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University of Edinburgh

Department of Computer Science

The IMP-77 Language

by

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UNIVERSITY OF EDINBURGH

DEPARTMENT OF COMPUTER SCIENCE

Departmental Handbook

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INTRODUCTION

The Department of Computer Science was created in 1966 when the then Computer Unit was sub-divided as a consequence of the Flowers Report on computing for the Universities and Research Councils. The Department inherited responsibility for teaching and research in Computer Science. There already existed a Postgraduate Diploma and a first-year course in the subject, together with a major research and development project, the Edinburgh Multi-Access Project, from which sprang the interactive computing system (EMAS) which provides the service now enjoyed by the University. The Flowers Report established major Computing Centres at Edinburgh, London and Manchester and the Edinburgh Regional Computing Centre was soon active in the role of providing service to the University and research institutes in the Edinburgh area.

As funds became available, the Department purchased its own small computers and the number of staff was increased from the original half-dozen. Second and third year courses were introduced in 1968 and 1970 - the latter made possible by the co-operation of the Mathematics Department in setting up a joint Honours school. At this time the Department moved to new accommodation in the James Clerk Maxwell Building, thereby acquiring the laboratory space required for the kind of teaching that it regarded as central to courses in Computer Science. By 1972 it became possible to launch a Final Honours year in the subject and an Honours degree in Computer Science alone became available. Joint degrees with Electronics, Management Science, Physics and Statistics are also now available. Undergrduate teaching was expanded in 1980 to provide a general first-year course Information Systems. In 1978 an M.Sc. course in Computer Systems Engineering was started and this is now part of the modular M.Sc. programme within the School of Information Technology.

Since then, teaching effort has been devoted to improving the structure and content of the course, not least as a result of the feedback from the first contingents of students to go through it. The Department has been fortunate in the level of support it has been able to achieve and the laboratory facilities have been continuously upgraded.

On the research side, the project on multi-access systems came to an end and was largely replaced by work on software for mini-computers. Early work on Computer-Aided Design has now been succeeded by a group actively working on design methodology for Very Large Scale Integrated (VLSI) circuits. In the last few years, work in the field of Theory of Computation has expanded and this is now a major research focus. Other areas include distributed systems, communications, graphics, advanced personal machines, databases and micro- processor control.

The Department is housed in the James Clerk Maxwell Building at The King's Buildings, which is the Science campus at Edinburgh University situated about two miles from the city centre. Few would claim that the appearance of the building is worthy of Edinburgh's architectural tradition, but it does provide extensive and modern accommodation for the six departments which occupy it, including lecture theatres, machine halls, a library and common-rooms.

UNDERGRADUATE DEGREES IN COMPUTER SCIENCE

Directors of Studies: R. Candlin, A. Wight, F. Stacey

Several Honours degrees are available at Edinburgh; a single Honours degree in Computer Science, and five joint Honours degrees in which Computer Science is combined equally with another subject. The following degrees are offered:

Computer Science
Computer Science & Electronics
Computer Science & Management Science
Computer Science & Mathematics
Computer Science & Physics
Computer Science & Statistics

An Honours degree normally lasts four years. During each of the first two years, students take three subjects, of which one is Computer Science. Students who intend to take a joint degree also have to take prescribed courses relevant to that subject. There is usually the possibility of taking one or two "outside" subjects, which are not essential components of a given Honours course, but which give students the opportunity to broaden their interest. In their final two years, students follow courses in their chosen speciality.

The degree structure is very flexible, and students can to a certain extent keep their options open until the end of their first or second year, as far as their choice of degree is concerned.

For example, a student registered for a joint degree can easily change to a single Honours degree in one or other component by opting to do so at the beginning of the third year. Note however that it is not possible to switch from Computer Science and Management Science to a B.Com. degree in Social Science. Many students take the first and second year courses of Computer Science as outside subjects for other Honours degrees (for example in Engineering or Business Studies). In some cases, they become so interested in Computer Science that they decide to transfer to Computer Science Honours. This can usually be done quite easily, provided that Computer Science has been included as a subject from the first year.

Computer Science is often an important component of the Ordinary B.Sc. degree, which provides a three-year course for those who do not wish to specialise. A recently introduced compromise between the unspecialised Ordinary B.Sc. degree, and the highly specialised Honours degree is the Ordinary B.Sc. in a designated discipline. For this degree, students continue their study of Computer Science into their third year, by following selected parts of the full Honours course.

Overall course description

For their first two years, students spend one third of their time on Computer Science. Many students have had experience of working with computers at school, but there are many who have not, and the first year forms a broad introduction to the subject. From the very first, students are expected to obtain a practical experience of using a computer, which in this case is the University's large multi-access system, 2900 EMAS. In the second and subsequent years they have the opportunity of working with a variety of other computer systems ranging from the Department's VAX multi-access system, down through small mini-computers, to microprocessor systems. In the early years, students write software for existing hardware configurations; later they construct their own hardware from standard

POSTGRADUATE STUDENTS - FULL-TIME Ph D/M Phil

Marek Bednarczyk	Logics of programming.
David Berry	Functional programming.
Gavin Brelstaff	Computer vision.
Ilaria Castellani	Concurrent processes and their semantics.
Murray Cole	Architectures for concurrent language implementation.
Frank Cringle	VLSI design methodology.
Mark Davoren	Distributed computing systems.
Alex Deas	VLSI design methodology.
Tatsuya Hagino	Theory of computation.
Tom Horton	Stylometry of 16,17 and 18th century poetry and drama.
Martin Illsley	Programming methodology and correctness.
Laurent Langlois	VLSI design methodology.
Kim Larsen	Theory of computation.
Richard Marshall	The construction of silicon compilers.
George McCaskill	Incremental programming environment for VLSI.
Eugenio Moggi	Theory of computation.
Ian Nixon	VLSI design methodology.
K.V.S.Prasad	Theory of computation.
Brian Ritchie	Programming languages with concurrent processes.
Oliver Schoett	Theory of computation.
Alistair Sinclair	Computational complexity: probabilistic models of computation.
Allen Stoughton	Semantics of concurrent languages.
Mads Tofte	Operational Semantics.
Rod Widdowson	VLSI design methodology.
Eric Wilson	Computational stylometry.

components, and have the opportunity to design their own VLSI chips.

Throughout the course, emphasis is laid on the idea that a computer system is a fusion of hardware and software design. The fundamental ideas behind computers and computing can also be represented in mathematical terms, and this abstract and theoretical treatment forms an important part of the third and fourth year courses.

Assessment

There is a written examination in June each year, which is referred to as a "degree" examination. Passes in the first, second and third years are counted towards an ordinary B.Sc. The Honours degree is awarded on the basis of the third and fourth year examinations. In all these examinations, work carried out during the year contributes towards the assessment.

In the first three years there are also less formal "class" examinations during the year, which enable students to check their own progress.

Entry Requirements

Prospective students must satisfy the University's "general entrance requirement", which demands a certain level of achievement over a range of subjects. Details can be found in the University Undergraduate prospectus. For most Computer Science Honours courses, qualifications above the minimum are required. Each application is considered on its own merits, but as there are more applicants than places, a good standard of performance in Higher or A-level examinations has become necessary for an applicant to be offered a place. In the past, grades of AABB at Higher, or BBC at A-level have been required. There is a considerable amount of mathematically-based material taught in the third and fourth years, so we require a student to have gained a good grade in Mathematics at higher or A-level. Applicants for joint degrees must of course satisfy the requirements of the other subject as well. In exceptional circumstances it may be possible to admit candidates whose background does not match the above requirements.

Admissions

Candidates for undergraduate degrees must apply through the Universities Central Council on Admissions. The UCCA Handbook - 'How to Apply for Admission to a University' - and an application form may be obtained from schools or from:

The Secretary,
UCCA,
P.O. Box 28,
CHELTENHAM, GL50 1HY

Further enquiries about admission should be addressed to:

Faculty of Science Office (Admissions),
University of Edinburgh,
West Mains Road,
EDINBURGH EH9 3JZ

COMPUTER SCIENCE 1

Aims - The aims of the course are principally
-- To develop skill and knowledge in computer programming;
-- To understand and classify the algorithms (i.e. methods) which underlie all computer programs;
-- To group some of the great variety of structure present in the data handled by computer software;
-- To study the main hardware and software components which go to make up a typical computer system.

The main vehicle for this work is PASCAL. In the first half of the course this programming language is learned in depth and used as a medium for expressing solutions to non-trivial computing problems. Later the emphasis gradually becomes more abstract, more concerned with the structure and design of both the algorithms and the data objects which are expressible in the language.

Topics
Basic principles and Programming
Computer Systems
Data Structures
Programming Techniques and Other Languages

COMPUTER SCIENCE 2

There are three "fat" half courses available: Computer Systems in the first half of the year, Foundations and Real-Time Systems in the second half. Depending on the intended degree students take

Computer Systems + Foundations
or Computer Systems + Real-Time Systems

Some students may take all three half courses.

Computer Systems 2h - This half course continues the study of programming and computer architecture begun in Computer Science 1.
Topics - Programming in the applicative language ML, Compilers, Computer Graphics, Computer Systems.

Foundations 2h - An introduction to some of the basic mathematical ideas required for a formal treatment of computer hardware and software systems.
Topics - Mathematical Foundatins, Automata, Semantics and Program Verification, Design and Analysis of Algorithms.

Real-Time Systems 2h - An introduction to the characteristics of real-time systems and techniques for implementing them. A study of the industrial application of computers for control and scheduling.
Topics - Real-Time programming, The Computer and its Environment, System Control, Industrial Applications.

SECRETARIAL STAFF

Heather Carlin	Secretary to Head of Department (part-time)
Kate Duncan	Secretary to Professor Michaelson
Alison Fleming	Secretary/typist
Eleanor Kerse	Secretary to Professor Burstall
Dorothy McKie	Secretary to Professor Milner (part-time)
Margaret Melvin	Secretary/typist (part-time)

TECHNICAL STAFF

Ian Conkie	Junior technician
John Dow	Maintenance manager
Jimmy Johnstone	APM production
Peter Lindsay	Real-time systems
Ian Mathers	APM servicing
Michael Warburton	Communications installation and maintenance

RESEARCH STAFF

Neil Bergmann	VLSI
John Cartmell	Programming methodology
Bob Harper	Machine assisted proof
Kevin Mitchell	Machine assisted proof
Andrew Morton	Stylistic Analysis
Janet Procter	VLSI
George Ross	Computer systems, graphics and personal machines
Don Sannella	Programming methodology
John Scott	Machine assisted proof
Niklas Traub	VLSI
Xu-Sheng Zhang	VLSI
Andrew Zisserman	Computer Vision

Robin Milner	Professor. Semantics of programming languages. Application of mathematical logic to formalise the statement and proof of assertions concerning programs. Abstract models of concurrent computation.
Moira Norrie	Lecturer. Operating Systems. Database systems.
Gordon Plotkin	Reader. The denotational semantics of programming languages with emphasis on concurrency. Computational and inductive logic.
Rob Procter	Lecturer. Micro-computer systems. New technology for graphical devices. Social impact of computers.
David Rees	Senior Lecturer. VLSI deisgn and associated design tools. Design and implementation of multi-access operating systems.
Peter Schofield	Senior Lecturer. Chairman of Department. Programming techniques. Data structures.
Frank Stacey	Lecturer. Systems software, combinatorial mathematics, parallel computation.
Alex Wight	Lecturer. Computer performance evaluation. Computer systems modelling. Workload characterisation. Capacity planning. Network performance.

COMPUTING OFFICERS

David Baines	Software development and maintenance for real-time systems teaching.
John Butler	APM systems. Real-time systems teaching.
George Cleland	Management of VAXes.
Kathy Humphry	First year teaching (part-time).
Fred King	Hardware design for APM. Hardware and software for very high performance personal computers.
Man-Chi Pong	Software systems. Programming environments. Interactive computer graphics.
Alistair Scobie	CAD tools.
Rainer Thonnes	Maintenance and development of communications and system software. CAD.

COMPUTER SCIENCE 3

Introduction - The full-time third year course provides a basic foundation for the design and implementation of computer systems. The software oriented lectures concentrate on the overall design of software systems and their interaction with the underlying hardware. The hardware lectures reflect recent developments in methods of hardware implementation. Throughout the course the theoretical foundations of computation are examined.

Structure - The eight lecture modules each consist of 18 lectures. There are two major practical exercises associated with the other six modules. Joint Honours courses include a subset of the lecture modules and practical exercises. While the practicals are set in relation to the particular courses, students are encouraged to read as widely as possible and draw from their experience in other courses. Both examinations and coursework are assessed. A combined figure is carried forward to be used together with the final Honours year assessment in awarding the appropriate class of degree.

Lecture Modules

Computer Structures 1 - Detailed anatomy of computers. Microprogramming. Gate level primitives and logic design. Implementation methods including VLSI. Computer arithmetic. I/O mechanisms and bus organisation.

Computer Structures 2 - The influence of high level languages and systems on mainframe architecture. Evolution of the microprocessor. Asynchrony. The influence of technology on architectures. Cost and performance evaluation. The computer as an embedded component. Micro-computers in systems.

Formal Languages and Computability - Finite Automata and Regular Languages. Context Free Languages. Turing machines. Undecidability, the Halting and other problems. Simulation arguments.

selection problems. NP-completeness. Fast algorithms for multiplying integers and polynomials. Discrete Fourier transform. Matrix problems, algorithms and reductions.

System Modelling - Probability. Queueing theory. Markov processes. Network models. Discrete-event simulation. Pseudo-random numbers. Statistical analysis of simulation results.

Programming Methodology - Program design. Formal and informal specification. The ML language. The ADA language and project.

Operating Systems - Concurrent processes and their synchronisation. Virtual addressing. Operating system kernels. Design and implementation of time- sharing multi-access systems. Single-user systems.

Database Systems - Roles, functional requirements and application design. Data models - relational, network and functional. Access structures. Query processing.

Major Practicals

Operating Systems. Microprogramming.

COMPUTER SCIENCE 4

Introduction- The final year honours course in Computer Science is intended to provide students with an opportunity to:
- Add to the core curriculum of the first three years;
- Study subjects from earlier years to greater depth;
- Undertake a project involving a major implementation or research work.

Assessment - For full-time Computer Science students the following restrictions apply:
- VLSI Design is compulsory;
- One Theory of Computation course is compulsory;
- Digital Communications is compulsory;
- At least two and at most three other courses must be done.

Restrictions for joint degrees vary, depending on the other subject. Assessment is based on two equal parts, namely the best five results and the project. Honours are awarded on third and fourth year results.

Courses

Advanced Graphics - The course consists of a section of core material followed by a choice between two further sections. The core aims to teach fundamental techniques for generating line-drawings and realistic shaded images of three- dimensional scenes. One of the further sections extends this to include "ray-tracing" techniques colour and texture. The other section discusses software design of CAD systems and window managers.

Compiler Techniques - The course explores some of the issues involved in the production of a service compiler, with particular emphasis on factors which affect the speed of compilation, the quality of code produced and the usefulness of the error reports. The major factors considered are the problems caused by particular language features and particular machine architectures.

Computational Complexity - Machine-based complexity theory involves studying the resources, primarily time and space, required to solve problems using computing machines.

Computer Systems Performance Evaluation- The problems of measuring, predicting and improving the performance of computer systems. Tools, techniques, workload characterisation and capacity management.

Conceptual Modelling - Data modelling, knowledge representation and data abstrction in programming languages. The use of conceptual models in database design.

Denotational Semantics- Valuation functions; semantic domains; lambda notation; sequential execution; recursion and fixed points; side-effects; jumps and continuations; environments, stores and declarations; standard semantics.

Digital Communications - The techniques used to implement networking, starting from transmission of data bits along physical connections and building up to the distribution of computations over many processors. Local and wide-area networks.

The Theory of Communicating Systems - The course discusses the formalisation of languages for the specification of concurrent systems where several independent but interconnecting processes are active.

Very Large Scale Integrated Circuit Design - MOS devices and circuits. Integrated system fabrication. Data and control flow in systematic structures. Circuit topology. Patterning geometry. Wafer fabrication. Overview of an LSI computer system. Architecture and design of system controllers.

VLSI Circuit Design Practical- The goal of this practical course is the design of a digital subsystem using the VLSI design techniques introduced in the VLSI Circuit Design lecture course.

MEMBERS OF STAFF

TEACHING STAFF

Andrew Blake	Lecturer and Royal Society/IBM Research Fellow. Computer vision: description by computer of visible surfaces.
Gordon Brebner	Lecturer. Computational complexity. Parallel computation. Computer networks. VLSI layout algorithms.
Irene Buchanan	Lecturer (part-time). Computer-aided design and VLSI.
Rod Burstall	Professor. Programming methodology: correctness proofs, program transformation, specification languages. Semantics using an algebraic/categorical approach.
Rosemary Candlin	Lecturer. Introductory teaching. Specialised micro-processor systems. Real-time systems.
John Gray	Lecturer (part-time). Computer-aided design and VLSI.
Igor Hansen	Lecturer (part-time). Microcoded hardware description and analysis. Computer system architecture. Micro-programmable processors for graphics, communications and high level languages. Multiprocessor systems.
Matthew Hennessy	Lecturer. The mathematical semantics of programming languages and the design of program-oriented logical proof design.
Roland Ibbett	Professor (from 1/7/85). Computer architecture, local area computer networks.
Mark Jerrum	Lecturer. Complexity of computation: combinatorial algorithms, algebraic models of computation.
Kyriakos Kalorkoti	Lecturer. Complexity of computation, algebraic models of computation.
Clemens Lautemann	Lecturer. Complexity of computation, probabilistic algorithms.
David McCarty	Lecturer (jointly with Epistemics). Mathematical logic. Theories of computation.
Eric McKenzie	Lecturer. Computer architecture, VLSI and graphics.
Sidney Michaelson	Professor. The study of literary style with special reference to problems of authorship and chronology. Queue-related models of computing systems. Distributed computing systems.
George Milne	Lecturer. Formal models for the description of circuit behaviour.

COMPUTING FACILITIES

The Department is rapidly moving to the point where the principal computing facility will be powerful personal work-stations with common filestores on an Ethernet-type communication network. These advanced personal machines were designed in the Department and 50 are now in service in offices and public areas. Another 14 are being built. The machines are currently based on an M68000 processor and 2 megabytes of memory. Some are equipped with fast high-resolution graphics processors.

The workstations use central filestores rather than local disk storage. There are currently 3 of these filestores, also based around 68000 processors, providing close to 1 Gigabyte of file space.

The other substantial departmental computing facility is a VAX 11/780 housed in the Department's machine halls. This machine was installed at the end of 1978 and has since been upgraded to 4 Megabytes of main store and 1200 Megabytes of disk storage. It supports a maximum of around 40 simultaneous users under the VMS operating system and is connected to both the Departmental and ERCC networks. The main languages available are Pascal, IMP, ML and Fortran.

Other research machines include a VAX 11/750 running UNIX, a SUN 2/120 running UNIX and 5 PERQs. There are also three high-quality graphics terminals based on PDP-11 processors.

The Department and ERCC were jointly concerned with the setting up of the micro-computer laboratory in the Appleton Tower of which the Information Systems course is a major user.

The Real-time systems laboratory is situated in the machine halls and is equipped with a variety of mechanisms and microprocessor prototyping kits which are used for experiments in automation. There is also a well-equipped electronics workshop which contains a selection of electronic measuring equipment and hand tools.

The computing facilities provide access to a variety of special-purpose peripherals including high quality laser document printers, plotters and two robot arms.

For first year teaching and certain specialised applications, the department also uses the main University computing service provided by the Edinburgh Regional Computing Centre. The principal mainframe facility is the twin ICL 2976 system housed in the James Clerk Maxwell Building. This installation runs the Edinburgh Multi-Access System (EMAS) to support in excess of 100 simultaneous users at interactive terminals sited throughout the University and connected by a local network. Two ICL Distributed Array Processors are attached to this system. The network also permits access to a number of other processors, including another large ICL 2900 (EMAS) installation, an Amdahl V7 (EMAS) (available October 1985) and to a variety of devices such as printers, plotters and type-setters.

INFORMATION SYSTEMS 1

The motive in presenting this first level course is to increase the number of people in society who are well informed about computers. Decisions about the applications of computers cannot become or remain the prerogative of the computer scientists alone. It is important that future managers, politicians, lawyers, doctors, journalists etc, should be well equipped to make or influence such decisions. It is the aim of this course to nudge them into taking an interest in this field and initiating them into the acquisition of the relevant knowledge. Students from any faculty, in any year with any background (other than having already attended a Computer Science course) will be welcome.

Topics -
Computer Technology, Pascal Programming, Computer Operating Systems and Tools, Computers and Society, Principles of Information Retrieval, Graphics, Large Scale Systems, Management Information, Computing and the Professions, Natural Language and Speech, Expert Systems.

POSTGRADUATE STUDY

The Department offers facilities to study for the Research degrees of **M Phil** and **Ph D** and to participate in a course leading to an **M Sc** degree in Information Technology: Computer Systems Engineering.

Postgraduate Admissions - For further information or application forms, write to:-

Miss Eleanor Kerse,
Department of Computer science,
University of Edinburgh,
King's Buildings,
Edinburgh EH9 3JZ,
Scotland or phone (031) 667-1081, ext: 2782

RESEARCH DEGREES

For the Research degrees, the normal period of registration is two years for the **M Phil** and three years for the **Ph D**. Candidates are normally registered in the category of 'Supervised Postgraduate Student' for the first year of study, prior to transfer to the degree course considered appropriate, with back-dating of registration.

During their first year, postgraduate students are expected to participate in an appropriate study programme. For those interested in computational theory a specific course is provided. Students intending to pursue systems and other research may be directed to particular advanced courses, and are expected to participate in postgraduate study seminars. It is normally expected that, during their first year, students will focus their attention on one of the programmes of research being pursued within the Department. Some accommodation of interests is possible, but it is usually in the student's interest to be associated with one of the existing active research areas.

M Sc in INFORMATION TECHNOLOGY: COMPUTER SYSTEMS ENGINEERING

Introduction- This one-year postgraduate course consists of eight lecture modules examined by written examinations followed by a full-time project of six months duration examined by dissertation. A minimum of four lecture modules are chosen from those offered by the Computer Science Department. The remainder may be chosen from any of three departments: Computer Science, Electrical Engineering and Artificial Intelligence.

Course Modules

VLSI design (I and II) (two modules)
CAD tools for VLSI
Digital Communications
Programming techniques and software tools
Introduction to operating systems
Modelling and system performance
Database systems
Advanced graphics

In addition to the modules above the following modules are available from other Departments within the School of Information Technology.

Department of Electrical Engineering-
Silicon wafer fabrication (I and II)
LSI circuit design (I and II)
Microprocessors
Test and reliability.

Department of Artificial Intelligence-
Artificial intelligence programming (I and II) (Prolog and LISP)
Natural language processing techniques
Expert systems
Machine vision
Robot control.

Part-time study - There are two possible schemes of part-time study spread over a period of up to three years.

composition can be verified for correctness.

Hardware Verification

Hardware verification is a research area of increasing importance due to the technological advances of VLSI fabrication and the resulting complexity of potential designs. Techniques are being developed which allow the correctness of a circuit design to be established by mathematical proof prior to fabrication. Central to this formal approach to circuit validation is a behavioural model in which to naturally and accurately represent the inherent concurrency of circuit behaviour.

Current research, funded by the Alvey Directorate(Software Engineering) explores the modelling capabilities of CIRCAL, a model of concurrent systems, both hardware and software, developed by George Milne. This has resulted in the discovery of a number of powerful validation techniques which allow both verification by proof and validation by simulation to be performed in a way which reflects the constructive, modelling philosophy adopted.

Behavioural Languages for VLSI Design

This project is funded by the Alvey Directorate(VLSI) and involves the collaboration of Edinburgh University (George Milne et al) with Ferranti Electronics Ltd and Lattice Logic Ltd.

New VLSI design languages are required to support the design of verifiably correct devices using both manual and automatic design techniques. Such languages should permit the expression of behaviour as well as structure with the design process being viewed as the iterative replacement of behaviour by structure. A hierarchical design methodology is adopted with every design step requiring to be shown to be correct; that is the design meets its specification.

Related research involves the design of correct silicon compilation algorithms where the correctness of the mapping algorithm ensures that the class of automatically generated designs are correct with respect to their source code specifications. This research builds on work done by George Milne and others at Edinburgh on models of concurrent computation.

SEMANTICS of NON-DETERMINISTIC and CONCURRENT COMPUTATION

This research, which is being conducted by Robin Milner, Gordon Plotkin, Matthew Hennessy and Colin Stirling concerns the foundations of non-deterministic and concurrent computation. The aim is to provide a uniform framework containing mathematical models for the intuitive ideas of an event, of process communication and of synchronisation. The mathematics involved is continuous, as advocated by Scott, and uses tools from algebra and category theory.

STYLISTIC ANALYSIS

Stylometry has been defined as the scientific study of the usage of words in an attempt to resolve literary problems of authorship and chronology. The traditional methods of stylistic analysis have often been based upon subjective evaluation of internal textual evidence, often with unsatisfactory results. With the availability of computers as tools, new ideas have burgeoned and new approaches to these age-old problems have led to an increased need for statistical analysis of observational data. For example, it has now become practicable to study the usage of the most common words (such as determiners, conjunctions and prepositions) in a text: because of their number, such function-words have previously been neglected by literary scholars. Study of the positions of such words within the sentence or the poetic line has revealed that authors can be distinguish problems of authorship and chronology is being brought into being by the study of such habits of composition.

Before any new technique is applied to disputed texts, it must be tested on texts of known provenance - as with other observational sciences. A wide range of texts is available for such testing, as well as an ever-growing collection of unanswered questions ranging from the composition of the Iliad to disputed wills in the U.S.A. Recent work has concentrated on the thorny problems of authorship of Elizabethan and Jacobean drama and on the development of techniques for investigating poetry as well as prose.

This research into the methodology of answering such questions necessarily involves the development of further techniques and associated software. The amounts of data to be handled are often large and the processing poses interesting problems for the computer scientist.

This work is being carried out by Sidney Michaelson, Andrew Morton and two research students.

VERY LARGE SCALE INTEGRATION

The two main themes of activity are firstly Compter Aided Design (CAD) tools and secondly Formal Verification techniques. In addition, however, VLSI architectures for concurrent systems are attracting increasing interest and this may become a more significant aspect of the research in the future.

CAD

The work in this theme is led by David Rees and the overall aim is towards Silicon Compilation. That is, systems which accept high-level descriptions of either the structure or the required behaviour of circuits and from them synthesize complete designs ready for fabrication. Considerable progress has already been made in this direction. Two such silicon compilers have appeared. The so-called 'First' silicon compiler was aimed at bit-serial signal processing applications (produced jointly with the EE department) and 'U2' which is aimed at nucleonic instrumentation applications. Work is also in progress at an intermediate level of the design process, that of textual language based composition systems which specify the floorplanning and layout of chips in such a way that

POSTGRADUATE STUDY PROGRAMME IN COMPUTATION THEORY

Outline and purpose of the programme

The Department of Computer Science at Edinburgh University offers a postgraduate study programme in the Theory of Computation, both pure and applied. In their first year, students attend an informal course of about 150 lectures, plus seminars, designed to give them a suitable grounding for research in this area. As the first year proceeds they are also guided towards a research topic.

These lectures are open to all, and a small number of one-year visitors and non-graduating students, who wish to attend but not to register for a degree may be accommodated.

Students require considerable mathematical training, for example an undergraduate degree in Mathematics, Mathematics and Computer Science or Mathematical Physics. Some computing experience is expected but a substantial knowledge of Computer Science is not a requirement.

The aim is to develop skill in applying mathematical ideas to computing problems, notably the proof of properties of programs, the quantitative analysis of algorithms, the complexity of computing tasks and the semantics of programming languages. Much progress has been made in the last ten years using ideas from mathematical logic, algebra, analysis, recursion theory, combinatorics and other branches of mathematics. This work is now beginning to affect methods of developing reliable and efficient software. Students will develop both mathematical understanding and practical programming skills.

Course Structure

The lectures, numbering about 150 in all, are given in the Autumn term and early Spring term, and are divided into three broad sections: Complexity, Program Methodology and Semantics. More advanced topics are covered in seminars in the second half of the Spring term. Theoretical and programming exercises are set in conjunction with the lectures. Most of the formal teaching is finished by Easter, to enable students to concentrate fully upon their research topics thereafter.

Topics -

Complexity- Analysis of algorithms. Computational complexity. Algorithmic graph theory. Research surveys.

Program Methodology - Program design. Formal tools for program development. Program logics and automatic deduction. Program specification. Prolog.

Semantics - Denotational semantics. Theory of communicating systems. Domains. Algebras and categories. Models of parallelism. Operational semantics.

RESEARCH

COMPUTATIONAL COMPLEXITY and ALGORITHMS

This research, carried out by Gordon Brebner, Mark Jerrum, Kyriakos Kalorkoti and Clemens Lautemann studies the fundamental limits on the resources such as time and space used by computations. Topics explored include a unified algebraic theory of the complexity of algebraic and combinatorial problems, general purpose parallel computers, algorithms with good probabilistic behaviour, and upper and lower bounds on problem complexity.

COMPUTING SYSTEMS,GRAPHICS and PERSONAL MACHINES

The Department has been active in basic system software - operating systems and language support - over many years. More recently it has built up expertise in the area of hardware design and implementation, particularly in relation to local area networks, micro-programmed controllers and high-speed processors. These strands have been drawn together in a Departmental project, now well advanced to implement a complete modular computer system. This provides substantial local computing capability but relies on a network for services such as filing and printing.

A major aim of this development has been to provide maximum flexibility of configuration, so that it would be possible within the overall framework to experiment with a variety of architectures and processors. Accordingly , the system is conctructed round a high-performance memory bus, shareable by several processors and permitting easy expansion of memory capability. The bus supports full 32-bit data operands and 32-bit (byte) addresses, with separate data and address lines.

What we are calling the Advanced Personal Machine is one version of this system. The basic version of the APM has a single processor board utilising the Motorola 68000 microprocessor chip, memory as required up to 8 megabytes and a network controller board providing access to an ethernet-type Local Area Network. Usually the system will be configured with a graphical processing capability, which provides bit-map graphics under the control of a micro-programmed controller. In due course the processing capability of the system will be enhanced by the provision of separate user-level processor boards, with the basic processor board retained as an input/output controller and diagnostic monitor. Because of the generality of the design, the system is not tied to one particular microprocessor range and plans for user level processors await the availability of 32-bit processors with satisfactory arrangements for supporting virtual memory. We shall also see the machine used for experimentation with novel architectures.

The operating system for the Advanced Personal Machine is aimed at matching the modularity of the hardware. It consists of a small core concerned with process creation and synchronisation, together with an open-ended set of facility modules, selectable at will according to configuration and user requirements. This approach permits a number of different user interfaces to be provided and its extension to provide support for complete alternative operating systems is now being investigated. Emphasis is being laid on designing the programming support invironment on a multi-lingual basis, at least to cover a family of broadly similar languages.

The distributed system now provides the major contribution to the Department's computing power and supports a large part of the teaching and research of the Department.

The recent appointment of a Professor whose special area is computing hardware will expand research interests to include supercomputers and very high speed networks.

COMPUTER VISION

Computer vision research is concentrating on the theme of the "2 1/2 D sketch" - generation of descriptions of visible surfaces from stereo images. The aim is that 3D vision processes should be able to recognise objects by matching stored object-models to such surface descriptions.

The project is led by Andrew Blake and involves Andrew Zisserman and a Ph.D. student funded by a CASE award with IBM(UK). The work is part of a large multi-site ALVEY project in AI/IKBS vision. This project, which involves both industrial and academic collaborators, is investigating the interpretation by computer of stereo and moving images. Expected applications include automatic assembly and vehicle guidance systems.

MACHINE-ASSISTED PROOF

Previous projects designed LCF, a fully interactive proof system in which properties of computations (for example, of programs) may be rigorously verified by a mixture of automatic and interactive methods.

The most recent project, carried out under the direction of Robin Milner , focussed upon case-studies of proof. The main aim was to evaluate the LCF methodology, consisting principally of (1) the organisation of problems and problem areas in a hierarchic structure of theories, and (2) the use of a powerful metalanguage ML (a high-level programming language in its own right) to raise the quality of interaction by programming and combining partial proof strategies. Of particular interest were the verification of compilers and parsers, and establishing properties of useful abstract types. Completed studies are: the verification of a simple but non-trivial compiler, the modelling and analysis of Backus' FP systems, and the investigation of some abstract data structures (for example, binary search trees). Further projects are planned to continue this work.

PROGRAMMING METHODOLOGY

This project, carried out by Rod Burstall, Don Sannella, John Cartmell and postgraduate students, is funded by the SERC. The main topics are :-

a) Specification of problems and development of programs. We have developed specification languages such as Clear and ASL. We have studied the techniques for formal development of programs from specifications so as to obtain programs which are guaranteed correct relative to the specification.

b) Advanced programming languages, with particular emphasis on functional programming and modular structure of large programs. We have worked on ML and Pebble, both strongly typed functional languages. ML is the intended vehicle for much of our research work and Pebble is a kernel language developed with Lampson of DEC System Research Center, Palo Alto.

c) Applications of algebra and category theory. We have studied applications to program specification and development categorical programming and the categorical formulation of algorithms.

SEMANTICS of ABSTRACT DATA TYPES

The aim of this project, carried out by Gordon Plotkin and his students is to develop further the application of Scott's theory of computation to the study of the synthetic approach to abstract data types. It is intended to pursue a wide variety of topics ranging from the detailed study of practical examples to theoretical problems and to include systematic comparisons with other approaches.

THE IMP-77 LANGUAGE

As implemented by

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A REFERENCE MANUAL

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INTRODUCTION

IMP-77 is an "ALGOL-like" high-level language. Relative to ALGOL 60, the language adds program structuring, data structuring, event signalling, and string handling facilities, but removes (or retains in a modified form) intrinsically inefficient features such as the ALGOL 60 name (substitution) parameter.

The language, based on Atlas Autocode, was originally designed as the implementation language for the Edinburgh Multi-Access System - hence its name - but has since been used successfully for implementing systems, teaching programming and as a general-purpose programming language on many different machines.

Two of the major design aims were:

1. The language should compile to efficient machine code.

2. The syntax of the language should be verbose rather than obscure.

Most IMP systems provide comprehensive compile-time and run-time diagnostics, together with an option to suppress generation of run-time checks when compiling tested programs.

Input/output facilities are provided through the external procedure mechanism and are therefore open-ended and can be defined as required, though a standard set of procedures is supported.

This manual describes the language as implemented initially in version 6 of the compiler.

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{comments}

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function

not

record function

record map

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PROGRAM LAYOUT CONVENTIONS

An IMP program is a sequence of statements constructed using the ASCII character set extended with an underlined alphabet. Underlined letters, which are used to form keywords, are generated using the shift character percent (%), which is defined as underlining the following letters, the underlining being terminated by any non-alphabetic character.
Hence the following statements are equivalent:

```
%STRING(7)%ARRAY %NAME P
%STRING (7)%ARRAYNAME P
```

and both represent:

string(7)array name P

In this manual, keywords are in lower case and underlined.

Newline

The NEWLINE (or LINE-BREAK) character is ASCII character 10 (LF). Newlines are always significant (see Termination).

Spaces

Except when used to terminate keywords or when between quotes (q.v.) spaces are ignored by the compiler and may be used to improve the legibility of the program.

Lower Case Letters

Except when enclosed in quotes (q.v.) lower case letters are equivalent to upper case letters.

Quotes

Several language constructions call for one or more characters to be enclosed in quotes; between quotes all characters are significant and stand for themselves.
N.B. Space, newline, and percent characters may appear between quotes and stand for space, newline, and percent.

Two quote characters are used:

```
'    -    character quote e.g. 'A'
"    -    string quote    e.g. "FRED"
```

If it is required to include the delimiting quote within the text it must be represented by two consecutive quotes; e.g.

```
''''              -       the symbol quote
"a ""big"" dog" -         a string of 11 characters
```

However, note: '"' and "it's mine"

Identifiers

An identifier is a sequence of any number of letters and digits starting with a letter, e.g. MAX, X, CASE 1, case 2, CASE 2b
All letters and digits are significant.

Except in the cases of simple labels and recordformats (q.v.) all identifiers must be declared before they may be used (see Declarations).

STATEMENTS

A STATEMENT is a sequence of atomic elements (keywords, constants, identifiers etc.) arranged according to the syntactic rules of IMP.

Termination

Every statement must be terminated by a newline or a semicolon (however, see Comments).

Null Statements

There are two types of null statement, both of which are ignored by the compiler. They may be used to improve the legibility of the program.

1. Redundant terminators, E.g. blank lines

2. Comments
   A comment is either a statement starting with an exclamation mark (!) or the keyword comment, and terminated by a newline, or any sequence of characters (excluding } and newline) enclosed within a pair of curly brackets. The second form of comment may occur anywhere except between quotes.

   e.g. comment Deal with exceptional cases
   ! beware of zero
   if X=0 {empty} or x=limit {full} start

APPENDIX 5

IMP KEYWORDS

alias	and	array			
begin	byte				
c	comment	const	constant	continue	cycle
dynamic					
else	end	event	exit	external	
false	file	finish	fn	for	format
frozen	function				
if	include	integer			
list	long				
map	monitor				
name	normal	not			
on	of	or	own		
predicate	program				
real	reals	record	repeat	result	return
routine					
short	signal	spec	start	stop	string
switch	system				
then	true				
unless	until				
while					

APPENDIX 4

DATA PRECISION SPECIFICATION

On some machines it is possible to offer a range of precisions for variables of type integer or real. The precision is specified by the use of one of the following prefixes:

short- smaller range than by default

long - larger range than by default

byte - large enough to hold a character (unsigned)

E.g.

byte integer	or byte
short integer	or short
long integer	or long
long real	

If the machine on which the program is to be run cannot support the required precision the prefix will be ignored.

E.g. On the IBM 360 (or ICL 4/75)

byte integer	8-bits unsigned
short integer	16-bits signed
integer	32-bits signed
real	32-bits
long real	64-bits

Note that checks may be applied to ensure that any quantity assigned to a variable is within the correct range of values.

E.g.
```
shortinteger S
integer X
X=16_FFFF
S = X
```

will fail at run-time, as "16_FFFF" is a POSITIVE integer value but a NEGATIVE short integer value.

The assignment operator "<-" may be used to force truncation if required (see Assignment).

The statement reals long will cause all subsequent real keywords to be interpreted as long real. This effect may be terminated by the statement reals normal.

Instructions

The term instruction refers to an assignment, a Routine call or a control transfer.

Continuation

Any statement, excluding comments, may extend over several physical lines provided that each line-break occurs after a comma or a binary operator, or is preceeded by the keyword c. E.g.

```
if X = Y then P = 1 c
          else P = 0
```

which is exactly equivalent to:

```
if X = Y then P = 1 else P = 0
```

Notes

1. The line-break following c causes underlining to be terminated.
2. %C between quotes stands for the two characters percent and C.

Listing Control

During the compilation of a program a line-numbered listing is produced. The statements list and endoflist may be used respectively to enable or disable the listing for selected parts of a program. The default is for listing to be enabled.

Include

A file of statements (terminated by the statement end of file) may be compiled into a program by giving a statement of the form:

include {file specification}

where {file specification} is a string constant representing a (system dependent) file name. E.g.

include "ECSC17.LISTVARS"

Refer to the relevant system manual for details of system-dependent limitations on the use of include.

Integer Constants (Fixed Point)

a) DECIMAL constants
A decimal constant is a sequence of decimal digits. For example:
7, 43, 2195, 0, 8, 100 000 000

b) NON-DECIMAL constants
The prefix {decimal constant}"_" may be used to specify the base of the following constant. The letters a, b, .., z are used to represent the 'digits' 10, 11, .., 35
E.g.
2_1010 - BINARY TEN
8_12 - OCTAL TEN
16_A - HEXADECIMAL TEN

c) CHARACTER constants
The ASCII code value of any character may be obtained by enclosing the character in single quotes. When the required character is a single quote it must be represented by two consecutive single quotes.
Examples: 'A', 'a', '+', '0', '*', '''', ' ', '
'
Note the last three examples, which represent respectively the code values for single quote, space, and newline.

The predefined named constant NL may be used in place of the rather cumbersome form of a single newline character enclosed in quotes.

d) MULTI-CHARACTER constants
The previous form may be extended to pack together the codes for several characters to form a single integer constant.

'OVER', 'Max', '1+2', '*@@#'

The exact nature of the packing and the maximum number of characters which may be so packed are both machine dependent.

An integer expression with operands which are constants may be used wherever an integer constant is required (see Expressions).


```
  1 %begin
  2    %begin
  3       %realname Q
  4       %integer VALUE, X, X
*                               ! copy
  5       %string(256) S
*  size
  6       %switch SA(1:4), SB(5:4)
*  bounds
  7       %routine %spec CHECK
  8       %integer %functionspec KEY(%integer LOCK)
  9       %if X = 4 %stary
*                       ! atom
 10          VALUE = KEY
*                           ! form
 11          X = VALUW
*                ! name
 12          X = X+1
 13  sa(5):
*           ! index
 14          VALUE = 0
 15       %finish
*  %start missing
 16       %exit %if X < 0
*  %cycle missing
 17       %stop
 18       X = 0
?  access
 19       %on %event 4 %start
*  order
 20          %integerfn KEY(%real LOCK)
*  match
 21            NEWLINE
 22            PRINTSYMBOL('=') %for X = 1, 1, 12
? Non-local
 23          %end
*  result missing
?  LOCK unused
 24          Q == VALUE
*                    ! type
 25          x = Q&7
*                    ! type
 26 %endofprogram
*  %end missing
*  %finish missing
*  CHECK missing

Program contains 17 faults
```

APPENDIX 3

SAMPLE PROGRAM LISTINGS

```
      Computer Science IMP77 Compiler.  Version 6.00

 1  %begin;                    !program to paginate a file
 2     %constant %integer page size = 64;      !lines per page
 3     %constant %integer form feed = 12;      !FF character
 4
 5     %integer sym
 6     %integer lines left = page size
 7     %integer line number = 0
 8
 9     %on %event 9 %start;              !Input ended
10        newline
11        %stop
12     %finish
13
14     selectinput(1);  selectoutput(1)
15
16     %cycle
17        sym = nextsymbol;              !get input ended
18                                       !before printing
19        line number = line number+1
20        write(line number, 4);  space
21
22        %cycle
23
24           %if sym = form feed %start;        !newpage
25              lines left = 0
26              sym = nl
27           %finish
28           %exit %if sym = nl;                !end of line
29           printsymbol(sym)
30           skipsymbol
31           sym = nextsymbol
32        %repeat
33
34        skipsymbol;                           !skip newline
35        newline
36        lines left = lines left-1
37        %if lines left <= 0 %start;           !end of page
38           lines left = page size
39           printsymbol(form feed)
40        %finish
41     %repeat
42
43  %endofprogram

  36 statements compiled
```


Real Constants (Floating Point)

A real constant is a sequence of decimal digits optionally including one decimal point.
The constant may also be followed by a scaling factor of the form @{signed integer constant} meaning "times ten to the power {signed integer constant}". For example, the following real constants all represent the same value (ignoring machine-dependent precision limitations):

120.0, 120, 1.2@2, 12@1, 1200@-1

Note that a decimal integer constant is a special case of a real constant.

String Constants

A string constant is a sequence of not more than 255 characters enclosed in double quote characters - a double quote being represented inside a string constant by two consecutive double quotes.

E.g. "STARTING TIME", "x = y*4+x", "a ""red"" hood"

a) "A" is a string constant of one character.
   'A' is a character (integer) constant.

b) The null string, a string of no characters, is permitted and is represented by two consecutive double quotes ("").

EXPRESSIONS

1. Arithmetic Expressions

An arithmetic expression is a sequence of arithmetic operands and operators obeying the usual rules of arithmetic expressions. An operand is either a constant, a variable, a function call, a map call, or a numerical expression enclosed in parentheses (see Declarations and Procedures).

a) Integer Expressions

All the operands and operators in an integer expression must yield an integer value. Real values may be converted into integer values using the functions INT and INTPT (refer to the relevant library manual).
The operators available are:

+	addition
-	subtraction or unary minus
*	multiplication
//	integer division (the remainder of the division, which is of the same sign as the dividend, is ignored).
\\	integer exponentiation. The second operand (the exponent) must be a non-negative integer.

b) Real Expressions

All the operands and operators in a real expression must yield real (or integer) results. Where an operator will take either real or integer operands (E.g. +) and the types of the given operands differ, the integer operand will be converted to a real value, otherwise the result of the operation will be of the same type as the original operands. The pre-defined real function FLOAT may be used to force the conversion of an integer expression into a real expression.
The operators available are:

+	addition
-	subtraction or unary minus
*	multiplication
/	division
\	real exponentiation The second operand (the exponent) must be an integer operand.

The modulus (absolute value) of an expression (integer or real) may be obtained by enclosing that expression between vertical bars.
E.g. |X-Y|

APPENDIX 2

COMPILER MESSAGES

ERRORS

Any errors detected by the compiler will generate messages of the form: * {message}

In most cases a marker (¦) will be output to indicate the position in the statement at which the error was detected.

ATOM	-	unknown atomic element. Usually a spelling mistake or % misused.
BOUNDS	-	invalid bounds for an array or switch declaration, or wrong number of constants for an array initialization.
CONTEXT	-	formally correct statement given in the wrong context. E.g. return inside a function.
COPY	-	attempt to redefine a local identifier.
FORM	-	incorrectly formed statement. Usually the addition or omission of an atom.
FORMAT	-	use of a record with an undefined format.
INDEX	-	switch label index out of bounds.
MATCH	-	procedure definition does not match a previous spec.
NAME	-	undeclared identifier
ORDER	-	formally correct statement in wrong sequence. Usually declarations after an on statement.
PROTECTED	-	attempt to modify (or unfreeze) a frozen variable.
SIZE	-	constant out of range.
TOO COMPLEX	-	statement too long or complex to analyse.
TYPE	-	object of the wrong type.
%BEGIN MISSING	-	too many end statements
%CYCLE MISSING	-	a repeat with no matching cycle.
%END MISSING	-	unterminated blocks remain at end of program or end of file.
%FINISH MISSING	-	outstanding start at end or repeat.
%REPEAT MISSING	-	outstanding cycle at end or finish.
RESULT MISSING	-	a function, map, or predicate can reach its end.
%START MISSING	-	a finish with no matching start.
"{id}" MISSING	-	undefined procedure, label, or format.

WARNINGS

? {id} unused	-	an identifier has been defined but not used.
? Non-local	-	a for statement uses a non-local control variable.
? Access	-	this statement can never be reached.
? } missing	-	a short comment has not been terminated.

APPENDIX 1

A NOTE ON THE GRAMMAR

?	- indicates a rule is optional
*	- indicates zero or more instances of a rule
,	- separates alternatives
()	- define the scope of the above items
{}	- enclose phrase identifiers
""	- enclose literal strings (keywords are simply underlined)

E.G.

```
"A" ("B" "C")?      ->    A
                      or  ABC

"A" ("B" "C")*      ->    A
                      or  ABC
                      or  ABCBC    etc.

"A" ("B", "C")      ->    AB
                      or  AC

"A" ("B", "C")*     ->    A
                      or  AB
                      or  AC
                      or  ABB
                      or  ABC
                      or  ACB      etc.
```


Notes

1. Unary minus is treated as 0-...
2. Unary plus (+) is not accepted.
3. An expression may not contain two adjacent operators - they must be separated by parentheses E.g. 23*(-14)
4. Integer values will be converted to real where necessary, but real values will never be converted to integer unless this is explicitly specified using the pre-defined functions INT or INTPT.

2. Bit-Vector Expressions

All operands must yield bit-vector (integer) values. The operations are performed on a bit-by-bit basis using the operators:

&	AND
!	INCLUSIVE OR
!!	EXCLUSIVE OR
<<	LEFT SHIFT (logical)
>>	RIGHT SHIFT (logical)
~	COMPLEMENT (unary not)

It is possible to mix integer and bit-vector expressions but the full implications of this may be machine dependent.

3. String Expressions

All operands of a string expression must yield values of type string. The only operator available is "." for concatenation (joining together). No sub-expressions in parentheses are permitted.

E.g. "MR ".SURNAME

Precedence of Operators

Highest:	1.	~ (unary not)
	2.	\, \\, <<, >>
	3.	*, /, //, &
Lowest:	4.	+, - (unary and binary), !, !!

In general, sub-expressions with operators of equal precedence are evaluated from left to right.
The precedence rules may be over-ridden by means of parentheses.

Note:

```
-1\\2 = -1
(-1)\\2 = 1
2\\2\\3 = 4\\3 = 64
```

DECLARATIONS

All identifiers (except simple labels and record formats) must be declared at the start of a block before they are used. The scope of an identifier is the rest of the block in which it is declared, including any blocks subsequently defined therein (see Block Structure and note 3 on Labels and Jumps). In the following discussion the phrase {type} has four variants:

1. integer
2. real
3. string "(" {max} ")"
4. record "(" {format} ")"

and {max} is an integer constant in the range 1<=max<=255 defining the maximum number of characters which may be held in the string.

{format} defines the structure of the record (see Records).

When used to define pointer variables or maps(q.v.) ({max}) and ({format}) may be specified as (*) meaning that the defined object may reference any string variable or any record variable.

1. Variables

a) Simple Variables

{type}{idlist}

```
integer J,K,COUNT
real PRESSURE
string (30) COUNTRY, TOWN
record (CARFM) MINI, ROVER
```

Each variable is allocated an appropriate (machine dependent) amount of storage to hold a value of the stated type.

b) Pointer Variables

{type} name {idlist}

```
integer name P
real name DATUM
string (15) name WHO,WHERE
record (CARFM) name CAR
```

Each variable is allocated enough storage to hold a pointer to (i.e. the address of) a simple variable of the stated type.

At any time during the execution of a program an event may be signalled by executing an instruction of the form:

signal event {n}{qual}?

where:

```
{n}     ::= an integer in the range 0 <= N <= 15
{qual}  ::= "," {sub event}{extra}?
{extra} ::= "," {extra info}
```

and {sub event} and {extra info} are integer expressions.

The instruction causes event {n} to be signalled with sub-event (default zero) and extra information (default zero).

```
signal event 15;              ! event 15,0,0
signal event 14,7 if X < 0;   ! event 14,7,0
signal event 13,1,Y if Y#0;   ! event 13,1,Y
```

Note 1. In both the on and signal statements the keyword event is optional and may be omitted.

2. An event signalled inside an incarnation of an on-body will never be trapped into that incarnation. Instead the search for a trap will start from the block which invoked the current block.

Three functions are provided to give information about the last event to have been signalled.

```
integerfnspec EVENT
integerfnspec SUB EVENT
integerfnspec EVENT INFO
```

If no event has been signalled each of these functions returns zero.

The classes of event and the sub-classes of them are:

EVENT	SUB-CLASS	MEANING (+EXTRA INFORMATION)
0		TERMINATION
	-1	abandon program
	0	normal termination (stop)
	>0	user generated error
1		ARITHMETIC OVERFLOW
	1	integer overflow
	2	real overflow
	3	string overflow
	4	division by zero
2		EXCESS RESOURCE
	1	not enough store
	2	output exceeded
3		DATA ERROR
	1	symbol in data (+symbol)
4		CORRUPT DATA
	1	data transmission error
5		INVALID ARGUMENTS
	1	for cannot terminate
	2	illegal exponent (+exponent)
	3	array inside-out
	4	string inside-out
	5	illegal parameter for READ
6		OUT OF RANGE
	2	array bound fault (+index)
	3	switch bound fault (+index)
	4	Illegal event signal
7		RESOLUTION FAILS
8		UNDEFINED VALUE
	1	unassigned variable
	2	no switch label (+index)
9		STREAM ERROR
	1	input ended
	2	illegal stream (+stream no)
10		LIBRARY PROCEDURE ERROR
11 - 15		GENERAL PURPOSE

Note that some of the events may not be signalled automatically in certain implementations or when the program has been compiled without checks. Refer to the relevant implementation notes for details.

c) Array Pointer Variables

{type} array name {idlist}
{type} name array name {idlist}

```
integer array name AN
real array name VALUES
string (20) array name NAMES, ADDRESSES
record (CARFM) array name MAKE
integer name array name POINTERS
```

Each variable is allocated enough storage to hold a pointer to (i.e. the address of) a single dimensional array of the stated type.

{type} array "(" {dim} ")" name {idlist}

is provided for declaring pointers to multi-dimensional arrays. E.g.

```
real array (4) name SPACE TIME
```

SPACE TIME may now be pointed at an array of dimension 4.

2. Arrays

{type} array {adefn}("," {adefn})*
{type} name array {adefn} ("," {adefn})*

{adefn} ::= {idlist} "(" {pair}(","{pair})* ")"
{pair} ::= {integer exprn} ":" {integer exprn}

```
integer array A(1:10),B,C(-4:LIMIT)
real array Q(1:J+K, 1:J-K)
string (12) array CLASS(-7:16)
record (CARFM) array TABLE(LOWER:UPPER)
integer name array POINTERS('A':'Z')
```

The bound pairs, {pair}, are evaluated and the required amount of storage is allocated to each identifier.

note 1. In each bound pair the value of the first expression (lower bound) must be less than or equal to the value of the second expression (upper bound).

2. The number of bound pairs (the dimension of the array) usually may not exceed six, but this is implementation dependent.

3. Records

A record is a named collection of variables, arrays and records. The components (elements) of a record may be any of the forms discussed in (1) and (2) above, with the following limitations:

a. Arrays within records must be one dimensional and have constant bounds.
b. A record may not contain a simple record (or a record array) of its own format. However it may contain record pointer variables of its own format.

The internal structure of a record is defined using a record format statement.

record format {id} "(" {declaration list} ")"

```
record format F(integer X, record(F)name LINK)
record (F) HEAD
record (F) array CELL(1:15)
```

Note 1. Within a format each identifier must be unique but will not clash with any identifiers outwith that format.

2. When space is allocated to a record variable the elements are laid out in the order in which they were declared. However see the relevant appendix for machine dependent alignment considerations.

A format may be defined as an ordered list of formats:

```
recordformat A(.....)
recordformat B(.....)
recordformat C(.....)

recordformat D(A or B or C)
```

Records defined using such a format may be qualified by selectors from any of the component formats (see Record element selection). The amount of storage required for such records is the amount required for a record of the largest format in the list.

The formats of two records are considered equivalent if they contain a common alternative.

Within record format definitions, record pointer variables may be declared using format identifiers that have not yet been defined. The format must be defined before the record is used.

```
recordformat X(record(Y)name P, real VALUE)
recordformat Y(record(X)name Q, integer VALUE)
```


EVENTS

During the execution of a program several (synchronous) events may occur, such as failure of resolution, array bound fault etc. (see Faults). Normally such events will cause the program to be terminated with an error report and possibly diagnostic information. However events may be trapped and used to control the subsequent execution of the program.

The first non-declarative statements of any block may be of the form:

```
on event {event list} start
      ! ON-BODY STATEMENTS
finish
```

where {event list} is a list of integer constants representing the events to be trapped.

On entry to the block the on body is skipped and execution continues from the statements following the finish. If an event specified in the {event list} is signalled during the execution of the statements between the finish of the on event group and the end of the block, control will be passed to the on-body (and may well pass through the finish to the following statements). If the event is not trapped in the current block a 'return' is forced and the event is signalled in the new block at the point from which the old block was entered. The process is repeated until either the event is trapped or the outermost block of the program is reached, in which case the event is reported as a fault and the program terminates.

While the actual procedures which are predeclared may vary from machine to machine, the following are standard and may be assumed present:

INPUT/OUTPUT

```
routine READSYMBOL(name S)
routine SKIPSYMBOL
integer function NEXTSYMBOL
routine READ(name N)

routine PRINTSYMBOL(integer N)
routine PRINTSTRING(string(*) S)
routine WRITE(integer N, PLACES)
routine NEWLINE
routine NEWLINES(integer N)
routine SPACE
routine SPACES(integer N)

routine SELECTINPUT(integer STREAM)
routine SELECTOUTPUT(integer STREAM)
```

STRING HANDLING

```
string(1) function TOSTRING(integer SYMBOL)
string(*)  fn  SUBSTRING(string(*)name  S,  integer  F,T)
integer function CHARNO(string(255) S, integer N)
integer function LENGTH(string(255) S)
```

EVENT HANDLING (see Events)

```
integer function EVENT
integer function SUB EVENT
integer function EVENT INFO
```

STORE MAPPING

```
integer function ADDR(name V)
integer map INTEGER(integer ADDRESS)
real map REAL(integer ADDRESS)
string(*)map STRING(integer ADDRESS)
record(*)map RECORD(integer ADDRESS)
```

Refer to the relevant system library manual for detailed specifications of these and other standard procedures.

RECORD ELEMENT SELECTION

Selection of a specific element from a record is achieved by following the record identifier by:

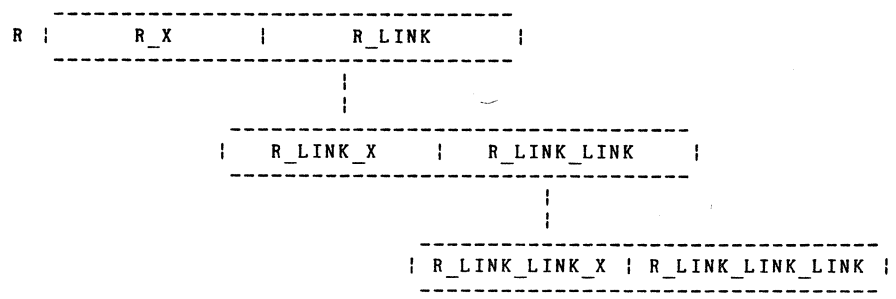
"_"{element id}

E.g. given the declarations:

```
record format F(integer X, record(F) name LINK)
record (F) R
```

some valid references to variables are:

R	- a record of format F
R_X	- an integer
R_LINK	- a pointer to a record of format F
R_LINK_X	- an integer
R_LINK_LINK	- a pointer to a record of format F
R_LINK_LINK_X	- an integer



If the record had been defined using a format declared to be a list of formats, the search for the element identifier would consider each of the formats in the list in the order specified. This means that if two of the formats in the list contain a common element identifier the first will be used. The identifiers of the formats comprising the list may be used as element identifiers to select a particular format as long as the format identifiers do not clash with any of the component element identifiers. e.g.

```
recordformat X(integer Q, R)
recordformat Y(real P, Q)
recordformat Z(X or Y)

record(Z) W

W_Q = 0;        !an integer
W_P = 0;        !a real
W_Y_Q = 1.2;    !a real
```

OWN VARIABLES

Each variable declared in a block (q.v.) is allocated storage when that block is entered, the storage being released when the block is left. This means that local variables (and the values in them) are lost between traverses of the block.

If, however, the prefix own is applied to a declaration the variables are allocated statically (at load time) and so retain their values when the block is not being executed (see Procedures). The scope of the identifier is unchanged.

Own arrays must be one-dimensional and have constant bounds.

INITIALISATION

Simple variables and pointer variables may be given initial values when they are created; if no initial value is specified the content of a variable is initially undefined (see Assignment).

```
integer A,B=4, C=-1-B
! the initial value in A is undefined
real R=1.234@-5
string (7) WHO="ANON"
integer name POINT == A
```

Own variables are initialised once (effectively before the program begins execution) but ordinary variables are initialised each time the containing block is entered.

Arrays may only be initialised if they are own or constant (q.v.).

If an own array is to be initialised, every element in the array must be given a value. In order to simplify this, each initial value may be followed by a repetition count in parentheses, and a star, (*), may be used to represent the number of remaining elements in the array. For convenience a repetition count of zero is permitted and means that the initialising constant is to be ignored. For example the following declarations are all equivalent:

```
own integer array A(2:5) = 7,7,7,7
own integer array A(2:5) = 7(4)
own integer array A(2:5) = 7(*)
```

The list of constants may extend over several physical lines without the need for a continuation mark if each line ends with a comma; a line-break is also allowed after the equals sign.

ALIAS

Any identifier being declared as external may be followed by alias {string const} where the string constant specifies the string to be used for external linkage. From within the module the external object will be identified in the usual way.

E.g. externalrealfnspec SIN alias "MATH$DSIN" (real ARG)

PREDEFINED PROCEDURES

Every separately compiled module, whether a begin-end of program block or a file of external procedures is compiled within a conceptual "outermost block" in which are declared a number of standard procedures such as READ and WRITE. This means that these procedures are global to all parts of a program and so may be used without having to be declared. Note that as these procedures are global they may be redefined within the program.

There are no restrictions on the use of the pre-defined procedures other than those naturally imposed by their definition (routine, function etc.). In particular, predefined procedures may be passed as procedure parameters. Further, own, constant or external identifiers may be declared in this outermost block and will be global to the whole of the file.

```
own integer CALLS = 0

external routine DO SOMETHING
   CALLS = CALLS+1;          ! RECORD TIMES ENTERED
   .
   .
end

external integer function ENTRIES
   result = CALLS
end

end of file
```

Note that the function ENTRIES is used to make the value in CALLS available to other modules without their being able to change that value, even by mistake, other than by calling DO SOMETHING.

For example the following is a complete file of external procedures:

```
integer function SHIFT(integer SYM)
   result = SYM-'a'+'A';    ! LOWER - UPPER CASE
end

external predicate LETTER(integer SYM)
   true if 'A' <= SYM <= 'Z'
   true if 'A' <= SHIFT(SYM) <= 'Z'
   false
end

external predicate DIGIT(integer SYM)
   true if '0' <= SYM <= '9'
   false
end

external predicate ALPHANUM(INTEGER SYM)
   true if LETTER(SYM) or DIGIT(SYM)
   false
end

end of file
```

Note a. The function SHIFT is local to the file - it cannot be called from a different module.

b. The normal scope rules apply within the file, so that ALPHANUM may call both LETTER and DIGIT.

c. External procedures may not be nested within any blocks.

If a module requires to use an externally defined procedure it must first supply an external procedure specification. For example:

```
external predicate spec LETTER(integer S)
```

This is similar to a procedure specification but only requires the specified procedure to have been defined by the time the module is executed.

However, a spec for a procedure contained in the same module as the spec statement must not have the external attribute (because the procedure is not external to the module).

An external ... spec may be given wherever other declarations would be valid.


```
own string (3) array MONTH(1:12) =
   "JAN", "FEB", "MAR",
   "APR", "MAY", "JUN",
   "JUL", "AUG", "SEP",
   "OCT", "NOV", "DEC"
```

Any number of null statements may be placed between the lines of constants.

```
own integer array OPCODE(0:20) =;          !opcode values

   16_5800,  16_4800,  16_5000, 16_4000,
!     L         LH        ST       STH
   16_5A00,  16_5B00,  16_5C00, 16_5D00,
!     A         S         M        D
   16_1A00,  16_1B00,  16_1C00, 16_1D00,
!     AR        SR        MR       DR
   -1(*);                                  !all the rest
```

FROZEN VARIABLES

Variables may be created to contain initial values which, once given, may not be changed. Both values and references may be so frozen. Note that the frozen attribute does not affect the existence of objects; they are created and destroyed in the same way as their non-frozen equivalents.
For example:

```
frozen integer       FI  = X+1
frozen integer name FIN == Y
integer frozen name IFN == Z
```

FI is given the value X+1 and subsequently may not be altered.
FIN may reference any integer variable (initially Y) but the variable it references may not be altered via FIN, i.e. FIN==Z is valid but FIN=0 is not.
IFN is initialised to reference Z and may never reference another integer, however the integer it references may be changed, i.e. IFN==X is not valid but IFN=0 is.

CONSTANT IDENTIFIERS

Named constants may be declared using the prefix constant. A constant integer may be used wherever an integer constant is required.

```
constant integer MAX = 17
constant real PI = 3.14159
constant string (7) VERSION = "vsn:1.6"
constant integer array VAL(1:MAX) = 1,6,9,-1(*)
```

The keyword constant may be abbreviated to const.

constant ..... arrays are effectively own frozen ... arrays.

ASSIGNMENT

There are three forms of assignment:

1. {variable} "=" {expression}

```
X = Y
A(P) = A(P)+1
Y = BIT<<12
PERSON = INITIALS.SURNAME
```

The expression is evaluated and the resulting value is stored in the given variable. The expression may be of type integer, real, or string, and the variable must be of the corresponding type; in the case of a real variable an integer expression will have its result converted to real before being assigned.

Valid types of assignment are:
{integer variable} "=" {integer expression}
{real variable} "=" {real expression}
{real variable} "=" {integer expression}
{string variable} "=" {string expression}

Note that if N and M are (for example) integer name variables the statement N=M copies the value in the variable pointed at by M into the variable pointed at by N.

2. {pointer variable} "==" {variable}

The pointer variable is dynamically made equivalent to the given variable; the types of both sides of the assignment must be identical - this includes the formats of records, and the maximum lengths of strings.
The assignment may be thought of as the assignment of the address of the variable to the pointer.
Once equivalenced the pointer variable may be used as an alternative to the variable.

```
integer name N
integer J
integer array A(1:6)
J = 1
N == A(J);              ! N IS NOW EQUIVALENT TO A(1)
J = 2;                  ! N HAS NOT CHANGED
N = 0;                  ! SAME AS A(1) = 0
```


EXTERNAL LINKAGE

A complete program may be divided into several separately compiled modules which are linked together before (or possibly while) the program is executed. This linkage is achieved by giving the external attribute to relevant indentifiers.
The keyword external may be replaced by system or dynamic but the effect of this is implementation dependent.

1. external DATA OBJECTS

An external variable is declared in the same way as an own variable with the keyword own replaced by external.

```
external integer CHOICE=4, WAIT = -5

external real array MEAN(-6:6)
```

The identifiers are then available for use by any program that references them. A separately compiled module that requires to use any of these variables must first declare them using an external specification.

```
external integer spec WAIT, CHOICE

external real array spec MEAN(-6:6)
```

note 1. No initialization may be given in an external specification.

2. External arrays must be one-dimensional and have constant bounds.

3. Even though all of the characters in the identifier of an external entity are significant to the compiler, the system loader software might impose constraints on the number of significant characters. Refer to the relevant appendix for system dependent restrictions.

2. external PROCEDURES

A procedure may be made available to other modules by prefixing the procedure heading with the keyword external.

```
external routine TRIAL(string(63) S)
```

Such procedures must be compiled in a file comprising only external procedures (and possibly some non-external procedures and own or external declarations). The whole module is terminated by the statement end of file.

OTHER CONTROL TRANSFER INSTRUCTIONS

stop

Execution of the instruction stop causes control to be returned to the program which initiated the execution of the current program. This is also the effect of reaching the statement end of program.

monitor

This instruction causes the run-time diagnostic package to be invoked to produce diagnostic information. If no diagnostic package is available this instruction will be ignored (in some limited implementations the production of diagnostics causes execution of the program to be terminated).

For convenience all other control transfer instructions are gathered here.

return	return from a routine.
result={exp}	return the result of a function
result=={reference}	return the result of a map.
true	return from a predicate.
false	return from a predicate.
exit	jump out of the current cycle to the statement following the matching repeat.
continue	jump to the repeat of the current loop.
signal event	see Events.

3. {variable} "<-" {expression}

This is similar to 1. above except that the value of the expression will be truncated if necessary (see Data Precision Specification).

E.g. string(4) S

```
S = "12345"; ! fails String Overflow at run-time.

S <- "12345"; ! will assign "1234" to S.
```

RECORD ASSIGNMENT

Two extra assignments exist for records.

1. {record variable} "=" {record variable}

The right-hand record is copied bit by bit into the left-hand record. The formats of the two records must be equivalent.

2. {record variable} "=0"

Each bit of the record is set to zero.

STRING RESOLUTION

The contents of a string variable may be searched for a sub-string and decomposed accordingly.
The format of a resolution is:

{string var}"->"{string var}."("{string exp}")."{string var}

where either the second string variable, the third, or both may be omitted (any dangling full stops also being omitted).

```
        S -> T.(",").U
TITLE(J) -> ("Sir").REST
      WHO -> WHO.(LETTERS."B.Sc.")
        S -> ("HELLO".T)
        A -> B.(C).D
```

The string expression, C, is evaluated and the first variable, A, is searched from left to right to find that string of characters. The fragment of the string to the left of the sub-string so found is assigned to the second variable, B, and the fragment to the right is assigned to the third string variable, D.
The resolution is deemed to have failed if the required sub-string is not found or either of the second or third string variables has been omitted and would have been assigned a non-null string. No assignments are performed if the resolution fails.

For example, the following resolutions all fail if the string variable S contains the string "ABCDEFG"

```
S -> T.("H").U
S -> ("CD").U
S -> T.("EF")
S -> ("ABCDEF")
```

and the following all succeed:

```
S -> T.("CDE").U
S -> ("ABC").U
S -> T.("G")
S -> ("ABCDEFG")
```

A resolution may occur in two contexts:

1. as an instruction, in which case failure of the resolution causes an event to be signalled (see Events)

   ```
   S -> A.(WANTED).B;  S = A.B
   ```

2. as a simple condition (see Conditions), in which case failure of the resolution deems the simple condition false and success deems it true; in the latter case the resolution is performed and the necessary assignments are made.

   ```
   if WHO -> ("Sir ").WHO then KNIGHT = 1
   ```



```
switch LET('A':'Z')
.
.
LET('A'):LET('E'):LET('I'):LET('O'):LET('U'):

! DEAL WITH VOWELS
.
.

LET(*):!  ALL THE REST I.E. CONSONANTS
```

The specific label to which a jump will be made is dependent on the value of an integer expression.

```
->SW(N) if N > 0
->SW(100+N)
->SW(6)
```

Note 1. Not all of the declared switch labels need be defined (in the previous examples SW(5): and SW(8): are undefined) but an error will occur at run time if an attempt is made to jump to a non-existent switch label.

2. Simple labels may be used before they are defined.

   ```
   -> MISSING if HERE = 0
   .
   .
   MISSING:
   ```

3. The scope of both types of label is limited to the block in which they are defined, not including any blocks defined therein. Therefore it is not possible to jump into or out of a block.

4. The identifiers used for labels must not conflict with other local identifiers.

5. The results of entering a for loop with a jump and not through the for statement are undefined.

CONTROL TRANSFER INSTRUCTIONS

LABELS and JUMPS

1. Simple Labels

Any statement, excluding declarations, may be given one or more simple labels, where a simple label is of the form: {id} ":"

Each label is written to the left of the statement.

```
NEXT:          P = P+1 if P < 0
ERROR1:ERROR2:FAULTS = FAULTS+1
```

Control may be passed to a labelled statement by executing a jump instruction: "->" {id}

```
-> NEXT

-> ERROR1 if DIVISOR = 0
```

2. Switch Vectors

A vector of labels may be declared in a similar manner to an array, using the declarator switch.

```
switch SW(4:9)
switch S1, S2(1:10), S3(11:20)
```

Note a. The vector must be one dimensional.

b. The bounds must be constants.

Once declared, switch labels may be defined in the same way as simple labels, the particular label required being selected by an integer constant.

```
SW(4):        CHECK VALUE(1)
SW(6):SW(7): ERROR FLAG = 1
LAST: SW(9): !  ALL FINISHED
```

A star (*) may be used in the definition of a switch label to define any elements within the vector which would otherwise be undefined.

CONDITIONS

Conditional statements are specified using the phrase {condition}, which is defined as:

```
{condition} ::= {simple cond} (and {simple cond})*,
                {simple cond} (or {simple cond})*
```

where {simple cond} has seven forms:-

1. {expression}{comp}{expression}

```
{comp} ::= "="          - IS EQUAL TO
           "#", "~="    - IS NOT EQUAL TO
           "<"          - IS LESS THAN
           "<="         - IS LESS THAN OR EQUAL TO
           ">"          - IS GREATER THAN
           ">="         - IS GREATER THAN OR EQUAL TO
```

The given expressions are evaluated and compared. The simple condition is true or false depending on the validity of the relation specified by the comparator. Both expressions must yield values of the same type.

2. {expression} {comp} {expression} {comp} {expression}

This form of simple condition may be thought of as a contraction of the form:

({x1}{comp1}{x2} and {x2}{comp2}{x3})

except that the middle expression {x2} is only evaluated once. Note that the third expression is only evaluated if the condition specified by the first two expressions is true.
Such a simple condition is frequently used to check for a range of values, E.g.

```
0 <= VALUE <= 100
```

3. {reference to variable} "==" {reference to variable}
{reference to variable} "##" {reference to variable}

The two references, which must be of the same type, are compared for equivalence, that is their addresses are compared.
Note that the address of a pointer variable is the address of the variable to which it is equivalent.

4. {predicate call} - see Procedures

The given predicate is called and the simple condition is true or false depending on whether the exit from the predicate was performed using true or false respectively.

5. {resolution} - see String Resolution

The resolution is attempted. If it fails the simple condition is deemed false, otherwise the resolution is performed and the condition is deemed true.

6. "(" {condition} ")"

This form of simple condition is provided to enable the use of both and and or in a condition, as these connectives are considered to have equal precedence. The connectives and and or may not appear in the same condition except at different levels of parenthesis. E.g.

A=0 or (B=1 and C=2) or D=3

7. not {simple cond}

The given simple condition is evaluated and its truth is negated. F.g. the following simple conditions are exactly equivalent:

```
A # 0
not A = 0
```

Evaluation of conditions

The evaluation of a condition proceeds from left to right, simple condition by simple condition, terminating as soon as the inevitable result of the condition is known.

For example, consider the condition:

A # 0 and B//A # C

If the variable A has the value zero the condition will be deemed false without attempting the evaluation of "B//A # C".

PROCEDURE SPECIFICATION

In several situations it is necessary to use a procedure before it is possible (or desirable) to define it. For example, where two or more procedures call each other (mutual recursion) or where a procedure is to be defined externally (see External Linkage).
As all procedure identifiers must be declared before being used a procedure specification statement is introduced.
This takes the form of the normal procedure heading with the keyword spec inserted before the procedure identifier.

E.g. routine spec MAX(real SIZE)

This has no effect other than declaring the identifier to be a procedure of the specified type which takes the given parameters. Except in the case of external procedure specifications the procedure must be defined later on in the block to which the spec is local.

For example:

```
routine spec B(integer X)

routine A(integer Y)
   .
   B(Y-1)
   .
end

routine B(integer X)
   .
   A(X+3)
   .
end
```

Note that the spec statement and the procedure heading must correspond, that is, the type and form of the statements must match, as must the type, form, order and number of any parameters.

The following is a complete list of formal parameter declarators:

integer	real	string({max})
integer name	real name	string({max})name
integer array name	real array name	string({max})array name
integer fn	real fn	string({max})fn
integer function	real function	string({max})function
integer map	real map	string({max})map

record({fm})

record({fm})name

record({fm})array name

record({fm})fn

record({fm})function

record({fm})map

routine

predicate

name

integer name array name

real name array name

string({max}) name array name

record({fm}) name array name

CONDITIONAL GROUPS
(see Block Structure)

The general form of conditional statements is:

```
if {condition 1} start
   !Statements to be executed if
   !{condition 1} is true.
finish else if {condition 2} start
   !Statements to be executed if {condition 1} is false
   !and {condition 2} is true.
finish else if {condition 3} start
   ..........
   ..........
finish else start
   !statements to be executed if all the previous
   !conditions are false.
finish
```

Any or all of the else clauses may be omitted. start-finish groups may be nested to any depth.

ALTERNATIVE FORMS

1. If the start-finish brackets enclose only one instruction the start-finish group may be replaced by:

   ```
   if {condition} then {instruction} .....      or
   ..... else {instruction}
   ```

2. The keyword if may always be replaced by unless with the effect of negating the whole of the condition. For example, the following two statements are equivalent:

   ```
       if X = 0 then Y =  1 else Y = -1
   unless X = 0 then Y = -1 else Y =  1
   ```

3. In a statement of the form: "finish .... start" both the finish and the start may be omitted e.g.

   ```
   if A = 0 start
      FLAG = 1
   else if A = 12
      FLAG = 3
   else if A < -4
      FLAG = 0
   else
      FLAG = -1
   finish
   ```

4. A statement of the form:
   if {condition} then {instruction}
   may be rewritten in the more natural form:
   {instruction} if {condition}
   e.g.
   NEWLINE if CHARS >= 60

REPETITION (LOOPS OR CYCLES)
(see Block Structure)

a. Indefinite Repetition

A group of statements may be repeated indefinitely by enclosing them between the statements cycle and repeat.

```
cycle
   GET DATA
   PROCESS DATA
repeat
```

Subsequently the group of statements between cycle and repeat will be referred to as the cycle body.

b. Conditional Repetition

1. while {condition} cycle

   Before each execution of the cycle body the specified condition is tested. If the condition is true the cycle body is executed, otherwise control is passed to the statement following the matching repeat.

2. for {control} "=" {init} "," {inc} "," {final} cycle

   where
   {control}::= {integer variable} - CONTROL VARIABLE
   {init} ::= {integer expression} - INITIAL VALUE
   {inc} ::= {integer expression} - INCREMENT
   {final} ::= {integer expression} - FINAL VALUE

   On each entry to the cycle the address of the control variable and the values of the three expressions are evaluated and saved; thus the cycle body cannot change them. The control variable is assigned the value "{init}-{inc}".
   At the start of each iteration the value in the control variable is compared with the value {final}. If they are equal control is passed to the statement following the matching repeat, otherwise the value {inc} is added to the control variable and the cycle body is executed.

PROCEDURE PARAMETERS

In addition to being able to pass variables to procedures it is possible to pass procedures as parameters. This is achieved by using the procedure heading as the 'declaration' of the formal parameter.

```
E.g. routine TRY(routine R(integer X))
        integer J
        R(J) for J = 1, 1, 10
     end
```

The routine TRY may now be called with a single parameter which must be the name of a routine which has one integer parameter. In this context the formal parameter names used to specify the parameters of a procedure parameter are otherwise ignored.

Note: If the routine TRY is itself to be passed as a parameter the heading of the receiving routine would be something like:

```
routine CHECK(routine P(routine Q(integer R)))
```

and the call would be:

```
CHECK(TRY)
```

GENERAL TYPE PARAMETER

In several situations it is useful to be able to pass to a procedure a reference to any type of variable. This is done by specifying an untyped name parameter.

```
E.g. routine WORK(name REF)
```

Such a parameter is intended for system-dependent interface procedures and has severely limited uses. In particular it may only be passed on to another procedure requiring an untyped name parameter.

An example of the use of such a parameter is in the pre-declared READ routine which will accept an integer, real, or string parameter.

```
E.g. integer X
     real Y
     string (15) Z
     READ(X); READ(Y); READ(Z)
```

PARAMETERS

In the previous discussion about procedures the phrase {param def}? was used. This stands for an optional parameter list definition.

{param def} ::= "(" {dec list} ")"

where {dec list} is a list of declarations defining the FORMAL PARAMETERS. The declarations may be of any data type except array - arrays may only be passed to a procedure as array name parameters.

E.g. routine SWOP(integer name P, Q)
integer function MAX(integer array name A, integer F, T)
predicate EQUIV(record(FM)name LEFT, RIGHT)

Parameters are identical to any local variables declared inside the procedure, except that the parameters are initialised each time the procedure is called.
When a procedure is called a list of ACTUAL PARAMETERS must be supplied which must match the formal parameters exactly in number, order, and type. Parameters are effectively assigned using "==" for those passed by name (E.g. integer name, real array name) and using "=" for those passed by value (E.g. string(10), integer).

For example assuming the declarations:

```
integer L, M, N
real R
integer array V(-7:7)
record (FM) ONE, TWO
```

valid calls on the procedures mentioned in the previous example are:

```
SWOP(L, M)
SWOP(V(L), V(M))
N = MAX(V, -1, 0)
M = MAX(V, L, 7)
N = M if EQUIV(ONE, TWO)
```

N.B. IMP name type parameters are called by reference and not by substitution (c.f. ALGOL 60).

On exit from the cycle the control variable will contain the value it held immediately prior to the point at which the cycle terminated, usually {final}.

Note The execution of the cycle body must not alter the value of the control variable - the results of doing so are indeterminate.

3. The final form of conditional cycle is:

```
cycle
    ! CYCLE BODY
repeat until {condition}
```

In this construction the cycle body is executed at least once, terminating when the condition becomes true.

cycle-repeat groups may be nested to any depth.

SIMPLE FORMS OF LOOP

If the cycle body comprises only one instruction the loop may be rewritten in the form:-

{instruction} {loop clause}

i.e. {instruction} while {condition}
{instruction} for {control}"="{init}","{inc}","{final}
{instruction} until {condition}

For example

```
A(J) = 0 for J = 1, 1, 20
READSYMBOL(S) until S = NL
SKIPSYMBOL while NEXTSYMBOL = ' '
```

CYCLE CONTROL INSTRUCTIONS

Two instructions are provided to control the execution of a cycle from within the cycle body.

1. exit - causes the cycle to be terminated and control to be passed to the statement following the matching repeat.

2. continue - causes control to be passed to the repeat of the current loop.

JOINING INSTRUCTIONS USING and

Several simple instructions may be joined together using and to form a more complex instruction. The execution of such an instruction is achieved by executing each of the component simple instructions in the order given. This construction is used to simplify small start-finish or cycle-repeat groups.

```
E.g. if X = 0 start
        P = 1; Q = 1
     finish
```

may be rewritten:

```
P = 1 and Q = 1 if X = 0
```

or:

```
if X = 0 then P = 1 and Q = 1
```


4. predicate {id}{param def}?

A predicate is a procedure which tests the validity of an hypothesis and then returns, being either true or false. Predicates may be used wherever a simple condition is required.
When a predicate is called its statements are executed until either of the instructions true or false is executed. This causes the predicate to terminate accordingly.

Note that a predicate does not return any value.

```
E.g. integer N
     predicate SINGLE DIGIT
        true if 0 <= N <= 9
        false
     end

     N = N//10 unless SINGLE DIGIT
```

Notes

a. A routine may terminate by reaching end; all other types of procedure must not be able to reach end, otherwise the compiler will report a fault.

b. Procedure definitions may be nested within any form of block.

c. Procedures may be recursive, that is, a procedure definition may contain a reference to itself.

d. It is not possible to jump out of a block. Similarly a procedure can not be terminated by executing the appropriate statement (return etc.) contained in an inner block. If it is required to force a return from several blocks the signal mechanism should be used (q.v.).

2. {type} function {id}{param def}?

A function is a procedure which calculates a value of the specified type (integer, real, string, or record) and may be used wherever an operand of the specified type is required.
When a function is called its statements are executed until the execution of an instruction of the form:

```
result "=" {expression}
```

This causes the function to terminate, returning the value of the expression as the value of the function.

```
integer X,Y,Z
integer function SUM
   result = X+Y
end
Z = SUM;          ! same effect as "Z=X+Y"
```

The keyword function may be abbreviated to fn.

3. {type} map {id}{param def}?

A map is a procedure which calculates a reference to a variable of the specified type (integer, real, string, or record), and may be used wherever a variable of the specified type is required.
When a map is called its statements are executed until the execution of an instruction of the form:

```
result "==" {variable reference}
```

This causes the map to terminate, returning a reference to (i.e. the address of) the given variable.

```
E.g. integer X,Y
     integer map MIN
        if X < Y then result == X else result == Y
     end

     MIN = 0
     ! the above statement is exactly equivalent to:
     ! if X < Y then X = 0 else Y = 0
```


BLOCK STRUCTURE

An IMP program is constructed using one or more blocks. Blocks may be nested one within another; the depth to which this nesting may be performed is implementation dependent.

Note that start - finish (see Conditional Groups) and cycle - repeat (see Repetition) do not define blocks, they merely define the scope of conditions and loops.

BEGIN BLOCKS

The simplest type of block is enclosed between the statements begin and end and is referred to as a begin block. If the block is the outermost block of a complete program it must be terminated by the statement
end of program, rather than by a simple end.

For example, a complete program might take the form:

```
begin
   integer COUNT, LIMIT
   .
   begin
      real SUM
      .
   end
   .
end of program
```

A begin block is entered by executing the begin and is left by passing through the end to the following statement. The main uses of begin blocks are to declare arrays with bounds calculated at run-time, and to enable the re-use of space taken up by large arrays which are only needed for part of the program.

```
begin
   integer UPPER
   UPPER = ...;    ! CALCULATE VALUE FOR UPPER BOUND
   begin
      integer array CASES(1:UPPER)
      .
   end
end of program

begin
   .
   begin
      integer array TEMP(1:10000)
      .
   end
   begin
      real array WORK AREA(1:11000)
      .
   end
end of program
```

LOCAL AND GLOBAL VARIABLES

An identifier is described as being local to a block if it was declared at the head of that block. Any identifiers which are in scope but which were not declared in the block in question are referred to as being global to the block.
Clearly identifiers may be local to only one block but may be global to many.

```
begin;                  ! start of outer block
   integer X;           !  X is local to this block
   begin;               ! start of inner block
      integer Y;        !  Y is local to this block
      X = 0;            !  X is global to this block
   end;                 ! end of inner block
end;                    ! end of outer block
```

Identifiers may always be redeclared in any block to which they are global - the local incarnation taking precedence over the global one.

```
begin
   integer X
   begin
      integer X
      X = 0;            ! uses the X of the previous line
   end
end
```

An attempt to redeclare a local variable will be faulted by the compiler.

On entry to a block, storage is allocated to local variables and when the block is left the storage is deallocated (but see Own Variables).

PROCEDURES

A procedure is a block which has an associated identifier; a complete procedure block may be considered as the declaration of the procedure identifier.
Unlike begin blocks, procedures are not entered simply by reaching their first statement (this results in control being transferred to the statement following the matching end). Instead, procedures are activated when they are called by giving the procedure identifier in a context determined by the type of procedure.
The effect of a call is to suspend the current flow of control and to pass control to the procedure. When the procedure terminates, the previous flow of control is resumed.

There are four forms of procedure, the exact form required being specified by the first statement of the block.

The phrase {param def}? stands for the optional parameter definition and will be described later (see Parameters).

1. routine {id}{param def}?

   When a routine is called its statements are executed until either the end is reached or the instruction return is executed. This causes the routine to terminate and the previous flow of control to be resumed.

```
integer X, Y
routine CONVERT
   if X < Y start
      X = X+Y
   finish else start
      X = X-Y
   finish
end
..
..
CONVERT
..
CONVERT unless X = 0
```

Table A: EMAS Internal Character Code

0	NUL	32	space	64	@	96	`
1	SOH	33	!	65	A	97	a
2	STX	34	"	66	B	98	b
3	ETX	35	#(£)	67	C	99	c
4	EOT	36	$(¬)	68	D	100	d
5	ENQ	37	%	69	E	101	e
6	ACK	38	&	70	F	102	f
7	BEL	39	'	71	G	103	g
8	BS	40	(	72	H	104	h
9	HT	41	)	73	I	105	i
10	LF(NL)	42	*	74	J	106	j
11	VT	43	+	75	K	107	k
12	FF	44	,	76	L	108	l
13	CR	45	-	77	M	109	m
14	SO	46	.	78	N	110	n
15	SI	47	/	79	O	111	o
16	DLE	48	0	80	P	112	p
17	DC1	49	1	81	Q	113	q
18	DC2	50	2	82	R	114	r
19	DC3	51	3	83	S	115	s
20	DC4	52	4	84	T	116	t
21	NAK	53	5	85	U	117	u
22	SYN	54	6	86	V	118	v
23	ETB	55	7	87	W	119	w
24	CAN	56	8	88	X	120	x
25	EM	57	9	89	Y	121	y
26	SUB	58	:	90	Z	122	z
27	ESC	59	;	91	[	123	{
28	FS	60	<	92	\(¬)(¬)	124	¦
29	GS	61	=	93	]	125	}
30	RS	62	>	94	↑(^)	126	~
31	US	63	?	95	←	127	DEL