second model is of the general circuitry involved in the muscle stretch reflex. It is hoped that this model will show that the 1a inhibitory interneurones are alone sufficient to generate co-contraction of agonist-antagonist muscle pairs.

Equipment used These neural network models are extremely computationally intensive. The peristaltic reflex model has so far been run in a limited fashion on a Macintosh II computer, but has reached the limits of that machine. The ideal way to improve the computational performance is to exploit the natural massive parallelism in the neural networks themselves. This can be done to a limited extent on a machine such as the Sequent S27. The peristaltic model is running on a single processor on the Sequent and work will continue into 1990 to parallelise the model. It is anticipated that the muscle stretch reflex model will also be implemented in parallel on the Sequent in 1990.

Publications

Coop A D, A neural net simulation of the peristaltic relfex in the guinea-pig small intestine, Honours Thesis, Division of Neuroscience, John Curtin School of Medical Research.

7.8 Software for Variance Estimation on Vector Processors

Principal Investigator: Dr M R Osborne
Statistics Research Section
School of Mathematical Sciences

A suite of estimation programs is being prepared consisting of the following components:

(i) Software for the generation of likelihoods and reduced/residual likelihoods for stochastic mixed models.

For problems in one independent variable a new discrete Kalman filtering plus smoothing algorithm has been derived. It promises to have improved stability characteristics in important classes of smoothing and estimation problems. Asymptotic expansions which permit the residual likelihood to be derived and implemented as a limiting case of a random effects model have been derived. These appear to resolve numerical stability problems encountered in earlier work. The extensions to more than one independent variable is being studied.

(ii) Estimation subroutines based on Fisher scoring.

This method has important advantages in the likelihood case and these have been studied in detail. It is important to understand the link between the good performance of the scoring algorithm and the adequacy of the stochastic modelling because these prove to be closely coupled in general (so that if the numerical procedure fails to work well then the results are anyway of no interest).

(iii) Optimization software based on the symmetric, rand-one, update for the Hessian.

Estimation procedure based on Quasi-Newton updates of a Hessian estimate provide a useful supplement to scoring in certain important situations. For example:

(a) As a fall back when scoring fails to work well because the stochastic information is inadequate, and

(b) In problems where derivative information is inefficient or impractical - variance estimation provides an important example when the dimension of the data space is very large compared to that of the parameter space.

An important new finite termination property has been obtained for an optimally scaled version of the symmetric rank-one update, and extensive testing of associated software has been undertaken. Current plans call for this software to be vectorized as the next stage in its development.

Equipment used This work was carried out using a large IBM personal computer purchased with a grant from the Centre for Information Science Research.

Publications

Dietrich C R & Osborne M R, *Maximum likelihood estimation of covariance parameters for Gaussian random fields*, CMA Report CMA-R15-89.

Osborne M R & Prvan T, *What is the covariance analog of the Paige and Saunders information filter*, School of Mathematical Sciences Report SMS-006-90.

Osborne M R, *Fisher's method of scoring*, School of Mathematical Sciences Report SMS-044-90.

Sun L, Scaling rank-one updating formula and its application in unconstrained optimization, ANU PhD thesis 1990.

In Press
Osborne M R & Prvan T, A direct derivation of the interpolations smoother, *Applied Mathematics Letters.*

7.9 Program Verification in Modula-2

Principal Investigator:	Dr M C Newey Department of Computer Science The Faculties
CISR-funded Investigator:	Professor C H Brink Automated Reasoning Project, RSSS

The aim of the project is to develop a system in which moderate sized Modula-2 programs can be proven (with mathematical certainty) to satisfy their specifications.

The first stage of the project is to produce a formal semantics of Modula-2 that can be used for reasoning in the context of an interactive tool like the LCF system. Next, theorem proving approaches which rely on the semantics must be developed, the aim being to allow the system to work with as little manual intervention as possible. The final stage involves the design of a suitable interface to a software engineering environment.

At the outset, it was thought that the LCF system would be the most appropriate vehicle for machine assisted proof of program properties. Although the logic of the LCF system is eminently suited to the domain of computation, a decision to change direction was made in 1989 in favour of using the HOL system (actually a descendent of LCF). The underlying logic of the HOL (High Order Logic) will suffice for many applications. The main reason for the change is the relatively meagre support that can be expected for the LCF system, whereas HOL enjoys quite widespread use in the field of hardware verification. Another factor in this choice has been the success of structured operational semantics in describing programming languages. Coupled with the move to HOL was the change from denotational semantics to the operational style of language definition.

Some work has been done on the representation of the semantics of Modula-2 but most effort has been invested in adapting the HOL system to the needs of the project.

Professor Brink developed a case study in the context of Boolean Algebras by way of exploring the use of Universal Algebra in the context of program verification. Dr Newey found the HOL system to be quite suitable on the whole for working with his theory of deadlock but concluded that the existing theory of arithmetic was inadequate in scope and not sufficiently well organised to act as the basis for semi-automatic verification of simple Modula-2 programs. The new theory of arithmetic being developed will be presented at the HOL Users Meeting in 1990 and should replace the existing one in later distributions of the system.

Professor Brink also worked on the development of a model checker for Petri Nets in collaboration with his PhD student, Mr P J A de Villiers. Petri Nets are used to model the dynamic behaviour of concurrent systems and a branching-time temporal logic is used to specify the properties of such a system. Model checking is a technique for verifying mechanically that a given Petri Net satisfies its specification. They have developed an algorithm for such a model checker and illustrated the technique with with an example.

Publications

de Villiers P J A and Brink C, *A model checker for Petri Nets*, Technical Report TR-ARP-6/89, Automated Reasoning Project, RSSS. Also to be published in *The Computer Journal.*

7.10 Parallel Processing in Human Vision

Principal Investigator: Professor A W Snyder
Optical Sciences Centre, RSPhysS

CISR-funded Investigator: Dr G W Stuart
Centre for Visual Sciences

Co-Investigator: Dr T R J Bossomaier
Centre for Visual Sciences

Human and animal brains have an unsurpassed ability to process extremely large amounts of information in short time intervals, despite their dependence on computing elements which transmit information slowly relative to electronic circuits. This is achieved by the extensive use of parallel processing strategies.

The present project is concerned with parallel processing in human vision, from several viewpoints. We are concerned with what may be termed 'modular parallelism', that is, the processing of various aspects of the visual input such as colour, stereoscopic depth, movements in separate channels. The number of, and relationship between, these channels can be studied using psychophysical tests. We are currently investigating the role of colour-sensitive channels in the computation of movement and stereoscopic depth. Using visual search techniques we have established that the visual angle size of objects is a property of the visual scene which is processed in parallel.

A second aspect of parallel processing that is being investigated using both psychophysical methods and computational modelling is the distributed representation of object boundaries. This is based on recent physiological finds indicating that a temporal code may be used to segregate ensembles of neurons involved in the cooperative coding of object boundaries. These subgroups of neurons fire in synchrony. We have been able to model this behaviour in a self-organising artificial neural network composed of physiologically realistic integrate-and-fire neurons.

Equipment used The experimental work is carried out on an IBM-compatible 386 computer with a transputer-based high resolution 8-bit graphics card, and a high quality Barco Calibrator colour monitor. We will soon add seven additional transputers to the system. Computational modelling was done initially on the Centre for Visual Sciences' Apollo DN10000 graphics workstation, but the software will be converted for use on the transputer array.

Publications

Submitted
Stuart G W & Bossomaier T R J, Cooperative representation of visual borders, *Perception.*

In Preparation
Stuart G W, Bossomaier T R J & Johnson S, Parallel processing of object size.

Bossomaier T R J & Stuart G W, Optical illusions - spurious order out of chaos?

7.11 Highly Reactive Systems with Application to Robotics Operating Software

Principal Investigator: Professor R B Stanton
Department of Computer Science
The Faculties

CISR-funded Investigator: To be appointed

Co-Investigator: Dr B P Molinari & Dr C W Johnson
Department of Computer Science
The Faculties

The project involves developing highly reactive systems with reliable behaviour that are applicable to robotics operating software. The work is planned in two phases:

1. Project initialisation

2. Directed research in selected topics in highly reactive systems.

The first phase is the analysis of the various mechanisms which cause embedded systems constructed from 'conventional' components not to be reliably reactive. The basic descriptive technique to be used will be software levels: the operating system, the programming language and the inference engine of the rule-based layer.

The second phase will involve research into selected areas of this hierarchy consistent with the research interests of the investigators. This will involve:

1. A description of a virtual machine for a high-level programming language (tentatively Modula-2) and its detailed implementation in terms of an underlying real-time operating system.

2. The development of knowledge representation techniques which support partial, or approximate, answers according to time bounded computational resources.

Broadly speaking, the two phases capture the distinction between the lower level software engineering of real-time systems and the problems of effective use of such systems in specific application domains.

Publications

Stanton R B, Wanless D, Molinari B P, Johnson C W & Mackerras P, A planner for time-space coordination of robots in a structured workspace, *Proceedings of IEEE International Workshop on Tools for Artificial Intelligence*, Herndon, Virginia, USA, October 1989.

8. SCHOLARSHIPS

The Centre has funds from two sources, Fujitsu Australia Limited and the CSIRO, to provide scholarships for graduate students in the information sciences. The Management Committee of CISR decides the award of these scholarships.

Fujitsu Supplementary Scholarships In 1987, Fujitsu Australia Limited provided $50,000 p.a. for three years for the award of supplementary scholarships of $5,000 each. A condition of the scholarships is that the candidate must hold either an Australian Postgraduate Research Award or an ANU PhD or Masters degree scholarship or a similar award. Fujitsu scholarships are awarded to candidates of proven ability with the intention of fostering high quality research. By December 1989, six Fujitsu scholarships had been taken up and a further scholarship holder was due to start on course early in 1990. It is hoped that three more scholarships will be awarded in the January 1990 scholarship round. Brief reports on the research activities of Fujitsu scholarship holders follow.

Mr S. Crisafulli, Department of Systems Engineering, RSPhysS
On scholarship from 13 February 1989.
PhD Research topic: Quantization Algorithms for Speech Processing.
Adaptive quantizer algorithms have traditionally been based on heuristics and simulation. In this work the adaptive quantizer problem has been posed as a linear optimal control problem. New algorithms have been derived which give superior performance on real speech to those commonly used at present.

Mr B. James, Department of Systems Engineering, RSPhysS
On scholarship from 29 March 1989.
PhD Research topic: Acquisition and Tracking of a Periodic, Nonsinusoidal Signal in Noise.
Research is being carried out into the amplitude, frequency and phase estimation of multiharmonic signals in noise, such as those received by hydrophones in submarine tracking applications. Initial work on the problem involved applying an Extended Kalman Filter to the received signal. It can be shown that, under certain conditions, the amplitude and phase-frequency estimation problems separate, providing some simplification. Currently, an analysis is being undertaken of the general phase-frequency estimator in order to demonstrate, via computer simulation, phenomena similar to those of classical FM demodulation, e.g. threshold effects, capture regions, etc. Other approaches to the problem have employed Hidden Markov Models, better known for their application to automatic speech recognition. A future task is to make the two approaches coherent, utilising the best features of each.

Mr S. Keronen, Department of Computer Science, The Faculties
On scholarship from 1 March 1988.
PhD Research topic: Natural Deduction Based Logic Programming
The aim of the project is the construction of a logic programming system possessing the following attributes, in contrast to current systems, such as Prolog:
1. A richer fragment of a first order language is available for describing the problem domain and for expressing queries;
2. Knowledge about how to solve problems in the domain can be expressed in logic;
3. The evaluator reasons about its problem-solving activity, creating plans and monitoring the construction of derivations. It has been decided to base this system on natural deduction in preference to the traditional resolution refutation scheme. Natural deduction provides a good representation of derivations as objects. This is important as problem-solving knowledge and planning are intimately related to this representation. A testbed system has been implemented which constructs normal form derivations under user control. The next stage is to focus on finding good abstractions for expressing problem-solving knowledge and making use of this knowledge in planning execution. Run-time structures that make efficient implementation possible will be further investigated.

Mr G.W. Pulford, Department of Systems Engineering, RSPhysS
On scholarship from 13 February 1989.
PhD Research topic: New Channel Equalization Structures.
The work to date has involved a study of various adaptive equalization techniques as well as maximum likelihood sequence estimation with full and reduced state Viterbi decoding. The phenomenon of merging in the Viterbi algorithm is being investigated. A new equalizer structure, the 'Block Decision Feedback Equalizer' is being studied. This equalizer gives performance between that of the ordinary decision feedback equalizer and full MLSE or Viterbi decider depending on the block size. Error recovery analysis in the nonadaptive case is underway and simplified decision devices are being sought to reduce the scheme's complexity.

Ms S. Ran, Computer Sciences Laboratory, RSPhysS
On scholarship from 19 June 1989.
PhD Research topic: Automatic Speech Recognition.
Several areas were explored initially to find a suitable topic for doctoral research. Areas studied included neural networks and spatial data bases. Ms Ran took a course in parallel computing run by CISR and also gained some knowledge of VLSI array processors. At the end of the year she decided to undertake research on automatic speech recognition.

Mr J.M. Riche, Automated Reasoning Project, RSSS
On scholarship from 28 September 1987.

PhD Research topic: Automated Reasoning and Non-Standard Logics.
Research has been carried out on various theorem provers, one of which is the 'Kripke' theorem prover (TP). Work has involved porting different versions of the code (Dec 10, Unix) on the VAX and on the FACOM. The aim was to run the TP on the VP100. After some evaluation of the problems to be faced, mainly due to the unavailability of a Pascal compiler at that time, it appeared that more productive and efficient work could be done on a parallel version of the theorem prover. A production version of this version of the TP has now been prepared for distribution. Research shifted to a Prolog version of the TP and has mainly consisted of improving the efficiency of it through the implementation of a Prolog-C interfacing and internal database and some trials in adapting techniques used in classical theorem proving.

CSIRO Scholarships Shortly after the Division of Information Technology became a constituent research group of the Centre, CSIRO undertook to provide $24,000 p.a. for three years to fund scholarships for graduate students attached to the Centre. Two supplementary scholarships of $5,000 p.a. have been awarded to Mr P.A. Fletcher and Mr W.H. McIlhagga, and a full scholarship of $14,000 p.a. has been awarded to Mr G. Vezina. Brief reports of the research activities of these scholarship holders follow.

Mr P.A. Fletcher, Computer Sciences Laboratory, RSPhysS
On scholarship from 16 January 1989.
PhD Research topic: Image Processing
Research is being carried out on image reformatting techniques on sequential and parallel computers. It is hoped to expand on some algorithms published by Dr Don Fraser of ADFA which allow for many different storage formats to be specified in the same way. The aim is to extend this work by providing the means to map sub-components of image dimensions onto one or two dimensional processor arrays and by producing some parallel and sequential algorithms for resorting an image between any of these formats. A general sequential machine (SUN Sparcstation) and a two dimensional processor array (the MasPar recently acquired by CSIRO) is being used for this work, and it is planned to use a one dimensional processor array currently being designed at the University of Newcastle.

Mr W.H. McIlhagga, Optical Sciences Centre, RSPhysS
On scholarship from 26 February 1988.
PhD Research topic: Human and Machine Vision.
One aspect of Mr McIlhagga's research is the interpretation of line drawings. Humans find it easy to understand line drawings as 3D scenes but this ability has not been emulated by computer programs, except in restricted domains. This project aims at a theoretical and practical understanding of line drawing interpretation in unrestricted domains. The interpretation has been divided into two sequential stages: finding

surfaces and grouping surfaces into objects. Exact algorithms for the tasks of the first stage and some of the second stage have been developed. While they are all NP-problems, there are many simplifications and heuristics (mostly in the form of constraints) which appear to improve the efficiency of solutions.

Mr G. Vezina, Division of Information Technology, CSIRO
On scholarship from 1 September 1989.
PhD Research topic: Visualization using Parallel Image Processing Techniques.
The aim of the project is to develop a portable image processing library for SIMD machines and to use its tools to visualize scientific data. The main emphasis is on surface manipulation and rendering. So far SIMD machines have been thoroughly studied and the MasPar's MP1 has been found to be of particular interest. Some time has been spent on writing down ideas on a visualization framework (VisiTool), on specifying a SIMD model and designing a portable image processing library structure. A set of scan-line primitives has been written in C and MPL.

9. SCHOLARS

When the Centre for Information Science Research was established, provision was made for graduate students in the information sciences to enrol in PhD and Master degree courses (research only) with the Centre. During 1989 CISR enrolled its first two graduate students, Mr M.G. Nagle and Mr G. Vezina. It is envisaged that with the establishment of the Graduate School at ANU during 1990, graduate students in the information sciences will be enrolled in the Graduate Program in Computer Science and Technology, with which CISR will be linked. The research activities of Mr G. Vezina have been outlined above. Below is a brief report on the work of Mr M.G. Nagle.

Mr M.G. Nagle, Visual Sciences, RSBS
Started on course on 10 May 1989.
MSc Research topic: Seeing Aid for the Blind.
Insects navigate extremely well around their environment using a very small amount of processing hardware (neurons). The aim of this project is to copy the principles that insects use to extract enough essential detail from the environment to convey to visually impaired people the information they need to move about. No object recognition or categorization is needed for this task. Conceptually the project can be divided into three major blocks: the input device, the processing unit and the output device. To date most time has been spent on the input and processing stages, but work is now beginning to be concentrated on the output stage.

10. TRAVEL SUPPORTED BY CISR

Apart from funding overseas travel by the Executive Director of CISR and others involved in joint collaboration agreements with Fujitsu, CISR provided travel grants of $2,000 each to Dr M.C. Newey and Dr P. Tang of the Department of Computer Science, The Faculties, to carry out work associated with CISR's interests.

Dr Malcolm Newey made a six week trip in December 1988 and January 1989 to Europe and the USA. One of his aims was to acquire software needed to support the verification project which receives funding from CISR. Dr Newey visited Edinburgh University, the University of Cambridge, the Rutherford-Appleton Laboratory of the Science and Engineering Council in the United Kingdom and Bell Laboratories and Stanford University in the USA from each of which he acquired software on tape. He also had discussions at these institutions and at Princeton University, the University of Rome and at the POPL-89 Conference which radically changed the choice of tools with which to proceed in the verification project. In particular, the decision was taken to move away from the LCF (Logic for Computable Functions) system in favour of the HOL (High Order Logic) system. The first copy of sources for HOL was acquired from Cambridge on this trip.

Dr Peiyi Tang visited the USA for two weeks in September/October 1989. He attended the 13th Annual International Computer Software and Applications Conference where he presented a paper entitled 'A Parallel Linked List for Shared-Memory Multiprocessors' and had discussions with many researchers from both industrial and academic institutions. He then spent a week at the Center for Supercomputing Research and Development of the University of Illinois at Urbana-Champaign where he had been a doctoral student several years ago. There he did some research on data synchronization instruction generation with his former supervisor, Professor P C Yew. He had discussion with other members of the staff and acquired two software tools: MaxPar (an execution-driven simulator for measuring parallelism of Fortran programs) and Parafrase-2 (a tool for parallelizing, partitioning, synchronizing and scheduling programs on multiprocessors).

11. LECTURES, SEMINARS, WORKSHOPS

Two visitors to the Centre gave open lectures to members of the University and other interested persons during 1989. Professor Terrence Sejnowski from the Salk Institute at San Diego, USA, spoke on 'Computational Neuroscience' on 22 September as part of the Robertson Symposium organised by the Centre for Visual Sciences.

Professor Alan Robinson from Syracuse University, New York, gave a lecture entitled 'Computation, Logic and Thought: The Mechanisation of Deductive Reasoning' on 23 November. Professor Robinson spoke about the problem of building machines capable of reasoning deductively. He outlined the history of attempts to solve the problem, surveyed the current technology and assessed the prospects for the future.

In connection with the establishment of the Argonne link, making CISR the first international affiliate of the Advanced Computing Research Facility, Professor Ewing Lusk of ACRF visited the Centre in November. During his visit he gave a seminar on 'Parallel Computing. Logic Programming and the Human Genome Project: Recent Activities at Argonne National Laboratory'.

A three day workshop on Programming Parallel Computers was held on 8-10 August. The new Sequent S27 parallel computer was the main machine used and participants were given 'hands on' experience. The course was conducted by members of three constituent research groups of CISR: the Automated Reasoning Project, the Department of Computer Science and the Computer Sciences Laboratory. They based it on one regularly given by the ACRF at Argonne, and used the book by Lusk et al., *Portable Programs for Parallel Processors*, but they supplied additional notes and articles and enhanced the course in various ways. The workshop was well attended and will be given again at intervals in response to demand.

12. VISITORS IN 1989

Professor J von zur Gathen (jointly with the School of Mathematical Sciences)
University of Toronto, Canada
Three months from 1 March 1989

Professor E Lusk (jointly with the Automated Reasoning Project, RSSS)
Advanced Computing Research Facility
Argonne National Laboratory, USA
Three weeks in November 1989

Professor J.A. Robinson (jointly with RSSS)
Syracuse University, USA
Four weeks in November 1989

Mr H. Sawamura (jointly with RSSS)
International Institute of Advanced Studies in the Social Information Science)
Fujitsu Ltd, Japan
One year from 21 September 1989

Professor T.J. Sejnowski (jointly with Visual Sciences Centre)
The Salk Institute, San Diego, USA
One week from 19 September 1989

Professor Li Xiang (jointly with RSSS)
Guizhou University
People's Republic of China
Six months from 24 September 1989

APPENDIX 1: CISR AFFILIATE MEMBERSHIP TO 30.11.1990

Division of Information Technology, CSIRO
Dr D Abel
Dr T Freeman
Dr H Mackenzie
Dr P Robertson
Dr J Smith

Division of Radiophysics, CSIRO
Dr N Fletcher

Developmental Neurobiology, RSBS
Dr K G Hill

Visual Sciences, RSBS
Dr M V Srinivasan

Computer Sciences Laboratory, RSPhysS
Dr T R J Bossomaier
Dr I D G Macleod
Dr J B Millar
Dr H Schröder

Department of Applied Mathematics, RSPhysS
Dr S Marcelja

Department of Systems Engineering, RSPhysS
Dr R R Bitmead
Professor J B Moore
Dr M Niedzwiecki
Dr D Williamson

Automated Reasoning Project, RSSS
Dr R A Girle
Dr J K Slaney
Dr E P Martin
Dr P Thistlewaite

Department of Philosophy, RSSS
Dr R Sylvan

Department of Computer Science, The Faculties
Dr C W Johnson
Dr B P Molinari
Dr A V Peterson
Dr B D McKay
Dr M C Newey
Dr J M Robson

Department of Philosophy, The Faculties
Professor N W Tennant

APPENDIX 2: STAFF APPOINTED TO CISR RESEARCH PROJECTS

Name	Date Appointment Began
Dr C H Brink Senior Research Fellow Automated Reasoning Project RSSS	31 December 1988
Dr D R Colaco Osorio Research Fellow Visual Sciences RSBS	2 October 1989
Dr R A Kennedy Research Fellow Department of Systems Engineering RSPhysS	19 December 1988
Dr P M Lenders Research Fellow Computer Sciences Laboratory RSPhysS	5 September 1988
Mr M G Nagle Senior Technical Officer Visual Sciences RSBS	10 May 1988
Mr G F Quinn Programmer (Half-time) Division of Neuroscience JCSMR	21 May 1989
Dr G W Stuart Research Fellow Centre for Visual Sciences	6 March 1989