Stichting Mathematisch Centrum

Scientific Programme 1989

Long-Range Plan 1990-1994

Part 1

Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science

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Preface

As of September 1st, 1988, CWI has regrouped part of its research departments, reducing their number from 8 to 6. The former departments of Pure Mathematics and Applied Mathematics are now united into a new department called Algebra, Analysis and Geometry. The project Cryptology moved from the department of Pure Mathematics to the department of Algorithmics and Architecture. The departments of Mathematical Statistics and of Operations Research and System Theory have been fused into one department of Operations Research, Statistics, and System Theory.

In summary, CWI now has the following 6 research departments (abbreviations in brackets are derived from the Dutch department names) and department heads:

- Algebra, Analysis and Geometry (AM), M. Hazewinkel;
- Operations Research, Statistics, and System Theory (BS), J.K. Lenstra;
- Numerical Mathematics (NW), P.J. van der Houwen;
- Software Technology (AP), J.W. de Bakker;
- Algorithmics and Architecture (AA), L.G.L.T. Meertens;
- Interactive Systems (IS), P.J.W. ten Hagen.

Each department contributes a scientific program. Also included is a scientific program of the department of Computer Systems and Telematics (CST), headed by D.C.A. Bulterman.

Contents

Department of

Algebra, Analysis and Geometry

Given the more specific tasks and better defined areas of specialization of the other two groups in mathematics at the CWI, a rather large and diverse area is left for the department AM to move around in, more or less well described by the words algebra, analysis and geometry; this with the understanding that functional analysis, topology, logic and discrete mathematics are also included (at least in principle). All that is of course a far too large area to cover adequately with a group of some twenty odd scientists, and so choices will have to be made.

Globally speaking this department has two rather different principal tasks. First of all to do quality research in selected areas largely determined by the expertise and talents of the available staff. This aspect is embodied in the nine projects labelled AM 1 - AM 9 and described in more detail below. The second task is to serve as a bridge of knowledge and expertise, and as an instant consulting group for all aspects of mathematics which could turn up in the researches of the other five departments at the CWI. Both these tasks were explicitly emphasized by the report of the evaluation panel of April 1988.

Both tasks may of course entail acquiring further expertise and knowledge in areas not adequately covered at the moment.

Given the need for choice the group prefers to concentrate on areas where several aspects of mathematics and/or applications interact. This is not particularly unique, being in line with global tendencies of the development of mathematics as a whole at the present time. Two examples are the interaction between algebraic geometry and number theory (arithmetic algebraic geometry) and the interactions between gauge theories and integrable systems in physics on the one hand and differential/algebraic topology/geometry on the other hand. Both areas scored a Fields medal in 1986. The first of these two is given practically no attention at all at the CWI except in its interaction with

conformal field theories (Arakelov intersection theory and field theory over the integers), but is adequately covered elsewhere in SMC; the second interaction area gets attention in projects AM 2 and AM 4. It should be noted that the development of integrable system theory was heavily dependent on computer experiments. A third area of major interactions involves the fields of bifurcation theory, chaotic dynamics (also a child of computer experiments) and theoretical mechanics with for certain parts a good deal of symplectic geometry thrown in. This mix, combined with yet further greatly improved computer experiments, resulted in a total revival of theoretical mechanics, particularly hydrodynamics.

Thus in addition to a tendency to concentrate on interaction areas, we aim at such research projects where fruitful use can be made of machine assistance (computers). We believe that a great deal of insight can be gained from the systematic use of computers as an experimental tool in mathematical research and aim to make a significant contribution to this emerging, and so far in the Netherlands not yet very well developed, way of doing mathematical research.

Doing computer experiments can, depending on the subject, involve both symbolic manipulations (computer algebra) and (numerical) simulation. The last aspect is particularly important for the study of dynamical systems (both stochastic and deterministic), which, in one form or another turn up in quite a few of the ongoing research projects in AM (and BS). Some of these (study of stochastic simulations e.g.) also involve symbolic aspects in the form of packages such as REDUCE or MACSYMA (often with the use of some form of LISP).

The department therefore feels the need of building up and maintaining something like a 'dynamical system laboratory'. This consists, besides the necessary hardware, essentially of a large collection of special computer programs, which can be used to investigate and simulate problems from biology, physics, chemistry, engineering and elsewhere. There exists a few such 'laboratories' elsewhere in the world but so far none in the Netherlands. One also needs the personnel to run the available software of course and to maintain and improve it.

A similar situation is present with respect to symbolic computations (computer algebra). Again we aim at developing, acquiring, improving, and maintaining an adequate collection of algorithms implemented in the form of usable packages well related to each other. Here usable does not mean only usable by the original author on his special machine, but usable by reasonably knowledgeable amateurs (as far as both programming and the specific area expertise is concerned). E.g. a non-expert-programmer and non-Lie-theorist, who for example happens to be an integrable system theory specialist should be able to use the package 'Lie' (at present being developed by us) to calculate say 'branching coefficients'. The evaluation panel report supports this stated aim and even suggests to extend things in the direction of building up a maximally complete library for such things.

It is clear that the two 'program library related' aims just briefly described will tend to reinforce each other. In addition it should be remarked that the

presence of a dynamical system laboratory will most likely have interesting side effects vis-à-vis such topics as numerical bifurcation theory, pattern recognition, computer graphics, and artificial intelligence; all topics which impinge on activities both within the department and elsewhere in the CWI.

The function of the department as a reservoir of expertise in the most general possible sense is also of relevance in the European context. It is our belief that (pure) mathematics has developed an enormous array of tools, which combined with numerical and simulation work (whence the need for a 'dynamic systems laboratory' again), are ready to be applied to an enormous range of practical industrial problems. Which techniques and results can be applied where is a totally different matter; and that is why, as has often been remarked, the industrial mathematician needs to be a 'generalist' or at least must have a few of those 'generalists' in his immediate neighbourhood. The CWI is a charter member of ECMI (the European Consortium for Mathematics in Industry) and recently cooperation agreements have been signed with GMD and INRIA. In both contexts the department hopes to make adequate contributions in the form of a knowledge pool.

There is, as has already been indicated, a remarkable and growing appreciation of what can be done with various highly abstract parts of mathematics in theoretical physics. In addition more and more abstract and sophisticated tools are being used in physics, chemistry, biology and engineering, especially electrical engineering and signal processing. And in turn these fields are excellent sources of new and challenging problems. However, when tackling such problems it would be a mistake to stick too close to the original question. A good problem soon develops its own subfield complete with tools, concepts, and its own inner momentum, esthetics, and criteria of relevance. Often contact with the original question field is (temporarily) lost. This gives the room and freedom to develop concepts, tools, results, and ideas, which then, often much later, finally turn out to be applicable to the original set of questions, and, quite frequently, to a number of other, apparently unrelated, sets of problems as well. In particular letting the mathematics go its own way has often led to surprising insights which would probably not have been achieved if the mathematical community had stuck close to the original problem source.

Thus, too much stress on immediate applicability is definitely unhealthy, but so is the not uncommon attitude of not wanting to know anything about the problems which at the moment are emerging out of application fields, such as quoted above.

At the moment research of the department AM is divided into nine projects of varying size. There are quite a few interrelations between the various projects as will be apparent from the more detailed descriptions below. The nine projects are:

AM 1 Algebra, discrete mathematics and computer algebra
AM 2 Analysis on Lie groups and symmetric spaces and the connection with special functions
AM 3 Classical analysis and number theory
AM 4 Algebraic mathematical physics
AM 5 Dynamical systems
AM 6 Asymptotics
AM 7 Nonlinear analysis and biomathematics
AM 8 Image processing and reconstruction
AM 9 History of mathematization

Department of Algebra, Analysis and Geometry

List of projects

AM 1 Algebra, discrete mathematics and computer algebra
AM 2 Analysis on semisimple Lie groups and symmetric spaces and the connection with special functions
AM 3 Classical analysis and number theory
AM 4 Algebraic mathematical physics
AM 5 Dynamical systems
AM 6 Asymptotics
AM 7 Nonlinear analysis and biomathematics
AM 8 Image processing and reconstruction
AM 9 History of mathematization

	Projects											working			
Name	AM1	AM2	AM3	AM4	AM5	AM6	AM7	AM8	AM9	BS3	misc.	hours	regu-lar	de-tached	guests
appointed															
Hazewinkel				•					•	•		1.00	1.00		
Bon, van	•											1.00	0.88		
Brouwer	•											0.10	0.10		
Cohen	•											1.00	1.00		
Ruitenburg	•											1.00	0.80		
Smit, de	•											0.20	0.20		
advisor	•											-	p.m.		
Koornwinder		•										1.00	1.00		
Lune, v.d.			•									0.75	0.75		
Ruijsenaars				•								1.00		1.00	
Scholma				•								1.00	0.33		
Vries, de					•							1.00	1.00		
Roozen						•						1.00	0.33		
Temme						•						1.00	1.00		
Diekmann							•					0.60	0.60		
Metz (adv.)							•					-	p.m.		
Heesterbeek							•					1.00	1.00		
Neerven, van							•					1.00	1.00		
Heijmans							•	•				1.00	1.00		
Kretzschmar							•					1.00			0.50
Inaba							•					1.00			1.00
Roerdink								•				1.00	1.00		
Zwaan								•				1.00	1.00		
Hofstee								•				1.00		1.00	
advisor								•				-	p.m.		
Alberts									•			1.00	1.00		
Baayen									•			-	p.m.		
Dijkhuis											•	1.00	1.00		
total appointed													15.99	2.00	1.50
regular priority															
scient.ass.1												0.20	0.20		
scient.res.1	•											1.00	0.40		
scient.res.2						•						1.00	1.00		
scient.res.3		•										1.00	1.00		
scient.res.4				•								-	p.m.		
scient.res.5								•				-	p.m.		
scient.ass.2												-	p.m.		
scient.res.6	•											-	p.m.		
scient.res.7							•					-	p.m.		
total priority													2.60	0.00	0.00
total estimated													18.59	2.00	1.50

PROJECT AM 1

TITLE: Algebra, discrete mathematics and computer algebra

TITEL: Algebra, discrete wiskunde en computeralgebra

ABSTRACT
This project concerns Chevalley groups and their associated geometries and, more generally, geometries of Buekenhout-Tits type. It is also concerned with some of the more algebraic and discrete mathematical aspects of the theory of Lie groups such as e.g. the classification of the finite subgroups of the exceptional Lie groups. In addition there are (associated) activities concerning coding theory, the theory of designs, and the theory of graphs (especially distance-regular graphs). Finally there are activities concerning the systematic use of computer algebra (symbolic manipulations) in these and other investigations.

SAMENVATTING
Dit project omvat onderzoek naar Chevalley-groepen en de bijbehorende meetkunden en meer algemeen Buekenhout-Tits-type meetkunden. Verder wordt onderzoek gedaan naar enkele algebraïsche aspecten van de theorie van de Lie-groepen zoals welke eindige groepen voorkomen als deelgroepen van de exceptionele Lie-groepen. Daarnaast wordt aandacht besteed aan coderingstheorie, de theorie van designs, en de grafentheorie (i.h.b. afstandsreguliere grafen). Tenslotte zijn er activiteiten betreffende het systematisch gebruik van computeralgebra (symbolische berekeningen) op deze en andere terreinen.

PROJECT MEMBERS
dr. A.M. Cohen (project leader), dr. G.C.M. Ruitenburg, drs. J.T.M. van Bon, prof.dr. A.E. Brouwer, B. de Smit, advisor

EXTERNAL CONTACTS
drs. R. Sommeling (Nijmegen), dr. J. Brinkhuis (Rotterdam), prof.dr. F. Buekenhout (Brussels), prof.dr. R.L. Griess (Ann Arbor), prof.dr. J.H. van Lint (Eindhoven), prof.dr. B. Cooperstein (Santa Cruz), prof.dr. D.B. Wales (Pasadena), dr.ir. H.A. Wilbrink (Eindhoven)

START OF PROJECT: 1984

CLASSIFICATION CODES
NWO-classification : P110, P120, P150
1980 Math. Subj. Class. : 05-XX, 06-XX, 20-XX, 51Exx, 52-XX

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

It is precisely in the interaction between geometries, seen as incidence systems, the theory of groups, combinatorics, and algebraic geometry that there are at the moment a substantial number of interesting problems. This appears for instance in the study of distance-regular graphs, codes, and designs. In addition groups can be studied fruitfully through their geometric representations. And, inversely, using group theoretical ideas one can deduce global information on geometries from local data. In this connection symmetries of the geometries appear of which the existence had not been assumed previously. A central research question here is to what extent the global properties are determined by the local structure of a geometry. For the coming periods there are the following plans:

- Continued research concerning the interactions of finite groups, finite geometries and graphs. Specific plans involve the classification of distance-regular graphs and the determination of hyperplanes of polar spaces.
- Finishing the researches concerning the finite subgroups of groups of Lie type.
- Research concerning the covariants of SL_2, with particular emphasis on the constructive theory of Gordan.

The first year of activities concerning computer algebra saw the (start of the) development of a package called Lie which contains many algorithms (and programs) for the calculation of all kinds of data associated to (the representation theory) of Lie groups and algebras (multiplicities, root space decompositions, highest weights and highest weight vectors, character formula, decompositions of tensors, restriction of representations to subgroups and calculation of the corresponding decompositions, word problems in Coxeter groups,...).

In the next few years efforts will be made to build up similar packages for other areas; for example in graph theory, using many of the programs and algorithms developed largely ad hoc here and elswhere.

In this connection we believe now in 'modularly structured' programs consisting of lots of related (modifiable) smaller units (steered by a central kernel) rather than in massive all-encompassing systems. That is we favour the approach of something like MAPLE over the approach as exemplified by a system like MACSYMA. Still for a centre like ours it is imperative that all widely used symbolic manipulation systems be available and operational. According to the report of the evaluation panel we should in addition make a serious effort to build up a software library (collection) in this area.

A brief summing up of some of the research areas where we expect to use and or are using symbolic computer manipulations follows:

- Theory of covariants (A.M. Cohen).
- Bernstein polynomials (G.C.M. Ruitenburg, AM 2).
- Finite subgroups of Lie type (A.M. Cohen).
- Universal noncommutative formal groups (M. Hazewinkel).
- Stabilization of twin helicopters (M. Hazewinkel).

- Nonlinear filtering and simulation of stochastic dynamical systems (M. Hazewinkel, using Le-Lisp, Reduce, MACSYMA and packages developed at INRIA and the Univ. of Maryland).
- Explicit calculation of partial differential operators that commute with or induce a shift of the radial part of the Laplacian associated to a root system (T.H. Koornwinder, AM 2).
- Characteristic polynomials defined in singular points of ordinary differential equations. Connection with λ-rings and Dieudonné determinants (R. Sommeling, Nijmegen).

PROJECT AM 2

TITLE: Analysis on semisimple Lie groups and symmetric spaces and the connection with special functions

TITEL: Analyse op halfenkelvoudige Lie-groepen en symmetrische ruimten en het verband met speciale functies

ABSTRACT
The purpose of this project is harmonic analysis on (pseudo-) Riemannian symmetric spaces, the study of special functions and their group theoretical interpretation. This includes in particular extensions of the correspondence representations - special functions to the setting of quantum groups such as the twisted SU(N) groups.

SAMENVATTING
Doel van dit project is de harmonische analyse op (pseudo-) Riemannse symmetrische ruimten, de bestudering van speciale functies, en hun groepentheoretische interpretatie. Dit omvat ook de uitbreiding van de interrelatie tussen representatietheorie en speciale functies tot het geval van quantum-groepen in het bijzonder de getwiste SU(N) groepen.

PROJECT MEMBERS
dr. T.H. Koornwinder (project leader)
junior researcher (vacancy)

EXTERNAL CONTACTS
prof. G. van Dijk (Leiden), dr. G.J. Heckman (Leiden), prof. L. Woronowicz (Warsaw), drs. H.T. Koelink (Leiden), prof.dr. H.G. Meijer (Delft)

START OF PROJECT: 1972

CLASSIFICATION CODES

NWO-classification : P120, P130, P140
1980 Math. Subj. Class. : 22E30, 22E46, 43A80, 43A85, 43A90, 33A75, 33A65, 33A30, 10-XX, 30-XX

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

Project AM 2 shall in the next few periods be mainly concentrated on the topic of q-deformations. Such deformations attract at the moment a great deal of international attention. Thus there are for example the Hecke-algebra deformations of the group algebra of a Weylgroup, the quantum group deformations of the algebra of polynomials on a complex semisimple Lie group or of the algebra of continuous functions on a compact semisimple Lie group and the q-hypergeometric function deformations of the usual hypergeometric functions. In addition their are various interrelations between all these q-deformations.

In particular the research will encompass the following aspects:

- *q-orthogonal polynomials associated to root systems.* In 1987 I.G. Macdonald (London) developed a theory of q-Jacobi polynomials associated to an arbitrary root system. This theory can be extended and refined. Possibly taking a limit as q goes to 1 there can be obtained results which fit in the theory of hypergeometric functions associated with root systems as developed by Heckman (Leiden) and Opdam.

- *Special functions and quantum groups.* Of the various approaches to quantum groups (Drinfeld, Jimbo, Woronowicz) the one due to Woronowicz seems to offer the best possibility for explicit calculations. Recent work here at the CWI and in Japan (Masuda a.o.) indicates that the so-called little q-Jacobi-polynomials occur as matrix elements of irreducible representations of the quantum group $S_\mu U(2)$. This suggests that the quantum groups associated to root systems form the right framework for the 'group theoretical' interpretation of q-hypergeometric orthogonal polynomials. Such a framework was missing up to now for most polynomials of this type. In cooperation with H.T. Koelink (Leiden, Ph.D. topic) more will be done in this direction.

- *q-hypergeometric functions.* Also quite apart form the developments around quantum groups there have been interesting recent new results in the theory of this special class of special functions (Askey, Andrews, Gasper, Rahman) and the number of applications is growing fast. In cooperation with the group around H.G. Meijer (Delft) attention will be paid to the recent developments resulting, possibly, in new results in these directions.

- *Infinite-dimensional Lie algebras and groups.* In a seminar joint with the group around M. Hazewinkel (AM 4), with E.G.F. Thomas (Groningen), G.F. Helminck (Twente) and S.N.M. Ruysenaars (CWI) recent developments will be followed. There are many open problems concerning the precise mathematical foundations of the structure theory of infinite-dimensional Lie groups such as the loop groups. Research in this direction will depend on which researchers can be attracted in the nearest future.

PROJECT AM 3

TITLE: Classical analysis and number theory

TITEL: Klassieke analyse en getallentheorie

ABSTRACT
This project concerns the study of problems of a number-theoretic nature.

SAMENVATTING
Dit project bestudeert problemen van getaltheoretische aard.

PROJECT MEMBERS
dr. J. van de Lune

CONTACTS
dr.ir. H.J.J. te Riele (dept. of Numerical Mathematics), prof.dr. P. Mullender (Doorwerth), dr. A. Odlyzko (Bell Labs, USA), dr. E. Wattel (Free University, Amsterdam).

START OF PROJECT: 1972

CLASSIFICATION CODES

NWO-classification : P120, P130
1980 Math. Subj. Class. : 10H05, 30-XX

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

The following topics will receive attention:

- Numerical research concerning the zeros of the Riemann zeta-function; in particular the nature of these zeros and their relations with various number-theoretic phenomena (with H.J.J. te Riele and A. Odlyzko).
- Calculations related to the Goldbach conjectures (with H.J.J. te Riele).
- The writing of a book on number in theory (in cooperation with P. Mullender).
- Numerical work on Gauss' lattice point problem and Dirichlet's divisor problem (with H.J.J. te Riele and E. Wattel).
- Generalizations of the latter.

PROJECT AM 4

TITLE: Algebraic mathematical physics

TITEL: Algebraïsche mathematische fysica

ABSTRACT
The investigation of algebraic (and algebraic-geometrical), combinatorial and representation theoretical aspects of completely integrable Hamiltonian systems (both quantum and classical), the exactly solvable models from lattice statistical mechanics and parts of gauge theory and representation theory which are related to this. This project consists of the following subprojects:
AM 4.1 Relations between finite degree of freedom, infinite degree of freedom and lattice, and classical integrable models;
AM 4.2 Relativistic and quantum integrable systems.

SAMENVATTING
Bestudering van de algebraïsche (en algebraïsch meetkundige), combinatorische en representatie-theoretische aspecten van volledig integreerbare Hamiltoniaanse systemen (zowel quantum als klassiek), de exact oplosbare modellen uit de rooster-statistische mechanica en de hier onmiddelijk mee verband houdende stukken van ijktheorieën en representatietheorie. Dit project bestaat uit de volgende deelprojecten:
AM 4.1 Relaties tussen eindige-vrijheidsgraden, oneindige-vrijheidsgraden, en rooster, en klassieke, volledig integreerbare modellen;
AM 4.2 Relativistische en quantum integreerbare systemen.

PROJECT MEMBERS
prof.dr. M. Hazewinkel (project leader)
dr. S.N.M. Ruijsenaars (C&C Huygens grant)
drs. J. Scholma
scientific assistant (vacancy)

EXTERNAL CONTACTS
prof.dr. H. Capel (Theoretical Physics, University of Amsterdam) prof.dr. R. Martini (University of Twente), drs. Th.J. Smit (University of Utrecht, via FOM/SMC Samenwerkingsverband Mathematical Physics), drs. H.-J. Imbens (Mathematical Institute, University of Utrecht; supervision M. Hazewinkel), prof.dr. B. de Wit (Theoretical Physics, University of Utrecht)

START OF PROJECT: 1982

CLASSIFICATION CODES

NWO-classification : P120, P130, P140, P150, P190
1980 Math. Subj. Class. : 14K25, 22E65, 82A67, (81E10), 58F07

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

General

Until recently there were but four models in mathematical physics (both classical and quantum) which were exactly solvable. Now, some twenty years after the discovery of the first integrable systems, there are some thirty of them, and these include several of the most important nonlinear partial differential equations of mathematical physics. (As a matter of fact instead of a single completely integrable system one usually has an infinite 'hierarchy' of them, but as a rule only the first one or two members of such a hierarchy are of immediate applied interest, meaning that they occur as models of physical phenomena that are seriously studied.)

Symmetry aspects and Lie groups play an important role in integrable system theory. Indeed, in some (not yet fully understood) sense, integrable systems are systems of partial differential equations with an unusually large symmetry group. On the other hand many integrable systems can be obtained from finite- or infinite-dimensional Lie algebras (by means of a decomposition of the Lie-algebra and the Lie-Kirillov-Kostant symplectic structure on coadjoint orbits). It is still an open (and most important) question whether all integrable systems are obtainable in this way. Also still unclear is the precise relation between the original Lie group (Lie algebra), the integrable systems (there are several different constructions possible) which can be obtained from it, and the symmetry group of these integrable systems.

Many integrable systems are solvable using τ-funcitons (= generalized theta functions). In a certain precise sense these are special functions belonging to an infinite dimensional Lie group. But much more than this general remark is not yet available. See also the description of project AM 2 above. In particular there is so far nothing which would be called harmonic analysis on the associated infinite dimensional Grassmann manifold.

These Grassmann manifolds in turn relate to bosonic strings, conformal field theory, quantum groups and even knot polynomials; some aspects of the interrelations between these four topics (and integrable systems) forms the subject matter of the thesis work of Th.J. Smit in Utrecht (thesis advisors: B. de Witt, M. Hazewinkel).

Other aspects of integrable system theory, centering around the use of Jacobians and τ-functions to solve Kortweg-de Vries type equations, form the subject matter of the thesis work of H.-J. Imbens, Utrecht (thesis advisor: M. Hazewinkel).

All in all, the world of integrable systems constitutes a large area of research in which many research groups are active. As a rule each of the groups has its own favourite (and successful) approach and, except perhaps very recently, the interrelations between the various approaches have been largely ignored. There is still much to be done in that respect.

A detailed and thorough investigation of the interrelations between the various approaches would be a large and beautiful coherent project which would involve an unusual number of different mathematical specialization areas. The very limited, indeed disturbingly limited, research capacity in mathematics at the CWI, however, forces us to limit ourselves to such a few particular aspects of all this.

SUBPROJECT AM 4.1

TITLE: Relations between finite degree of freedom, infinite degree of freedom lattice, and classical integrable models

MEMBERS
prof.dr. M. Hazewinkel
drs. J.K. Scholma
dr. S.N.M. Ruijsenaars

FIELD OF STUDY
There exist various kinds of integrable systems: systems of ordinary differential equations; systems of difference equations; systems of partial differential equations (p.d.e.) and difference-differential equations; relativistic and quantum-mechanical versions; lattice models in the sense of statistical mechanics. Many types (KdV, Toda..) occur in most of these incarnations. This gives rise/leads to the following research problems:

- Do there exist systematic relations between the various incarnations? Is there e.g. a systematic method to construct an integrable lattice model from an integrable p.d.e. (and conversely)? In the case of SL_2 this is solved by Izergin and Korepin; generalizations of this construction to SL_3 and higher dimensions will be one of the fields of interest for the next period. It is already clear that new structures will be needed in order to solve this problem.
- Try to find the missing incarnations of the more well-known integrable systems (e.g. the Calogero-Moser systems). This is the second (at the moment most promising) field of interest.
- Many integrable systems arise from Lie algebras via a construction known as the Adler-Kostant-Symes construction. It is an important open question whether this is the case for all of them. This is in particular open for the Calogero-Moser systems. That particular problem has been solved and extensions of the resulting generalized AKS construction will be investigated.

SUBPROJECT AM 4.2

TITLE: Relativistic and quantum integrable systems

MEMBERS
dr. S.N.M. Ruijsenaars

RESEARCH PURPOSE AND SCIENTIFIC INTEREST
The research project belongs to the general area of quantum and classical integrable systems. The aim is to study a novel class of integrable relativistic N-particle systems, especially with an eye on obtaining new insights regarding known finite- and infinite-dimensional integrable systems, e.g., the Calogero-Moser and Toda systems, the sine-Gordon theory, the 8-vertex and Potts models.

In the near future research will be focused on the explicit diagonalization of the commuting classical and quantum Hamiltonians. At the classical level this involves symplectic geometry and spectral analysis. There there are also connections with the theory of Lie algebras and symmetric spaces.

Connections with the latter areas are especially important at the quantum level: the diagonalization which is sought for can be viewed as a generalization of the spherical Fourier transform from the theory of symmetric spaces. However, in the present case the commuting operators are not differential operators, but analytic difference operators. This type of operators has not yet been studied from the viewpoint of Hilbert space theory, and it is envisaged to remedy this situation. Moreover, the problems at the quantum level are intimately connected with the theory of special functions and of analytic functions of one or several variables.

The relations with infinite-dimensional integrable systems already mentioned above also lead to questions in the area of Kac-Moody and Virasoro algebras, and there are also hints of connections with supersymmetry and string theory. It is envisaged to study these areas with an eye on clarifying these relations.

RELATED RESEARCH
- Kac-Moody algebras and integrable systems (H.-J. Imbens, Ph.D. project in Utrecht supervised by M. Hazewinkel).
- Vertex operators and bosonic strings (Th.J. Smit, Ph.D. project in Utrecht financed by SMC/FOM and supervised by M. Hazewinkel and B. de Wit).

PROJECT AM 5

TITLE: Dynamical systems

TITEL: Dynamische systemen

ABSTRACT
Research on dynamical systems, with emphasis on topological and measure-theoretic aspects. Later on possibly also chaotic and stochastic aspects (e.g. stochastic (partial) differential equations and their applications) will be studied.

SAMENVATTING
Onderzoek aan dynamische systemen, met de nadruk op topologische en maattheoretische aspecten. Later eventueel ook de bestudering van chaotische en stochastische aspecten (b.v. stochastische (partiële) differentiaalvergelijkingen en hun toepassingen).

PROJECT MEMBERS
dr. J. de Vries

START OF PROJECT: 1976

CLASSIFICATION CODES

NWO-classification : P120, P130, P140, P150, P170
1980 Math. Subj. Class. : 54H20, 58Fxx, 60Hxx

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

The theory of dynamical systems deals with groups and semigroups of transformations of a space into itself. This space is to be considered as the state space of a fictitious physical (or: chemical, biological, ...) system, and the transformations from the (semi) group are to be seen as possible transitions between states. These transitions are often described by differential or difference equations (see e.g. [1]). In studying such systems one is interested in recurrent and asymptotic behaviour of points under the (semi) group of transformations.

Depending on the original concrete (physical, chemical, etc.) problem one assumes that the space on which the (semi) group acts has an additional topological, measure-theoretic or differentiable structure. Thus, in Topological Dynamics groups of homeomorphisms on topological spaces are investigated (topological transformation groups; cf. [2]), in Ergodic Theory one studies measure preserving transformations in measure spaces (cf. [3]), and in Differential Dynamics diffeomorphisms on manifolds (cf. [4]).

The geometry of the 'phase portrait' (= the global picture of all orbits under the action of the (semi) group) may depend discontinuously on an external parameter (bifurcation: see e.g. [5]). A recent branch of the investigations in dynamical systems is the study of so-called strange attractors and of chaotic behaviour of dynamical systems, in which deterministic systems behave like stochastic ones; see [6] and [10]. For the relevance of these topics for e.g. classical mechanics we refer to [7] and [8], and for biomathematics to [9]. In general, these topics are important for the proper understanding of all phenomena in which nonlinear aspects of equations are dominant. But there are also applications of Topological Dynamics and Ergodic Theory of a completely different character, e.g. in Coding and in Information Theory; see [11].

From the abundance of topics for research in this field a choice has been made. This choice is partly determined by the research that was done in the past within this project, namely, Abstract Topological Dynamics and Ergodic Theory.

In Abstract Topological Dynamics one studies topological problems that have their origin in the qualitative theory of differential equations. A suitable context for such problems is the theory of topological transformation groups: see [2] and [12]. An important unsolved problem is the classification of compact minimal sets under the action of a given topological group T. Recently much has been published about this problem, and we plan to write a book on this topic. The research in this direction has many connections with Ergodic Theory (cf. [3] and [13]). In these areas we have contacts with researchers from the University of Delft (prof.dr. M.S. Keane, prof.dr. J.M. Aarts) and, outside the Netherlands, with prominent researchers like J. Auslander (Univ. of Maryland, USA) and S. Glasner (Univ. of Tel Aviv, Israel).

WORKING PLAN 1989

To complete the book *Elements of Topological Dynamics.* To publish incidental new results that don't fit in this book. To study the existing literature on Ergodic Theory and Global Analysis.

WORKING PLAN AFTER 1989

The research will gradually be shifted so as to cover more aspects of a stochastic and a global analytic nature.

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PROJECT AM 6

TITLE: Asymptotics

TITEL: Asymptotiek

ABSTRACT
This project includes research on asymptotic expansions of integrals, and solving problems on analysis and asymptotics (with numerical aspects) from physics, biology, and statistics. In a subproject one investigates the effect of stochastic perturbations of dynamical systems.

SAMENVATTING
Er wordt voornamelijk onderzoek verricht aan asymptotische ontwikkelingen van integralen. Voorts wordt gewerkt aan problemen op het gebied van de analyse en asymptotiek (met numerieke aspecten) uit de fysica, biologie en statistiek. In een deelproject wordt gewerkt aan stochastische storingen van dynamische systemen.

PROJECT MEMBERS
dr. N.M. Temme (project leader)
ir. H.N.M. Roozen
junior or scientific researcher (vacancy)

EXTERNAL CONTACTS
dr.ir. J. Grasman (University of Utrecht)
prof. R. Wong (Winnipeg, Canada)
prof. K. Soni (Knoxville, USA)
prof. L. Gatteschi (Torino, Italy)

START OF PROJECT: 1975

CLASSIFICATION CODES

NWO-classification	: P130, P140, P170
1980 Math. Subj. Class.	: 41A60, 65D20, 33-XX
1982 CR Classification Scheme	: G.1.2

PROBLEM FORMULATION AND SCIENTIFIC SIGNIFICANCE

1. ASYMPTOTIC EXPANSIONS OF INTEGRALS

For many fysical and biological problems asymptotic methods are important scientific tools for obtaining qualitative information on solutions of equations and for constructing approximations of solutions. In this way one can gain insight on the dependence of parameters in these problems. This, for instance, cannot always be derived from numerical methods. Also, asymptotic methods can save a lot of computing time when small or large parameters are involved.

In the last decade the department has acquired a lot of skill and experience for tackling problems in asymptotics. Especially on asymptotics for integrals and special functions and on numerical algorithms for special functions, encyclopaedic knowledge is built up. Consequently, the department is consulted by many workers from inside and outside the CWI concerning problems on complex analysis, integrals, integral equations and differential equations. Repeatedly interesting problems of a relevant scientific character are formulated in this way. Planning of this part of the research is not always possible, but the project reserves part of the personnel equipment for this aspect.

Apart from this ad hoc and problem oriented research, there is a systematic plan to keep oneself informed on standard methods and new techniques and to support these with new developments and fundamental methods. In asymptotics of integrals we mainly concentrate on uniform expansions, and we focus our attention on transformations of the integrals to standard forms and to rigorous estimates for remainders in the expansions. Quite recently these aspects are initiated by Olver and Wong. OLVER [1] developed fundamental methods for differential equations, whereas, until now, the theory for integrals is rather neglected, and asks for new ideas. The source of inspiration usually comes from the well-known functions of mathematical physics and mathematical statistics. The approach, however, is quite general, but we concentrate on problems which are relevant in view of applications. Moreover, we pay attention to the numerical aspects; the results are evaluated with respect to their numerical usefulness. For instance, it does not always make sense to implement straightforwardly uniform expansions in numerical algorithms for special functions. The resulting codes may become very complicated, especially when the program is designed for smaller environments (PC's).

Reference [5] gives an overview of existing and new techniques for handling uniform expansions for integrals, together with a list of open problems on standard forms that need further attention.

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2. STOCHASTIC PERTURBATIONS OF DYNAMICAL SYSTEMS

The analysis of deterministic finite dimensional dissipative systems is mainly based on research on the behaviour of solutions on a large time scale. One looks for stable equilibrium points, limit cycles, and other limit sets, as strange attractors. In general the system will tend to a state that corresponds with one of the above mentioned stable solutions. Usually, the system is a model in which several influences of the real world are not taken into account. It is very difficult to mathematize these influence, and therefore one includes a stochastic perturbation term in the model to simulate these influences. This may lead to a significant modification of the behaviour of the solution. For instance, on a large time scale, the system may tend to several different stable solutions. In this subproject one investigates the behaviour of mechanical structures under influence of loads with a small stochastic component. It is important to obtain information on the life time of such structures.

Literature

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WORKING PLAN 1989

1. Asymptotic expansions of integrals

1. Earlier started research on uniform expansions for Laplace-type integrals will be continued. Several examples of special functions serve as model problem. For some examples uniform expansions already exist and are obtained by using other methods (say, differential equations). In [7] we introduced new methods to investigate the regularity of mappings used in transforming the integrals to standard forms. These methods will be applied to the earlier studied case of Laguerre polynomials.
2. A monography on uniform expansion is in preparation. Several earlier

papers are rewritten for this project. New topics will be included. A soft deadline of this work is December 1989.

3. Algorithms for the numerical evaluation of special functions will be reconsidered for the cases where uniform asymptotic methods can be used efficiently. A special technique is developed to avoid the computation of complicated terms in the expansions, and will be applied to well-known functions. For example, the modified Bessel function $K_{ia}(x)$, where a is real, will be considered. For this function published software is not available.

2. Stochastic perturbations of dynamical systems

As a continuation of the former project TW 1, we study the effect of stochastic perturbations on dynamical systems. Recently, we have considered stochastic systems for which the associated deterministic system had a stable equilibrium [see the CWI reports AM-R8602, AM-N8602, AM-R8702], or a neutral equilibrium [AM-R8801]. The former reports were written in a biological context, the latter in a mechanical one. The emphasis was on the determination of characteristics related to the problem of exit from a domain in state space, like the expected exit time and the most probable exit point(s) on the boundary of the domain, asymptotically for small noise intensity. This subproject will terminate at the end of April 1989. Until that time we intend either to undertake an application of an exit model to a concrete problem, or to go into a more detailed study of the ray method (this method plays a role in the asymptotic solution for small noise intensity of the exit problem for systems with a stable deterministic equilibrium).

PROJECT AM 7

TITLE: Nonlinear analysis and biomathematics

TITEL: Niet-lineaire analyse en biomathematica

ABSTRACT
Analysis of (ordinary, partial and functional) differential equations and integral equations which correspond to mathematical descriptions of biological processes. Development of a general mathematical modelling methodology, in particular for the dynamics of structured populations.

SAMENVATTING
Analyse van (gewone, partiële en functionaal-) differentiaalvergelijkingen en integraalvergelijkingen die corresponderen met wiskundige beschrijvingen van biologische processen. Ontwikkeling van algemene wiskundige modelbouwmethodologie, in het bijzonder voor de dynamica van gestructureerde populaties.

PROJECT MEMBERS
prof.dr. O. Diekmann (project leader)
prof.dr. J.A.J. Metz (University of Leiden, advisor)
ir. J.A.P. Heesterbeek, drs. J.M.A.M. van Neerven
dr.ir. H.J.A.M. Heijmans
H. Inabe, B.Sc. (Institute of Population Problems, Tokyo, Japan; in 88/89 and 89/90 guest at University of Leiden and CWI)
dr. M. Kretzschmar (Mathematical Institute, Tübingen, FRG; in 88/89 guest at CWI)

EXTERNAL CONTACTS
drs. F. van den Bosch, drs. A.M. de Roos (University of Leiden), prof.dr. Ph. Clément (Delft Technological University), drs. S.A.H. Geritz (University of Leiden), dr. A. Grabosch, dr. G. Greiner (Eberhard-Karls-Universität, Tübingen, FRG), dr. M. Gyllenberg (Helsinki University of Technology, Finland), prof. Y. Nishiura (Kyoto Sangyo University, Japan), prof. M. Mimura (Hiroshima University, Japan), prof.dr. S.A.L.M. Kooijman (Free University Amsterdam), prof. R.M. Nisbet (University of Strathclyde, Glasgow, Scotland), prof.dr. M.W. Sabelis (University of Amsterdam), dr. H.R. Thieme (University of Arizona, Tempe, USA), dr. S.M. Verduyn Lunel (Georgia Institute of Technology, USA), prof.dr. H-O. Walther (Ludwig Maximilians Universität, München, FRG)

START OF PROJECT: 1975

CLASSIFICATION CODES

NWO-classification : P130, B 110
1980 Math. Subj. Class. : 92-XX, 34-XX, 35-XX, 45-XX, 47D05, 47Hxx, 58Fxx

DESCRIPTION OF THE PROBLEM AREA AND SCIENTIFIC AIMS

As the name indicates, this project has two, mutually interacting, components. During the next few years the central issue will be the dynamics of populations with an internal, physiological structure. This concerns balance laws which relate the life history of individuals to the development of the population as a whole. Taking into account relevant differences at the individual level enables the modeller to incorporate a detailed description of the interaction of the population and its environment (including other populations) based on relevant physiological facts. Concrete applications abound (e.g. the biological control of pests and the use of experimental results concerning the effect of toxic chemicals at the individual level to predict the consequences at the population level). The state-of-the-art is described in *The Dynamics of Physiologically Structured Populations,* J.A.J. Metz & O. Diekmann (eds), Lect. Notes in Biomath. 68, Springer 1986.

The balance laws are first order partial functional differential equations. A general aim of the project is to develop a qualitative theory for such equations. Our work till now has made clear that the theory shall centre around duality. Therefore we shall concentrate on the role of duality in the geometric theory of infinite dimensional dynamical systems.

The biological aspects of the work are embedded in a cooperation program (AIO netwerk) with the Institute of Theoretical Biology, University of Leiden, and the Group in Applied Theoretical Biology at the Free University Amsterdam. In addition there are close contacts with the Group in Pure and Applied Ecology of the University of Amsterdam. The existence of chains of communicating people guarantees the mutual influence between concrete applied work in physiological ecology and abstract theoretical work in dynamical systems with a biological signature.

The mathematical aspects of the work prosper due to international cooperation with (former) visitors at the CWI. It is a general strategy of the project to enhance the mathematical work by a visitors progam.

Nonlinear science is going through a period of very rapid development. It is conceivable and even desirable to start a 'Centre for Nonlinear Dynamics' (including computing facilities which deserve to be called a 'Dynamical Systems Lab') at the CWI. Such an effort is, however, beyond the scope of the present project.

WORKING PLAN 1989

1) *Infectious diseases*

In the first half of 1989 we shall organize a colloquium on 'The Spread of Infectious Diseases in Structured Populations' jointly with the Institute of Theoretical Biology, Leiden.

In four to six one-day meetings an overview of biological aspects and mathematical models will be presented. The emphasis will be on the influence of various kinds of 'structure' on the dynamics. Here 'structure' refers to such properties as age (measles), wormload (Schistosomiasis), spatial position (plant diseases) and individual variability in sexual

behaviour (AIDS). Publication of proceedings will be considered, but the decision will depend on the actual coherence and quality of the colloquium contributions.
In preparation for the colloquium a study group will be formed in the fall of 1988. It is expected that in particular J.A.P. Heesterbeek and our guests H. Inaba and M. Kretzschmar will be very active in this group. The former intends to write his thesis on the subject.

2) *Dual (Population) evolution equations*
As an extension of our earlier work, which primarily applies to the case of a one-dimensional individual state, we shall exploit the duality between the general Kolmogorov backward- and forward equations to give an existence- and uniqueness result for population problems in which the interaction proceeds via the (finite dimensional) environment. Next the standard local stability and bifurcation theory has to be developed in this setting and relevant prototype examples have to be studied in detail.
The range and strength of the duality point of view in the investigation of nonlinear semigroups generated by operators with a special structure will be determined.
J.M.A.M. van Neerven will start doing research in this direction. The cooperation with Ph. Clément, M. Gyllenberg and H.R. Thieme will be continued.

3) *Blood cell production systems*
The way in which blood cells in living organisms are being produced is a complex and poorly understood process. Realistic models should take into account that the cell cycle is subdivided in several stages and that the production of red blood cells in the bone marrow is controlled by several hormones. Recently, A. Grabosch (Tübingen) and H.J.A.M. Heijmans have formulated a structured model describing the evolution in time of the bone marrow stem cell population. This model will be analyzed mathematically (and numerically) in the near future.

4) *Functional differential equations*
H.O. Walther, S.M. Verduyn Lunel and O. Diekmann are writing a book on the Functional-, Complex- and Nonlinear Analysis of Delay Differential Equations. There will be three parts dealing with, respectively, perturbation theory for dual semigroups, exponential type calculus for entire functions of order one, and local- and global nonlinear methods. In optimistic moods we expect the manuscript to be ready by the fall of 1989.

5) *Necessary and sufficient conditions for 'linear chain trickery' in structured population models*
Under certain conditions on the birth-, death- and individual- growth rates it is possible to describe the infinite dimensional population dynamical system completely in terms of solutions of a system of ordinary differential equations. J.A.J. Metz and O. Diekmann aspire to deduce necessary and sufficient conditions.

6) *Prey-predator patch problems*
This concerns joint work with M.W. Sabelis (University of Amsterdam) on the interaction of spider- and predatory mites in a multitude of colonies on host plants. The influence of an aggregative response (predators find large spider mite colonies much easier than small ones) on the stability will be investigated. Next a model for the interaction of two predator species with two prey species will be formulated. The aim is to determine evolutionary stable strategies for prey selection and to study the related question of invasibility by a new prey species. Insight in such matters is urgently needed now that biotechnology has increased the pace with which genetic changes may occur. Related experimental work will be performed at the Universities of Amsterdam and Leiden under the guidance of M.W. Sabelis and J.J.M. van Alphen (University of Leiden).

7) *Control of plant diseases*
Research on criteria for evaluating the efficacy of certain control measures for plant diseases will be continued by J.A.P. Heesterbeek and H.R. Thieme.

8) *Characteristic equations*
The stability analysis of equilibrium solutions of evolution equations can quite often be reduced to questions about the position of the roots of a transcendental equation in the complex plane. We need combinations of analytical and numerical methods by which such questions can be answered systematically and effectively.

WORKING PLAN AFTER 1989

Not all of the above plans can be realized in one year and part of the work will be carried out in 1990 or later.

It is intended to pay relatively more attention to nonlinear analysis in the following years in particular to nonlinear semigroup theory and global generic results (like in J.K. Hale, L.T. Magalhaes & W.M. Oliva, *An Introduction to Infinite Dimensional Dynamical Systems-Geometric Theory,* Springer, 1984). To realize such plans it is necessary to appoint a post-doc (for instance S.M. Verduyn Lunel in 89/90 and 90/91) and to have visitors (for instance G. Greiner in 89/90 or 90/91).

PROJECT AM 8

TITLE: Image processing and reconstruction

TITEL: Verwerking en reconstructie van beelden

ABSTRACT
- Research on mathematical aspects of image processing and reconstruction by means of mathematical and numerical analysis, mathematical statistics and computer science.
- Development of algorithms and software.
- Contact with medical investigators, biologists, physicists and research laboratories.

SAMENVATTING
- Onderzoek naar de wiskundige aspecten van beeldverwerking en -reconstructie door middel van wiskundige en numerieke analyse, statistiek en informatica.
- Ontwikkeling van algoritmen en software.
- Contacten met medici, biologen, fysici en ontwikkelingslaboratoria.

PROJECT MEMBERS

dr.ir. H.J.A.M. Heijmans
dr. J.B.T.M. Roerdink (project leader)
drs. M. Zwaan
drs. P. Hofstee (TEG)
1 visitor or/and post-doc (p.m.)
1 advisor
dr. J.W. van der Woude (p.m., BS 3.5)

EXTERNAL CONTACTS

This is a joint project with Image analysis (project BS 6) of the department of Operations Research, Statistics and System Theory. dr.ir. J.J.M. Cuppen, dr.ir. F.A. Kuijpers (Philips Medical Systems, Best) dr. F.J. Jacobs (Royal/Shell Exploration and Production Laboratory, Rijswijk) dr.ir. J.H. van Schuppen (CWI) prof.dr. W. Vervaat (Catholic University Nijmegen) prof.dr.ir. D.E. Boekee, dr. J. Biemond (Delft Technological University) prof.dr.ir. F.C.A. Groen (University of Amsterdam).

START OF PROJECT: 1985

CLASSIFICATION CODES

NWO-classification : P150, P170
1980 Math. Subj. Class. : 69K22, 44A15, 69K40, 69L30

PROBLEM FORMULATION AND SCIENTIFIC SIGNIFICANCE

In many areas one is increasingly confronted with information in the form of images, e.g. television, X-ray images, satellite pictures etc. The (re)construction, processing, transmission and analysis of such images are creating a promising research area involving mathematics, computer science and technology. Many branches of mathematics are involved on the theoretical side: analysis, algebra, topology, numerical mathematics, statistics and systems theory. On the other hand an essential role is played by computer science since nowadays the handling of images is to a large extent a computer-assisted process. Computer image processing is conventionally described as having phases of reconstruction (back transformation as in e.g. tomography), compression, enhancement and restoration (noise removal, filtering) and last but not least, description and analysis (measurements, classification, decisions). The research at CWI currently concentrates on two topics: (i) reconstruction and (ii) description and analysis. However the various phases of image processing can sometimes be profitably combined or exchanged, and in fact the whole process is circular since, for example, a good description leads to better compression techniques. Topics covered under reconstruction will be: reconstruction methods for moving magnetic resonance (NMR) images; inverse scattering of seismic images. Under description and analysis the research effort will focus on: the theory and application of mathematical morphology; probabilistic modelling and statistical analysis. We discuss the proposed research in the various areas although these cannot always be clearly separated.

a. Reconstruction

Advances in computer aided tomography in recent years have been spectacular; for instance the Nobel prize for medicine went in 1979 to A.M. Cormach and G.N. Houndsfield for their work on computerized tomography (CT) (also called computer-assisted tomography: CAT). There are many techniques (emission and transmission tomography; NMR, X-ray, gamma-ray, ultrasound, electron beam, ...) all however presenting a similar mathematical problem: how to reconstruct an n-dimensional object given (some of) its $n-1$ (or less) dimensional projections. (Here n is usually 2 or 3, but can also be 4 if time plays a role too). A mathematical solution in the form of an inversion formula was given in 1917 by Radon. However this hardly ever supplies a practical solution since these reconstruction problems are 'ill-posed' in Hadamard's sense: a small perturbation in the given data leads to a result totally different from that given by the inversion formula. Numerical methods to solve these problems fall into two classes: algebraic reconstruction techniques and transformation techniques (harmonic analysis, integral equations, special functions). Particularly challenging as well as mathematically difficult problems arise in the reconstruction of moving objects, e.g. imaging a moving human heart by the NMR technique. Among the industrial applications more and more importance is gained by seismic data and image processing with the aim to reconstruct the internal structure of the earth by inverse scattering techniques. Because of the noise and the limitations of the measuring process

statistical and system-theoretic considerations must be taken into account as well.

b. Mathematical morphology
An important development within the field of image processing is formed by mathematical morphology, which is both a mathematical theory and a source of practical image processing algorithms, which are part of most currently available image processing software packages. Within mathematical morphology images are considered as sets of points; logical relations between neighbouring points are used to define so-called morphological transformations with a clear geometrical interpretation. In this way a method is obtained to perform global quantitative measurements on images by the successive application of several morphological transformations. In practice one is again confronted with noise and other uncertainties, so that probabilistic and statistical ingredients (random sets, random fields) are being incorporated in the theory. There is an intimate connection between mathematical morphology and cellular automata, which is called cellular logic image processing (CLIP). Generations of ever more advanced image processing machines are based upon this principle (Texture Analyser, CLIP1-CLIP4, DAP: distributed array processor, MPP: massively parallel processor). A related area is that of multiresolution image processing, which considers simultaneous levels of resolution in an image, inspired by theories of how the human vision system functions. Important applications can be found in the area of computer vision, e.g. automatic product inspection, robot vision etc. The question of image decomposition which arises here is a natural one to be studied in the context of mathematical morphology.

c. Probabilistic modelling & statistical analysis
The probabilistic approach has led to great advances even in areas where a 'statistical approach' does not seem at all applicable. For instance, in restoration, though a (cleaned up) LANDSAT picture may not globally look at all like the result of some kind of homogeneous stochastic process, it is in fact the case that locally small parts of the image do look very much like (small parts of) the realization of a Markov random field. This fact has in the last five years been exploited by D. and S. Geman (Brown University, USA), by J. Besag (Durham, UK), P. Switzer (Stanford Univ., USA) and others, who have devised vastly superior image restoration algorithms based on an assumed stochastic model for the 'underlying scene', together with a probabilistic model for the noise which added to the scene produces the available picture. Novel techniques have been developed to actually efficiently solve the resulting optimization problem. In very recent work the approach has been applied to segmentation problems (line detection) using Markov line processes, and to inverse (tomography) reconstruction problems. As soon as the noise component of such images is more significant and has special structure - e.g. in positron emission tomography one is dealing with Poisson distributed counts,

not Gaussian noise - a statistical approach can lead to far better reconstruction and/or enhancement algorithms.

The time is definitely ripe for an explosion of advances in this area. Ingredients will come from such topics as

* stochastic geometry (the theory of random geometrical objects), which will provide us with models (e.g. random tessellation) and also answers to problems of digitalization (what happens when we intersect a fixed object with a random 'observation' grid);
* mathematical morphology, a toolkit of image transformations which will produce summary statistics and diagnostic plots for evaluating models; also it is, intimately connected with the theory of random sets and random fields;
* Markov fields, Gibbs states, as mentioned before in connection with the work of Geman & Geman, Besag, and others; important problems are to assess the propriety of using such scale dependent (through pixel lattice mesh size) and anisotropic (through the orientation of the pixel lattice) models for essentially scale invariant, isotropic phenomena;
* spatial statistics, an already well established field of statistics especially for the analysis of agricultural field trials, geophysical and ecological surveys, generalizing classical time series analysis to the analysis of measurements taken at an irregular collection of points in $\mathbb{R}^2$ or $\mathbb{R}^3$;
* fractal theory, another rich source of stochastic models for e.g. textures;
* stereology, the mathematics of making inference from sampled 2-D sections to a 3-D object.

Literature

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WORKING PLAN 1989

Within this project the following topics will be studied:

1. Reconstruction of NMR images. This research is carried out in cooperation with Philips Medical Systems (Best). The aim is to study reconstruction of magnetic resonance images of the beating heart, and particularly the effect of missing data (both in space and in time) upon the reconstructed images.
2. Mathematical morphology. Research will be carried out on developing the theory as initiated by Serra, Matheron and others in several directions:
   a. Deepening the mathematical basis of the theory, especially with respect to algebraic, topological and geometrical aspects.
   b. Extension of the theory to grey-value images.
   c. Study the stereological and probabilistic aspects of the theory (in cooperation with the department of Operations Research, Statistics and System Theory.
   d. Construct and implement new image analysis algorithms.

On the computational side we envisage the creation of a computer system (hard- and software) forming an experimental laboratory for image processing, allowing evaluation of new algorithms, simulation and modelling experiments, and general statistical and numerical analysis of results of image processing. The ideal environment for such activities is a network of workstations allowing high resolution graphical display and a large memory storage (a typical image consists of a megabyte of data and one will often want to manipulate several images at the same time). Also it will make meaningful international cooperation with similar research groups elsewhere possible. On the sort term we plan two large workstations with floating point accelerator and large disc storage; video input (frame grabber); software (TIPS, HIPS, VISIX, VISILOG). Part of this has been installed already in 1988.

WORKING PLAN AFTER 1989

All subprojects mentioned above are continued after 1988. The scope of these projects may be widened and new projects added, e.g.

1. Investigate the role of mathematical morphology in computer vision problems. Cooperation with the Delft Technological University and the University of Amsterdam is under way.
2. Image reconstruction for different modalities, e.g. ultrasound imaging. Here we can also mention contacts with the department of opthalmic surgery at the Catholic University Nijmegen (ultrasound imaging with very high noise levels).
3. Inverse scattering and image processing of seismic data. The first phase of the project (a system theoretic approach of one-dimensional models) is carried out by the department of Operations Research, Statistics and System Theory. When this is completed, we plan to investigate the applicability of image processing techniques in this area.

An expansion of the computational facilities is planned along the following lines:

a. Middle-term. Ethernet network of workstations, 6 smaller workstations, 50 Mbyte disc per node, software; perhaps a permanent (network) line to some applied field co-researchers.
b. Long-term. The reconstruction subproject will need a more powerful system to handle the large data sets occurring in medical or seismic reconstruction problems. The same holds if one wants to study 3-D or 4-D images. Here one will have to think of parallel processors. For output one will need a good frame buffer, e.g. a PIXAR machine.

PROJECT AM 9

TITLE: History of mathematization

TITEL: Geschiedenis van mathematisering

ABSTRACT
History of mathematical activity in the Netherlands over the period 1945-1960, in particular the history of founding the Mathematical Centre and of setting up the study course of Mathematical Engineer. Both events are being considered on the one hand in the general history context of their time, on the other hand against the background of the preceding development in the relation between mathematics and application.

SAMENVATTING
Geschiedenis van de Nederlandse wiskunde-beoefening in the periode 1945-1960, in het bijzonder van de oprichting van het Mathematisch Centrum en het instellen van de opleiding tot Wiskundig Ingenieur. Beide gebeurtenissen worden beschouwd enerzijds tegen de algemeen-historische achtergrond van deze periode, anderzijds tegen de achtergrond van de voorafgaande ontwikkeling in de relatie tussen wiskunde en toepassing.

PROJECT MEMBERS
prof.dr. P.C. Baayen (project leader)
prof.dr. M. Hazewinkel (p.m.)
drs. G. Alberts

EXTERNAL CONTACTS
dr. L.E. Fleischhacker (University of Twente)
netwerk Postdoctoraal Opleidingsprogramma Negentiende- en Twintigste-eeuwse Geschiedenis (prof.dr. J.C.H. Blom, University of Amsterdam)

START OF PROJECT: 1988

CLASSIFICATION CODES

NWO-classification	: P100, H250, H260
1980 Math. Subj. Class.	: 01A60, 00A25, 01A65, 01A74, 62-03, 65-03, 68-03, 90-03

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

> 'The mechanization of the world-picture during the transition from ancient to classical science meant the introduction of a description of nature with the aid of the mathematical concepts of classical mechanics; it marks the beginning of the mathematization of science, which continues at an ever-increasing pace in the twentieth century'
> ([9: p. 501] concluding sentence of Dijksterhuis' book)

Mathematization is defined as a specific view of reality which is inspired by the mathematical way of thinking: the outlook focussing certain quantitative relations or structural aspects of an object, under disregard of other perspectives. The concept of *mathematization as a cultural phenomenon* indicates the penetration of this view of reality into different areas of our culture, e.g. into the various sciences, into policy making or into management.

In the wake of the strong expansion of mathematization in the twentieth century mathematics has come to actual application in new fields. It is primarily to this increasing number of applications that the mathematicians respond with their initiatives to set up the education of Mathematical Engineer (1956) and to found the Mathematical Centre (1946). Timman, Van der Corput and Van Dantzig, the key figures in the episode under consideration, were able to do so, however, on the basis of a changing notion of mathematics and of it applicability [1], [2].

The social importance of mathematical thought is studied historically by the example of the rise of both these institutions: through the study of archival sources and literature and through interviews. Special notice is taken of the introduction of mathematical modelling [2: pp. 84 ff.].

Contemporary history of science and technology is emergent, e.g. [3], [11]. Simultaneously general history of the Netherlands pays increasing attention to the postwar period [7], [8], [12]. The present project, AM 9, links up Dutch research in the field of History and Social Function of Mathematics (GMFW) with these developments. In particular it follows the work of Fleischhacker [10], several publications on forerunners of the above mentioned mathematicians like F. Klein, R. von Mises, J. von Neumann and N. Wiener, e.g. [13], [14] and it follows general historical research on the Netherlands in the forties and fifties [12], [7], [8]. The project directly continues the work in [2].

The research on the Mathematical Centre is completed; the sources concerning the Mathematical Engineer's program were studied in 1988, the outcomes of it to be assimilated during 1989. Articles on Van Dantzig and on Tinbergen have been prepared for publication in 1989. The project aims at the publication of a completing monography in 1990.

Relevant literature

[1] G. ALBERTS (1986). Mathematics as a cultural and as a productive force; The mathematical Centre founded Februari 11, 1946. *CWI Newsletter 10,* 19-30.

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[3] Annals (1979 etc.). *AFIPS Annals of the history of computing 1* (etc.), Springer International.

[4] C.B. BOYER (1968). *A History of Mathematics,* John Wiley & Sons, New York.

[5] G. CANGUILHEM (1972). *La Mathematisation des Doctrines Informes,* Hermann, Paris.

[6] T.M.T. COOLEN (1969). *Wiskunde Gezien Vanuit Haar Toepassingen,* Report MCPM 69 ZW-15, Mathematisch Centrum, Amsterdam.

[7] H.W. VON DER DUNK o.a. (1981). *Herrijzend Nederland; Opstellen over Nederland in de Periode 1945-1960,* Martinus Nijhoff, 's Gravenhage.

[8] H.W. VON DER DUNK o.a. (1986). *Wederopbouw, Welvaart en Onrust; Nederland in de Jaren Vijftig en Zestig,* De Haan/Uniboek, Houten.

[9] E.J. DIJKSTERHUIS (1969). *The Mechanization of the World Picture,* Oxford UP, London.

[10] L.E. FLEISCHHACKER (1982). *Over de Grenzen van de Kwantiteit,* Dissertation, Mathematical Institute, University of Amsterdam.

[11] Jaarboek (1984 etc.). *Jaarboek voor de Geschiedenis van Bedrijf en Techniek 1* (etc.), Stichting Jaarboek GBT, Utrecht.

[12] E.H. KOSSMANN (1986). *De Lage Landen 1780-1970* (2 volumes), Elsevier, Amsterdam.

[13] T. LEGENDI, T. SZENTIVANYI (1983). *Leben und Werk von John Neumann,* Bibliographisches Institut, Mannheim.

Department of

Operations Research, Statistics, and System Theory

This policy plan is being written before September 1, 1988, when the Departments of Operations Research and System Theory and of Mathematical Statistics will be merged into one, and well before a new department head is appointed. Although we are not in the position to present an integrated plan for the new department, we have attempted to anticipate future developments by sketching a reorganization of the CWI activities in mathematical statistics and by indicating overall priorities for the vacant positions. We are confident that, on the basis of the current plan, a further coordination will be achieved.

Operations research and *system theory* concerns the investigation of mathematical models and methods that are designed for supporting optimal decision making in practical situations. Motivating problems occur, for instance, in industrial production, in communication and control, and in the social sciences. In a methodological sense, 'operations research and system theory' is a collection of widely diverging subjects. Results and techniques from virtually all parts of mathematics and computer science are applied. The unifying element is the potential practical use of the models and methods under investigation.

The CWI activities in this area are organized in three projects: BS 1 on combinatorial optimization, BS 2 on analysis and control of information flows in networks, and BS 3 on system and control theory.

Project BS 1 on *combinatorial optimization* is involved with the mathematical investigation of problems in which an optimal configuration of a number of discrete objects has to be determined. Traditional research themes are the complexity analysis of problems and the design and analysis of enumerative methods and approximation algorithms. In recent years, the study of parallel algorithms and of interactive methods has been emphasized. A reorientation

into the direction of geometric and stochastic methods is presently being considered.

Project BS 2 on *analysis and control of information flows in networks* concerns the mathematical modeling, analysis and control of information flows in computer systems (computer performance evaluation) and telecommunication networks (teletraffic analysis). The emphasis is on the stochastic analysis of the performance of queueing networks. Fundamental research in queueing theory is carried out, but the choice of models is motivated by their applicability in computer and communication systems. Recently, research has also been initiated on the reliability and availability of stochastic networks.

Project BS 3 on *system and control theory* aims at formulating and analyzing dynamical systems as models for phenomena that evolve in time, and at solving control and prediction problems. The motivation for this research comes from the need for control and signal processing algorithms in engineering, biology, economics and computer science. The thrust of this project is in fundamental problems and, to a lesser extent, in applications. Research effort is concentrated on realization and control problems. Applied research is in progress for the control of communication and computer systems and for seismic signal processing.

Research in *mathematical statistics* at CWI is concentrated on what U. Grenander has termed *abstract inference*: statistical inference when observations or model-parameters lie in abstract spaces, especially infinitely dimensional function spaces (spaces of curves, surfaces, ...). This area lies naturally at the heart of present developments in theoretical statistics, as well as being strongly linked to the theory of stochastic processes, the central developing area in probability theory. At the same time it is of intensive practical interest because of modern computational capabilities: one can analyze larger and more complex data sets, and thereby base oneself on more and more complex models. The two sides of abstract inference - abstract observations and parameters respectively - are reflected in the projects BS 4 on stochastic processes and BS 5 on semiparametric statistics. A project of a more applied nature, but intimately connected with BS 4 and BS 5, is BS 6 on statistical aspects of image analysis. All three projects are strongly undermanned at present, mainly due to a chronic shortage of young Ph.D. students in statistics.

Until 1989, the activities in mathematical statistics have been organized in four projects. The proposed regrouping into three larger projects takes account of shifts in research interests of the senior researchers in the five years since the previous structure was introduced. The proposal is only provisional, in view of the unforeseeable main research activities of the future department head.

Project BS 4 on *stochastic processes* represents CWI's only research in probability theory 'pur sang', although stochastic processes are studied from many points of view in other CWI projects, especially BS 2, BS 3, BS 5 and BS 6. As the statistical part of the previous project on stochastic processes has now been regrouped in BS 5, this leaves one senior researcher and one (externally

supervised) STW researcher working full time in this project. Very high priority goes to recruiting both senior and junior researchers to form a new BS 4. What the specific research direction should be must be allowed to depend on available candidates. However, in view of tradition and in view of the spectrum of research at other Dutch universities, we expect that CWI will continue to be primarily a centre for Dutch research in theoretical statistics rather than in probability theory.

The interaction between applied and theoretical research in *semiparametric statistics* has been emphasized by combining the previous projects on applied and semiparametric statistics into project BS 5. The previous subproject on the statistical analysis of stochastic processes has also been moved to BS 5. High priority goes to rebuilding strength in the fundamental statistical research on semiparametric models, as well as to starting a subproject specifically on computational aspects of semiparametric models. Furthermore, STW projects on software reliability and on the Wicksel problem (joint with NW) are being prepared.

Project BS 6 on (statistical aspects of) *image analysis* will finally get under way this year with the recruitment of a project leader and a junior researcher, and the acquisition of workstation facilities. This very promising research direction must be allowed to grow further. The close cooperation with applied mathematicians (AM 8) and with various external contacts will be maintained. Contacts will also be built up with the IS group. The project can be expected to exert a very stimulating effect on activities in computational statistics as well as in stochastic processes, since the statistical contribution to image reconstruction, processing and analysis largely lies in viewing these problems as problems of the statistical analysis of a stochastic process.

Before discussing each of the six projects in more detail, we review the vacancies that are mentioned under these projects and indicate their status c.q. priority.

The acquisition of a junior researcher in the control of discrete-event systems (BS 3.4, with Van Schuppen) is in progress. The appointment of a senior researcher in performance analysis (BS 2) and stochastic processes (BS 4.1) is expected in the Fall of 1988.

Among the other vacant positions, the selection of a new project leader for combinatorial optimization (BS 1) and of a junior researcher in image analysis (BS 6.1, with Baddeley) should have the highest priority. Four other junior researchers are requested: in geometric methods in combinatorial optimization (BS 1.2, with Schrijver), in computational statistics (BS 5.6, with Dzhaparidze), and, at a later stage, in performance analysis (BS 2.3) and in bootstrap methods (BS 5.2, with Helmers). Especially if a possible guest in stochastic processes (BS 4.1) cannot come to CWI, high priority also goes to recruiting a junior researcher here.

Department of Operations Research, Statistics, and System Theory

List of projects

BS 1 Combinatorial optimization
BS 2 Analysis and control of information flows in networks
BS 3 System and control theory
BS 4 Stochastic processes
BS 5 Semiparametric statistics
BS 6 Image analysis

	Projects						working			
Name	BS1	BS2	BS3	BS4	BS5	BS6	hours	regu-lar	de-tached	guests
appointed										
Lenstra	•						1.00	1.00		
Anthonisse	•						1.00	1.00		
Hoogeveen	•						1.00	0.42		
Lageweg	•						1.00	1.00		
Savelsbergh	•						0.80	0.40		
Veltman	•						1.00	1.00		
Oosterhout	•						1.00	1.00		
Schrijver	•						0.20		0.20	
Velde, v.d.	•						1.00		1.00	
Berg, dr. v.d.		•		•			1.00	1.00		
Berg, drs. J.L. van den		•					1.00	1.00		
Boxma		•					1.00	1.00	-0.20	
Groenendijk		•					1.00	1.00		
Wartenhorst		•					1.00	1.00		
Cohen (adv.)		•					-	p.m.		
Duijn Schouten, v.d.		•					0.80		0.20	
Kuijper			•				1.00	1.00		
Schumacher			•				1.00	1.00	-0.20	
Schuppen, van			•				1.00	1.00		
Woude, v.d.			•				1.00	1.00		
Waal, de			•				1.00		1.00	
Berbee				•		•	1.00	1.00		
Bakker					•		1.00		1.00	
Dzhaparidze				•	•		1.00	1.00		
Dekkers					•		-	p.m.		
Geer, v.d.					•		1.00	1.00		
Helmers					•		1.00	1.00		
Haan, de (adv.)					•		-	p.m.		
Baddeley					•	•	1.00	1.00		
Moyeed					•	•	1.00	1.00		
Gill					•	•	-	p.m.		
total appointed								20.82	3.00	0.00
regular priority										
scient.res.1	•						1.00	0.50		
scient.res.2						•	1.00	0.50		
scient.res.3	•						1.00	0.50		
scient.res.4					•		-	p.m.		
scient.res.5			•				-	p.m.		
scient.res.6				•			-	p.m.		
scient.res.7		•					-	p.m.		
scient.res.8					•		-	p.m.		
scient.res.9	•								1.00	
total priority								1.50	1.00	0.00
total estimated								22.32	4.00	0.00

PROJECT BS 1

TITLE: Combinatorial optimization

TITEL: Combinatorische optimalisering

ABSTRACT
Combinatorial optimization is the mathematical investigation of problems involving the optimal arrangement, grouping, ordering or selection of a finite number of discrete objects. The subprojects are:
BS 1.1 Design and analysis of algorithms;
BS 1.2 Geometric methods;
BS 1.3 Parallel computations;
BS 1.4 Multi-criteria machine scheduling;
BS 1.5 Interactive planning methods;
BS 1.6 Model and algorithm representation and manipulation.

SAMENVATTING
Combinatorische optimalisering houdt zich bezig met de wiskundige bestudering van problemen waarbij een optimale configuratie van een eindig aantal objecten wordt gezocht. De deelprojecten zijn:
BS 1.1 Ontwerp en analyse van algoritmen;
BS 1.2 Meetkundige methoden;
BS 1.3 Parallelle berekeningen;
BS 1.4 Machinevolgordeproblemen met meervoudige criteria;
BS 1.5 Interactieve planningsmethoden;
BS 1.6 Representatie en manipulatie van modellen en algoritmen.

PROJECT MEMBERS

J.M. Anthonisse	prof.dr. A. Schrijver
drs. J.A. Hoogeveen (NFI)	drs. S.L. van de Velde (NFI)
drs. B.J.B.M. Lageweg	drs. B. Veltman
prof.dr. J.K. Lenstra (project leader)	scientific researcher (STW)
drs. H. Oosterhout	junior researcher
dr. M.W.P. Savelsbergh (Shell fellow)	

EXTERNAL CONTACTS
E.G. Coffman, Jr. (Murray Hill, USA), W. Cook (New York, USA), A. Frank, L. Lovász (Budapest, Hungary), A.M.H. Gerards (Tilburg University), M. Grötschel (Augsburg, FRG), C.V. Jones (Philadelphia, USA), G.A.P. Kindervater, A.H.G. Rinnooy Kan, H.W.J.M. Trienekens (Erasmus University Rotterdam), E.L. Lawler (Berkeley, USA), C.L. Monma, P.D. Seymour, V.K. Wei (Morristown, USA), D.B. Shmoys, É. Tardos (Cambridge, USA), L. Stougie (University of Amsterdam), M.J. Todd (Ithaca, USA), K. Truemper (Dallas, USA)

START OF PROJECT: 1973

CLASSIFICATION CODES

NWO-classification	:	P160, P170, T120
NABS-code	:	N024, N059, N069, N089
1980 Math. Subj. Class.	:	90Cxx, 90Bxx

PROJECT DESCRIPTION

Field of study. - Combinatorial optimization concerns the mathematical investigation of problems in which an optimal configuration of a finite number of objects has to be determined. Problems of this type occur in many practical decision situations, such as time table design, distribution planning, production control, and facility location. Due to the practical relevance of these problems and their traditional formulation in terms of mathematical programming problems in integer variables, combinatorial optimization forms part of the mathematics of operations research. Results from areas like discrete mathematics, geometry and probability theory play an important role, and the interaction with computer science and computer engineering is of increasing significance.

Research themes. - Traditional research themes in combinatorial optimization are the following:

(1) the complexity analysis of combinatorial problems, with solvability in polynomial time and NP-hardness as central notions;
(2) the design of algorithms: polynomial-time algorithms on the one hand, and enumerative or approximation algorithms for NP-hard problems on the other hand;
(3) the empirical, worst-case and probabilistic analysis of algorithms.

There is an increasing interest in *geometric* and *stochastic* methods and in architectures for *parallel* and *interactive* computations. The selection of subprojects reflects these developments.

Policy. - It is our aim to carry out the following subprojects.

Design and analysis of algorithms (BS 1.1) is a long-term project, which emphasizes the development of solution approaches to NP-hard problems.

Geometric methods (BS 1.2) encompasses subjects such as polyhedral combinatorics and computational geometry, which enjoy an increasing amount of attention.

Parallel computations (BS 1.3) aims at the design and implementation of, first, parallel enumerative methods for NP-hard problems, and, secondly, algorithms for scheduling computation graphs on parallel processing models.

Multi-criteria machine scheduling (BS 1.4) involves the development of algorithms for scheduling problems with objective functions representing a combination of several criteria.

Interactive planning methods (BS 1.5) concerns the development of optimization algorithms for distribution planning, production control, and allocation problems and their embedding in interactive systems that support practical decision making in these areas.

Model and algorithm representation and manipulation (BS 1.6) moves on the boundary of combinatorial optimization and artificial intelligence, and aims at the development of representation schemes for models and algorithms arising in vehicle routing and scheduling problems.

External funding. - A Shell fellow is active in the research areas covered by BS 1.1, BS 1.5 and BS 1.6. BS 1.3 is supported by SPIN. Two junior researchers in BS 1.4 and BS 1.5 are supported by NFI.

SUBPROJECT BS 1.1

TITLE: Design and analysis of algorithms

MEMBERS
drs. B.J.B.M. Lageweg
prof.dr. J.K. Lenstra
dr. M.W.P. Savelsbergh (Shell fellow)

FIELD OF STUDY
This subproject concerns the complexity analysis of combinatorial optimization problems and the design, analysis and implementation of optimization and approximation algorithms for their solution.

RESEARCH ACTIVITIES
Current activities include:
1. Completion of the book *Scheduling* (Wiley, Chichester).
2. Compilation and editing of the volume *Computation* in the series *Handbooks in Operations Research and Management Science* (North-Holland, Amsterdam).
3. Completion of a Ph.D. thesis on combinatorial planning methods.
4. Completion of papers on the test covering problem and the interval scheduling problem.
5. The investigation of mixed integer programming models for production planning problems, with an emphasis on the use of polyhedral techniques for their solution (in the context of a Shell fellowship).

SUBPROJECT BS 1.2

TITLE: Geometric methods

MEMBERS
prof.dr. A. Schrijver
junior researcher

FIELD OF STUDY
This subproject concerns the design of polynomial-time algorithms and good characterizations with the help of geometric methods (polyhedra, homotopy, eigenvalues, finite geometries).

RESEARCH ACTIVITIES
Current activities include:
1. Completion of the book *Polyhedral Combinatorics* (Wiley, Chichester).
2. Derivation of decomposition methods for combinatorial optimization problems with the help of the decomposition results of P.D. Seymour (with A.M.H. Gerards, L. Lovász, P.D. Seymour and K. Truemper).
3. Development of homotopy methods for multi-commodity flow problems and VSLI-routing problems.

SUBPROJECT BS 1.3

TITLE: Parallel computations

MEMBERS
prof.dr. J.K. Lenstra
drs. B. Veltman

FIELD OF STUDY
It is expected that in the coming years parallel processors will become available in large quantities and at moderate costs. However, making applications run on parallel processors is currently a labor intensive and time consuming activity due to the lack of appropriate development and programming systems. The ParTool project, originated and financed by SPIN, is an attempt to overcome these difficulties and to create a powerful parallel processing development environment.

This subproject, which is also a subproject of the ParTool project, concerns the design and analysis of methods for the scheduling of a given computation graph on a given processor model. A schedule is an allocation of each computational task to one or more time intervals on one or more processing elements, such that the processing time and the data access requirements of the tasks, the precedence constraints between them, the individual processing speeds and the interprocessor communication speeds are taken into account and, in addition, one or more performance criteria are satisfied.

Some specific characteristics, which are usually not considered in traditional scheduling theory, are: data allocation, interprocessor communication, multiple criteria, incomplete information (on-line scheduling), and robustness.

RESEARCH ACTIVITIES
Our activities will be organized along the following lines.

(1) The existing literature on actual scheduling systems for parallel processors will be studied.
(2) One or more models of the scheduling problem that appear to be relevant in the context of the ParTool project as well as amendable to efficient solution by advanced scheduling algorithms will be formulated.
(3) Algorithms for these models will be designed and analyzed.
(4) A scheduling system that incorporates these algorithms will be implemented.

SUBPROJECT BS 1.4

TITLE: Multi-criteria machine scheduling problems

MEMBERS
drs. J.A. Hoogeveen (NFI)
prof.dr. J.K. Lenstra
drs. S.L. van de Velde

FIELD OF STUDY
This subproject concerns the investigation of the computational complexity of multi-criteria scheduling problems. The criteria to be considered are usually based on the job completion times and often involve job due dates.
We mention five type of problems.

(1) The hierarchical optimization of criteria. Here, the criteria are treated in a given order. At each stage, a single-criterion scheduling problem is solved subject to the optimality of the criteria considered at the previous stages.
(2) The optimization of one criterion subject to bounds on the values of the other criteria.
(3) The optimization of a weighted sum of the criteria.
(4) The determination of all efficient solutions. A solution is said to be efficient if there exist weight for which the weighted sum of the criteria is optimized by that solution.
(5) The determination of all Pareto-optimal solutions. A solution is said to be Pareto-optimal if it is not dominated by any other solution.

RESEARCH ACTIVITIES
We are preparing a survey of the results that have been obtained for problems of the above types. Our main activity is the theoretical investigation of this class of problems.

SUBPROJECT BS 1.5

TITLE: Interactive planning methods

MEMBERS
J.M. Anthonisse
drs. B.J.B.M. Lageweg
prof.dr. J.K. Lenstra
dr. M.W.P. Savelsbergh (Shell fellow)
drs. S.L. van de Velde (NFI)
scientific researcher (STW)

RESEARCH ACTIVITIES
At present, we are involved in the following activities:
(1) Development and implementation of an interactive system for the planning and control of an assembly process, in cooperation with the TNO Fibre Institute (NFI 54).
(2) Participation in an international exercise in the development of decision support systems for resource constrained project scheduling (in cooperation with IIASA, Laxenburg, Austria).
(3) Development of an interactive system for the allocation of airplanes to gates.
(4) Research on algorithms for the pickup and delivery problem, and their incorporation in an interactive environment (STW).

SUBPROJECT BS 1.6

TITLE: Model and algorithm representation and manipulation

MEMBERS
prof.dr. J.K. Lenstra
drs. H. Oosterhout
dr. M.W.P. Savelsbergh (Shell fellow)

FIELD OF STUDY
Modeling problem situations and selecting or constructing suitable solution methods is a difficult and time consuming task. This subproject aims at developing a system that provides support for these activities.

The system will have to represent and manipulate information at three different levels. At the first level, there is the real-life problem situation. It may contain many aspects that are not relevant to the selection of a solution method. At the second level, there is the abstract problem type. It is obtained from the real-life problem situation by determining and modeling the relevant entities that describe it in terms of decisions, objectives and constraints. At the third level, there are the algorithms. One that appears to be suitable in the situation at hand is selected or constructed.

As techniques for knowledge representation and knowledge manipulation are of crucial importance, the subproject will move on the boundary of combinatorial optimization and artificial intelligence.

RESEARCH ACTIVITIES
We are presently involved in the design of a system to support model and algorithm management in distribution planning, in cooperation with professor C.V. Jones (The Wharton School, Philadelpia) and dr. M. Desrochers (Montreal).

PROJECT BS 2

TITLE: Analysis and control of information flows in networks

TITEL: Analyse en besturing van informatiestromen in netwerken

ABSTRACT
The project concerns the mathematical modeling, analysis and control of information flows in computer systems and telecommunication networks. It comprises the following subprojects:
BS 2.1 Analysis of mathematical queueing models;
BS 2.2 Performance analysis of communication systems;
BS 2.3 Performance analysis of computer systems;
BS 2.4 Reliability and availability of networks.

SAMENVATTING
Het project betreft de wiskundige modellering, analyse en besturing van informatiestromen in computersystemen en telecommunicatienetwerken. Het bestaat uit de volgende deelprojecten:
BS 2.1 De analyse van mathematische wachtrijmodellen;
BS 2.2 Prestatie-analyse van communicatiesystemen;
BS 2.3 Prestatie-analyse van computersystemen;
BS 2.4 Betrouwbaarheid en beschikbaarheid van netwerken.

PROJECT MEMBERS

drs. J.L. van den Berg	drs. W.P. Groenendijk
prof.dr.ir. O.J. Boxma (project leader)	drs. P. Wartenhorst
prof.dr.ir. J.W. Cohen (advisor)	dr. J. van den Berg
prof.dr. F.A. van der Duyn Schouten	junior researcher (p.m.)

EXTERNAL CONTACTS
dr. J.P.C. Blanc, drs. J.A. Weststrate (Tilburg University), drs. G.A.P. Kindervater, drs. M. van Vliet (Erasmus University Rotterdam), drs. S.J. de Klein (University of Utrecht), prof.dr. H.C. Tijms (Free University Amsterdam), dr. F. Baccelli, dr. G. Fayolle, dr. Ph. Nain (INRIA, France), dr. B. Meister (IBM Zürich Research Laboratory, Switzerland), prof.dr. R. Syski (University of Maryland, USA), dr. Y.T. Wang (AT&T Bell Laboratories, Holmdel, USA)

START OF PROJECT: 1981

CLASSIFICATION CODES

NWO-Classification	:	P160, P170, T180, T280
NABS-code	:	N024, N025, N070, N0752, N076
1980 Math. Subj. Class.	:	60K, 68M, 90B
1982 CR Classification Scheme	:	C.4, D.4.8

PROJECT DESCRIPTION

Field of study. - The project comprises the mathematical modeling, analysis and control of information traffic flows in computer systems (computer performance analysis) and telecommunication networks (teletraffic analysis). Emphasis is on the analysis of congestion phenomena and the performance analysis of congestion control mechanisms. As the traffic flows are of a stochastic nature the congestion analysis is based on probability theory: the project belongs to the area of stochastic operations research.

The application area of the project concerns, apart from the traditional communication facilities such as telephone, also the communication between the various main constituents of a computer, between a computer and peripheral equipment and between computers mutually, as well as communication through satellites. The rapidly growing influence of computer and communication networks in daily life makes this project of considerable social importance. The scientific importance of the project lies in the development of mathematical techniques for analyzing complex stochastic systems.

The study object of the project is usually formulated in abstract terms as a network of service units and customers using these. This is called a queueing network. The mathematical queueing theory, dealing with congestion phenomena in queueing networks, studies congestion measures such as waiting- and sojourn times of customers, queue lengths and blocking probabilities.

Policy. - We intend to carry out the following four subprojects.

BS 2.1 *The analysis of mathematical queueing models*. This concerns fundamental research on basic models from queueing theory.

BS 2.2 *Performance analysis of communication systems*. Traditionally, teletraffic is the most important application area of queueing theory. The activities in the subproject are no longer restricted to telephony; following recent technical developments, they extend to the whole telecommunicaton area.

BS 2.3 *Performance analysis of computer systems*. This subproject concerns the mathematical analysis and optimization of the operational behaviour of computer systems. Computer performance analysis meets internationally with wide interest and is in full development. The subproject is supported by INSP.

BS 2.4 *Reliability and availability of networks*. In complex computer-communication and production networks the system availability is an important performance measure. Research on the availability of networks with repairable components will prevail for the time being, partly because of its close relation with queueing networks.

SUBPROJECT BS 2.1

TITLE: Analysis of mathematical queueing models

MEMBERS
prof.dr.ir. O.J. Boxma
prof.dr.ir. J.W. Cohen (advisor)
dr. J. van den Berg

FIELD OF STUDY
Queueing theory deals with the mathematical research on the performance of a system offering services for collective use. Such a system may be a hospital or bank, but also a 'flexible manufacturing system', telephone exchange or computer network. The mathematical models vary somewhat, but the problem remains the same. The subprojects BS 2.2 and 2.3 deal with some of the most important application areas of queueing theory. Subproject BS 2.1 pays attention to fundamental developments and problems within queueing theory itself. Emphasis will be on studying exact analytical techniques.

CURRENT RESEARCH ACTIVITIES
1. Completion of the book *Queueing Theory and Its Applications* (North-Holland, Amsterdam).
2. Formulation and solution of boundary value problems in the analysis of two-dimensional random walks and queueing models.
3. Analysis of time-dependent behaviour of queueing systems.
4. Modeling and analysis of congestion phenomena in the implementation of branch-and-bound algorithms on parallel computers (see also BS 1.3).
5. Capacity allocation optimization problems in queueing networks.

LONG-TERM PLANS
Emphasis on the activities 2, 3, 5; focusing of the last activity on multiproduct flexible manufacturing systems.

SUBPROJECT BS 2.2

TITLE: Performance analysis of communication systems

MEMBERS
prof.dr.ir. O.J. Boxma
prof.dr.ir. J.W. Cohen (advisor)
dr. J. van den Berg

FIELD OF STUDY
In the field of telecommunication great changes have taken place in the past two decades. Communication is becoming more and more digital. Computers communicate through (public) communication networks; and in the near future speech and images will be transmitted, in a digitalized form, through the same network as computer data. Such an integrated telecommunication network is indicated as ISDN (Integrated Services Digital Network). There is a strong need for quantitative information on the performance of communication networks. Queueing theory turns out to be the most suitable tool for obtaining this information. Important research issues where a queueing theoretical approach is used, are the throughput of messages, their sojourn time in the network, and the effect of admission and routing rules.

CURRENT RESEARCH ACTIVITIES
1. The development of methods for analyzing communication processes in automated production.
2. Overload control of communication systems (see also BS 3.5(2)).
3. An orientation on the performance analysis of ISDN.

LONG-TERM PLANS
Emphasis on the activities 1, 3. In 1, research should lead to a performance analysis of MAP (Manufacturing Automation Protocol), which is becoming the international standard for communication in automated production. Furthermore, queueing models of flexible, computer-guided, manufacturing systems will be developed and analyzed (see also BS 2.1). The research plan for 3 depends on the outcome of the current orientation.

SUBPROJECT BS 2.3

TITLE: Performance analysis of computer systems

MEMBERS

drs. J.L. van den Berg	drs. W.P. Groenendijk
prof.dr.ir. O.J. Boxma	dr. J. van den Berg
prof.dr.ir. J.W. Cohen (advisor)	junior researcher (p.m.)

FIELD OF STUDY

The performance of a computer system, or more generally a tele-information system, depends on the equipment and the operating system (including the control protocol) on one hand, and the size and nature of the work load on the other hand. Performance analysis of a computer system aims at investigating and optimizing the performance. In the performance analysis of isolated computer systems, one tries to reach optimal choices with respect to the degree of multiprogramming, memory hierarchy, size of memory blocks and buffers, etc. In the performance analysis of distributed systems attention is also paid to the organization of the communication system regarding admission and routing protocols, anti-congestion measures, etc. As was pointed out already in the description of BS 2.2, there is a merging of information processing and telecommunication; therefore the activities in BS 2.2 and BS 2.3 will overlap more and more.

CURRENT RESEARCH ACTIVITIES

1. The study of window flow control protocols in packet-switched networks.
2. Mathematical analysis of queueing systems with feedback mechanisms as occurring, a.o., in computer systems with time-sharing.
3. Mathematical analysis of various token-ring protocols in local area networks and comparison of the performance of these protocols. Also related protocols in distributed systems are being studied.
4. Expansion and distribution (a.o., via a newsletter) of CWI's available expertise on computer packages for the numerical analysis and simulation of congestion phenomena in networks of queues.
5. Stochastic analysis of machine sequencing problems and related bin-packing problems.

LONG-TERM PLANS

The completion of the Ph.D. thesis of J.L. van den Berg probably marks the end of the activities 1, 2. Activity 3 will continue after the completion of the Ph.D. thesis of W.P. Groenendijk. The research on the performance of distributed systems will be intensified. The scope of 5 will be broadened to cover the probabilistic analysis of deterministic and randomized algorithms; this might lead to the formulation of a new subproject.

SUBPROJECT BS 2.4

TITLE: Reliability and availability of networks

MEMBERS
prof.dr.ir. O.J. Boxma
prof.dr.ir. J.W. Cohen (advisor)
prof.dr. F.A. van der Duyn Schouten
drs. P. Wartenhorst

FIELD OF STUDY
Reliability theory concerns the reliability and operational availability of systems subject to breakdowns and wear, these two deterioration processes being modeled by stochastic processes. Nowadays there is a strong practical interest in the reliability of systems with many components, each having an extremely small breakdown probability (communication networks, transport systems, electricity powerstations, etc.). A reliability analysis of such complex networks leads to interesting stochastic problems. There is a strong similarity with the analysis of complex queueing networks - especially when defect components are repairable: in such cases a repairman may be regarded as server, and defect components as customers.

CURRENT RESEARCH ACTIVITIES
The analysis of simple decision rules for maintenance and replacement of two-component systems. Both performance measures concerning the system's long-term behaviour and availability criteria over finite time intervals are treated.

LONG-TERM PLANS
Expansion of the research in the direction of structural properties of optimal maintenance- and replacement strategies of multi-component systems.

PROJECT BS 3

TITLE: System and control theory

TITEL: Systeem- en regeltheorie

ABSTRACT
System and control theory aims at formulating and analyzing dynamical systems as models for dynamic phenomena, and at solving control and prediction problems. The subprojects are:
BS 3.1 Deterministic system theory;
BS 3.2 Stochastic system theory;
BS 3.3 Systems with a generalized state space;
BS 3.4 Control of discrete-event systems;
BS 3.5 Externally funded research.

SAMENVATTING
Systeem- en regeltheorie stelt zich ten doel dynamische systemen, als model voor dynamische verschijnselen, te formuleren en te analyseren, en regel- en voorspellingsproblemen op te lossen. De deelprojecten zijn:
BS 3.1 Deterministische systeemtheorie;
BS 3.2 Stochastische systeemtheorie;
BS 3.3 Systemen met gegeneraliseerde toestandsruimte;
BS 3.4 Regeling van systemen met discrete gebeurtenissen;
BS 3.5 Extern gefinancierd onderzoek.

PROJECT MEMBERS

dr.ir. J.H. van Schuppen (project leader)
prof.dr. M. Hazewinkel (AM)
drs. M. Kuijper
prof.dr. J.M. Schumacher
ir. P.R. de Waal (STW)
dr. J.W. van der Woude (Shell fellow)
junior researcher (p.m.)

EXTERNAL CONTACTS
prof.dr.ir. H. Kwakernaak, dr. H. Nijmeijer, dr. A.J. van der Schaft (University of Twente), prof.dr.ir. J.C. Willems, prof.dr. R.F. Curtain (University of Groningen), dr. F.C. Schoute (Philips Telecommunicatie en Data Systemen Nederland), dr.ir. R.K. Boel (Gent, Belgium), prof. G. Picci (Padova, Italy), prof. P. Varaiya (Berkeley, USA)

START OF PROJECT: 1977

CLASSIFICATION CODES

NWO-Classification	:	P170, T120, T190
NABS-code	:	N080
1980 Math. Subj. Class.	:	93-XX, 49-XX

PROJECT DESCRIPTION

Field of study. - System and control theory aims at formulating and analyzing dynamical systems as models for phenomena that evolve in time, and at solving control and prediction problems. The motivation for this research comes from the need for control and signal processing algorithms in engineering, biology, economics and computer science. System theory makes use of such diverse areas of mathematics as analysis, geometry, numerical linear algebra and probability theory. Some specific applications in which results of system and control theory are used, are: control of freeway traffic flow, shipsteering, robotics, overload control of communication systems and load balancing of computer systems.

Research themes. - Control and prediction problems lead to the following system theoretic problems:

1. *realization and system identification*: to determine a dynamical system in a specified class such that the input, output processes of this system equal or approximate a given pair of input, output processes;
2. *control*: to determine an input process for a dynamic system, often as a feedback law or a dynamic compensator, such that the state and output process of this system satisfy certain conditions;
3. *filtering*: to estimate the state of a dynamical system given observations of the input and output process.

Policy. - The thrust of this project is in fundamental problems of system and control theory, and, to a minor extent, in applications of control. The research effort is concentrated on the following themes and topics:

1. *realization*: realization of linear systems in the subprojects BS 3.1 & BS 3.3, stochastic realization in BS 3.2, and approximate realization in BS 3.5 (1);
2. *control and filtering*: control of linear systems in the subprojects BS 3.1 & BS 3.3, stochastic control in BS 3.2 & BS 3.5 (2), and control of discrete-event systems in BS 3.4.

External funding. - A Shell fellow carries out research on inverse scattering problems. The Technology Foundation (STW) funds subproject BS 3.5 (2).

SUBPROJECT BS 3.1

TITLE: Deterministic system theory

MEMBERS
prof.dr. M. Hazewinkel (AM)
prof.dr. J.M. Schumacher

PROBLEM, MOTIVATION AND APPROACH
Specification of dynamic relations between variables by means of systems of differential and algebraic equations occurs in many branches of sciences, such as mechanics, electrical networks, and econometrics. Mathematical system theory is concerned with the study of such systems of equations. In project BS 3.1 we concentrate on the aspects of this field that are listed below.

- *Theory of representations.* The same dynamic relation may be represented in various ways, and a crucial aspect of modeling is the transformation from a given representation to another, more suitable one. As such, the theory of system representation may be seen as a contribution to a general theory of modeling of dynamic phenomena. Concrete examples of representation problems are studied from this viewpoint. The field covered includes, but is not restricted to, *realization theory* in the usual system-theoretic sense.
- *Metrization and approximation.* Often, one is interested in representations under *approximate* equivalence; this may happen, for instance, when one wants to replace a complicated model by a simplified model. To study approximations of dynamic models, a notion of *distance* on classes of dynamic systems is needed.
- *Prediction and control.* Models for dynamic phenomena can be used to develop algorithms for prediction and control. An important issue here is *robustness*, i.e., the ability of an algorithm to behave well even if the model on which it is based is not very accurate.

RESEARCH ACTIVITIES
1. Completion of a book on linear systems (J.M. Schumacher, in cooperation with prof.dr.ir. J.C. Willems).
2. Representation of physical systems. Study of the role of energy-related concepts in modeling. Applications to the modeling of large flexible structures, such as satellites with appendages (J.M. Schumacher).
3. The geometry of the parameter space of linear systems, with application to identification problems (M. Hazewinkel).
4. Representation problems in econometrics. Study of the relation between cointegrated, error-correction, and errors-in-variables models (J.M. Schumacher).
5. Representations of discrete-event systems (J.M. Schumacher).

SUBPROJECT BS 3.2

TITLE: Stochastic system theory

MEMBERS
prof.dr. J.M. Schumacher
dr.ir. J.H. van Schuppen

PROBLEM, MOTIVATION AND APPROACH
The aim of this subproject is to develop stochastic system theory, in particular stochastic realization, filtering and stochastic control.

The motivation for this research lies in the need for control and signal processing algorithms. Examples of control and signal processing problems are: control of moored tankers, control of an ore crusher, overload control of a telecommunication switch, and the reconstruction of earth layers from seismic signals.

The approach in this subproject is to develop a conceptual approach to stochastic realization theory. Special cases, such as for finite valued processes and for factor analysis models, will be investigated. In stochastic control theory the efforts will be directed at proving structural properties of stochastic control laws.

RESEARCH ACTIVITIES
1. Approximate stochastic realization of Gaussian processes.
2. Stochastic realization and factor analysis.
3. The finite stochastic realization problem and a factorization problem for positive matrices.
4. Stochastic control problems motivated by communication and computer systems.

The subproject is carried out in cooperation with dr.ir. R.K. Boel (Gent, Belgium) and prof. G. Picci (Padova, Italy).

SUBPROJECT BS 3.3

TITLE: Systems with a generalized state space

MEMBERS
prof.dr. J.M. Schumacher
drs. M. Kuijper

PROBLEM, MOTIVATION AND APPROACH
Systems with a generalized state space (also called descriptor systems) form a more general class of linear systems than the well-known class of 'causal' systems. A state space representation of a linear system with prescribed in- and outputs cannot always be given in causal form, whereas a representation in descriptor form is always possible. Although there may be good reasons for assuming causality a priori, good results can be obtained in practice with non-causal representations. Systems with such representations are also called singular systems. A well-known example is the conventional model for a PID-controller. These controllers are often used in industry. Other examples of singular systems can be found in the theory of electric networks.

The purpose of this subproject is to extend the geometric approach that has been successfully developed for causal systems to descriptor systems. The research is closely related to the research under subproject BS 3.1.

RESEARCH ACTIVITIES
Determination of
- operational form for external equivalence of descriptor systems,
- integer invariants in terms of subspaces of the state space for descriptor systems,
- canonical form of state space representation for descriptor systems.

Disturbance decoupling by singular controllers.

SUBPROJECT BS 3.4

TITLE: Control of discrete-event systems

MEMBERS
junior researcher (p.m.)
dr.ir. J.H. van Schuppen

PROBLEM, MOTIVATION AND APPROACH
The problem is to synthesize control laws for discrete-event systems. Solution of this problem requires a suitable model in the form of a dynamical system. Therefore a second problem is to develop a useful definition of a discrete-event system.

The motivation of this subproject lies in the need for control algorithms for discrete-valued processes. Examples of such control and signal processing problems are those for adaptive equalization, query processing in databases, flexible manufacturing systems, computer networks, and networks of parallel processors.

The approach to this problem will be based on realization and control theory. Definitions of discrete-event systems may be based on controlled automata.

RESEARCH ACTIVITIES
1. Development of a definition of a discrete-event system for a concrete practical problem.
2. A control problem for a discrete-event system.

This subproject will be carried out in contact with prof. P. Varaiya (Berkeley, USA) and prof. W.M. Wonham (Toronto, Canada).

SUBPROJECT BS 3.5

TITLE: Externally funded research

MEMBERS
dr.ir. J.H. van Schuppen
ir. P.R. de Waal
dr. J.W. van der Woude

SUBPROJECT DESCRIPTION
Externally funded research in system and control theory is collected in this subproject. It concerns research sponsored by Shell Research B.V. through a fellowship, titled 'Inverse scattering and image processing of seismic data', and research sponsored by the Technology Foundation (STW) titled 'Overload control for communication systems'. Below a brief description of this research is presented.

BS 3.5 (1) INVERSE SCATTERING AND IMAGE PROCESSING OF SEISMIC DATA

PROBLEM, MOTIVATION AND APPROACH
The project is motivated by the need of oil prospectors to know the earth's subsurface structure. The purpose of the project is to develop algorithms for the reconstruction of this structure from seismic data using system theoretical techniques (inverse scattering). Initially, simple models for the earth's structure are studied (horizontal layers with equal travel time and vertical, lossless wave propagation). At a later stage, more general models will be studied and image processing techniques will be incorporated.

RESEARCH ACTIVITIES
1. Reconstruction of reflection coefficients from uncertain data using approximation techniques.
2. Incorporation in the model of loss, absorption and dispersion effects.
3. Non-vertical wave propagation.

BS 3.5 (2) OVERLOAD CONTROL FOR COMMUNICATION SYSTEMS

PROBLEM, MOTIVATION AND APPROACH
This project is motivated by the increasing use of computer controlled communication systems, e.g. the 'stored program controlled' (SPC) telephone exchanges. If no special precautions are taken, then the effective service capacity of such an exchange decreases considerably during periods of overload.

The control problem in this situation is to maximize the number of admitted call requests that result in successfully established connections. This is a typical problem for computer- and communication systems. The approach chosen is to develop stochastic models and control algorithms based on queueing and system theory.

This project is carried out in cooperation with Philips Telecommunicatie en Data Systemen and AT&T & Philips Telecommunicatie Bedrijven, both in Hilversum.

RESEARCH ACTIVITIES

1. Development of new stochastic models for a detailed description of task-handling in SPC-exchanges.
2. Development and performance analysis of control algorithms for SPC-exchanges.
3. Study of the optimal control problem for stochastic models of SPC-exchanges.

PROJECT BS 4

TITLE: Stochastic processes

TITEL: Stochastische processen

ABSTRACT
Fundamental research on stochastic processes with special emphasis on processes in space and time, and research on the statistical analysis of particular stochastic processes. The subprojects are:
BS 4.1 Stationary processes and their applications in physics;
BS 4.2 Statistical analysis of stochastic processes.

SAMENVATTING
Fundamenteel onderzoek naar stochastische processen met speciale nadruk op processen in ruimte én tijd en onderzoek naar de statistische analyse van bepaalde stochastische processen. De deelprojecten zijn:
BS 4.1 Stationaire processen en hun toepassingen in de fysica;
BS 4.2 Statistische analyse van stochastische processen.

PROJECT MEMBERS
dr. H.C.P. Berbee (project leader)
dr. K.O. Dzhaparidze
D.M. Bakker (TEG)
junior researcher (vacancy)

EXTERNAL CONTACTS

Traffic Science section of Dept. of Public Works
dr. E. Valkeila (Helsinki, Finland)
dr. S. Kalikow (Delft Technological University)

START OF PROJECT: 1981

CLASSIFICATION CODES

NWO-classification	:	P160
1980 Math. Subj. Class.	:	60G10, 60 G44, 60 G55, 60 G60, 60 K30, 62M10, 62M99, 90B20, 60 J99, 60K05, 60K35

SUBPROJECT BS 4.1

TITLE: Stationary processes and their application in physics

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

A stationary process has a dependence structure that can be studied in various ways. A broad but special class of such processes is the class of functionals of a Markov process. In Markov representation theory one tries to find for which stationary processes such a description can be given. In physics a different class of processes is described using 'interaction'; this is a considerably different point of view. A main goal of this project is to use this last point of view as a tool to investigate Markov processes. This is a fascinating area where important discoveries can still be made.

Special subjects from the theory of Markov representation will also be studied. In stochastic learning theory one investigates for instance chains with infinite connections. It was shown by H.C.P. Berbee that these chains can be described via a Markov representation. Discontinuity in these chains is still not well understood. Also in this connection limit theory is studied for functionals of Markov chains that can be considered as chains with infinite connections. Also different problems for stationary processes like tail σ-algebras and entropy and also averaging will be studied.

Another important research area in the theory of stationary processes concerns higher-dimensional lattices of random variables. In statistical mechanics one constructs equilibrium measures to model interaction between particles on a lattice. The question of possible uniqueness of this measure is connected with the phenomenon of phase-transition. A technique is developed to study this by connecting this with a suitable Markov chain. In the background duality plays a role. Its role can probably be improved considerably. In a different direction is the investigation of growth of a random area. In this connection there is some hope of making progress in renewal theory for first passage percolation. The problems in the research area have relationships with other fields: the formation of traffic jams is closely associated with phase-transition (see BS 4.3); time evolution of particle systems is related to the evolution of cellular automata in computer science, and in mathematical biology to growth or spread of epidemics. The models also play an important role in image analysis.

MEMBERS

dr. H.C.P. Berbee (project leader)
junior researcher

START: 1981

WORKING PLAN 1989

The research for functionals on a Markov chain will aim at limit theory for the likelihood and also at discontinuity. S. Kalikow may temporarily join our department and part of his interest is closely associated to this research. Also probabilistic aspects of image analysis (BS 6.1) will be investigated. Cooperation will take place with F. den Hollander (Delft) on several of the topics discussed above.

WORKING PLAN AFTER 1989

Continuation of the investigation, possibly with new subjects.

SUBPROJECT BS 4.2

TITLE: Statistical analysis of stochastic processes

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

In recent years the new branch of the general theory of stochastic processes has been developed which deals with such questions as absolute continuity of probability measures, contiguity, LAN etc. concerning a sequence of binary experiments on a filtered space. The answers to this kind of questions have been sought in terms of the so-called Hellinger processes, or some other related processes, associated with the sequence of experiments under study; see JACOD & SHIRYAEV (1987).

Together with E. Valkeila (Helsinki) we study the Hellinger type distances between two probability measures comprising a binary experiment. We intend to give certain useful inequalities for such distances, expressed in terms of the associated Hellinger and some other, auxiliary processes.

This research is strongly related to that in BS 5, especially BS 5.4, in the sense that the inequalities mentioned above will get the form applicable to the problems formulated there.

MEMBERS

dr. K.O. Dzhaparidze

START: 1989

WORKING PLAN 1989

As a measure of proximity of probability measures defined on filtered probability spaces, one often uses the so-called Hellinger distance between these distributions. As it turns out, however, for certain statistical purposes in the LAN theory of Ibragimov and Has'minskii, for instance, one is often forced to appeal to a more refined measure of proximity. To answer the standard questions of the above mentioned LAN theory, in particular, one introduces distances which we call here the Hellinger-type distances. However, these distances are studied much less intensively than the Hellinger distance itself - one of the reasons is that they are much more complicated objects. The inequalities for these distances we intend to obtain will fill this gap to a certain extent.

WORKING PLAN AFTER 1989

Dependent on previous results.

Reference

1. J. JACOD & A.N. SHIRYAEV (1987). *Limit theorems for Stochastic Processes,* Springer.

PROJECT BS 5

TITLE: Semiparametric statistics

TITEL: Semiparametrische statistiek

ABSTRACT

The construction of statistical procedures and the derivation of their properties for semiparametric models; i.e. models which are partly parametric and partly nonparametric in character. More generally, the study of statistical techniques of mixed parametric/nonparametric nature, e.g. bootstrapping. As well as fundamental theoretical research, applications are also considered especially in consultation, cooperative projects and STW projects. The subprojects are:

BS 5.1 Semiparametric estimation theory;
BS 5.2 Bootstrap methods;
BS 5.3 Statistics for sample extremes;
BS 5.4 Statistical analysis of partially specified models;
BS 5.5 Statistical consultation and cooperation;
BS 5.6 Computational statistics.

SAMENVATTING

Het afleiden van statistische procedures en het bepalen van hun eigenschappen bij semiparametrische modellen; d.w.z. modellen die deels parametrisch, deels niet parametrisch van aard zijn. Tevens fundamenteel theoretisch onderzoek, het bestuderen van toepassingen in consultaties, projecten in STW- en samenwerkingsverband.

PROJECT MEMBERS

dr. A.J. Baddeley (p.m.)
drs. A.L.M. Dekkers
dr. K.O. Dzhaparidze (project leader)
dr. S.A. van de Geer
prof.dr. R.D. Gill (advisor)
prof.dr. L. de Haan (advisor)
dr. R. Helmers (project leader)
R. van der Horst (programmer, STO)
B. Lisser (programmer, STO)
dr. R.A. Moyeed (p.m.)
junior researcher (p.m.)
junior researcher (p.m.)

EXTERNAL CONTACTS

prof. P. Janssen (Diepenbeek, België), prof. R.J. Serfling (Johns Hopkins Univ., Baltimore, USA), National NWO-project *Statistics for large parameter spaces,* prof. R. Chitashvili (Tblisi, USSR); H. Engels (AKZO Research) G. Moek (NLR) see further BS 5.5.

START OF PROJECT: 1988

CLASSIFICATION CODES

NWO-classification : P160
1980 Math. Subj. Class. : 62G05, 62G20, 62F35, 62E20, 62M99, 62P99, 62H30, 62F05, 62P10, 62Pxx

SUBPROJECT BS 5.1

TITLE: Semiparametric estimation theory

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

A statistical model can often be described by a class $\{P_\theta: \theta \in \Theta\}$ of probability measures, with Θ some metric space. In a sense, the metric structure of Θ determines how well θ can be estimated. This general observation can be quantified in several ways, see e.g. LECAM (1973) and BIRGÉ (1983). The latter for example shows that the minimax risk for estimating θ depends on the entropy of Θ. Related to results of this kind is the work of VAN DE GEER (1988a), who considers a regression model where observations y_k are assumed to satisfy $y_k = \theta(x_k) + e_k$, $k = 1,...,n$. Here θ, a function of the regressors x_k, is a member of a generally infinite-dimensional set of functions Θ, and e_k is unobservable error. The distribution of the errors is more or less unspecified, so a nuisance parameter is also present. Still it can be shown that if Θ is endowed with (pseudo-) metric $\|\theta\| = \{n^{-1}\Sigma_{k=1}^n |\theta(x_k)|^2\}^{1/2}$ then the entropy of Θ determines a rate of convergence for the least squares estimator. Similar results hold for the penalized least squares and the minimum L_1-norm estimator. The aim of the project is to investigate further generalizations and applications of these techniques.

The general structure of these regression problems is as follows. Consider a loss function $L(\theta)$ based on n independent observations. Suppose the estimator $\hat{\theta}$ is defined as the minimizer of $L(\theta)$, and that θ_0 minimizes the expectation $E_0 L(\theta)$ of $L(\theta)$ under θ_0. Now, define $\nu(\theta) = L(\theta) - E_0 L(\theta)$ and $d(\theta, \theta_0) = E_0 L(\theta) - E_0 L(\theta_0)$. Then we have the basic inequality $\nu(\theta_0) - \nu(\hat{\theta}) \geq d(\hat{\theta}, \theta_0)$. Using similar techniques as in empirical process theory (see e.g. POLLARD (1984)), one can study the increments of ν as process on the space Θ. By our inequality, this leads to a rate of convergence for $\hat{\theta}$ provided the pseudo-metric on Θ corresponds to $d(\cdot, \cdot)$ in a suitable way. In least squares estimation, $d(\theta, \theta_0) = \|\theta - \theta_0\|^2$ and ν can be studied using the metric $\|\cdot\|$ on Θ. This is of course not generally the case, but nevertheless, the inequality combined with knowledge about the increments of ν reduces the problem of finding rates of convergence to relating $d(\cdot, \cdot)$ to the metric on Θ. The increments of ν depend primarily on the entropy of Θ.

MEMBERS

dr. S.A. van de Geer

START: 1988

(This project supercedes the previous project, started 1983, of the same name, in which research on a rather different direction in the field of semiparametric statistics was carried out.)

WORKING PLAN 1989

Previous research shows that regression problems, with various loss functions and general Θ, can be dealt with in the way described above, i.e. the entropy and capacity of Θ determine a rate of convergence (see VAN DE GEER (1988b)). Thus, it appears possible to develop a general theory for the regression model. Apart from that, matters that need further investigation are firstly the question of optimality of the established rates. Secondly, in some instances the calculation of entropy is rather involved. For example, if $\Theta = \cup \Theta_M$, with $\Theta_M = \{\theta : \int |\theta^{(m)}|^2 < M\}$, then the entropy of Θ itself is in general infinite, and this makes it necessary to evaluate the entropy of each Θ_M in terms of M. A third issue is that the rates obtained are all in $\|\cdot\|$-norm; the results may be completely different when other metrics are considered.

It seems feasible to apply similar techniques to other estimation problems, e.g. density estimation, models with mixing distributions, nonparametric maximum likelihood, etc. Of course, since in the regression context the basic inequality plays a crucial role, the estimators considered should be minimizers of some loss function (e.g. minimum distance estimators) or maximizers of some reward function (e.g. penalized maximum likelihood estimators (SILVERMAN (1982)). However, it is to be expected that also estimators constructed in a different fashion can be studied using entropy considerations.

This research fits well in the national NWO project 'Statistics in large parameter spaces', and collaboration will take place with mathematical statisticians at the universities of Leiden, Utrecht, Delft, Nijmegen and Amsterdam (Free University).

WORKING PLAN AFTER 1989

Besides the further development of a general unifying approach, it is also of interest to consider some special cases in more detail. For example, the asymptotic distribution of the least squares estimator in isotonic regression can be investigated. The work of GROENEBOOM (1985) for a related problem suggests that this is indeed possible. A second topic is asymptotic normality of minimum L_1-norm estimators of a linear regression. The $O_P(n^{-1/2})$-rate of convergence for this situation follows from applying the general technique (VAN DE GEER (1988b)). In general, the derivation of a rate of convergence can be seen as a first step towards finding asymptotic distributions. Finally, in the case of least squares estimation with roughness penalty, it is of interest to investigate whether the cross-validated smoothing parameter (see e.g. WAHBA (1977)) is such that the optimal rate of convergence is ensured.

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SUBPROJECT BS 5.2

TITLE: Bootstrap methods

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

The study of bootstrap resampling for estimating distributions of statistical quantities has received much attention during the past few years. Also, many applications and extensions of this computationally-intensive method are currently being studied.

Bootstrap approximations may serve as an alternative to the use of the classical normal approximation or related empirical Edgeworth expansions. Both empirical evidence as well as heuristic arguments have suggested that the bootstrap performs usually very well. A mathematical justification - in the context of second order asymptotics - as to why the bootstrap works well was given in SINGH (1981) for linear statistics, which are basically of sample mean type (see also BABU & SINGH, 1983).

In HELMERS (1987) these results have been extended to an important class of nonlinear statistics, Hoeffding's class of U-statistics. This opens a way to obtain similar results for statistical quantities of different, more complicated, type, which occur in various statistical estimation problems. Related work establishing the asymptotic validity of the bootstrap approximation for generalized L-statistics (the same method of proof also yields the asymptotic accuracy of the bootstrap in this case) was reported in R. HELMERS, P. JANSSEN, R. SERFLING (1988a). The bootstrap has many applications in statistics and is also used in BS 5.5 (Statistical Consultation and Cooperation).

MEMBERS

dr. R. Helmers (project leader)
junior researcher (p.m.)
programmer STO (p.m.)

START: 1984

WORKING PLAN 1989

For Studentized statistical quantities it is known quite generally (see BABU & SINGH (1983) & HELMERS (1987)) that the bootstrap works better than the normal. A similar result holds true for the one-term empirical Edgeworth expansion estimate. Continuation of the research is planned in the following directions. Part of the programme outlined below will be carried out by a new Ph.D. candidate.

(a) In unpublished work of Bhattacharya and Qumsiyeh (1987) it was shown that when estimating the distribution function of the classical Student t-statistic the expected squared error of the bootstrap is asymptotically smaller than that of the two-term empirical Edgeworth expansion. In a way, the (theoretical) bootstrap approximation does better than the two-term Edgeworth expansion estimate in this case. It seems plausible that

this result can be extended to Studentized statistics of a more general type. Such extensions will be considered.

(b) The asymptotic comparisons mentioned above do not take into account the resampling error of the Monte-Carlo bootstrap. This also deserves attention.

(c) In R. HELMERS (1987) the jackknife was employed (in its simplest form) to estimate the variance of a U-statistic. Many other possibilities exist, in particular the bootstrap can be used too. Differences between these will typically show up in the higher order analysis of the bootstrap approximation. We intend to pursue this idea. Related problems arise in connection with the estimation of the cumulants of the Edgeworth expansion.

(d) In R. HELMERS, P. JANSSEN, R. SERFLING (1988b) statistics of the form $T(H_n)$, for $T(.)$ a general type of L-functional (includes generalized L-statistics, U-statistics, and the spread statistics of Bickel & Lehmann), and where H_n denotes a general empirical distribution function of U-statistic structure, are studied. For this large class of statistics bootstrap results will also be obtained extending results in R. HELMERS, P. JANSSEN, R. SERFLING (1988a). (The cooperation of this group of researchers will be continued).

(e) In each of the problems discussed in $(a)-(d)$ numerical work will be needed to supplement the asymptotics with finite sample results.

WORKING PLAN AFTER 1989

Further research on the asymptotic properties of bootstrap approximations and related empirical Edgeworth expansions. Also numerical work will be carried out to investigate the applicability of the asymptotics in finite samples. Extensions of the bootstrap to several non-standard situations will also be considered.

References

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SUBPROJECT BS 5.3

TITLE: Statistical inference using extreme order statistics

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

Since the publication of the key paper PICKANDS (1975) a number of authors have paid attention to threshhold methods in one-dimensional extreme-value theory and related with this to estimation of the tail of a distribution function, otherwise unspecified.

SMITH (1987) studied extensively the asymptotic properties of the estimators of the tail of a distribution based on excesses over a threshhold. His key idea is the assumption that the excesses follow exactly the generalized Pareto distribution. His results, based on this parametric model and on an asymptotic result of PICKANDS (1975), cover the three limiting types of extreme value theory. HILL (1975) proposed his well-known estimator for the tail of a distribution function in the case the distribution function does not have a finite tight endpoint. Asymptotic normality of this estimator is proved by HAEUSLER & TEUGELS (1985) if m (the number of upper order statistics used) tends appropriately to infinity with the sample size n. DE HAAN & RESNICK (1980) and HALL (1982a) give some estimates of the exponent of regular variation. Furthermore HALL (1982b) considers also estimation of the endpoint of the distribution.

There seems to be much need of good and asymptotically reasonable estimators for the tail-index of a distribution function and related to this for the extreme value index and for large quantiles of distributions. For estimating the main parameter of extreme value theory, classical extreme value theory makes use of only the highest observations of certain time intervals (e.g. yearly maxima). Other methods, like the Pickands estimator, use the m-upper order statistics of the sample, which involves much less order statistics. These methods put in general less restrictions on the distribution of the observations than e.g. Smith does.

DEKKERS & DE HAAN (1987a,b) have studied extensively Pickands' estimator for the index of the extreme value distribution. Under natural and quite general conditions they proved weak and strong consistency and asymptotic normality of the estimator. Furthermore they give estimators for large quantiles of a distribution and for the right endpoint of a distribution (if finite) and asymptotic distributions of these estimators are obtained. Another - apparently new - estimator is proposed for the index of the extreme value distribution in DEKKERS & DE HAAN (1987c). This estimator is an extension of Hill's estimator for the tail of a distribution. Asymptotic normality is established under almost the same natural and general conditions as in the other work, and large quantiles and the right endpoint are handled too. Also confidence intervals are given.

MEMBERS
dr. R. Helmers (project leader)
prof.dr. L. de Haan (advisor)
drs. A.L.M. Dekkers

START: 1986

WORKING PLAN 1989
Further research on the asymptotic properties of estimators for the main parameter of the extreme value distribution. Also simulation experiments will be carried out to investigate the applicability of the asymptotic results in finite samples. Higher order expansions for the bias of the estimators considered will be studied.

WORKING PLAN AFTER 1989
The project will lead to a Ph.D. degree in 1990.

References

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SUBPROJECT BS 5.4

TITLE: Statistical analysis of partially specified models

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE
Statistical problems are studied concerning the predictable characterisitics of a semimartingale, using the approach to asymptotic statistical inference of Ibragimov & Has'minskii. Special attention will go to examples such as counting processes (and in particular generalizations of Cox's regression model for censored survival data), and to nonlinear time-series models. A common feature of such models in practical applications is that they can often only be partially specified: for instance an applied researcher may be able to specify how various time-dependent, stochastic covariates influence failure intensity, but not give any model for the covariates themselves. Though partial-likelihood based procedures seem to be the right practical solution in such cases, there is at present no theory by which one can discuss asymptotic regularity and optimality in partially specified models (for which Radon-Nikodym derivatives and consequently the whole theory of LAN is not available). This will be remedied by introducing an appropriate subclass of 'asymtotically linear and regular' estimators within which a best estimator can be found.

The research in this project is strongly related to that in BS 5, especially BS 5.1. There will also be participation in the NWO national project: 'Statistics for large parameter spaces'.

MEMBERS
dr. K.O. Dzhaparidze

START: 1984

WORKING PLAN 1989
The large sample properties of the maximum likelihood estimates have been studied thoroughly in the case of the classical scheme of independent observations, in the case of diffusion type processes, point processes, etc.

However, the conditions usually imposed on marginal distributions, or diffusion drift, or point process intensity take a simple, agreeable form only in the case of a scalar unknown parameter, while in the vector-valued parameter case the conditions usually required become more and more restrictive with increasing parameter dimension.

Together with E. Valkeila (Helsinki, Finland) we will study the general scheme of a sequence of parametric families of experiments on a filtered probability space, which includes the schemes mentioned above as special cases. We will establish natural conditions under which maximum likelihood estimators possess the usual large sample properties. This will lead to a considerable improvement upon known results in the vector-valued parameter case, as our conditions tend to be less dependent on parameter-dimension. We intend also to investigate possibilities for extending these results to maximum partial

likelihood estimators, for instance, to Cox's estimator for intensity parameters of an observed point process.

The latter observation scheme is a typical representative of a so-called partially specified model encountered in various branches of statistics such as regression analysis, time series analysis, etc. Together with P.J.C. Spreij (Free University Amsterdam) and R. Chitashvili (Tblisi, USSR) we will develop a unified method for determining optimal statistical procedures of inference in partially specified models. It will be assumed that observations represent a sample path of a semimartingale with the unknown parameters involved in the compensator, and the best 'linear and regular' estimators for these parameters will be constructed. The particular case of observations in discrete time - the nonlinear regression scheme with stochastic (predictable) regressors and martingale-difference errors - will be further investigated, in order to improve the estimators by using a priori information about marginal distributions of the error.

WORKING PLAN AFTER 1989

We will continue studying asymptotically optimal inference for partially specified models in its semi-parametric setting. We will try and develop iterative or recursive statistical procedures of inference.

SUBPROJECT BS 5.5

TITLE: Statistical consultation and cooperation

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE
The aim of this subproject is to enrich mathematical statistics with renewing impulses from applied fields and conversely to make the results of theoretical research accessible for applied researchers and users of statistics. Many of the current subprojects have grown out of past consultation projects. Also by an active policy regarding acquisition of consultation and the initiation of cooperative projects, results from the more theoretical projects are made applicable and enriched by confrontation with the real world. In order to support these activities, a continuing effort is needed in supporting advanced statistical computing facilities (S, ISP, GLIM, etc.) on a variety of computer systems.

MEMBERS
dr. A.J. Baddeley
drs. A.L.M. Dekkers
dr. K.O. Dzhaparidze
dr. S.A. van de Geer
prof.dr. R.D. Gill (advisor)
dr. R. Helmers (project leader)
R. van der Horst (programmer, STO)
B. Lisser (programmer, STO)
dr. R.A. Moyeed

START: 1986

WORKING PLAN 1989
Two STW project applications are currently being prepared and can be hoped to start in this year. The first (in response to contacts with NLR) concerns the analysis of error-counting, debugging models in software reliability using techniques from the theory of counting processes: some commonly used models turn out to be very naturally described in terms of the intensity of a counting process and large sample behaviour of various statistical procedures can be nicely studied from this point of view. The innovations approach of E.V. Khamaladze will be used to develop goodness of fit procedures.

A second project will be formulated together with the dept. of Numerical Mathematics concerning the so-called Wicksel-problem from stereology. This is a simple example of many situations in stereology when the probability distribution of aspects of the shape and size of a 3-D aggregate of particles are only accessible through 2-D cross-sections: in this particular case one observes circle diameters of cross-sections of spheres of varying sizes. Inversion formulas can often be derived for recovering the desired distributions from the distribution of observable quantities but these are typically numerically very badly behaved and some kind of regularization (smoothing, discretization) has to be

employed. An obvious option is to use statistical techniques such as penalized maximum likelihood estimation but so far little experience exists with these - mainly because though such estimators can be discussed in theory, it is not at all clear how they can effectively be computed. These are actually semi-parametric models and one can try to determine optimum rates of convergence of an estimator. (In the Wicksell problem we actually have an example of a deconvolution problem, for which in general recent progress has been made by Groeneboom and Van Es at the University of Amsterdam). Finally one will in practice still have to insert a data-dependent smoothing parameter into the resulting procedures and will be interested in the applicability of the bootstrap; here simulations will certainly be necessary in order to get any indication of whether these modifications work. This problem arose in consultation with AKZO.

WORKING PLAN AFTER 1989
Not to be foreseen.

SUBPROJECT BS 5.6

TITLE: Computational statistics

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

Most of the optimal procedures for drawing statistical inference about unknown parameters are based on optimization of some criterion function, which is a function of the observations and of the unknown parameters. This optimization is then carried out over all admissible values of parameters, so an unconstrained global optimum is sought. Typically, however, the problem can be localized by constructing one or another preliminary, rough estimator for the unknown parameters, which then can be used as initial values in searching for a local optimum. Furthermore, in all cases in which really valid inference is available (e.g. asymptotically normal estimators can be constructed) the criterion function turns out to be an asymptotically quadratic function, as sample size increases, of the parameter-values.

As applied to the classical case of the maximum likelihood estimation of parameters of i.i.d. observations, these facts have been well-known since Fisher. He pointed out the asymptotic efficiency of the Newton-Raphson iterative procedure in this case, in the sense that the result of the very first iteration turns out to be as efficient as the maximum likelihood estimator, provided the likelihood function is smooth enough (asymptotically quadratic) to guarantee asymptotic efficiency of its roots, and provided the starting values are consistent. More lately LeCam has developed the rigorous mathematical theory of this type of 'one-step estimators' for general sequences of LAN experiments, including the classical scheme of i.i.d. observations as a special case. From a practical point of view the importance of this theory consists in deemphasizing the role of maximum likelihood estimators: the Newton-Raphson one-step estimators are not only easily constructed but they may, in principle, be used also in certain situations in which the maximum likelihood estimators do not behave or do not exist. In fact versions of this principle have now been proposed as a general approach to getting efficient estimators in quite general semi-parametric models; see BS 5 (with which this project has strong links).

Although the Newton-Raphson method is theoretically very attractive it may turn out to be quite unreliable in practice, especially when the number of unknown parameters is large. In order to mitigate some of the computational difficulties, unavoidable in the Newton-Raphson method, various refinements and modifications of this method have been introduced in numerical analysis, such as quasi-Newton methods and conjugate gradient methods. They preserve the quadratic termination property of the Newton-Raphson method: the maximum of a quadratic function is found in at most p iterations where p is the number of unknowns.

These advanced methods, or rather their appropriate stochastic modifications, may be applied instead of the Newton-Raphson method (or its stochastic modification - Fisher's scoring method) to statistical estimation problems too: in view of their quadratic termination property one should come

to the conjecture that a utilized method, as applied to the likelihood or some other criterion function, would perform in just p iterations as efficiently as the Newton-Raphson method.

The first result confirming this conjecture was obtained by BEINICKE & DZHAPARIDZE (1982), as it is discussed in DZHAPARIDZE (1983). However, a number of the important questions remain unanswered, such as determining the effect of inexact line search on estimation quality, or determining the amount of reliability of various updating procedures, etc.

To give the answers to these kind of questions, one must accumulate not only theoretical, but also experimental knowledge about the subject under consideration.

START: 1989

MEMBERS
dr. K.O. Dzhaparidze (project leader)
junior researcher (vacancy)
R. van der Horst (programmer, STO)

WORKING PLAN 1989
Literature study, formulation of a concrete research strategy, accumulation of experimental knowledge on the performance of various iterative procedures as applied to the classical observation schemes. Determination of the appropriate stochastic modifications of the iterative methods of numerical analysis, with stochastic updating and line search. Searching for in a certain sense 'optimal' stochastic updating and line search.

WORKING PLAN AFTER 1989
Studying the effects of increasing parameter-dimensionality in view of possible extensions to statistical schemes involving abstract parameters.

References

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PROJECT BS 6

TITLE: Image analysis

TITEL: Beeldanalyse

The aim of this project is to carry out research in the field of the statistical analysis of images. This means the investigation of methods for the solution of statistical problems, when the data are represented in the form of images. There is one subproject:
BS 6.1 Statistical aspects of image analysis and reconstruction.

SAMENVATTING
De doelstelling van dit project is onderzoek te doen op het gebied van de statistische analyse van beelden. Hiermee wordt bedoeld het onderzoek naar methodieken voor het oplossen van statistische problemen, waarbij de data worden gerepresenteerd door beelden. Er is één deelproject:
BS 6.1 Statistische analyse en reconstructie van beeldgegevens.

PROJECT MEMBERS
dr. A.J. Baddeley (project leader)
prof.dr. R.D. Gill (advisor)
dr. R.A. Moyeed
junior researcher (vacancy)
B. Lisser (programmer, STO)

COOPERATION
PROJECT GROUP AM 8
N. van Belzen (University of Utrecht and Hubrecht Lab., KNAW)
drs. L. Barendregt (ITI-TNO)
(more contacts to be established)

START OF PROJECT: 1986

CLASSIFICATION CODES

NWO-classification : P160
1980 Math. Subj. Class. : 62M99

SUBPROJECT BS 6.1

TITLE: Statistical aspects of image analysis and reconstruction

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

Image *processing* is the transformation of a digital image into another digital image through a process of enhancement, noise removal, reconstruction etc. Image *analysis* is a reduction of the image into a single number or small set of numbers serving to describe or summarise one aspect like 'size', 'shape' or 'pattern'. Image analysis is effectively a decision-making process and can be profitably treated by mathematical and statistical methods. The project aims to assess and develop new image analysis algorithms, numerical measures of algorithm performance, and techniques for analysing image data in scientific experiments. There is close cooperation with members of project AM 8 as well as the seismic imaging project BS 3.5 In the future the department of Interactive Systems will also be involved in the joint project.

MEMBERS

dr. A.J. Baddeley (project leader)
dr. H.C.P. Berbee
prof.dr. R.D. Gill (advisor)
dr. R.A. Moyeed
junior researcher (vacancy)
B. Lisser (programmer, STO)

START: 1986

WORKING PLAN 1989

In the initial period of the project there will be several areas of interest:

(1) *Serra's Mathematical Morphology.* This field provides a coherent, mathematically rigorous set of tools for image analysis tasks. Project activities will be
   (a) close study of recent work in mathematical morphology;
   (b) investigation of new pattern-recognition techniques by applying statistical multivariate analysis to morphological functions;
   (c) an attempt to define probabilistic counterparts of morphological operations.

(2) *Markov models.* Markov pixel-based models have recently been extremely successful in image reconstruction problems. The project will study modifications of this approach and look at joint probability distribution models for pixel neighbourhoods.

(3) *Bootstrap methods.* Computer simulation techniques for assessing statistical confidence will be adapted to the image analysis context.

(4) *Images in experimental design.* Possibilities for incorporating image data in analysis of variance (ANOVA) will be explored.

(5) *Software.* A software package, Bunyip, developed at DMS, CSIRO

(Australia) expressly for mathematical research in image analysis, will be extended and adapted to local conditions.

(6) *Consultation.* Initial contacts with a number of interesting applied image analysis problems (Organon, DSM) will be explored.

WORKING PLAN AFTER 1989

Not yet foreseen.

Department of Numerical Mathematics

Numerical mathematics is concerned with the construction, analysis and implementation of approximative methods for solving mathematical problems. Many problems originate from the natural sciences and give rise to (i) boundary-value problems or (ii) initial-boundary-value problems for partial differential equations. Because, in almost all cases, the explicit solution of these problems is impossible, numerical approximations are the main tool to get insight in the quantitative behaviour of the solutions. The numerical mathematics department concentrates on numerical solution methods for these two classes of problems.

The research areas 'boundary-value problems' and 'initial-boundary-value problems' are so wide, and have so many different aspects and possible applications that the department necessarily restricts itself to specific subareas. The central theme in the first area of research is the Multigrid Method, and in the second the Method of Lines. The investigations are carried out by two project groups: the group NW 1 'Discretization of Evolution Problems' and the group NW 2 'Steady Boundary-Value Problems'. In recent years, numerical methods for solving flow problems such as the Navier-Stokes equations and shallow-water equations have become increasingly important, firstly, because numerical methods are far more flexible and, now-a-days, much cheaper than scale models, and secondly, because numerical methods have become reliable for the simulation of a large variety of such problems. Therefore, a substantial part of the research of the groups NW 1 and NW 2 is concerned with the numerical solution of problems in fluid and gas dynamics. Furthermore, new research has started in 1988 on the semi-conductor device equations. In both groups the research ranges from highly fundamental to utilization (industry) oriented, and in both groups intensive contacts with industry are established, resulting in various contract research projects.

Numerical mathematics is permanently influenced by changes in computer hardware, not only by the increase in calculating speed and memory, but also by fundamental changes in architecture. The numerical analysts at CWI try to tune their research to such new developments. For example, the group NW 1 started the STW project 'Evaluation and stabilization of numerical methods for the shallow-water equations' in 1983 when the CYBER 205 computer of SARA (Stichting Academisch Rekencentrum Amsterdam) was just about to be installed. This motivated us to concentrate on numerical methods which can take full advantage of the CYBER 205 architecture, and to develop numerical methods and corresponding shallow-water software exclusively written for this, at the time, up-to-date computer. The CWI model released last year exploits the vector facilities in an almost optimal way and seems to be the most efficient shallow-water code now available on the CYBER 205. Another challenge is the design of algorithms that can take advantage of parallel facilities. The advent of the Alliant *FX*4 parallel processor (autumn 1988) will undoubtedly provide a stimulus for the practical investigation of parallel numerical algorithms.

Since software specifically developed for new computer architectures becomes increasingly important and because most of the projects carried out by the groups NW 1 and NW 2 have also a strong software component, it was decided in 1984 to form a new group NW 4 'Numerical Software' which was financially supported by CDC and INSP. This group concentrates on numerical algorithms for vector and parallel processors, on software in the programming language Ada, and, last but not least, on computational number theory. Computers and numerical methods play a vital role in the study and (approximate) solution of many problems in (analytical) number theory (like the location of the zeros of the Riemann zeta function and the factorization of numbers), and optimal use of facilities offered by vector and parallel processors makes it possible to solve such number-theoretical problems in a realistic amount of time.

Department of Numerical Mathematics

LIST OF PROJECTS

NW 1 Discretization of evolution problems
NW 2 Steady boundary value problems
NW 4 Numerical software

	Projects			working			
Name	NW1	NW2	NW4	hours	regu-	de-	guests
					lar	tached	
appointed							
Van der Houwen	•			1.00	1.00		
Blom	•			0.53	0.53		
Goede, de	•		•	1.00	1.00		
Sommeijer	•		•	1.00	1.00		
Hundsdorfer	•			1.00	1.00		
Verwer	•			1.00	1.00		
Zegeling	•			1.00		1.00	
Mooiman	•			1.00		1.00	
Wesseling (adv.)	•			-	p.m.		
Hemker		•		0.90	0.90		
Koren		•		1.00	1.00		
Molenaar		•		1.00	1.00		
Nooyen, van		•		1.00	1.00		
Zeeuw, de		•	•	1.00	1.00		
Kok			•	1.00	1.00		
Lioen			•	1.00	1.00		
Louter-Nool			•	0.60	0.60		
Mourik, van			•	1.00	1.00		
Riele, te			•	1.00	1.00		
Winter			•	1.00	1.00		
Vorst, v.d. (adv.)			•	-	p.m.		
Schlichting			•	0.50		0.50	
total appointed					16.03	2.50	0.00
regular priority							
scient.res. 1 Trompert	•			1.00	0.96		
scient.res. 2 v.d. Marel		•		1.00	1.00		
scient.ass. 1	•			-	p.m.		
total priority					1.96		
total estimated					17.99	2.50	0.00

PROJECT NW 1

TITLE: Discretization of evolution problems

TITEL: Discretisatie van evolutieproblemen

ABSTRACT
Analysis, development and documentation of algorithms for the numerical solution of evolution problems for differential equations and their application to industrial problems. Project NW 1 consists of the following subprojects:

NW 1.1 Stability and convergence;
NW 1.2 Vector and parallel computing;
NW 1.3 Differential-algebraic equations;
NW 1.4 Adaptive grid methods (STW);
NW 1.5 Lagrangian methods;
NW 1.6 3D Shallow water equations (RWS);
NW 1.7 Smoothing and filtering techniques;
NW 1.8 Boussinesq model (STW).

SAMENVATTING
Analyse, ontwikkeling en documentatie van algoritmen voor de numerieke oplossing van evolutieproblemen voor differentiaalvergelijkingen. Project NW 1 bestaat uit de volgende deelprojecten:

NW 1.1 Stabiliteit en convergentie;
NW 1.2 Vector en parallel rekenen;
NW 1.3 Differentiaal-algebraïsche vergelijkingen;
NW 1.4 Adaptieve roostermethoden (STW);
NW 1.5 Lagrange-methoden;
NW 1.6 3D Ondiep-watervergelijkingen (RWS);
NW 1.7 Smoothing- en filtertechnieken;
NW 1.8 Boussinesq-model (STW).

PROJECT MEMBERS
dr. J.G. Verwer (project leader NW 1.1-1.5)
prof.dr. P.J. van der Houwen (project leader NW 1.6-1.8)
drs. J.G. Blom
drs. E.D. de Goede
dr. W.H. Hundsdorfer
B.P. Sommeijer
prof.dr.ir. P. Wesseling (Delft Technological University, advisor)
drs. P.A. Zegeling (STW)
junior researcher (vacancy)
scientific assistant (p.m.)
ir. J. Mooiman (STW)

EXTERNAL CONTACTS

dr. A. Bellen (University of Triest)
dr. R.M. Furzeland (Shell Research Amsterdam)
ir. G.J.A. Loman (Hydronamic BV),
prof.dr. J. LI. Morris (University of Dundee)
prof.dr. J.M. Sanz-Serna (University of Valladolid)
dr. Th. van Stijn (RWS)
dr. G.K. Verboom (WL)
dr.ir. T.T.M. Verheggen (Shell Research Amsterdam)
dr.ir. F.W. Wubs (University of Groningen)

START OF PROJECT

Project NW 1 is a continuation of the departments research on numerical methods for stiff ordinary differential equations. During recent years the interest is gradually shifting towards partial differential equations.

CLASSIFICATION CODES

NWO-classification	: P170
1980 Math. Subj. Class.	: 65 LXX, 65 MXX, 76 B15
1982 CR Classification Scheme	: G1.8

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

The subject of project NW 1 is the analysis, development and documentation of algorithms for the numerical solution of evolution problems for differential equations. In this project, the research ranges from the very fundamental to utilization or practically oriented. Currently, the research concentrates on the numerical treatment of initial-boundary-value problems for partial differential equations. The scientific importance of this field is large and is for instance found in computational fluid dynamics problems. Needless to recall that due to the increasing processing power of modern computers, the scientific and practical importance of numerical mathematics and computational fluid dynamics is growing steadily.

In 1989 attention will be paid to the following four main subjects: convergence and stability analysis, adaptive and moving grid methods, difference schemes for hyperbolic problems, vector and parallel computation. The first subject, convergence and stability analysis, is of a fundamental nature. In the whole research group of project NW 1, fundamental questions, mainly related to convergence and stability theory, will get continuous interest in order to build up and maintain a sufficiently high level of theoretical knowledge and insight. It is stressed that a high level of theoretical knowledge and insight is needed for the successful application of algorithms to complex practical problems. The second subject, adaptive and moving grid methods, is more practically oriented. This type of numerical methods for time-dependent problems is of great importance for the efficient computation of solutions possessing rapid temporal and spatial transitions. For this subject we cooperate with the numerical group of the Royal/Shell Laboratory in Amsterdam in the STW project: 'Adaptive grid methods'. The third subject, difference schemes for hyperbolic problems, is also practically oriented. Here the research concentrates on the numerical treatment of the 3D shallow water equations and of 2D time-dependent Boussinesq terms. In these projects there is a close cooperation with engineers and numerical analysts of RWS and WL. Finally, in recent years the use of vector computers has obtained a firm footing in numerical mathematics. Anticipating on a similar development for parallel computers, or vector computers offering a high degree of parallelism, our research on the fourth subject of vector and parallel computation will be intensified.

WORKING PLAN 1989

NW 1.1 Stability and convergence

Research of project NW1.1 concentrates on the analysis of algorithms, specifically the fundamental notions of stability and convergence are studied. Here we cooperate with Prof. dr. J.M. Sanz-Serna from the University of Valladolid in Spain.

In the analysis very often the Method of Lines approach is followed, since this approach enables one to apply results from the numerical analysis of linear and nonlinear stiff ordinary differential equation problems, a field which has reached a high level of development. The plan for 1989 is to give particular

attention to stability and convergence questions for splitting methods for partial differential equations with several space variables. Among others, the phenomenon of order reduction will be studied along the lines of the *B*-convergence theory for Runge-Kutta methods. Results in this direction for the well-known Peaceman-Rachford method, which were obtained in 1987/88, will be extended to more general classes of alternating direction implicit methods.

NW 1.2 Vector and parallel computing
As a continuation of the research on vector codes for the odd-even hopscotch and ADI scheme for the time-dependent 2D Burgers' equation, which was carried out in 1987/88, the plan for 1989 is to extend our research on vector and parallel computing in various directions. This will include a general state-of-the-art study of parallelism in numerical analysis and, more specifically, the study of algorithms for specific methods such as splitting methods for multi-space dimensional problems, like ADI and hopscotch. To some extent the research will depend on the available hardware. The research will be carried out in consultation with the researchers responsible for the numerical software project NW 4, among others in behalf of the proposed ESPRIT project PRESCAN. Collaboration with the numerical analysis group from the University of Dundee, also in connection with a proposed ESPRIT project, is under consideration.

NW 1.3 Differential-algebraic equations
Such time-dependent equations occur in many applications, for example in the modelling of electronic networks and semi-conductors, and in incompressible fluid flow. Also various moving finite element and finite difference schemes for time dependent partial differential equations give rise to the use of systems of coupled differential and algebraic equations. The numerical solution of these types of equations is still much less understood than that of the pure differential equation form. For this reason alone it is desirable to keep track of interesting developments in this field. This will constitute the main activity within NW 1.3 in 1989. At this very moment no new specific activities on differential-algebraic equations have been planned yet.

NW 1.4 Adaptive grid methods (STW project)
Adaptive grid methods are numerical methods which compute numerical solutions on grids dynamically adapted to the solution at hand. These methods are meant for problems involving fine-scale structures that develop, propagate, decay, and/or disappear as the solution evolves. Examples include reaction zones in combustion processes, boundary and shear layers in viscous flows and shock waves in compressible flows. The numerical solution of these problems is difficult because the nature, location and duration of the fine-scale structures is usually not known in advance. Thus, conventional numerical approaches that calculate solutions on a prescribed (typically uniform) grid readily fail to adequately resolve the fine-scale phenomena at reasonable computational costs. By a suitable movement of the grid, ideally governed by reliable error indicators

or estimators, it is often possible to work with considerably less grid points and with a substantially higher degree of robustness and reliability.

The STW project NW 1.4, which started end of 1987, is carried out in joint cooperation with dr. R.M. Furzeland of the Royal/Shell Laboratory in Amsterdam. The aim is to develop moving grid software for systems of time dependent partial differential equations which can be implemented in the existing sophisticated Method of Lines software package SPRINT (developed by Shell Research at Thornton and by the University of Leeds). Currently a comparative study is made of three different techniques for 1D systems which all fit into SPRINT. The plan for the near future is to develop an interface based on one of these techniques, which should enable users of the SPRINT package to efficiently solve their problem on a moving space-time grid without as less intervention as possible. At a later stage this research will be continued into the direction of attaching the grid movement to genuine error estimation procedures and/or into techniques for 2D problems. Exchange of results will take place, among others, with dr. M. Berzins of Leeds University and prof.dr. J.E. Flaherty of Rensselaer Polytechnic, Troy, New York.

NW 1.5 Lagrangian methods (related to STW project NW 1.4)

The subject of project NW 1.5 also concerns adaptive and moving grid methods for time-dependent partial differential equation problems and mainly serves to support the STW project NW 1.4. While this STW project is practically oriented, the project NW 1.5 is necessary in order to meet the demand of fundamental background research. At present, attention is concentrated on the study of Lagrangian methods, since methods of this type offer the best prospects for efficient numerical time stepping, at least in one space dimension. The current STW research also deals with Lagrangian methods. Within NW 1.5 we collaborate with the numerical analysis department of the University of Valladolid (prof.dr. J.M. Sanz-Serna).

The research currently carried out will be continued. This involves methods for 1D problems. Specifically, we will study a method where the grid movement is governed by a coordinate transformation which 'softens' the solution behaviour in the temporal direction, thus achieving a very efficient time stepping process. However, such a grid movement must be accompanied with a spatial regridding procedure which should obey a spatial error criterion. The study of genuine spatial error estimation techniques is therefore planned. If time permits, we shall also start in 1989 work on methods for 2D problems.

NW 1.6 3D Shallow-water equations (RWS)

Rand Corporation, Delft Hydraulics and computation divisions of the RWS (Ministry of Public Works) cooperate in the design of time-dependent numerical models for simulating three-dimensional water flow in a variety of practical situations. This model aims at the computation of hydrostatic and weakly non-hydrostatic flows and transport processes, leading to a so-called multilayer model. In actual computation, such models require a multiple of the computational effort needed in two-dimensional models.

By order of RWS the Department of Numerical Mathematics of CWI was asked to develop an efficient computational model on vector computers and possibly parallel computers.

In 1989 we shall concentrate on the water flow in a rectangular box ignoring inhomogeneities and horizontal diffusion. Using symmetric finite difference space discretization, with and without so-called sigma transformations, various time integrators will be investigated. This research started in March 1988 and will be done in consultation with dr. Th. van Stijn and engineers of RWS.

NW 1.7 Smoothing and filtering techniques

This project provides fundamental background research for the RWS project NW 1.6. In view of the new computer architectures, explicit time integrators become of increasing interest because they vectorize and parallelize extremely well. In combination with stabilizing techniques, such as smoothing and filtering, explicit methods can compete with implicit methods and have the additional advantage of greater simplicity and flexibility. The research will concentrate on a general framework for smoothing techniques in one-step methods for hyperbolic differential equations.

NW 1.8 Boussinesq model (STW)

This project aims at the design of a numerical, two-dimensional Boussinesq model of at least third-order accuracy, both in space and time, for describing fairly long, free surface waves. Starting point is the numerical two-dimensional shallow-water model developed in the STW project: 'Evaluation and stabilization of 2D shallow-water solvers' which was carried out in the department by F.W. Wubs in 1983-1987. Boussinesq models are obtained by adding so-called Boussinesq terms to shallow-water models. The major problem in developing reliable Boussinesq models is the requirement that the underlying shallow-water model should be sufficiently accurate, that is, its order of accuracy should be at least four. Since the model of Wubs does have a fourth-order option, it is an ideal starting point for this project. The project is expected to start medio 1988 and will be carried out in close cooperation with dr.ir. G.K. Verboom (Delft Hydraulics) and ir. G.J.A. Loman (Hydronamic BV).

WORKING PLAN 1990-1994

(1) NW 1.1 will be continued, more or less along the lines of the research carried out in 1987/88.
(2) As far as research on vector and parallel computing is concerned, the experience with parallel computing for time-dependent problems is very limited. It is desirable that the research on parallel computing will be intensified. However, at the time of writing of this document the total available manpower for NW 1 is insufficient to be able to give the subproject NW 1.2 the attention it needs.
(3) Until further notice, NW 1.3 will have the lowest priority within NW 1.

(4) The STW project NW 1.4 will last until 1991. Consequently, in the coming years the moving grid work, including the subproject NW 1.5, will get a high priority.
(5) Likewise, the RWS project NW 1.6 will last until 1992, so that also research on the 3D shallow-water equations and the supporting project NW 1.7 will get a high priority.
(6) The STW project NW 1.8 will last until 1990 and has the same priority as the RWS project.

PROJECT NW 2

TITLE: Steady boundary-value problems

TITEL: Stationaire problemen

ABSTRACT
Development and analysis of modern techniques for the efficient numerical solution of steady boundary-value problems. In particular, the study of multigrid and related methods and their application to industrial problems. Project NW 2 consists of the following subprojects:

NW 2.1 Defect-correction and theoretical background;
NW 2.2 Singularly perturbed boundary-value problems;
NW 2.3 Adaptive methods;
NW 2.4 Application to fluid dynamics;
NW 2.5 Efficient techniques for the solution of the Euler and the compressible Navier-Stokes equations;
NW 2.6 Reliable and efficient methods for semiconductor device simulation equations.

SAMENVATTING
Ontwikkeling en analyse van moderne technieken voor de efficiënte numerieke oplossing van stationaire problemen. In het bijzonder de studie van multigrid and verwante methoden en de toepassing op industriële problemen. Project NW 2 bestaat uit de volgende subprojecten:

NW 2.1 Defect-correctie en theoretische achtergronden;
NW 2.2 Singulier gestoorde randwaardeproblemen;
NW 2.3 Adaptieve methoden;
NW 2.4 Toepassingen in de stromingsleer;
NW 2.5 Efficiënte technieken voor het oplossen van de Euler en de compressibile Navier-Stokes-vergelijkingen;
NW 2.6 Betrouwbare en efficiënte methoden voor de halfgeleidervergelijkingen.

PROJECT MEMBERS
dr. P.W. Hemker (project leader)
ir. B. Koren
drs. J. Molenaar
drs. R. van Nooyen (IOP)
drs. P.M. de Zeeuw
junior or scientific researcher (vacancy)
prof.dr.ir. P. Wesseling (Delft Technological University, advisor)

EXTERNAL CONTACTS

dr. W. Boerstoel (NLR, Amsterdam)
ir. N. Voogt (Fokker, Amsterdam)
ir. W.J. Bannink (Delft Technological University)
dr. C. Thompson (NAG, Downers grove, USA)
dr. A. Dervieux (INRIA, Sophia Antipolis, France)
dr. M.-H. Lallemand (INRIA, Sophia Antipolis, France)
dr. J.A. Desideri (INRIA, Sophia Antipolis, France)
drs. S. Polak (Philips, Eindhoven)
dr. W. Schilders (Philips, Eindhoven)
dr. P. Markowich (T.U. Vienna, Austria)
prof.dr. B. van Leer (Univ. Michigan, USA)
prof.dr. U. Trottenberg (SUPREMUM GmbH, Bonn, GFR)
dr. K. Stüben (GMD, St Augustin, GFR);
dr. D. Schröder (Techn. Univ. Hamburg-Harburg, GFR)
dr. U. Ascher (Univ. BC, Vancouver, Canada)

START OF PROJECT

Project NW2 concentrates on applications of multigrid methods since 1979, applications in fluid dynamics since 1983, applications in semiconductor problems since 1987.

CLASSIFICATION CODES

NWO-classification	: P170
NABS-code	: N10, N059, N0751
1980 Math. Subj. Class.	: 65Nxx, 65F10, 76Nxx

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

The numerical analysis of steady boundary-value problems is concerned with the design and development of methods for the numerical approximation of the solution of elliptic and hyperbolic partial differential equations and of integral equations. These equations frequently arise in technical applications (structural mechanics, fluid dynamics, electricity etc.). Because, in almost all cases, the explicit solution of these equations is impossible, numerical approximations are the main tool to get insight in the quantitative behaviour of the solutions.

The research area 'steady boundary-value problems' is so wide, and has so many different aspects and possible applications that this project necessarily restricts itself to a specific subarea. The central theme in the project is the 'Multigrid Method'. In fact, what is called 'Multigrid' is more an approach to problem solving than one particular method. The underlying multigrid idea is to use a sequence of discretisations together with (simple) iterative processes for getting control over the various components of the approximation error. The technique makes it possible to solve efficiently the very large systems of linear or nonlinear algebraic equations that arise from the discrete approximation of the boundary-value problems. It is the only solution method that can solve such large problems with a number of arithmetical operations that is asymptotically proportional to the number of unknowns.

The multigrid approach is a recent development in numerical analysis, which started in the mid-seventies. It yields a framework for new algorithms in which many variations are possible. What variants are suitable under given circumstances is an important subject of the research. In the last ten years the group has considered a number of diverse applications: elliptic partial differential equations, integral equations of the second kind, and the Euler equations in fluid dynamics. The kind of research has always been of a fundamental nature and ranges from purely theoretical research to the practical implementation of the methods in efficient computer codes. These codes come available e.g. through the NAG library of the Numerical Algorithms Group Ltd. (Oxford, UK).

At this moment two practical applications are the subject of research in particular: (i) the compressible Navier-Stokes equations, and (ii) the semiconductor device simulation equations. The choice for these subjects is made on basis of there practical relevance. The first subject is of interest e.g. for the NLR, Fokker and the HERMES project of the European Space Agency. The second challenging subject arose from cooperation with Philips Industries, Eindhoven, and is supported by the IOP-IC Technology program. Both applications have in common that they are of a complex structure and that, with the present state-of-the-art of the multigrid techniques, practical advantage of their application can now be expected. Further, the equations in both applications are of singular perturbation type (i.e. in some parts of the domain of definition, the diffusive part in the equation is dominated by a convective term). This is a special difficulty in their discretisation, for which a special expertise has been built up at the CWI in the last decade.

WORKING PLAN 1989

NW 2.1 Defect-correction and theoretical background
Many iterative processes for the solution of steady partial differential equations are of defect-correction type. In particular, the multigrid methods belong to this class. Although much progress has been made the last ten years in the construction of the theoretical foundation for the multigrid methods applied to standard elliptic PDEs and integral equations, many applications don't fall into these categories and additional theory is required to support the practical applications.

The study of defect-correction is a proper means to obtain insight into (new) possibilities for the method. and it is useful to see its relation and possible combination with other defect-correction processes.

NW 2.2 Singularly perturbed boundary-value problems
In view of the singular perturbation type of the two practical applications at hand it is useful to continue the study in this area of research. In particular non-standard finite element methods will be studied such as the Mixed Finite Element Method and different Streamline-Upwind and other Petrov-Galerkin methods.

NW 2.3 Adaptive methods
Multilevel algorithms now exist that can adapt to and resolve both local and global phenomena at costs commensurate with the resulting error. To effectuate this property it is important that the grids on which the discretizations are made are adapted to the solutions. Data structures and techniques that may realise this are studied in this subproject.

NW 2.4 Application to fluid dynamics
If the present contract for the HERMES project will be continued, until 1990 the research with respect to fluid dynamics will be restricted to the Euler- and Navier-Stokes equations (i.e. subproject NW 2.5).

NW 2.5 Efficient techniques for the solution of the Euler and compressible Navier-Stokes equations (ESA)
This subproject is based on a contract for the European Space Agency. First, for special applications the feasibility of a geometric multigrid method is investigated for the solution of the 2-D steady Euler equations. The method has been recently developed and it proved to be robust and very efficient for a number of standard and non-standard problems. Special attention will now be paid to the treatment of hypersonic flows around airfoils at high Mach number and high angle of attack.

The method has also been extended for 2-D steady Navier-Stokes equations with a high Reynolds number (the range between $Re = 250$ and $Re = 0$). This has been done by a defect-correction technique and in the same computation the Euler- or Navier-Stokes equations can be used in different regions of the

flow. The emphasis of the further investigations will be on the resolution of the boundary- and other thin layers in the flow. This will be effected by well-structured nested grid-refinements, which are consistent with the geometric multigrid approach. Specially the combination of the multigrid solution-procedure and the locally nested grids will be considered. By measuring local entropy variations or local relative truncation errors (natural quantities in a MG-solution procedure), the automatic mesh-refinement can be controlled. However, the nested grids will be constructed only partially automatic, so that a designer has still influence on the adaptive process. Because the idea of well-structured nested grid-refinements fits naturally in the geometric MG-approach, the adapted discretization and the efficient solution of the discrete nonlinear system will benefit from each other. By such an algorithm a prescribed accuracy can be obtained with a minimal amount of work. By this approach the computation of super and hypersonic flows will be studied, including temperature effects (local cooling), effects of sharp bends in aircraft surfaces, and shockwave-boundary layer interaction.

In 1989 we will carry out: Further testing of the Euler-Navier-Stokes method developed by means of a subset of the recently defined HERMES R&D test problems (the ramp problem and the double ellipse problem); Realisation of nested local grid-refinements in the existing Euler-Navier-Stokes multigrid code; Testing of the nested grid-refinements for the resolution of thin layer effects; Further studies of shock wave boundary layer interaction.

NW 2.6 Reliable and efficient methods for semiconductor device simulation equations (IOP)

An important tool for semiconductor device modelling is device simulation. For this purpose computer programs are used, that solve the partial differential equations which describe the behaviour of the device. As long as the modelling is restricted to the steady potential equation, the problem is well-solved. If, however, the model is extended with the continuity equations for the carriers of the negative and positive electric charges, the problem is considerably more difficult. The available numerical techniques are too slow and they are not sufficiently reliable. At a number of places, software has been developed to perform the simulation, and several packages are available for industrial applications (e.g. the CURRY program by the group MSW, Philips Corporate CAD Centre, Eindhoven). However, there are still a large number of interesting cases for which these programmes cannot find a solution (in a sufficiently short time). The programmes are too slow and they are generally not sufficiently reliable. The situation cannot be solved by simply using more computer power. The difficulties are more fundamental. The mathematical (mainly numerical) knowledge that is available for the solution of these problems falls short. In this project we are looking for better numerical techniques. The problem will be attacked from two different sides. First we shall reconsider the modern discretization methods that are available for the solution of singularly perturbed problems. (Here lies a relation with project NW 2.2) Secondly, multigrid methods will be studied for the efficient solution of the nonlinear

algebraic equations that arise from the discretization of the continuous equations.

WORKING PLAN 1990-1994

(1) Investigation of different criteria for automatic mesh-refinement. Based on the above mentioned test problems (see NW 2.5): study of temperature effects, effects of a sharply bended surface, and shock wave boundary layer interaction.
(2) Existing discretization techniques for the solution of the semiconductor device equations will be studied and reconsidered. Study of box-methods and non-standard finite element methods. If necessary, development of a new discretization scheme.
(3) Study of adaptive grid generation techniques that can be applied in combination with the multigrid method for the semiconductor device equations.
(4) Study of the application of a multigrid method to one-dimensional model problems (transistor).
(5) Development of a two-dimensional multigrid method for semiconductor device simulation. The aim is to constuct an adaptive method where part of the mesh generation for the discretization is done automatically.

PROJECT NW 4

TITLE: Numerical software

TITEL: Numerieke programmatuur

ABSTRACT
There are three subprojects.

NW 4.1 *Development of numerical software in the programming language Ada*

NW 4.2 *Vector and parallel algorithms.* Study of existing and development of new numerical algorithms in order to exploit the special features of vector and parallel computers. Development and production of numerical software for vector and parallel computers (in particular CYBER 205, the ETA10, NEC SX-2, CRAY X/MP).

NW 4.3 *Computational number theory.* Study of how vector and parallel processors can be used in an optimal way for the solution of those number-theoretical problems where modern computers and numerical techniques play a vital role.

SAMENVATTING
Het project bestaat uit drie subprojecten.

NW 4.1 *Ontwikkeling van numerieke programmatuur in de programmeertaal Ada*

NW 4.2 *Vectoralgoritmen en parallelle algoritmen.* Onderzoek van bestaande en ontwikkeling van numerieke algoritmen met het doel zo goed mogelijk gebruik te maken van de speciale faciliteiten van vectorcomputers en parallelle computers. Ontwikkelen en beschikbaarstellen van numerieke programmatuur voor vectorcomputers en parallelle computers (m.n. voor de CYBER 205, de ETA10, NEC SX-2 en de CRAY X/MP).

NW 4.3 *Getaltheorie m.b.v. de computer.* Onderzoek van de mogelijkheden van vectorcomputers en parallelle computers bij het oplossen van die getaltheoretische problemen, waarbij computers en numerieke technieken een essentiële rol spelen.

PROJECT MEMBERS
drs. J. Kok (project leader NW 4.1)
dr.ir. H.J.J. te Riele (project leader NW 4.2, NW 4.3)
H.P. Dijkhuis (programmer, STO)
drs. E.D. de Goede
drs. W.M. Lioen
drs. M. Louter-Nool
drs. P. van Mourik
B.P. Sommeijer

A.G. Steenbeek (programmer, STO)
C.Th. Everaars (programmer, STO)
prof.dr. H.A. van der Vorst (advisor, Delft Technological University)
D.T. Winter
drs. P.M. de Zeeuw
drs. J.J.F.M. Schlichting (CDC)

EXTERNAL CONTACTS
Dr.ir. T.T.M. Verheggen (Shell Research Amsterdam), dr. G.T. Symm (NPL, Teddington), dr. J. Dongarra (Argonne National Lab.), prof. A. Bellen (Univ. Triest), prof.dr. Th.J. Dekker (University of Amsterdam), dr. B. Ford (NAG, Oxford), Ada-Europe Numerics Working Group (Brussel), ESPRIT (Brussel), prof.dr. W. Borho (Gesamthochschule Wuppertal, FRG), prof.dr. M. García (City Univ. of New York, USA), dr. E.J. Lee (Fargo, ND, USA), prof.dr. A. Ivić (Univ. of Belgrado, Jugoslavia), dr. A. Granville (Univ. of Toronto, Canada), prof.dr. R.P. Brent (Free Australian National University, Canberra, Australia).

START OF PROJECT: 1981 (NW 4.1), 1984 (NW 4.2), 1976 (NW 4.3)

CLASSIFICATION CODES

NWO-classification	: P170, P120
1980 Math. Subj. Class.	: 65V05, 65-04, 10Axx, 10Hxx
1982 CR Classification Scheme	: D.2.2, F.2.1, G.1

SUBPROJECT NW 4.1

TITLE: Development of numerical software in the programming language Ada

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

The programming language Ada (US Department of Defense, 1983) has been designed primarily for real-time, embedded computer applications development. However, in view of the scale of effort that has been invested in its design, it is envisaged that it will also be widely used in other areas, including the important one of large-scale scientific computation.

Since numerical computations, ranging from very simple to extremely complicated ones, appear in many scientific and technical computer applications, the need for numerical libraries in Ada is obvious. The Ada design requirement of portability excludes the possibility of providing interfaces to existing libraries available in other languages. In order to implement numerical algorithms into portable Ada packages complete conformance is required regarding issued guidelines for the proper use of the new language features. These include new types, operators, structured design of libraries, separate compilation, error handling and distributed processing. The introduction and proper use of Ada is forcefully supported by the Commission of the European Community through its promotion of the production of large-scale, reliable, efficient and portable software.

Of particular interest for ongoing research in numerics mathematics are Ada's high-level features for programming parallel execution.

WORKING PLAN 1989

Within the framework of the international working group 'the Ada-Europe Numerics Working Group' in cooperation with the American working group 'ACM-SIGAda NUM WG', and possibly also in an EC-funded project (proposed) the followign activities will be carried out:

(1) The language Ada does not define basic mathematical facilities including scientific real types and operations, elementary functions and vector and matrix definitions. However, all necessary definitions can be provided in Ada, and they can be implemented even independent of a particular hardware configuration. Within the afore-mentioned framework new and available proposals for extension of the language Ada with standard mathematical facilities will be further developed and advanced to the suitable standardization bodies, such as the appropriate ISO working group.

(2) In a proposed project it is planned to investigate the design, and efficient and reliable implementation in Ada of parallel algorithms from several areas of numerical mathematics. Portable implementations will be made for exploiting the possibilities for parallel execution of specific hardware architectures.

WORKING PLAN AFTER 1989

Depending on available resources and hardware.

Literature

1. ANSI/MIL-STD 1815A. *Reference Manual for the Ada Programming Language.* US DoD, January 1983.
2. J. KOK, G.T. SYMM (1984). A proposal for standard basic functions in Ada. *Ada Letters, Vol. IV.3,* 44-52.
3. U. KULISCH, W.L. MIRANKER (eds.) (1983). *A New Approach to Scientific Computation,* Academic Press.
4. B. FORD, J. KOK, M.W. ROGERS (eds.) (1986). *Scientific Ada,* Ada Companion Series, Cambridge University Press.

SUBPROJECT NW 4.2

TITLE: Vector and parallel algorithms

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

Since the arrival of the CYBER 205 vector computer at SARA in 1984, the CWI has researched actively on vectorized and parallellized algorithms. Many algorithms need to be revised if they are to run efficiently on vector and parallel processors. Although research on parallel algorithms goes back at least to the sixties, the recent realization in practice of parallel computers (Alliant, Hypercube, Sequent, Connection Machine) has provided considerable impetus to research in this field:

1. Numerous conferences, symposia and workshops are being organized in the field of parallel architectures and applications.
2. Various journals, especially devoted to vector and parallel computing have emerged.
3. Many experimental parallel computers are being built, with more and more emphasis on the possibility to reconfigure the architecture according to the amount of parallellism in the problem at hand.
4. Apart from the classical attack of numerical modelling, new approaches are attempted in the simulation of physical phenomena (e.g. with the help of cellular automata).

As a consequence of these developments, researchers who have access to a good parallel computer system, with good parallellizing software, have a significant lead over those who have no access to such a system. Fortunately, CWI will have its own parallel computer which is suitable for research of parallel numerical methods at the end of 1988. This machine (an Alliant FX/4) will be used primarily to investigate coarse-grained parallelism in numerical algorithms. Fine-grained parallelism will, hopefully, be studied in the near future with the help of local memory machines (like the hypercube and transputer systems).

WORKING PLAN 1989

1. *NUMVEC-Library.* Purpose of this library is the provision of high-quality numerical software especially aimed at vector and parallel processors. The routines in this library may be written in portable ANSI FORTRAN 77 if this code is easy to vectorize, or else machine code may be used if this is necessary from efficiency considerations. Contributions to this library mainly came from the current research activities of the Department of Numerical Mathematics, viz., in the fields of initial and boundary-value problems in partial differential equations, and the field of computational number theory.
2. *Basic Linear Algebra Subroutines (BLAS).* The well-known BLAS are computationally intensive kernels which play a central role in linear algebra software libraries. Purpose of this research is to investigate the extent to which these routines can be automatically vectorized and parallellized

on various kinds of vector and parallel machines, and if necessary, to optimize these routines for specific machines by using machine code.
This research is partially carried out in the framework of the acting of the CWI as a test site in the so-called LAPACK-project. The LAPACK-project is a joint effort of Argonne National Laboratories, Courant Institute and NAG, Ltd. to develop a transportable linear algebra libary in Fortran 77 for efficient use on high-performance computers.

3. *Parallel algorithms for partial differential equations.* Depending on the availability of parallel computers at CWI, parallel algorithms for partial differential equations will be investigated, implemented and compared on various kinds of parallel computer systems. Particular attention will be paid to bridging the gap which traditionally exists between theoretical and practical aspects of this problem.

WORKING PLAN AFTER 1989

Depending on available financial means and parallel computer systems.

SUBPROJECT NW 4.3

TITLE: Computational number theory

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

Number-theoretic problems are often easy to state. Apart from the scientific interest, these problems often have an educational meaning. The excellent computing facilities of the CWI are an efficient aid in this project, especially when one is collecting experimental data, in order to get a 'feeling' for the problem. These data may disclose new phenomena and hints for mathematical proofs. In this respect, computational number theory may be compared with experimental physics.

In the course of years ample knowledge and experience has been gained in the field of computational number theory (zeros of the Riemann zeta function, the Mertens conjecture, the Goldbach conjecture, 'special' numbers like 'amicable' and 'hyperperfect' numbers, factorization of large integers). The discovery, in 1978, by Rivest, Shamir and Adleman that the difficulty of breaking certain cryptograhic codes depends on the difficulty of factoring large integers, has stimulated to a great extent the interest in the state-of-the-art with respect to factoring large integers on the fastest available (super) computers. The CWI has played a leading role in this field, in particular with respect to the use of large vector computers.

WORKING PLAN 1989

1. Study of factorization methods for very large numbers on vector and parallel computers (CYBER 205, NEC SX-2, SEQUENT, ...).
2. Study of zeros of functions related to the zeros of the Riemann zeta function: These functions involve the second moment of the Riemann zeta function itself.
3. Study of the Goldbach conjecture, in particular the smallest primes which occur in the Goldbach decompositions of the even numbers.
4. Continue the research and organizational work connected with the central role of the CWI in the field of amicable numbers ('Centre for Amicable Pairs').

WORKING PLAN AFTER 1989

Continuation of the 1989 plan.

Department of Software Technology

The department of Software Technology pursues research concerning programming theory, methodology and technology. In addition, computer science aspects of artificial intelligence are studied. The department has received up to now major support through the ESPRIT I program. In 1989, the three ongoing ESPRIT I projects will complete their final year. The department has devoted much effort to the preparation of ESPRIT II proposals. Since, on the one hand, the emphasis in the main (industrial) program of ESPRIT II is very much on applied informatics, and, on the other hand, the available funds for ESPRIT Basic Research are extremely limited, future external financing of the department's fundamental work is somewhat in jeopardy. Limited national external funding of our projects is available for AP 1 through the NFI's REX project and for AP 5 through the SPIN/PRISMA project. In addition, we expect the RACE-SPECS project to continue beyond 1989. In accordance with the CWI's Strategic Plan (Beleidsnota 1988-1993), a new project 'Term Rewriting Systems' (AP 4) has been included in the department's program. The project will exploit the considerable expertise available in the department, and contribute to a clearer distribution of the responsibilities in the sense that AP 4 will concentrate on fundamental research which provides (part of) the tools which are utilized in AP 2's more application oriented work concerning formal specification. In this way, we aim at implementing one of the recommendations of the NWO Evaluation Panel for the CWI. A list of the department's projects follows:

AP 1 Concurrency
AP 2 Formal specification methods
AP 3 Extensible programming environments
AP 4 Term rewriting systems
AP 5 Expert systems
AP 6 Logical aspects of artificial intelligence

Department of Software Technology

List of projects

AP 1 Concurrency
AP 2 Formal specification methods
AP 3 Extensible programming environments
AP 4 Term rewriting systems
AP 5 Expert systems
AP 6 Logical aspects of artificial intelligence

	Projects						working			
Name	AP1	AP2	AP3	AP4	AP5	AP6	hours	regu-lar	de-tached	guests
appointed										
Bakker, de	•						0.80	0.80		
Boer, de	•						1.00	0.50		
Rutten	•						1.00	1.00		
Olderog	•						1.00			0.80
Baeten		•					1.00	0.92		
Groote		•					1.00	1.00		
Ponse		•					1.00	0.75		
Bergstra (adv.)		•					-	p.m.		
Vaandrager		•					1.00	0.50		
Weijland		•					0.30		0.02	
Mauw		•					0.20		0.15	
Meulen, v.d.			•				1.00	1.00		
Heering			•				1.00	1.00		
Hendriks			•				1.00	0.75		
Klint			•				0.60	0.60		
Rekers			•				1.00	1.00		
H. van Dijk			•				1.00		1.00	
Koorn			•				1.00		1.00	
Klop				•			0.70	0.70		
Glabbeek, van				•			1.00	0.92		
Vries, de				•			1.00	1.00		
Kossen					•		1.00	1.00		
Gaag, v.d.					•		1.00	0.92		
Lucas					•		1.00	1.00		
Eliens					•		1.00	1.00		
Theunisse					•		0.50	0.32		
Spee					•		1.00	1.00		
Bezem						•	0.80	0.80		
Apt						•	1.00	0.67		
Bol						•	1.00	1.00		
Emde Boas, van						•	0.20		0.20	
total appointed								20.14	2.37	0.80
regular priority										
scient.res.1		•					1.00	0.83		
scient.res.2		•					1.00	0.50		
scient.res.3						•	1.00	1.00		
scient.res.4			•				1.00	0.25		
scient.res.5	•						-	p.m.		
scient.res.6	•						-	p.m.		
scient.res.7				•			-	p.m.		
scient.res.8						•	-	p.m.		
total priority								2.58	0.00	0.00
total estimated								22.73	2.37	0.80

PROJECT AP 1

TITLE: Concurrency

TITEL: Concurrency

ABSTRACT
Research into the semantic aspects of parallel computation according to various programming styles (imperative, logic, object-oriented, applicative); also proof and specification methodology for concurrent systems.

SAMENVATTING
Onderzoek van semantische aspecten van parallelle verwerking volgens diverse programmeerstijlen (imperatief, logisch, object-georiënteerd, applicatief e.d.); voorts bewijs- en specificatiemethodieken voor concurrente systemen.

PROJECT MEMBERS
prof.dr. J.W. de Bakker (project leader)
drs. F.S. de Boer
drs. J.J.M.M. Rutten
dr. E.-R. Olderog (visiting researcher)
junior researcher (REX)
junior researcher (ESPRIT BRA)

EXTERNAL CONTACTS
REX partners (University of Leiden, Eindhoven Technological University)
ESPRIT partners, in particular Philips Research Laboratories Eindhoven
Free University Amsterdam (dr. J.-J.Ch. Meyer)
SUNY at Buffalo (prof. J.I. Zucker)
University of Utrecht (drs. J.N. Kok)
Erasmus University Rotterdam (dr. A. de Bruin)

START OF PROJECT: 1984

CLASSIFICATIONS CODES

NWO-classification	: P120, P175, T120
NABS-code	: N076
1985 Math. Subj. Class.	: 68N15, 68Q10, 68Q55, 68Q60, 68Q90
1987 CR Class. Scheme	: D.1.3, D.2.1, D.2.2, D.2.3, D.2.6, D.3.0, D.3.4, F.1.2, F.3.2, I.1.3, K.3.2, K.8

DESCRIPTION OF THE PROJECT

The study of distributed systems constitutes at present a central area in both theoretical and applied computer science. A key role is played here by architectural developments, in particular by the current major activities in the design and use of parallel architectures. The concurrency project focuses on parallelism in a range of programming languages, with ramifications on the one hand towards foundational topics such as domain theory, on the other hand towards parallel computational models inspired by new computer architectures. Pioneering investigations concerning languages for concurrency are Hoare's *Communicating Sequential Processes* and Milner's *Calculus for Communicating Systems.* Both studies introduce a number of fundamental notions in the field of concurrency, and both have acted as source for an impressive body of further research developments. Mathematical modelling of concurrent programming concepts is essentially more difficult than of sequential ones. As to the latter, it mostly suffices to consider only the input/output behaviour of a program in the form of its associated (state transforming) function. For parallel programs, it is usually necessary to consider as well the history of the computation in the form of a structured representation of the intermediate actions and/or states. Moreover, in the analysis of concurrent phenomena one often has to address issues arising from infinite computations. Examples include a variety of embedded, reactive systems which serve their environment for, in principle, an infinite amount of time. New techniques are required, introducing ways of handling limits and continuity. Also, one encounters ensuing new problems such as those concerning 'fairness'. In general, concurrency semantics has interfaces with the theory of formal languages (in a wide sense, including as well, e.g. tree languages) which are not present in the sequential case. The project exploits metric process theory for the foundations of several semantic models, in which the history aspect of computations is reflected in the form of Plotkin's resumptions. A further goal of the project is to contribute to the semantic modelling of 'real-life' languages for concurrency, and to investigate soundness and completeness of proof systems designed for proving properties of parallel programs such as correctness or deadlock. Finally, the project will apply semantic insights in the verification and development of concurrent processes. Part of the project is organized under the auspices of the REX project - Research and Education in Concurrent Systems. This is an inter-university cooperation, sponsored by the NFI program (National Faciliteit Informatica), between the Eindhoven Technological University (prof.dr. W.P. de Roever), the University of Leiden (prof.dr. G. Rozenberg), and the CWI. The REX project has as general field of study syntactic, semantic and proof theoretic aspects of concurrency. Moreover, AP 1 participates as subcontractor in the ESPRIT 415 project 'Parallel Architectures and Languages for AIP: a VLSI directed approach'. Prime contractor of this project is Philips Research Laboratories Eindhoven (PRLE), partners are GEC (UK), Bull (France), AEG (FRG), CSELT (Italy), and Nixdorf (FRG). Project AP 1 contributes to the Working Group on Semantics and Proof Techniques of this ESPRIT project. Also, we shall continue working on the semantics and proof

theory for POOL, the parallel object-oriented language designed by drs. P. America of Philips. Together with AP 4 (J.W. Klop) and AP 6 (K.R. Apt), AP 1 participates in a consortium (with CWI as coordinating contractor) which has submitted an ESPRIT Basic Research Action Proposal. Theme of the action is 'Integrating the Foundations of Functional, Logic and Object-Oriented Programming'. Further partners are the Ecole Normale Supérieure, Paris, the University of Pisa, Imperial College, London, UNINOVA (Lisbon), and PRLE.

WORKING PLAN 1989

- domain theoretic foundations for concurrency, using techniques from category theory and (metric) topology; as new topic we shall investigate so-called true concurrency, where parallelism is not modelled by interleaving;
- comparative concurrency semantics, in particular continuing previous investigations concentrating on uniform versions (either no, or arbitrary interpretations for the atomic actions), now also addressing problems having to do with full abstraction;
- semantic studies of POOL, continuing earlier work on relating the previously developed models; as new topic we aim at the design of a (sufficiently abstract) semantics for POOL objects;
- semantic studies of parallel logic programming languages such as Concurrent Prolog or Guarded Horn Clauses; in particular, we shall follow the approach of applying the methods developed previously in the group for the semantics of parallel imperative languages;
- proof theory for (approximations to) POOL, in particular investigating to what extent the traditional techniques for completeness proofs have to be refined and extended;
- completion of J.N. Kok's (former AP 1 member) Ph.D. thesis on *Semantic Models for Parallel Computation in Dataflow, Logic and Object-Oriented Languages*;
- completion of the (joint) Ph.D. thesis of P. America and J.J.M.M. Rutten: *A Parallel Object-Oriented Language: Design and Semantic Foundations*;
- publication (by Wiley) of the book *Languages for Parallel Architectures: Design, Semantics, Implemetation Models* (J.W. de Bakker ed.) and publication (by Springer) of the book *Linear Time, Branching Time and Partial Order in Logics and Models for Concurrency* (J.W. de Bakker, W.P. de Roever, G. Rozenberg, eds.);
- continuation (by E.-R. Olderog, jointly with K.R. Apt) of the work on the book *Verification of Sequential and Concurrent Programs,* and continuation (by E.-R. Olderog) of the work on the book *Nets, Terms and Formulas: Three Views of Concurrent Processes,* a revised version of Olderog's habilitation thesis.

WORKING PLAN AFTER 1989

Continuation of the research.

PROJECT AP 2

TITLE: Formal specification methods

TITEL: Formele specificatiemethoden

ABSTRACT
Research concerning process algebra, specification languages, executable specifications and system development methodology.

SAMENVATTING
Onderzoek betreffende procesalgebra, specificatietalen, executeerbare specificaties en systeemontwikkelingsmethodologie.

PROJECT MEMBERS
dr. J.C.M. Baeten (project leader)
prof.dr. J.A. Bergstra, advisor (University of Amsterdam, University of Utrecht)
drs. J.F. Groote
drs. S. Mauw (University of Amsterdam)
drs. A. Ponse
drs. F.W. Vaandrager
drs. W.P. Weijland

EXTERNAL CONTACTS
ESPRIT-partners
University of Amsterdam (Programming Research Group)
University of Utrecht (Applied Logic Group)
Philips Research Laboratories Eindhoven

START OF PROJECT: 1982

CLASSIFICATION CODES

NWO-classification	:	P120, P175, T120
NABS-code	:	N076
1985 Math. Subj. Class.	:	68N05, 68N15, 68Q10, 68Q40, 68Q45, 68Q55
1987 CR Class. Scheme	:	D.1.3, D.2.1, D.2.2, D.2.4, D.2.6, D.3.1, D.3.3, F.1.2, F.3.1, F.3.2, I.1.3, K.3.2

PROBLEM AREA AND SCIENTIFIC RELEVANCE

For the most part, research takes place in the framework of ESPRIT project 432 Meteor 'An Integrated Formal Approach to Industrial Software Development'. Prime contractor in this type A project is Philips; the other partners are CGE (F), APT (B), COPS (IRL), TXT (I), CWI (NL) and the University of Passau (D).

Central in this research is the work on formal methods for (1) specification languages and (2) system development methodology. More specifically, in (1) we look at: logics like equational logic, first order logic and temporal logic. Further, we look at 'configuration descriptions' and object-oriented specifications. Specific themes in (2) are: initial requirements, construction methods, life cycle problems. CWI is mostly involved with (1). The work concerning (1), formal methods for specification languages, has the following subareas:

(i) Process Algebra. We want to develop this theory further, to deal with the specification and verification of protocols, and to furnish really parallel operational semantics. Apart from this, process algebra can serve to develop a uniform framework for different algebraic semantics for processes; apart from the bisimulation semantics of Milner and the failure semantics of Hoare, several other semantics, up till now not correlated, can be algebraically described in this framework. In particular, the relation with Petri nets is being studied. We also want to study the interaction of process algebra with different logics, in particular the use of Hoare logic in order to work with predicates on state spaces. The work on process algebra is in cooperation with AP 4.

(ii) Module Algebra. In this algebra, a formalization is given of notions like module, import, export, parametrization. This work is in cooperation with AP 3; most of the work takes place in AP 3.

(iii) Implementation techniques. We shall install software development tools that are developed in other places, shall study their use and evaluate their usefulness. We shall develop case studies, and study algorithms on algebras and relations between algebras (e.g., homomorphic embeddings), and the role of term rewriting systems in implementation. Concerning term rewrite systems, we shall work together with AP 4. This project will end in October 1989.

Secondly, we participate in the RACE project SPECS, 1046: SPECS (Specification and Programming Environment for Communication Software). Partners in this project are GSI-TECSI, CNET, STET-CSELT, DNL, IBM France, NSC, TFL, INESC, GEC, PKI, EB and Alcatel NV. The CWI share is 0.8 fte. This project aims to specify a methodology to provide maximum automation and optimization of the whole software process from requirements and specification through design, implementation, test, execution, and maintenance.

Concerning educational activities: we plan to continue with the PAO-course *Software Engineering*. This course is offered semi-annually by AP 2 and AP 3, with the help of some lecturers from outside the CWI. Apart from this, AP 2 participates in the new PAO-courses *Protocol Verification* and *Algebraic*

Specifications, which will both be offered for the second time in the fall of 1988. In the spring of 1989, an advanced course at the University of Amsterdam will be taught by a member of AP 2 (for the third time).

WORKING PLAN 1989

For the main part, we will work on the ESPRIT project Meteor and the RACE project SPECS. A new ESPRIT project, Atmosphere, will start (we have a subcontract from PRLE). Other sources of funding will be considered, to replace (part of) the funding of Meteor (that will stop in October 1989).

More specifically, the research in 1989 will concentrate on process algebra and algebraic specifications (the latter in cooperation with AP 3). Some topics that will be relevant:

- verification of algorithms with the help of process algebra;
- development of a tool set for process algebra (in cooperation with the University of Amsterdam);
- synchronous vs. asynchronous cooperation;
- the relation of Hoare logic and process algebra;
- module algebra and the algebraic specification formalism ASF (Meteor and GIPE);
- the publication of two books on process algebra in the series CWI Monographs.

WORKING PLAN AFTER 1989

Continuation of the research.

PROJECT AP 3

TITLE: Extensible programming environments

TITEL: Uitbreidbare programmeeromgevingen

ABSTRACT
Algebraic specification of programming environments, incremental development of language definitions, implementation of algebraic specifications.

SAMENVATTING
Algebraïsche specificatie van programmeeromgevingen, incrementeel ontwikkelen van taaldefinities, operationalisatie van algebraïsche specificaties.

PROJECT MEMBERS
J. Heering
drs. P.R.H. Hendriks
prof.dr. P. Klint (project leader)
drs. E.A. van der Meulen
drs. J. Rekers
drs. H. van Dijk (BSO, on assignment at CWI)
W. Koorn (BSO, on assignment at CWI)

EXTERNAL CONTACTS
BSO, INRIA, SEMA (Partners in ESPRIT project GIPE) Programming Research Group, University of Amsterdam, Software Engineering Research Centre (Utrecht)

START OF PROJECT: 1982

CLASSIFICATION CODES

NWO-classification	: P175, T120
NABS-code	: N076
1980 Math. Subj. Class.(1985)	: 68N05, 68N20, 68Q40, 68Q45, 68Q50
1987 CR Class. Scheme	: D.1.2, D.2.1, D.2.2, D.2.3, D.2.4, D.2.5, D.2.6, D.3.1, D.3.4, F.3.1, F.3.2, F.4.2, I.2.2

DESCRIPTION OF THE PROJECT

Programming environments are an aid for the software engineer and consist of collections of tools for constructing and processing programs. Earlier investigations in this project led us to the insight that the various *modes* in a programming environment (such as, e.g., subsystems for editing and debugging, each with its own command language) can be integrated into a single linguistic framework. This leads to systems with a higher consistency and lower complexity than conventional ones. However, in many applications it is desirable that the user can extend such a system with its own application languages. Even an integrated system gives little help under such circumstances: the implementation of a new application languages and its supporting tools have to be constructed from scratch.

In this project we investigate how the components of a programming environment can be generalized in such a way that the effort needed for adding a new language to it can be reduced drastically. For this purpose, the environment is based on language definitions, from which a syntax-directed editor, pretty printer, incremental typechecker and evaluator for the defined language can be derived automatically. The user who adds a language definition thus obtains automatically an environment for that particular language. It is important that new language definitions can re-use parts of already existing definitions. This avoids duplications and improves the uniformity of the system.

How should new languages be defined in such a system and how can these definitions be made operational? Various formalisms already exist for the definition of the syntactic aspects of languages (i.e. regular grammars for lexical syntax, context-free grammars for concrete syntax, and signatures for abstract syntax). These have been integrated in SDF (Syntax Definition Formalism) a formalism which has been developed in the context of this project. For the definition of semantics we have opted for the algebraic specification method. The reason being that such specifications are easily amenable to modularization and that many results from the area of term rewriting systems can be used for compiling them to an executable form. The specification language ASF (Algebraic Specification Formalism) has been developed for this purpose.

As we currently envisage, a language definition will consist of three parts:

1. A definition of concrete and abstract syntax of the language. A syntax-directed editor can be generated on the basis of this definition.
2. An algebraic definition of the *static semantics* of the language, from which an incremental typechecker will be derived.
3. An algebraic definition of the *dynamic semantics* of the language, from which an incremental evaluator and debugger will be derived.

The incremental development of language definitions and the generation of incremental tools from these definitions (parsers, typecheckers, etc.) form a

promising area of research to which this project has already made several contributions.

The work is carried out as part of ESPRIT project 348 'GIPE-Generation of Interactive Programming Environments' which started in November 1984 and will continue until November 1989. Intensive cooperation exists with INRIA (G. Kahn, Sophia-Antipolis and B. Lang, Rocquencourt), the Dutch softwarehouse BSO en the French softwarehouse SEMA. In addition to this, cooperation exists with CWI project AP 2, the Programming Research Group of the University of Amsterdam, the Software Engineering Research Centre (SERC) in Utrecht and with several other Dutch Universities.

WORKING PLAN 1989

- Definition and implementation of the integrated formalism ASF/SDF.
- Application of lazy/incremental techniques to the implementation of the modularity constructs in ASF/SDF (e.g. import, export, renaming, parameter binding).
- Development of new parser generation techniques for the modular composition and modification of generated parsers.
- Generation of integrated syntax-directed editors and typecheckers on the basis of ASF/SDF definitions.

WORKING PLAN AFTER 1989

- Application of the language definition formalism in various case studies, with the goal of studying particular language features (e.g., concurrency, type systems based on inheritance).
- Continuation of the research on deriving incremental implementations from given, non-incremental, language definitions.
- Optimization of the codegeneration process for algebraic specifications by extended analysis of language definitions.

PROJECT AP 4

TITLE: Term rewriting systems

TITEL: Termherschrijfsystemen

ABSTRACT
(i) Foundational research centering around term rewriting systems, with an emphasis on algebraic and syntactic methods.
(ii) Foundational research in process algebra.

SAMENVATTING
(i) Grondslagenonderzoek betreffende termherschrijfsystemen, met name algebraïsche en syntactische aspecten.
(ii) Grondslagenonderzoek betreffende procesalgebra.

PROJECT MEMBERS (PROPOSED)
prof.dr. J.W. Klop (CWI, Free University Amsterdam, project leader)
drs. R.J. van Glabbeek
dr. F.J. de Vries
junior researcher(s) (depending on acceptance of three ESPRIT BRA proposals)

EXTERNAL CONTACTS
Free University Amsterdam (Applied Logic section)
University of Amsterdam (Programming Research Group)
University of Utrecht (Applied Logic Group)
University of Nijmegen
possible ESPRIT BRA partners

START OF PROJECT: JANUARY 1989

CLASSIFICATION CODES

NWO-classification	: P175, T120
NABS-code	: N076
1985 Math. Subj. Class.	: 68N05, 68N15, 68Q10, 68Q40, 68Q45, 68Q50, 68T15
1987 CR Class. Scheme	: D.1.1, D.1.3, D.2.4, D.2.6, D.3.1, D.3.3, F.1.2, F.3.1, F.3.2, F.4.1, F.4.2, K.3.2

PROBLEM AREA AND SCIENTIFIC RELEVANCE

Relation with previous work

The objective of AP 4 is to perform foundational research in the field of (primarily but not exclusively) term rewriting systems. In the last few years the study of theoretical aspects of TRSs has been a small side-activity of project group AP 2 (Formal specification methods). A more substantial effort in AP 2 was the likewise foundationally oriented study of process algebra (as in 'comparative concurrency semantics'), next to process algebra research aiming at applications such as protocol verification and the development of concurrency sections in specification languages. The presently proposed project group AP 4 intends to elevate the study of the theory of term rewriting systems from side-activity to main theme. Further, AP 4 intends to carry on that part of the work on process algebra that is purely foundational and therefore does not fit seamlessly in the various project contracts sponsoring AP 2, which often call for more directly applicable results.

Scientific relevance

The primary theme of AP 4, term rewriting systems, and the secondary theme, process algebra, are not unrelated. Investigations in both subjects, as intended in this project group, strictly adhere to the algebraic-axiomatic methodology. Just as TRSs are nothing else but equational axiom systems with oriented equations, the core of process algebra consists of a family of (mainly) equational axiom systems, which have been explicitly designed to be amenable for a term rewriting analysis. This ensures both the possiblity for rigorous proofs of consistency of axiomatizations and the possibility - in principle - of a further development towards executability (and thus, in the long run, towards mechanical tools assisting in manipulating process expressions and system specifications). (The last possibility is not to be explored by AP 4, but rather by AP 2.)

Apart from falling under the scope of the same research methodology it is useful to study the two subjects in combination in view of present attempts by several research groups to formulate a workable theory combining data and processes, where 'data' are determined by TRSs.

We now discuss in more detail the scientific relevance of the theme TRSs. (For a similar discussion concerning process algebra see the section contributed by AP 2.)

(1) TRSs are a theoretical tool to analyze *abstract data type specifications* or algebraic specifications (consistency properties, computability theory, decidability of word problems, theorem proving).

(2) TRSs provide the foundation for *functional programming.* Historically, the paradigm TRSs Combinatory Logic and Lambda Calculus served to formalize the concept of computable or recursive number theoretic function; especially the Lambda Calculus has been viewed as a rudimentary functional programming language. Several functional programming languages have been based on Lambda Calculus or Combinatory Logic, starting (of

course) with LISP and recently Miranda. Theory about TRSs, concerning for instance evaluation strategies, has been proved to be of direct relevance in a proper understanding of existing functional language features as well as in the design of new functional languages. Further, TRSs are relevant for implementations of functional languages; especially the relation between term rewriting and 'graph rewriting' is of importance here (this is the substance of BRA project proposal SemaGraph, see below).

(3) Recently, there is a surge of interest in combining the functional programming style and the logic programming style. Various proposals are being developed at many research sites for integrating the concepts of term rewriting and 'resolution', the main derivation method in logic programming. (This is the substance of part of the BRA project proposal Integration, see below.)

Specific research subjects

- Modular properties of TRSs. In cooperation with prof. H.P. Barendregt (Catholic University Nijmegen) and dr. Y. Toyama (NTT, Tokyo) a study has been initiated determining properties of TRSs that are preserved under unions of TRSs with disjoint signature.
- Hierarchical TRSs. Development of theory about TRSs with a hierarchical structure; a beginning has been made in 'Semi-complete termherschrijfsystemen' (authors J.A. Bergstra, J.W. Klop, Kluwer Programmaturserie 1987)
- An investigation of the relationships between Knuth-Bendix completion, narrowing, and conditional rewriting. Insight here is especially important in attempts to combine functional and logic programming, one of the major goals of BRA proposal Integration, see below.
- In implementations of functional languages it is important to 'share' subterms when rewriting; this gives rise to 'graph rewriting'. An investigation to determine what part of the theory for TRSs carries over to graph rewrite systems is one of the goals in BRA proposal SemaGraph, see below.

External contracts

We participate in the following ESPRIT Basic Research Action proposals:

(i) Integration: Integrating the Foundations of Functional, Logic and Object-Oriented Programming. Partners: CWI, LIENS (Paris), Imperial College, Univ. of Lisbon, Univ. of Pisa, Philips Research Labs. CWI participation: 3.5 fte over 4 years, of which 1 fte over 4 years for AP 4.

(ii) Concur. Theories of Concurrency: Unification and Extension. Partners: Univ. of Edinburgh; Univ. of Oxford; Univ. of Amsterdam; CWI; Univ. of Sussex; INRIA; Swedish Institute for Computer Science. Participation of each partner: 1 fte over 5 years.

(iii) SemaGraph: Semantics and Pragmatics of Generalised Graph Rewriting. Proposal Nr. 3074. Partners: Univ. of East Anglia; CWI; Imperial

College; Catholic University Nijmegen; LIENS (Paris). CWI participation: 1 fte over 4 years.

WORKING PLAN 1989

(i) Independent of acceptance of project proposals as mentioned above:
- Completing a survey chapter on TRSs in the *Handbook of Logic in Computer Science* (eds. Abramsky, Gabbay, Maibaum).
- Completing a paper with Barendregt and Toyama about modular properties of TRSs.
- Starting to write a monograph on TRSs, with dr. R.C. de Vrijer (Free University Amsterdam).
- Completion of a Ph.D. thesis (subject: comparative concurrency semantics) by Van Glabbeek at the end of 1988 is planned (with a possible overflow to 1989).
- Educational: continuation of educational activities such as tutorials, PAO courses.

(ii) Depending on acceptance of BRA proposals:
- Investigation of term rewriting vs. graph rewriting (SemaGraph).
- Investigation of combining term rewriting and logic programming (Integration).
- Scientific coordination of first year project Concur.

WORKING PLAN AFTER 1989

- As far as not completed, continuation of the projected activities as in the working plan for 1989 under (i).
- Other plans highly depend on the allocation of personnel which cannot be predicted at this moment. If possible, a begin should be made with an investigation of type theories (polymorphic lambda calculus, Theory of Constructions of Huet and Coquand, Automath, Martin-Löf etc.).

PROJECT AP 5

TITLE: Expert systems

TITEL: Expertsystemen

ABSTRACT
Research into the applicability of methods of knowledge representation and automated reasoning in expert systems. Distributed problem-solving in expert systems. The development of prototype expert system tools.

SAMENVATTING
Onderzoek naar de toepasbaarheid van methoden van kennisrepresentatie en automatisch redeneren in expertsystemen. Gespreide probleem-oplossing in expertsystemen. De ontwikkeling van experimentele programmatuur voor de constructie van expertsystemen.

PROJECT MEMBERS
drs. A. Eliëns
ir. L.C. van der Gaag
drs. L. Kossen
drs. P.J.F. Lucas (project leader)
drs. J.W. Spee
M. Teunisse

EXTERNAL CONTACTS
Erasmus University Rotterdam
Philips Research Laboratories Eindhoven
University of Leiden
University of Twente
University of Amsterdam

START OF PROJECT: 1985/1986

CLASSIFICATION CODES

NWO-classification	: P175, T120
NABS code	: N076
1980 Math. Subj. Class.	: 68T01, 68T20, 68T30
1982 CR Class. Scheme	: I.1.2, I.1.3, I.2.1, I.2.3, I.2.4, I.2.5, I.2.8

RESEARCH AREA AND SCIENTIFIC IMPORTANCE

Research in Artificial Intelligence aims at the development of computer systems that are capable of fulfilling tasks which normally require some kind of 'intelligent' behaviour. This behaviour is modelled by providing such systems with large stores of task-dependent problem-solving knowledge. Since methods for the representation and manipulation of knowledge lie at the heart of these systems, the research topics of knowledge representation and automated reasoning are shared by the various distinct subareas of Artificial Intelligence. As a consequence, in architectures for AI systems frequently two major components are distinguished: a component where knowledge is to be specified, the knowledge base, and a component which applies the knowledge in order to solve given problems on the basis of entered data, called the inference engine. The subarea of AI-research covered by the project group is that of expert systems, where such a separation between knowledge and inference is usually imposed. The background of the research is formed by experience in developing rule-based expert systems in solving medical and technical diagnostic problems, and partly by the development of various prototype expert system tools.

Most of the work in the project group is carried out within the SPIN project PRISMA. This project which is led by Philips Research Laboratories Eindhoven (dr. H.H. Eggenhuisen), aims at the development of a coarse-grained data and knowledge-based multiprocessor machine. Other participants in the project are the University of Twente (prof.dr. P.M.G. Apers), the DAISY group at CWI (dr. M.L. Kersten), the University of Amsterdam (prof.dr. L.O. Hertzberger), the University of Utrecht (prof.dr. J.A. Bergstra) and the University of Leiden (prof.dr. G. Rozenberg). The project started at the end of 1986 and will last until the end of 1990. The research within the context of this project is carried out along the lines of small experiments in which various approaches to parallelism in expert systems are investigated for their viability. Several rule-based systems have been studied with regard to their suitability for exploiting explicit parallelism. In these systems, domain knowledge is represented using object-attribute-value tuples and production rules. However, it was felt that a major disadvantage of the production rule formalism is its lack of a declarative semantics: a number of production rules in every rule base is used purely in an operational manner for imposing control on the inference engine. It was discovered that a large part of the knowledge in a typical rule-based expert system permits reformulation to many-sorted first-order predicate logic, which has a clear declarative semantics, thus clarifying the meaning of a knowledge base. The practical use of many-sorted logic as a method of knowledge representation for building expert systems has been demonstrated by the implementation of an inference algorithm for consistency checking and model generation in the PROLOG language and by the conversion of an existing rule base to many-sorted logic. Suitable syntactic constrains could be imposed on the many-sorted logic by the nature of the problem domain, which made it possible to develop a feasible inference algorithm. The formalism is further studied for its suitability for incorporating parallel inference control strategies in a POOL-X system based on the formalism.

For the development of logic-based knowledge representation formalisms the results of research in the area of logic programming at AP 6 are clearly relevant for the project group. Contrary to the area of logic programming, in expert systems the representation techniques employed are highly dependent of particular problem classes. It is in the incorporation of such problem-dependent characteristics in a knowledge representation formalism where the main contributions from the area of expert systems to the development of languages for knowledge representation lies.

Frequently, in an expert system some model for plausible reasoning is employed, which enables the system to reason with incomplete and uncertain information. Such models for the representation and manipulation of uncertain and incomplete information in expert systems are being investigated from the perspective of incompletely specified probability measures. This work is carried out in collaboration with prof.dr. R.D. Gill of the Mathematical Institute at the University of Utrecht. Initial work has been devoted to the investigation of the certainty factor model of Shortliffe and Buchanan, a model frequently employed in expert systems. The model has been analyzed with regard to the soundness of its basic assumptions from the perspective of Bayesian probability theory.

The availability of some realistic problem domain is of great importance for expert systems research, since such a domain provides evidence for suitable language restrictions on a particular knowledge-representation scheme, and also offers an experimental setting for the investigation of the suitability of a particular approach. Within the PRISMA project much of the information concerning possible syntactical restrictions on many-sorted logic for making inference feasible came from the examination of a medical knowledge base, called Hepar. The Hepar project is a collaborative effort of the University Hospitals of Leiden and Amsterdam, the Department of Social Health Care at the Erasmus University Rotterdam and CWI. The manpower available only permits to further develop this system on a small scale.

WORKING PLAN 1989

- Implementation of POOL-X prototype expert systems within the context of PRISMA and study of their performance. Experiments on the single and 8-node prototype multiprocessor PRISMA machine.
- Further studies concerning the properties of knowledge-representation formalisms in certain problem areas.
- Study of the mathematical properties of incompletely specified probability measures from the perspective of expert systems.

WORKING PLAN AFTER 1989

- The implementation of a POOL-X prototype system on the full 64-node PRISMA machine and performance evaluation experiments on this machine.
- Investigation of the properties of knowledge-representation formalisms that support the process of knowledge engineering.

PROJECT AP 6

TITLE: Logical aspects of artificial intelligence

TITEL: Logische aspecten van kunstmatige intelligentie

ABSTRACT
Research concerning logic programming, deductive and knowledge based database systems, theorem proving and non-monotonic reasoning.

SAMENVATTING
Onderzoek betreffende logica programmeren, deductieve databases en kennisbanken, 'theorem proving' en non-monotone redenering.

PROJECT MEMBERS
prof.dr. K.R. Apt (project leader)
dr. M. Bezem
drs. R. Bol
dr. P. van Emde Boas
junior researcher
junior researcher (ESPRIT BRA)

EXTERNAL CONTACTS
University of Syracuse, USA
University of Pisa, Italy
University of Victoria, Canada
Free University Amsterdam (Applied Logic Section)
University of Amsterdam (Logic and Computation Theory, ITLI)

START OF PROJECT: 1987

CLASSIFICATION CODES

NWO-classification	:	P110, P175, T120
NABS-code	:	N076
1980 Math. Subj. Class. (1985)	:	68P15, 68Q40, 68T15, 68T30
1987 CR Class. Scheme	:	F.3.2, F.4.1, H.2, I.2

DESCRIPTION OF THE PROJECT

Many aspects of Artificial Intelligence are intimately connected with certain areas of Mathematical Logic. This allows us to better understand the issues at hand and to use logic to model concepts originally developed in the area of Artificial Intelligence. Without aiming at completeness let us mention here automated theorem proving, knowledge representation, reasoning and commonsense reasoning as examples of such subjects.

The aim of this project is to investigate the logical foundations of the above mentioned areas of Artificial Intelligence, additionally studying the subject of deductive databases and knowledge based management systems. More specifically, the research has been conducted in the following areas.

1. Logic programming.

Logic programming is a simple and powerful formalism allowing us to model reasoning and knowledge representation in a single framework based on a fragment of first order logic. It forms a basis of the widely used programming language PROLOG. Recently, logic programming has been successfully used to model non-monotonic reasoning and knowledge based database systems. In our research in this area we have investigated several aspects of logic programming, in particular its semantics in the presence of negation, the corresponding proof theory and the recursion and complexity theoretic aspects.

2. Deductive databases and knowledge based database systems.

Deductive databases and knowledge based database systems form an extension of databases allowing us to model a limited form of reasoning and certain modal aspects of knowledge, like 'necessity' and 'possibility'. Additionally incomplete information in the form of null values, distributed information and non-monotonic reasoning is of relevance here. Our research in this area has concentrated on a study of model theoretic semantics for such database systems which takes into account the incomplete, dynamic and modal character of the knowledge. In our future work in this area non-standard logic systems will be studied and their semantics investigated. In particular the intensional and epistemic logics will be studied in order to provide an adequate semantics for such database systems.

3. Non-monotonic reasoning.

Non-monotonic reasoning naturally arises when dealing with an incomplete and evolving information over a dynamically changing environment. It is modelled by a number of non-standard proof systems and methods including the circumscription method, default theory, autoepistemic theory, various forms of closed world assumptions and logic programming. In our research in this area we have investigated the logical and recursion theoretic status of these theories, their semantics and relation to each other. In our future work we intend to study their usefulness to model the behaviour of dynamically changing knowledge bases arising when studying commonsense reasoning.

4. Automatic theorem proving.
The resolution method with its various extensions and modifications has become a powerful proof method used in most theorem provers. We have investigated its recursion and complexity theoretic aspects and completeness of certain forms of it.

5. Natural language processing.
Depending on a possible hiring of a researcher working on natural language processing we envisage a research in this area. Our interest in this domain derives from the observation that knowledge as used in knowledge based database systems is often described in a natural language. Successful representation and use of such a knowledge requires good understanding of syntax and semantics of natural language. As an example of an important line of research in this area we would like to mention the use of time in a description of knowledge. Successful treatment of such problems requires a good knowledge of linguistics and various non-standard logics like logic of time or epistemic logics.

WORKING PLAN 1989
We plan to study the following aspects of the above-mentioned domains of Artificial Intelligence:
- semantics of logic programming with equality and negation and its relation with proof theory;
- recursion and complexity theoretic aspects of logic programming and automatic theorem proving;
- semantics of knowledge based database management systems based on the use of non-standard logics, like intensional logic and epistemic logic;
- study of incomplete information in the context of deductive databases, in particular the use of null values and disjunctive information;
- use of non-monotonic reasoning to model behaviour of dynamically changing knowledge bases arising when studying commonsense reasoning;
- depending of hiring a researcher in the area of natural language processing a research in one of the subjects of this domain.

WORKING PLAN AFTER 1989
Continuation of the research initiated in 1989.

Department of

Algorithmics and Architecture

The subject of the research in the area of algorithmics and architecture is formed by systems relating in a broad sense to information processing. These systems may be formal systems, such as languages or automata, software systems, such as operating systems or information systems, or hardware systems, such as processor architectures. In all cases the interplay between algorithmic and architectural aspects plays a crucial role in the research topics selected. In particular, distributed algorithms and systems form an important focus of our current interest.

The choice of research themes has generally been guided by considerations of their fundamental or strategic importance. Abstraction and formal methods are important tools in the research undertaken. Generally, our aim is not only to develop basic principles or other fundamental results, but also to let our research activities result in the construction of prototypes, possibly followed by pre-development.

The research of the department has been grouped together in the following projects:

AA 1 Algorithms and complexity
AA 2 Distributed systems
AA 3 Computer systems and ergonomics
AA 4 Distributed adaptive information systems
AA 5 Constructive algorithmics
AA 6 Cryptology

Department of Algorithmics and Architecture

List of Projects

AA 1 Algorithms and complexity
AA 2 Distributed systems
AA 3 Computer systems and ergonomics
AA 4 Distributed adaptive information systems
AA 5 Constructive algorithmics
AA 6 Cryptology

	Projects						working			
Name	AA1	AA2	AA3	AA4	AA5	AA6	hours	regu-	de-	guests
								lar	tached	
appointed										
Meertens			•		•		0.70	0.70		
Vitanyi	•						0.80	0.80		
Kranakis	•						1.00	1.00		
Krizanc	•						1.00	0.83		
Kissin	•						0.40	0.40		
Mullender		•					1.00	1.00		
Algeo		•					1.00	0.67		
Jansen		•					1.00	1.00		
Shizgal		•					1.00	1.00		
Rossum, van		•					1.00	1.00		
Zee, v.d.		•					1.00		1.00	
Dijk, F. van			•				1.00	1.00		
Krijnen			•				1.00	1.00		
Pemberton			•		•		1.00	1.00		
Boeve			•				1.00		1.00	
Kersten				•			0.80	0.80		
Berg, C.A. van den				•			1.00	1.00		
Siebes				•			1.00	0.67		
Verbrugge				•			1.00	1.00		
Voort, v.d.				•			0.80	0.80		
Jeuring					•		1.00		1.00	
Fokkinga					•		1.00		0.90	
Chaum						•	0.20	0.20		
Bos						•	1.00	1.00		
Heijst, van						•	1.00	1.00		
Boer, den						•	1.00		0.58	
Coster						•	1.00		1.00	
Schippers							-	pm		
total appointed								17.87	5.48	0.00
regular priority										
scient.res.1				•			1.00		1.00	
scient.res.1					•		1.00		1.00	
scient.res.2		•					1.00	0.33		
scient.res.3				•			1.00	0.33		
scient.res.4						•	1.00	1.00		
scient.res.5			•				1.00	0.92		
scient.res.6					•		-	p.m.		
scient.res.7	•						-	p.m.		
scient.res.8						•	-	p.m.		
scient.res.9				•			-	p.m.		
scient.res.10										
scient.res.11			•				-	p.m.		
total priority								2.59	2.00	0.00
total estimated								20.45	7.48	0.00

PROJECT AA 1

TITLE: Algorithms and complexity

TITEL: Algoritmen and complexiteit

ABSTRACT
The design and analysis of algorithms in distributed computing and VLSI. Fundamental studies and research in complexity theory.

SAMENVATTING
Het ontwerp en de analyse van algoritmen voor gedistribueerde berekeningen en VLSI. Fundamenteel onderzoek op het gebied van complexiteitstheorie.

PROJECT MEMBERS
prof.dr.ir. P.M.B. Vitányi (project leader)
dr. E. Kranakis
dr. G. Kissin (visitor)
dr. D. Krizanc (visitor)
junior researcher (p.m.)

EXTERNAL CONTACTS
Within the CWI there has been collaboration with researchers from project AA 2 (S.J. Mullender), AP 2 (J.W. Klop), as well as with the department of Operations Research, Statistics and System Theory. Outside the CWI, but within the Netherlands, there is contact with the University of Amsterdam (P. van Emde Boas) and the University of Utrecht (group of J. van Leeuwen). Outside the Netherlands there is collaboration with Massachusetts Institute of Technology (B. Awerbuch, F.T. Leighton, N. Lynch, J. Lundelius), Boston University (P. Gacs, L. Levin), Boston College (P. Clote), Patras Computer Technology Institute (L. Kirousis), Harvard University and York University (M. Li), Technion (A. Israeli), Northeastern University (L. Longpré), the Bell Labs (K. Oikonomou), University of Rochester (J. Seiferas).

START OF PROJECT: 1980

CLASSIFICATION CODES

NWO-classification : P175
1985 CR Classification Scheme : F.2.2, C.2.2, D.4.1, G.2.2, F.1.1, F.1.2

PROJECT DESCRIPTION

Numerous computer developments, ranging from optimal VLSI design to the construction of user-friendly programming environments, together with an ever-increasing complexity of the problems handled by computers, produce challenging demands requiring the invention of new more efficient algorithmic designs. CWI research into non-conventional computer networks and distributed information systems comprises a significant algorithmic component. Such research questions cover the design, construction and use of hardware, as well as applications. Solutions to these problems are sought via improved networks and parallel architectures, in combination with efficient algorithms. The present project involves realistic models for multicomputers, the design and analysis of algorithms suitable for distributed computations, as well as fundamental research in complexity theory.

PLANS FOR NEW RESEARCH

In the foreseeable future the research will be directed towards the development of a theory for advanced distributed systems such as computer networks, multiprocessor systems and integrated circuits. Particular attention will go to architecture, communication protocols and the interaction between the two. Important questions here include

- the development of a formal computational model for multi-computers, whereby communication costs are treated realistically,
- the development of a theory of asychronous communication interfaces,
- implementing concurrent objects in a wait-free environment and proving the validity of correctness of the implementation.

Research studies will also be carried out in analyzing the complexity of computation in various important algorithmic problems.

- In collaboration with Ming Li, our efforts will concentrate in studying algorithmic information theory (Kolmogorov Complexity) as it applies to establishing optimal complexity bounds to concrete problems from Turing Machine computations, VLSI algorithms, theory of learning, cryptography, pseudo-random generators, etc.
- In collaboration with Peter Clote, additional effort will be devoted to studying the invariance groups of VLSI modules (viewed as boolean functions) and establishing classification results concerning the parallel complexity of boolean functions and formal languages. Research in this area is expected to yield useful applications in the bottom-up design of efficient chips.

PERSONNEL

For the successful implementation of the above stated research goals, as well as for the attainment of research standards at a high international level, we have profited from our contacts and collaboration with researchers at comparable research institutes and establishments abroad. In particular, we have found it advantageous to have at least one, long-term, foreign visitor every year.

PROJECT AA 2

TITLE: Distributed systems

TITEL: Gedistribueerde systemen

ABSTRACT
Research on performance, transparency, fault tolerance and scalability in distributed systems. Research themes for the next five years are multimedia support (voice and video) and applications in distributed systems, distributed computing over wide-area networks, user interfaces for distributed and parallel applications, design of a multiprocessor kernel, structuring fault tolerance in replicated services.

SAMENVATTING
Onderzoek op het gebied van efficiency, transparantie, fout-tolerantie en uitbreidbaarheid in gedistribueerde systemen. In de komende vijf jaar zal het onderzoek zich met name met de volgende gebieden bezighouden: Multimedia (spraak en video) support en applicaties in gedistribueerde systemen, gedistribueerde systemen over wide-area networks, user interfaces voor gedistribueerde en parallelle applicaties, ontwerp van operating system kernels voor multiprocessors, structurering van fout-tolerantie in gerepliceerde services.

PROJECT MEMBERS

dr. S.J. Mullender (project leader)
C. Algeo B.S.
A.J. Jansen
I. Shizgal M.S.
drs. G. van Rossum
S. van der Zee

EXTERNAL CONTACTS
The distributed systems project is being carried out in close collaboration with similar groups at the Faculty of Mathematics and Computer Science of the Free University in Amsterdam and the Cambridge University Computer Laboratory.

An *Esprit* Basic research proposal has been made to fund a collaborative research project on distributed computing over wide-area networks with Free University, Cambridge University, University of Bologna, Queen Mary College London and the University of Lancaster.

CWI will be a subcontractor in the *Esprit*-II Integrated Systems Architecture project, a project on standardization of Open Distributed Processing.

The research at CWI is partially sponsored by Digital Equipment Corporation in the European External Research Programme.

START OF PROJECT: 1984

CLASSIFICATION CODES

NWO-classification : P175, T120
1985 CR Classification Scheme : D.4, C.2

PROJECT DESCRIPTION

The Amoeba distributed operating system forms the basis of the project. Amoeba was developed at the Free University Amsterdam and the Centre for Mathematics and Computer Science. The Amoeba group itself has been using Amoeba for two years now. Several other research groups spread over Europe are beginning to use Amoeba in their research projects. Amoeba was chosen as one of the operating system vehicles in the proposed Esprit-II ISA project.

Amoeba is an object-oriented high-performance distributed system based on the client/server model: To invoke an operation on an object, client processes send requests to the service that manages the object; the service carries out the operation and returns a reply to the client. A service may consist of several server processes. Client requests are delivered to one of the servers for the addressed service.

The Amoeba protection mechanism is capability based. Clients can only invoke operations on an object by presenting the appropriate capability for that object to the server. These capabilities are protected against forgery by cryptographic means. No trust has to be placed on the security of the operating system kernel. The Amoeba protection mechanism is described in detail in [1].

The interprocess communication mechanism in Amoeba provides a high-speed request/response protocol allowing (in principle) messages of up to one gigabyte in size to be passed between client and server. On bare hardware, the Amoeba protocols are among the fastest in operation (on Sun 3/50 and Ethernet, the remote null operation takes 1.4 ms; user-process-to-user-process bandwidth is 5.2 Mbit per second). In addition, Amoeba protocols can be run over various standard protocols, such as X.25 or IP.

The Amoeba kernel is the operating system basis of the Amoeba system. It provides process abstraction and interprocess communication facilities. On top of the Amoeba kernel, traditional operating system facilities, such as a file system and a window manager, are available as user-level Amoeba services. The kernel could thus be kept small (50 kbytes code), which makes it easily portable. The Amoeba kernel runs on VAXen, Suns and several other M68000-based machines, on the NS-32000 family of computers, and IBM PC. Ports to Intel 80386 and to several multiprocessors are underway.

A variety of user-level services takes the place of the traditional file I/O operating system interface and the mechanisms for manipulating directories. The *Bullet Service* is a fast file server for small and medium-sized immutable files. The Amoeba *Directory Service* provides a mechanism for mapping ASCII path names onto capabilities.

A Unix support library and an X-server are available on Amoeba, allowing most Unix applications to run on Amoeba without modification. Additionally, an Amoeba interface can be installed on Unix systems, allowing Amoeba software to be tested under Unix.

So far, the Amoeba project has resulted in some 60 publications, 30 of which in international refereed periodicals and conferences. An overview of Amoeba can be found in [2]. A collection of papers on Amoeba was published in [3].

Plans for new research

Multimedia Research

The natural way for human beings is to communicate interactively, using a combination of speech, gestures, documents, graphs, pictures, and in the lecture room, for instance video images or computer animation. We only use the phone because a person is too far away to talk to directly.

The natural form of communication between human beings is multimedia communication. The technology currently available - the phone, the terminal, or the envelope - restricts us to only a single medium.

It is fairly obvious that the multimedia workstation will have a bright future. We can communicate much more efficiently if we can send text, accompany it with spoken commentary, if we get instant feedback, if we can point at things, and make gestures.

The technology that makes the multimedia workstation a viable proposition is just emerging: networks are now beginning to be fast enough to carry voice and video; network phones are already on the market; computer-generated voice is no longer anything special; colour bit-mapped displays have become fast enough for displaying computer-generated animated graphics (it is even possible to display real-time video in a display window).

Very few projects, however, have made an attempt to integrate multimedia communication in a coherent way, to design user interfaces that allow people to use the multimedia workstation in a natural way, and to design operating system support that can handle multimedia communication in real time.

Yet, work in this area urgently needs to be done. As technology progresses, technological projects in research and development tend to grow. Even today, it is quite common that a large project is carried out by groups of people in different countries. The European Community's Esprit Programme, for instance, sponsors such collaboration so that, in the future, more and more projects will be carried out by geographically dispersed teams in need of efficient multimedia communication.

The aim of the Multimedia project of CWI and Cambridge University Computer Laboratory is to design and build a distributed multimedia system that spans a large geographical area. It is the explicit intention to use the multimedia system in the project itself, primarily for evaluation purposes and to get feedback about performance and ergonomics, but also to learn about carrying out a project with a dispersed group and multimedia assistance.

The full-blown 'multimedia workstation' will consist of one or several powerful CPUs, a bit-mapped colour display, keyboard and pointing device, a voice unit with voice input/output device and voice generator, and a video camera. A high-speed network will provide the connection between workstations. Another important component of the system will be a multimedia storage server, a server that can absorb and play back multimedia data streams (in real time, obviously).

The software for the system will consist of a multimedia operating system kernel, which, apart from the normal distributed operating system functions, is capable of managing multimedia streams. On the multimedia workstation there will be a 'multimedia shell' which provides the interface to the user of the workstation. Using this shell, the user can place multimedia calls, manage incoming calls, play back and edit multimedia documents.

To realize this, research is required in the following areas:

1. Multimedia networks
   High-speed (i.e., > 100 Mbps) network technology, protocols and interfaces. Gateway design for minimum delay. Interfaces to public networks. Synchronization of multiple, parallel networks.
2. Multimedia streams
   Synchronizing multiple isochronous streams, synchronization of isochronous data (e.g., sound) with anisochronous data (e.g., text document), device-independent and network-independent multimedia stream definitions.
3. Multimedia workstation
   Handling incoming and outgoing high-speed data streams without affecting normal workstation performance. Structuring the hardware to achieve this (e.g., avoid direct CPU involvement in multimedia data transfers).
4. Multimedia storage
   Design file servers that can handle multimedia streams in real time. On editing operations, avoid copying multimedia data where possible to save space. Integrate multiple storage media and multiple types of multimedia data.
5. Multimedia shell
   Designing an interface to come to grips with multimedia streams. Accept commands from multiple media (e.g., keyboard, mouse, voice).
6. Multimedia applications
   Autoanswering, call forwarding, directory service, and sundry telephone-like services. Multimedia stream editor, making use of sound editor, video editor, text editor, graphics editor, etc.

Distributed Computing over Wide-Area Networks

A consortium, consisting of CWI, Free University Amsterdam, Queen Mary College London, University of Bologna, and the University of Lancaster has submitted an ESPRIT Basic Research Proposal for carrying out research on distributed computing over wide-area networks.

The research at CWI will concentrate on basic operating system support for distributed computing over wide-area networks.

In the ESPRIT Basic Research project, CWI will do research in the following areas:

1. *Naming and locating objects in very large distributed systems.* A very large distributed system has very many objects and needs a very large name space. It is desirable to allow objects to *migrate* through the system; it is

also desirable to have *replicated and objects* for more efficient access and higher fault tolerance. Given an object's name, it is the system's task to find the physical location of the object. In an environment where objects can be replicated and where objects can migrate this is a difficult problem which becomes even more difficult as the system grows larger.

A theoretical foundation for this problem was developed at CWI, [4] the goal in this project will be to discover both the fundamental and the pragmatic problems of locating objects in very large distributed systems.

2. *Protection mechanisms spanning organizational boundaries.* Traditional time-sharing systems have protection mechanisms built into the operating system kernel. The assumption is made automatically that the operating system is secure, so all users accept the authentication information provided by the system.

   In distributed systems this approach does not work. When a message purportedly comes from user *X*, does this mean *X* really sent it, or could some intruder have forged the message? Distributed systems often have an *authentication server* to resolve such questions, but then every user has to trust the authentication server.

   In a multi-organizational environment, a single trusted authentication service probably will not work: One organization will not wish to trust an authentication server managed by another organization, and, in any case, a centralized (thus far away) authentication server would form an unacceptable bottleneck, especially for local communication.

   CWI plans to research protection and authentication policies and mechanisms for very large systems managed by many autonomous organizations.

CWI will also be the coordinating institute in the project and as such act as the project's software distribution centre.

Work on Multiprocessors

Computer usage is bursty. While a user is editing a file, for instance, the demands on the system are usually low, but when the command to recompile a large program consisting of dozens of files is given, multiple CPUs can be used in parallel to carry out the work. The Amoeba *pool processor model* is designed to make this possible. Usually, the user's work will be carried out on the workstation itself, but, when needed, extra processors can be allocated from a processor pool to carry out a lot of work in a very short time. After this, the pool processors are free again to be allocated to another burst of activity. We aim to obtain good interactive response both for CPU-intensive activities by using the processor pool and for highly interactive activities (e.g., using mouse and bit-mapped display) by running the application on the workstation where it does not incur extra communication overhead.

A multiprocessor workstation combines the properties of processor pool and workstation: interactive activities have direct access to the display, keyboard and cursor position and CPU-intensive activities can run on several processors at once.

The 'Amoeba on the Firefly' project consists of two parts. The first part is the development of an Amoeba kernel for a multiprocessor. This requires redesigning the operating system interface to exploit the parallelism of multiprocessors. It also requires almost total redesign and reimplementation of the Amoeba kernel.

The second part consists of experimentation with Amoeba services and applications on a multiprocessor. In collaboration with Cambridge University we are in the process of designing a 'Very-High-Performance File Server'. As a side line to this project we are interested in building a multiprocessor file server to see what the performance characteristics of such a server are.

A multiprocessor workstation is a workstation with a built-in processor pool. This allows the supporting services for an interactive application to run on the same machine as the application. We are interested in comparing performance of the multiprocessor workstation and the 'ordinary' workstations with processor pool backing. We expect, for instance, to get some interesting results in the area of file-caching strategies this way.

PERSONNEL

Currently, the Amoeba staff at CWI consists of one project leader, two researchers and two programmers. When the ESPRIT Basic Research proposal is granted, an extra researcher and programmer are required for a period of four years. Funding for this has been requested in the proposal.

At this stage, it is not clear what form the multimedia project will take. Possibilities for collaboration with a number of partners are being investigated and the level of funding and participation from CWI depends on the results of the negotiations. Current thoughts are that one or two extra people may be needed.

EQUIPMENT

The Amoeba project is being sponsored by Digital Equipment Corporation under an EERP grant. It is expected that this sponsoring will continue in the coming years.

In 1990, the amount of file storage space and the processor pool capacity will need expansion. Additionally, workstation capacity will have to grow when the Amoeba staff grows.

If the multimedia project comes off, a major investment will be needed in multimedia hardware: colour displays, voice hardware, high-speed networks, video cameras, high-speed mass-storage devices. The amount of money involved will be several millions of guilders, some of which will have to be found by CWI. It is our hope, however, that the bulk of the funding can be obtained in the form of industrial grants.

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PROJECT AA 3

TITLE: Computer systems and ergonomics

TITEL: Computersystemen en ergonomie

ABSTRACT
The Computer Systems and Ergonomy project is concerned with the methodology of integration of functions and applications in computer systems in order to provide end-users with easily manageable tools. The project consists of two subprojects:

AA 3.1 The ABC Project;
AA 3.2 Human-Computer Interfaces (Views).

SAMENVATTING
Het project Computersystemen en ergonomie houdt zich bezig met de methodologie van de integratie van functies en toepassingen in computersystemen om zodoende eindgebruikers te voorzien van eenvoudig te gebruiken hulpmiddelen. Het project bestaat uit twee subprojecten:

AA 3.1 Het ABC-project;
AA 3.2 Mens-Computer Interfaces (Views).

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drs. T.J.G. Krijnen
prof. L.G.L.T. Meertens
S. Pemberton (project leader)
junior researcher (vacancy)

EXTERNAL CONTACTS

START OF PROJECT: 1985

CLASSIFICATION CODES

NWO-classification : P175, T120
1985 CR Classification Scheme : H.12, K.8, D.2.6, D.3, I.3.6, D.2

PROJECT DESCRIPTION

Subproject AA 3.1: The ABC Project

The decline in prices for computers has brought 'personal computing' within the reach of many, both at home and at work. The software that comes with most personal computers however, represents a major obstacle for most users of the systems, and often prevents the full use of the potential of the systems. The inflexibility of most application programs can quickly force users to resort to developing their own programs. On numerous personal computers Basic is the only supplied language available for self-development of programs. This language is unsuitable for methodical programming, and despite its apparent simplicity, is difficult to use. This observation is even more applicable to the 'Job Control Language', if available; other languages like Pascal are completely out of the reach of most users.

The aim of the ABC project is to design, implement, and promulgate a simple, structured, interactive programming language, integrated into an environment, that answers the needs of the user of a personal computer. In this subproject the language ABC has been designed. This language is suitable for methodical programming, and because of its simplicity, both in learning and in use, is extremely suitable for use by inexperienced programmers. The advantages of ABC are:

1) ABC allows you to to become acquainted with programming and using programs, without having to learn all the details of computer systems;
2) Using ABC encourages a good approach to programming, which can also usefully be applied to other programming languages;
3) The development of ABC put ease of use for the user as first priority, even at the cost of run-time speed. This ensures that the power offered by the ever more powerful new generations of computers can be put to good use by the programmer.

'Ease of use' is also heavily dependent on the interface offered with the system. To make the interactive use of ABC as easy as possible, the language is embedded in a fully ABC-oriented environment. The 'command language' for the ABC system is ABC itself, along with editor commands. The editor is an integral part of the ABC environment; in particular, all communication from the user with the system passes through it. This ensures a high degree of uniformity in the user interface, with the editor determining the degree of user ease. The editor also knows about the structure of the documents that it has to deal with, and can use this knowledge to report syntax errors interactively or even to avoid the errors altogether by automatically producing syntax skeletons that the user can then fill in. This can also be used to offer an advanced 'data-entry' facility.

To make a new language acceptable to the public, more is needed than just a definition and an implementation. Equally important are supporting material like teaching books, example programs, the possibility for using different input and output channels, protection facilities, and so on. Since there is no separation of programming language and command language in ABC, these problems

fall back on the language itself, and it is necessary to address them centrally within the language, to prevent the proliferation of different and inferior solutions. The special applicability of ABC for teaching demands a special effort to introduce the language within education circles, via experiments, demonstrations, and courses.

WORKING PLAN 1989
Maintenance of the ABC implementation.
Publication of articles concerning the design, implementation and use of ABC.

PROJECT DESCRIPTION

Subproject AA 3.2: Human-Computer Interfaces (Views)
The accessibility of computer systems for end-users depends to a large extent on the level of integration of the functions and resources in such systems. The usual situation is a collection of poorly cooperating and inflexible sub-systems, each with its own user-interface. The use of such a system forms a continual and unnecessary high cognitive load for the user. In the first place, the user is continually forced to switch context, each time having to adapt to the formulation necessary for the subtask in hand. This is a major source of errors of formulation, albeit without disastrous effects, but all the same irritating; worse is that it forces the user to bring the formulation into the cognitive attention-field, interfering with the planning and development of the actual problem-oriented task. In the second place there is a continual interruption of the task-handling process at a conceptually high level, through having to adjust the outputs of one sub-system to the format required by the next. This easily leads to the user 'losing the thread': parts of the plan and of the status of the development get lost.
Corner stones of modern user interfaces are the WYSIWYG principle (what you see is what you get) and the related principle of 'direct manipulation'. Through a consistent application of these principles (to a much greater extent than is usual), user interfaces can be developed where the problems described occur to a far lesser extent. As a starting point, the basic philosophy of the ABC environment can be used (see AA 3.1). The research problems are then to what extent this philosophy can be expanded to wider and more general information systems, while maintaining modularity in the system architecture.

WORKING PLAN 1989
Design of an initial functional model of the Views system, and prototype implementations of some sub-systems.

WORKING PLAN AFTER 1989
Continuation of the research.

PROJECT AA 4

TITLE: Distributed adaptive information systems

TITEL: Gespreide adaptieve informatiesystemen

ABSTRACT
Research on datamodels for adaptive information systems, programming languages for their applications, and their associated machine architectures. In the coming five years, our research efforts will be further focussed on the object-oriented approach for database modelling, the development and the evaluation of object-oriented database language concepts, and the development of software prototypes on (virtual) machines especially designed for an object-oriented programming environment.

SAMENVATTING
Onderzoek op het gebied van data modellering, programmeertalen en machine architecturen voor adaptieve informatiesystemen. In de komende vijf jaar zal het onderzoek zich verder concentreren op de object-georiënteerde benaderingswijze, zoals het modelleren van een object-georiënteerde database, het ontwikkelen en het toetsen van taalprimitiva voor object-georiënteerde database applikaties en het realiseren van software prototypes op een hierop toegesneden (virtuele) machine-architectuur.

PROJECT MEMBERS

dr. M.L. Kersten (project leader)
drs. A.P.J.M. Siebes
drs. C. van den Berg (SPIN)
drs. N.T. Verbrugge (SPIN)
drs. M.H. van de Voort (ESPRIT II)
junior researcher (NFI)

EXTERNAL CONTACTS
The distributed adaptive information systems project is being carried out in close collaboration with the Computer Science Department of the University of Twente, Philips Research Laboratories in Eindhoven and the Faculty of Computer Science of the University of Amsterdam. This collaboration is funded by the 'Stimuleringsprojektteam Informaticaonderzoek' (SPIN) through the PRISMA project.

Additional funding is expected from the ESPRIT-II project TROPICS, a project on the development of highly parallel machine for office environments. CWI will be a subcontractor in this ESPRIT-II project.

A 'Nationale Faciliteit Informatica' (NFI) project proposal has been made to foster further research cooperation in the area of information system design and analysis.

START OF PROJECT: 1985

CLASSIFICATION CODES

NWO-classification : P175
1985 CR Classification Scheme : H.2, D.3, I.2.5

PROJECT DESCRIPTION

The research being carried out within the DAISY group at the CWI is focussed on distributed adaptive information systems, i.e. information systems which are distributed over time and location, where the organization of the data and the applications changes frequently, and where the content of the database is only guaranteed to be locally consistent. Adaptive information systems can be found in office environments, (financial) trading environments, in design environments, and scientific environments where the kinds of data being collected change often and the way in which the data is being used to produce information cannot be frozen for long periods.

Since its inception, the DAISY project is organized around subprojects, which study the problems of adaptive information systems from three different, yet complementary perspectives. They are described in more detail below.

An object-centered database programming language

The Godal subproject aims at the development of an object-centered database language for adaptive information systems. In contrast with contemporary database languages, such as SQL and LDL, the database schema in Godal is not frozen, but evolves over time. The language uses an implicit binding between the database scheme and the actual data stored within the database to avoid repetitive database re-organizations. That is, objects are automatically classified through a declarative expression over their properties.

The concept explored for application modelling is called the *guardian*. In a nutshell, the guardian is a process which reacts algorithmically to a declaratively described state of the database. Guardians can be used to model various kinds of integrity constraints, including those that require a conversation with a user for the provision of additional data.

During the preceding years we have described an initial language definition, and a rationale for our approach. Moreover, several (partial) prototypes to experiment with this approach have been implemented. The short term goal is to finalize the language definition and the design of the Godal abstract machine. It will be complemented with a workable prototype programming environment. The software for the user interface is being developed within projects AA 2 and AA 3. The long term goal is to study persistency and concurrency control within an object-oriented database language, while we envision many research opportunities in the area of optimizing compilers and machine architectures for object-oriented database languages.

A functional object-oriented datamodel

A significant drawback of the relational data model is that it lacks concepts and facilities to accurately describe the semantics of the intended application domain. Indeed, the freedom to combine the relational operators introduces many caveats for the database designer, such as view update problems. Moreover, using relational tables for storing information in new application areas, such as CAD/CAM, turns out to be inadequate, because the intrinsic structure of the entities being dealt with is lost. To alleviate these problems, a new

datamodel is needed which both restricts the use of operators to semantically meaningful ways and which better supports modelling of complex objects with their semantics.

In the preceding years we have developed a functional datamodel that explicates the database semantics through entity and function definitions and which limits their use along well-defined paths; this approach is based on the design philosophy that all relevant semantic information should be modelled explicitly on the proper level of abstraction. This way we achieved a unified description of both the database intension and its extension. In particular, we have shown that generalization/specialization hierarchies are naturally cast into proper subgraph hierarchies in the type hierarchy. Moreover, we have shown how the limitations imposed on the entity type construction can be used to model relations with functional-, multivalued- or join-dependencies.

The short term goal is to alleviate the second problem mentioned above by extending the functional model with complex objects. This will lead to an object-oriented datamodel in which the application semantics can be formally described. Subsequently, structure equivalences among objects are being studied, and they will be used to define a new query language. Furthermore, traditional query optimization can be improved, because the datamodel contains more explicit semantic information. The long-term goal is to study the interaction between the static and the dynamic aspects of a Universe of Discourse within the context of this object-oriented datamodel, such as the preservation of integrity constraints by transactions. Moreover, there are many research opportunities in the area of design tools to aid the database designer in questions such as consistency, reachability, and finite satisfiability, and lifeness/deadlock, on the schema designs. These issues and the connection between various database design techniques will be studied within the context of the NFI project.

This NFI project proposal is a joint effort of the University of Twente, the University of Leiden, the University of Limburg and the Eindhoven Technological University. Its research goals are: defining a unified model, such that the results of various database design techniques can be translated to each other, and the design of a set of design tools for this unified model.

A main-memory database machine

The work on main-memory database machines is being carried out within the context of the PRISMA project. This project aims at the development of a highly parallel machine for data and knowledge processing. The research theme addressed within our group is how a very large main-memory can be effectively used to represent a relational database and how an extensible database handler should be designed.

During the first year we worked on the proposed implementation language POOL-X. In particular, we studied the feasibility of POOL-T (and successors)

as an implementation language for a database management system. Furthermore, we laid down the requirements for a massive main-memory database system. After that, we designed an architecture and wrote a functional design of the PRISMA database software.

The short-term objective is the construction of a, so-called, one-fragment manager in POOL-X. Next, we have planned an evaluation study of this software within a prototype of the PRISMA hardware, after which we can start with a second design to optimize our approach. The long-term objective is to use the PRISMA software as a basis for the ESPRIT-II project TROPICS, which is described in more detail below.

Plans for new research

A database of grammatical objects

A central research theme in the coming period will be to use formal language theory as a means to generalize the relational approach to database management, such that a system architecture emerges in which grammatical objects, i.e. objects described by a grammar, can be processed efficiently. The short-term research goal is to describe such a data model in more detail and to provide the rationale for building adaptive information systems, in particular an office automation environment, on this concept. The motivation for this line of research is described below.

A grammatical-object model

Grammatical objects play a crucial, often hidden role in computer applications, such as text editors, text formatters, communication protocols, compilers, programming languages, etc., where they are used to represent an intermediate state of processing. During their lifespan they are subjected to many kinds of transformations: they are parsed during the document preparation phase, they are transformed during a document recognition/translation phase, and they are transformed to an encoded format to optimize storage and subsequent access.

Our focus, in this respect, is to analyze the possible mappings of the grammatical-object model to both the traditional relational model and to investigate the opportunities of the non-first normal-form (NF2) relational model and object-oriented systems. By this we gain knowledge about the semantic intricacies introduced by such a generalized model and how we should interpret the concepts and the results of formal language theory within a database environment.

A grammatical-object query language

The grammatical-object model should be complemented with a SQL-like query language. This way we capitalize on the large SQL user community, who do not have to learn a new query language when they switch to a grammatical database approach. One option is to map Grammatical-SQL into SQL directly, which enables early experimentation and results in a portable system.

Query optimization
The efficiency of a database management system is largely determined by the effectiveness of its query optimizer. This raises the issue where and which optimizations can (should) be performed in a grammatical database management system. One area of interest is semantic query optimization, because unlike the relational model a grammatical model contains more information about the meaningful manipulations.

Storage techniques for G-objects
Although for experimentation a mapping of grammatical-objects to a relational system will suffice, an efficient system is likely to depend on the specific requirements posed by the application and the techniques applied by the system. Therefore, we should develop a prototype storage manager to handle large collections of grammatical objects in an efficient and reliable way. The research theme here is how the grammar, augmented with use and frequency information, can be used to improve storage and processing.

ESPRIT-II project TROPICS
Our goal in the ESPRIT-II project TROPICS is to enhance the PRISMA/DB machine such that it becomes a viable tool for office automation. The approach taken is based on the grammatical model for databases described above.

The advances of this project are indicated below from three perspectives: the PRISMA hardware, the database functionality, and the operational feasibility. The integration of the proposed solutions within an existing office environment, its human-interface, document transformation, and document-flow methodologies are beyond the scope of this subproject. They are partially a focus of interest within the projects AA 3 and AA 2.

The PRISMA hardware
The ultimate goal is to enhance the PRISMA database machine such that it becomes a viable tool for a wide range of applications. More specifically, the PRISMA database machine already provides an abundance of processing power and a very large main-memory, which seems a good basis for dealing with many of the problems encountered in an office environment. For example, the size of the database easily accommodates the storage of signature files within main-memory and automatically exploits parallelism for subfile extraction. Moreover, the availability of many processors simplifies the maintenance of document indices and the DOOM multi-processor component can be called upon for CPU-intensive tasks, such as voice/picture analysis.

Database functionality
The common technical issue in the different views encountered in an Office environment is that the documents can be described as complex objects over different domains. However, we do not have to deal with arbitrarily complex objects, because the transport/edit approaches are limited to tree-oriented

structures. In the database view, a document can thus be seen as a sentence covered by the grammatical interpretation of the conceptual schema. The underlying model is that of a grammar, which describes the allowable document structures, and a database of parse trees, called grammatical objects or G-objects, that represent the document base.

Therefore, the necessary functional extension to PRISMA/DB is the support of G-objects as one of their built-in types, to provide query operators for G-objects, and to optimize their storage and access.

Operational feasibility

The prime operational issues are the integration with a document archiver and the integration with other, existing database management systems. We will indicate how they are dealt with in the PRISMA/DB context.

The architecture of the PRISMA/DB has been designed such that it can operate in a distributed environment and can be expanded with components to support specific needs. The former is achieved by providing a standard SQL interface on top of the system. The latter is achieved by designing PRISMA/DB as a distributed DBMS from scratch and to anticipate customized data managers to be included in the future.

Both architectural design concepts make PRISMA/DB extensible and flexible. In particular, a document archiver can be included either through the SQL interface or by inclusion of a customized data manager. The prime advantage of the latter approach is that it will benefit from the query processor that exploits the potential parallelism within the machine.

PERSONNEL

Currently, the DAISY staff at CWI consists of one project leader and four researchers/software developers. Three out of those four are already externally funded, i.e. through the PRISMA project and the forthcoming TROPICS project. To capitalize on the experience gained in both externally funded projects and to improve their critical mass we envision that in the coming period three extra persons, including a post-doc, are needed (two persons funded by the CWI and one through TROPICS).

If the NFI project is granted, then the DAISY group will need an extra researcher to work with A.P.J.M. Siebes on analytical methods for information systems design. Funding for this person has been requested in the proposal.

EQUIPMENT

The distributed adaptive information systems project currently uses the computer infra-structure of the CWI. In the near future we need several additional workstations, fully equipped with main-memory to fulfil our software development commitments in PRISMA and TROPICS. We foresee substantial additional investments in equipment after 1990 when the first PRISMA machines will become available.

PROJECT AA 5

TITLE: Constructive algorithmics

TITEL: Constructieve algoritmiek

ABSTRACT
The Constructive Algorithmics project is concerned with the development of concepts, notations, formalisms and methods, on a high level of abstraction, for deriving algorithms from a specification. The aims include the unification of specification formalisms and formalisms for denoting algorithms, and the development of specialised theories for certain data types or classes of problems.

SAMENVATTING
Het project Constructieve Algoritmiek beoogt de ontwikkeling van concepten, notaties, formalismen en methoden op een hoog abstractieniveau om algoritmen uit een specificatie af te leiden. Tot de doelstellingen behoort het unificeren van specificatieformalismen om algoritmen te beschrijven, alsmede het ontwikkelen van gespecialiseerde theorieën voor bepaalde gegevenstypen of probleemklassen.

PROJECT MEMBERS
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prof. L.G.L.T. Meertens (project leader)
S. Pemberton
junior researcher (NFI)

EXTERNAL CONTACTS
Dr. R.S. Bird (University of Oxford, UK); professors H.A. Partsch and C.H.A. Koster (Catholic University Nijmegen); prof. S.D. Swierstra (University of Utrecht); prof. R.C. Backhouse (University of Groningen).

START OF PROJECT: 1977

CLASSIFICATION CODES

NWO-classification : P175
1985 CR Classification scheme : B.6.3, B.7.2, D.1.2,D.2.1, F.3.1, I.2.2

PROJECT DESCRIPTION

Aims

Program design and implementation is an important part of all applications of Computing Science. Two prominent concerns here are correctness and efficiency. Efficient algorithms are usually complex, and therefore hard to get correct. Evidently correct algorithms, on the other hand, are often not of an acceptable efficiency. An approach to the design of correct *and* efficient algorithms is the following. Start with a high-level specification, paying only attention to its correctness. Next, derive an efficient implementation from it by a sequence of meaning-preserving 'transformations'. In this last phase, the concern for efficiency guides the selection of the steps to be tried. The formal concern, however, is only not to make calculation errors. In principle, it should be possible to check this mechanically. This approach is also known as 'Transformational Programming'.

In a nutshell, then, the aim of the Constructive Algorithmics project at CWI is to improve the applicability of this approach. Important aspects are (i) the unification of specification formalisms and formalisms for denoting algorithms proper; (ii) the unification of various algorithmic styles (imperative, functional, deductive); (iii) the development of concepts, notations, formalisms and methods, on a higher level of abstraction than the usual current concepts and notations, which tend to be too baroque and too dedicated to some particular architecture to be susceptible to formal manipulation.

EXTERNAL CONTACTS

The work is performed in close cooperation with the group of dr. R.S. Bird of the Programming Research Group at the University of Oxford, UK. An international forum for the exchange of results is offered by IFIP Working Group 2.1, which has been focussing on this general problem area for the last ten years. On a national scale, the project at CWI forms part of the STOP project (Specification and Transformation Of Programs), a joint effort with the Catholic University Nijmegen (prof. H.A. Partsch and prof. C.H.A. Koster) and the University of Utrecht (prof. S.D. Swierstra), sponsored by the NFI (Nationale Faciliteit Informatica). An important aim of the STOP project is to increase the level of expertise in this area in the Netherlands, among other means by holding seminars and workshops and inviting foreign experts. Of the further cooperation in the Netherlands, that with prof. R.C. Backhouse of the University of Groningen is worth mentioning separately. A national forum for exchanging results is provided by the special interest group on Constructive Algorithmics of WPA-SION (Werkgemeenschap Programmatuur en Architectuur - Stichting Informatica-Onderzoek Nederland), which meets twice a year and in which researchers from most of the Dutch universities and several industries (as well as some Belgian researchers) participate.

Research problems and approaches

The aspiration of the constructive-algorithmics approach is to cover, eventually, large parts of the 'tricks of the trade' of the practice of computing, including - just to mention some examples - parser construction and incremental document formatting, and to provide a coherent body of concepts, notations and theories with which the methods and results in such areas can be described and taught in a systematic way. This situation can of course only come about if research in this area is pursued on a larger scale than it is today, which by itself is a reason to attach importance to cooperation. In any case, actual progress requires tackling, one by one, specific problems which by themselves are of a modest scale.

Most of the results that have been obtained to date are characterized by taking an algebraic view on certain important *data types* (e.g., lists or trees), and considering homomorphisms on the algebraic structures obtained. This has proven a surprisingly fruitful approach. For each type examined thus far, there has turned out to be a lemma characterizing its homomorphisms as the composition of certain 'elementary' homomorphisms. Many important 'program transformations' then turn out to be expressible as simple algebraic identities. By specializing on a particular data type, a powerful theory for that type can be obtained.

This productive approach has by no means been exhausted. Of the many kinds of trees that are important to the practitioner of Computing Science, only a few have begun to be examined. For the important types of tables (finite mappings) and various kinds of graphs, little or no theory is yet available. Next to the development of such specialized theories, the results that have been obtained display a certain commonality that suggests it may be worthwhile to try and extract an 'embracing' theory of data types, necessarily less powerful but of a wider scope of applicability. One issue that should be covered by such an embracing theory is that of switching the algebraic viewpoint - for example, viewing a linear list as a table, or a set as a bag.

Among the construction methods that are emerging from this research, the most important one is that by *constructive hypothesis:* posit the existence of an algorithmic solution to some specification in a generic form (as suggested by theory), and derive enough consequences to determine the parameters of the generic form. In the general case it has to be verified that the algorithm found satisfies the original specification, but if it is already known that there is a solution of that general form, verification afterwards is not necessary. This is entirely analogous to the way some ordinary differential equations can be solved analytically. This may seem to be an obvious method to apply, but only through the development of a concise 'algebraic' notation for algorithms has it become possible at all to formulate such constructive hypotheses.

An important special case is that of constructive function inversion. Often the most natural formulation of an initial specification involves a clause of the form: some known function applied to the result to be computed yields some known value. (This subsumes predicative specifications, in which the result has to satisfy some predicate.) It may be the case that the function in question

is not injective, and so does not have a unique inverse. (Other clauses of the specification may constrain the result to be computed to the point of uniqueness.) This leads in a natural way to considering generalized, multi-valued inverses, and thus to so-called *indeterminate* specifications. Allowing indeterminacy has certain important advantages (in particular, where the conciseness of formulas is concerned), but it also raises unmistakable problems: certain laws are only valid for determinate forms, and by being careless paradoxical results can ensue. In defining the meaning of indeterminacy mathematically, there are several options, and it is not clear *a priori* which choice results in the most manageable algebra. Examining this in detail, and developing a sound set of rules for dealing with indeterminacy, has a high priority.

A final line of approach is given by starting from a *class of problems* (and methods); for example, parsing, or computing minimal closures, or branch-and-bound. The - as of yet cursory - excursions to such areas suggest the following general method. Consider the calling tree of a recursive algorithm solving the problem as a 'real' tree of some suitable data type, and the result to be computed as resulting from the application of some homomorphism to the tree. The properties that allow certain optimizations in the computation can then generally be expressed as algebraic properties (for example, that some operation has one or more left zeros), and the optimizations can be deduced as algebraic identities. The tree on which the homomorphism is computed is itself the result of constructing the inverse of some other function on the input data. As a final step, the computations of the homomorphism and the inverse function can be fully or partially merged. As with the examination of data types, this line will not be developed by trying to formulate the general method formally, but by specializing it to sharply delimited problem classes one at a time.

WORKING PLAN

See the project description.

PROJECT AA 6

TITLE: Cryptology

TITEL: Cryptografie

ABSTRACT
The research in this project concerns all aspects of cryptology related to information security. This involves in particular the construction and analysis (from the points of view of crypto-analysis, information theory, and complexity theory) of cryptographic protocols and their underlying cryptographic algorithms, and the mathematical proofs of their soundness and reliability.

There is special emphasis on the protection of privacy of individuals in protocols for the transmission of messages, payment systems, and the treatment of personal data by various organizations.

SAMENVATTING
Dit onderzoek bestrijkt die delen van de cryptografie die te maken hebben met 'information-security'. Daaronder valt het construeren en analyseren (vanuit de gezichtspunten van crypto-analyse, informatietheorie, en complexiteitstheorie) van cryptografische protocollen en de onderliggende algoritmen, en de mathematische onderbouwing van deze algoritmen wat betreft betrouwbaarheid en doeltreffendheid.

Speciaal aandacht wordt besteed aan het beschermen van de 'privacy' van individuen in protocollen voor het versturen van boodschappen, voor betalingssystemen en voor de behandeling van persoonlijke gegevens door verschillende organisaties.

PROJECT MEMBERS
dr. D. Chaum (project leader, NFI)
dr. H. den Boer (NFI)
dr. M.J. Coster (NFI)
ir. J.N.E. Bos
ir. E. van Heijst
A.G. Steenbeek (STO)
junior researcher (vacancy)

START OF PROJECT: 1980

CLASSIFICATION CODES

NWO-classification : P175
1980 Math. Subj. Class. : 05-XX, 94Bxx

PROJECT DESCRIPTION

Cryptology has been an area of research in which special mathematical and computational techniques were developed and examined to secure confidential data. Nowadays, cryptology includes more.

One of the new aspects of cryptology is called authentication. This is the study of methods to prevent information that is sent over unsafe channels from being forget by the receiver or an outsider, or from being denied by the sender. It includes the commercially important digital signatures.

Another new aspect is identification and untraceability. Briefly, the first is to give a proof of one's identity by being able to answer numerical questions. The second creates situations in which transactions made between individuals and organizations (such as banks, retailers, insurers, and government agencies) cannot be linked to individuals. The two approaches have common ground in digital pseudonyms, which form a basis for digital signatures.

A third new aspect is not yet sharply defined. It includes the so-called zero-knowledge- and zero-information-proofs. A simple example is: can two persons determine which is the oldest, without revealing their age? Zero-information protocols allow some (and even all) participants to protect their secrets against an adversary having unlimited computational resources. Such unconditional protection is quite appropriate for protecting the privacy of individuals.

Today, many designs for cryptographic algorithms are based on public key algorithms, while before 1976 all systems were based on secret key algorithms. In general, a cryptographic algorithm is a mapping determined by a key. In secret key systems, both the mapping and its inverse can readily be computed using the key. In public key systems, the mapping is easily computed by anyone using the public key, but inverting the mapping requires a trap-door private key. When, as in most known example public key systems, a homomorphism property is present, they can be used to construct untraceability protocols.

WORKING PLAN 1989

As the international leader in untraceability protocols, the primary activity of the group is devoted to furthering the theoretical and practical developments of these new techniques. Included are such areas as payment, credentials, voting and communication systems.

Various secondary areas of investigation are anticipated, as experience has shown that they tend to supporting the ongoing primary activity and have proven fruitful for the group in the past. One such area is zero-information and related protocols. Another is the design and evaluation of underlying cryptographic algorithms. Yet another is computational methods in number theory with cryptographic application.

Naturally, interaction with visitors and other researchers in the field is expected to continue to be an important stimulant to the work program.

WORKING PLAN AFTER 1989

Continuation of research.

Department of Interactive Systems

Research in this department is aimed at fundamental problems of computer systems communicating with the outside world, and at constructing systems capable of such communication. The exchange of information can be with a human user or with physical devices or processes such as robots and chemical processes. The technical realization of systems for communicating with users may be quite different from those communicating with processes. The fundamental problems of both classes have many similarities.

One of the most important developments in using computers is the interactive manipulation of data represented as pictures on a screen. A large fraction of the research of the department somehow involves pictures. The construction of system components for interaction using computer graphics plays a central role. On the long term emphasis may shift towards exploiting artificial intelligence and parallelism in interaction. Also machine-machine communication will be used in experimental systems.

The department currently has five project groups:

IS 1 Computer graphics
IS 2 User interfaces
IS 3 Dialogue programming
IS 4 Intelligent CAD systems
IS 5 User controlled systems

Department of Interactive Systems

List of projects

IS 1 Computer graphics
IS 2 User interfaces
IS 3 Dialogue programming
IS 4 Intelligent CAD systems
IS 5 User controlled systems

	Projects					working			
Name	IS1	IS2	IS3	IS4	IS5	hours	regu-lar	de-tached	guests
appointed									
Ten Hagen		•	•	•	•	1.00	1.00		
Kuyk	•					1.00	1.00		
Blom		•				1.00	1.00		
Trienekens	•					1.00		1.00	
Blake	•					1.00		1.00	
Veen	•					1.00		0.38	
Born, van den	•					1.00		0.38	
Herman	•					1.00	1.00		
Dijk, M. van	•					0.80	0.31		
Ruiter, de		•				1.00	1.00		
Vegt, v.d.		•				0.80	0.80		
Liere, van			•			1.00	0.92		
Schouten			•			1.00	0.50		
Otten				•		1.00	1.00		
Veerkamp				•		1.00	1.00		
Rogier				•		1.00		0.75	
Spilling					•	1.00	1.00		
total appointed							10.53	3.50	0.00
regular priority									
scient.res.1					•	1.00	1.00		
scient.res.2			•			1.00	0.50		
scient.res.3				•		1.00		1.00	
scient.res.4				•		1.00		1.00	
scient.res.5					•	1.00		1.00	
scient.res.6			•			1.00	1.00		
scient.res.7		•				-	p.m.		
scient.res.8	•					-	p.m.		
scient.res.9				•		-	p.m.		
scient.res.10					•	-	p.m.		
total priority							2.50	3.00	0.00
total estimated							13.03	6.50	0.00

PROJECT IS 1

TITLE: Computer graphics

TITEL: Computergrafiek

ABSTRACT
The design of functionally complete basic graphics systems, with special support for interactive use. Results to be made available, on the one hand as (contribution to) international standards, on the other hand as implementations, with special attention to efficiency required for high quality interaction.

SAMENVATTING
Het ontwerpen van functioneel complete grafische basissystemen, met speciale aandacht voor interactief gebruik. Beschikbaarstelling van het resultaat, enerzijds als (bijdrage aan) internationale standaards, anderzijds in de vorm van implementaties, wederom met speciale aandacht voor op hoogwaardige interactie gerichte efficiëntie.

PROJECT MEMBERS

dr. M. Bakker (STO)	drs. D. Soede (STO)
E. Blake M.Sc.	mw.ir. C.G. Trienekens
F.J. Burger (STO)	junior researcher (p.m.)
drs. A.A.M. Kuijk (project leader)	drs. M. van Dijk
B.P. Rouwhorst (STO)	I. Herman (M.Sc.)

EXTERNAL CONTACTS
National: Project partners: University of Twente (prof. Herrmann), Dataflow Technology Nederland b.v. (ir. D. de Vries), Parallel Computing b.v. (dr. A.H. Veen, R. v.d. Born), PTL (Groningen) (dr. K. Stok), Philips (ir. M. Corthout), and various universities.
ISO-related activities: NNI; IS coordinates all the work concerning ISO/TC97/SC24.
International: On parallelism in Computer graphics: Univ. of East Anglia (dr. D.B. Arnold), GMD Bonn (dr. K. Kansy), INRIA (dr. A. Ducrot). On VLSI for Computer Graphics: prof. W. Strasser, Univ. of Tübingen (Promotor). IS is organizing a series of workshops on advanced graphics hardware in close cooperation with EUROGRAPHICS.

START OF PROJECT: 1980

CLASSIFICATION CODES

NWO-classification : P175, T120
1980 Math. Subj. Class. : 69K31, 69K32
1982 CR Classification Scheme : I.3.1, I.3.2, I.3.6, I.3.7

PROBLEM AREA AND SCIENTIFIC RELEVANCE

The most important problem inherent to generating and manipulating pictures is to integrate the diverse functionality into one system. The progressing integration of complex functionality leads towards simple programming since then the graphics system can perform the coupling of basic functions. New architectures for graphics workstations must bring about the extra capacity to perform this integration. The ultimate integrated practical system consists of a programmers interface and development tools.

Up to now, the integration of abstract geometry and appearance (colour, line width, real-time movement) has been successfully effectuated for two-dimensional pictures. Three more integration steps are still in progress: three-dimensional line drawings, pictures built out of areas and interaction supporting feedback techniques. The first two will lead to an integrated programming system suited to be standardized. The last primarily leads towards a newly designed architecture.

At the CWI research takes place on the basis of GKS-3D, PHIGS, RGF and the so-called Radicals-system which is one of the prototypes for the next generation of graphics standards.

WORKING PLAN 1989

In 1989 cooperation with respect to ISO activities will be continued. CWI will support these activities in the area of window management, interaction, and input functionalities, and in the area of representation of curved lines and surfaces.

Results obtained in the research groups IS 2 and IS 3 will form the basis for development to international standards within IS 1.

IS has been charged by NNI on behalf of ISO to convene and conduct two international study groups, one on window management and the other on graphical interaction. Both studies should provide the technical framework for international standards in this area.

The STW-project 'A new architecture for rastergraphics on the basis of VLSI' (in cooperation with the University of Twente) will complete a study of the algorithmic limitations as set by the technology of VLSI. Based on the results of this study a decision will be made on which parts of the colour evaluation algorithms can be realized with current VLSI technology.

In 1989 the realisation of the rasterisation hardware will take place. Meanwhile the development of incremental algorithms, specific for the fast rasterisation hardware, is continued.

Embedding new RGF (Raster Graphics Facilities)-primitives in the PHIGS-hierarchy will adhere to the proposed PHIGS+ extensions.

The DTN-project will design and implement a set of instructions on the DFC processor configuration, which is capable of outputting 3D-graphical primitives onto a graphics display. These primitives include primitives for window management. In this architecture massive parallelism will be exploited on the basis of dataflow hardware.

On top of this instruction set GKS-3D will be implemented. A number of

test and demonstration programs will be designed and implemented to illustrate the correct functioning and the performance of the system components.

WORKING PLAN AFTER 1989

The STW project will continue to develop the set of RGF-primitives and design and implement incremental picture change algorithms. This especially aims at fast and high level interaction support. These algorithms and the other algorithms needed for picture generation will be analyzed to find out which (parts) are candidates to be realised in VLSI. A whole new system of 3D-interaction techniques will be developed for this new generation of hardware. The basis for these techniques is the real-time animated 3D feedback, which will become possible with new hardware.

The ISO-activities are aimed at a new generation of graphics standards to be completed by 1993. The department plans to participate in these activities in close cooperation with the Dutch software industry.

PROJECT IS 2

TITLE: User interfaces

TITEL: Gebruikersinterfaces

ABSTRACT
Information systems are increasing in size and complexity. At the same time such systems must be accessible to users after minimal training. This can only be realized through the availability of high level, natural user languages to address such systems. The user interface is then to provide the mappings between the user language and the abstract system concepts. Attempts are being made to enrich user languages by supporting speech-recognition and -generation, natural language instructs and picture elements (e.g. sketches). This project focusses on picture interpretation. This is a new area. The major difference with computer vision being that with picture interpretation the computer is actively involved in the picture construction process. The emphasis therefore is on correlating pictures with other information.

SAMENVATTING
De toenemende omvang en complexiteit van informatiesystemen enerzijds en de wens om deze toegankelijk te maken voor gebruikers met een minimum aan training anderzijds, stellen steeds hogere eisen aan de afbeeldingsfuncties tussen gebruikerstaal en abstracte systeemconcepten. Derhalve worden pogingen gedaan de gebruikerstalen te realiseren waarin spraak-herkenning en spraak-generatie, natuurlijke talen en beeld-elementen (b.v. schetsen) mogen voorkomen.

In dit project gaat de aandacht vooral uit naar beeldinterpretatie. Dit is een nog vrijwel onbetreden terrein. Het grote verschil met 'computer vision' (herkenning van een door een camera geregistreerd beeld) is dat de computer actief betrokken is bij de opbouw van het beeld. De nadruk komt dus te liggen op de correlatie met andere informatie.

PROJECT MEMBERS

drs. C.L. Blom (project leader)
drs. P.J.W. ten Hagen
drs. M.M. de Ruiter (project leader)
mw.drs. J. van der Vegt
junior researcher (p.m.)

EXTERNAL CONTACTS
National: Catholic University Nijmegen (Dept. of Psychology) on ergonomics. Also the "Waterloopkundig Laboratorium". International: IS 2 is participating in a newly started EUROGRAPHICS activity on AI and Computer Graphics.

START OF PROJECT: 1984

CLASSIFICATION CODES

NWO-classification	: P175, T120
1980 Math. Subj. Class.	: 69D54, 69K32
1982 CR Classification Scheme	: I.3.6, D.4.7

PROBLEM AREA AND SCIENTIFIC RELEVANCE

A user interface is the collection of means through wich a user can access an information system. It can have many different realizations. Examples are: a control panel, a command language and a draughting system. A user interface contains all necessary functions to map between abstract system information and concrete representation, using text, pictures and sounds, for the user. The growing size and complexity of information systems on one hand and the need to provide access to such systems for minimally trained users on the other, put increasing demands on the capabilities of workstations for providing presentations. An obvious improvement would be to have workstations that can generate or understand natural language and that can interpret pictures. The latter is a relatively new territory. The difference with computer vision being that instead of recognizing a picture recorded by a camera, the workstation is instrumental in defining or constructing the picture. The emphasis is therefore not on the recognition but on the correlation with other information. For this research a language model for pictures will be used to investigate the possibilities to exploit artificial picture languages. The interactive functionality will serve primarily to define the picture-syntax in order to use, say, component pictures and hierarchies. Both components and structure will be significant for the associated semantics (i.e. the correlations with other information). In addition the workstation must be enhanced with techniques to present the picture as well as the interpretation. This theme will be approached in three ways:

1. Picture editing: the syntactical treatment of pictures. Basic problems with picture editing are: the non-sequential nature of pictures. Consequently the user will not easily guess the way the picture description has been structured; the inherent difficulty for the user to accurately specify picture elements, requiring tolerance and support from the system.

2. Constructive input: to support user input on the basis of semantic information. The system attempts to deduce the meaning of input and exhibits this by amending the construction process (e.g. styling or anticipation). The experimental system developed in the study is a 3D-sketching environment.

3. Workstation management: to generate the right context for a given task. This includes connecting to the workstation resource manager (e.g. window management), and installing dynamically the appropriate picture-syntax parser and semantic interpreter. The implementations will use logic- and object-oriented programming.

WORKING PLAN 1989

Picture editing:

The two-level syntax for pictures will be used for analysing various methods for automatic structuring. These methods can be applied in various mixtures according to the known or observed usage of the pictures. For the experimental editor an additional mode will be added to predefine command sequences

and administer intermediate results. This mode can effectively be turned into the environment that supports the close to ideal structuring for a given situation. This research will continue after 1989.

Constructive input:
The strategy developed in 1988 will be followed further. In order to put emphasis on the semantic aspects of interaction a most simple picture syntax is used with relatively rich semantics. It turns out that constructive input is almost equivalent with piecewise constructing the semantics of a given picture, in casu consisting of sketched line segments. In 1989 the feedback mechanisms will be designed that exhibit in real-time the semantic interpretation. Both the semantic recognition and the associated feedback will be specified through rules. These rules will embody, among other things, the anticipating power of the sketch-support systems. The experimental sketch-system will be capable of constructing a 3D-model from the 2D sketches. After 1989 the abilities of embedding a sketch system in a resource managed environment will be tested. This can follow the same method as developed for the picture editor. In fact this will be the opportunity to see whether richer-syntax systems can be enhanced with constructive input. Hence, we will attempt to merge the result of both projects.

PROJECT IS 3

TITLE: Dialogue programming

TITEL: Dialoogprogrammering

ABSTRACT
The project is aimed at the development of a complete programming method for interactive dialogues. Currently a prototype system (DICE) exists which is being applied to a number of test applications. The experimental system has revealed a further set of fundamental problems which will be addressed in the next version. This will allow us to widen the scope of application to machine-machine dialogues and simplify the embedding in a variety of general purpose programming languages. Previous results concerning methodology of graphical interaction and window management will in the next few years form the basis of a new generation of international graphics standards.

SAMENVATTING
Doel van het project is een complete programmeermethode (b.v. met ontwikkelomgeving) voor interactieve dialogen. Een prototype systeem (DICE) bestaat en wordt uitgeprobeerd op een aantal test toepassingen. De experimenten hebben een aantal fundamentele problemen blootgelegd die zullen worden behandeld alvorens te komen tot de volgende meer definitieve versie. In die meer geavanceerde versie worden ook nieuwe transactie omgevingen zoals machine-machine dialogen binnen het applicatiebereik gebracht. Tevens kan het nieuwe systeem in een grote verscheidenheid van moderne programmeertalen worden ingebed. Tot nu toe verworven inzichten omtrent interactie zullen in de komende jaren de basis vormen voor een nieuwe generatie grafische standaards.

PROJECT MEMBERS

drs. P.J.W. ten Hagen (project leader)
R. van Liere
drs. H.J. Schouten
drs. D. Soede (STO)
junior researcher (vacancy)

EXTERNAL CONTACTS
National: There exists an active working group on dialogue programming with participants from TNO-IBBC, TNO, Océ, Philips, Univ. of Amsterdam.

At several institutions the DICE system is experimentally being used: PTL (Groningen), University of Twente (dept. of Manufacturing) and Philips CAD-centre.

International: On the formal description of DICE: Rutherford Laboratories (dr. D. Duce), University of Southern California (prof. F. Arbab).

On User Interface Management: TH Darmstadt, GMD Bonn, University of Tokyo (prof. F. Kimura).

For ISO the project will conduct a study on methodology of interaction.

START OF PROJECT: 1983

CLASSIFICATION CODES

NWO-classification	: P175, T120
1980 Math. Subj. Class.	: 69K36, 69D43
1982 CR Classification Scheme	: I.3.6, H.1.2, D.2.2

PROBLEM AERA AND SCIENTIFIC RELEVANCE

The communication between a human and a computer system or between two computer systems can be viewed as a dialogue, i.e. a sequence of transactions between both participants. Dialogue programming is the specification of all possible questions and answers, as well as the state of the visible interface at every moment during the dialogue. The method we have developed is based on input-output units, called dialogue cells. The incentive is to make user friendly (or ergonomic) systems. These systems are easy to understand, efficient to handle, the communication is at a high level, and not error prone.

Dialogue cells

Dialogue Cells are programmed using three types of grammar rules for initialization, activation and communication respectively. These rules can be nested in a hierarchy. Together the grammar rules specify the complex correlations between input and output in the i-o units. By restricting the specification to the correlations, the representations of input and output themselves can be taken from the existing hardware and software environments. The correlation mechanism takes care of a large variety of tasks, such as input parsing, screen control, communication with algorithms and errorhandling.

The DICE environment contains a new type of graphics system, called the Radicals System, primarily designed for interaction, but capable of handling any type of graphical output for multiple output streams. This system will form the basis for a library of advanced graphical interaction techniques, including 3D elements handling.

WORKING PLAN 1989

The DICE system in its revised version will be used in a variety of applications e.g. picture editors, constructive input (IS 2), CIM systems user interfaces, distributed AI systems and in general user interface management systems. On the basis of DICE, an extension of software design methods à la IDEF will be developed in collaboration with software industry and major research institutions. At the same time the DICE system itself will become more formally described so that interesting properties can be proven.

The DICE group will continue contributing to the ISO-work on graphics standards to produce the next generation of standards (see also under IS 1).

The DICE system will also be the starting point for the intelligent user interface of the IIICAD system (see IS 4).

WORKING PLAN AFTER 1989

Further research into network type correlations rather than strictly hierarchical ones. Securing support for the user community of DICE and, maybe, further commercializing the result.

PROJECT IS 4

TITLE: Intelligent CAD systems

TITEL: Intelligente CAD-systemen

ABSTRACT
The project will, through the use of AI based methods and techniques, attempt to produce CAD systems which will be more complete, integrated, and have a high quality user interface. To implement such a system a language is being developed, based on the object-oriented and logic programming paradigm. This language (IDDL, Integrated Data Description Language) has special dedicated features to encode knowledge about the design object and about the design process and about their relations.

SAMENVATTING
Door gebruik te maken van kunstmatige intelligentie methoden wordt gepoogd CAD-systemen te verbeteren, vooral met betrekking tot uitbreiding en integratie van ontwerpwerkzaamheden en de kwaliteit van de gebruikersinterface. Voor de implementatie wordt een programmeertaal ontwikkeld die logisch- en object-georiënteerd programmeren combineert. Deze taal (IDDL, Integrated Data Description Language) heeft constructies speciaal voor het coderen van informatie en kennis over respectievelijk het te ontwerpen object, het ontwerpproces en de relaties tussen beide.

PROJECT MEMBERS

drs. P.J.W. ten Hagen (project leader)	drs. P.J. Veerkamp (NFI)
ing. D.B.M. Otten	scientific researcher (NFI)
ir. J.L.H. Rogier (NFI, detached from TNO)	scientific researcher (NFI)

EXTERNAL CONTACTS
TNO-IBBC (ir. F. Tolman), University of Amsterdam (dr. J. Treur), University of Twente (dr. L. James), University of Tokyo (prof. T. Tomiyama), Bilkent University (Ankara) (prof. V. Akman), University of Southern California (Los Angeles) (prof. F. Arbab), Computer and Automations Institute (Budapest) (Ms. Zs. Ruttkay, M.Sc.), University of Strathclyde (prof. K. MacCallum).

START OF PROJECT: 1985

CLASSIFICATION CODES

NWO-classification	: P175, T120
1980 Math. Subj. Class.	: 69D22, 69D43, 69K10, 69L60, 69H20
1982 CR Classification Scheme	: I.2.4, H.3.4, D.3.3, I.2.1, J6, H2

PROBLEM AREA AND SCIENTIFIC RELEVANCE

CAD (Computer Aided Design) programs assist a designer in specifying an artefact, e.g. a house, a machine, or an electronic circuit. The assistance can range from mere registration of the design results to analyzing the proper functioning of the designed object, maybe, through simulation. More advanced forms of assistance include problem solving activities such as optimization (e.g. lay out), pathfinding (e.g. routing) and even suggesting a solution based on given specifications. The latter acitivities will become more dominant when the assistance could be extended to the earlier (more difficult) phases in the design.

In the sequel we will describe some of the problems of CAD on the basis of the two major assistance categories, being: assisting the design process and assisting the recording of the design object.

The design process can in an abstract way be defined as transforming a set of specifications into a set of attributed objects, which together perform as required by the specifications. The process can be structured according to so-called design stages (e.g., analysis, synthesis, evaluation), by decomposition into subprocesses for parts of the partitioned design. Moreover there may be forms of backtracking (undoing decisions), iteration, detailing, etc. In each CAD system a specific design process is, at least de facto, represented. The more a design system will support interaction, the more a conscious representation of the design process is needed.

Internally the design process can be characterized by the way it will interact with the design object. An important major goal is to find appropriate means for describing the design process and define the semantics in terms of design object transactions. Following this a coherent solution for integrating the various design activities as well as the user interfaces can be researched.

The design object is to be represented in the computer during the whole transformation from specifications to solution. Each design task is characterized by the part of the design information which is involved in this task and in what way. For each task an appropriate partial object representation must be made available.

Much of the designers activities are to manipulate the design object for adding new information, changing and inspecting. In advanced systems the context in which these take place may vary in time. Even the purpose of such activities may be initially unspecified. This may, for instance, influence the way the corresponding transactions are visualized. An important aspect of representing the design object is to identify the status of the object information, e.g.: proposed, decided, changeable, etc. Much of the interaction between process- and object-representation is dependent on the status information. In particular the information must be allowed to be incomplete, inaccurate or even inconsistent (in a given situation).

ICAD systems (Intelligent CAD systems) try to solve the above mentioned problems more adequately by exploiting methods from the domains of Artificial Intelligence. This can be formulated in two major questions:

1. How can an ICAD system be constructed which allows for easily applying AI-methods such as for encoding expert knowledge and for using, say, a truth maintenance system;
2. Which AI-techniques must be further developed first because they are urgently needed for ICAD [Akman et al. 1988].

The effect of ICAD on the end-user will be that he will have more direct control over both design process and -object, also in more user friendly terms. This requires a novel approach to the user interface to CAD. For instance, relevant semantic information will, in the form of rules, be processed directly by the user interface so that the visualization can be influenced in real-time.

Last but not least it is necessary to put the entire complex of problems and solutions to the hard test of some real applications (are the problems representative?, are the solutions adequate?). To this end some carefully selected applications (from the domain of civil engineering and architecture) will be prepared, implemented and evaluated for this purpose.

The entire project will be governed by three joint (all members) studies which will continue throughout the projects lifetime:

- to develop a design theory;
- to design and implement a language to describe a design process and an ICAD architecture;
- to evaluate the results on the basis of the selected applications.

WORKING PLAN 1989-1994

The activities in the project are centered around three joint studies: the design theory, the ICAD-language and architecture and the evaluation of experimental ICAD applications.

The design theory study will combine three activities, each of which must contribute to the theory in a specific way:

- description of design processes and design types as they are in practice must lead to a realistic theory;
- a sound logical basis must be found for characteristic aspects of (realistic) design such as: incomplete descriptions, complex patterns of reasoning and a multi-world mechanism;
- the theory must provide a specificational framework for the experimental system (called IIICAD) and its language (called IDDL).

The ICAD language and systems will be developed around the concepts of scenarios (for the design process) and the meta-model (for the design object). The way the scenarios work with the meta-model leads to an evolutionary meta-model which can be viewed as a sink and a source of models to be generated by/for scenarios.

Specific topics to be studied in this context are: the multi-world mechanism, the partitioning strategy for the supporting knowledge base and the user interface monitor (which can modify interactions based on context information).

The evaluation study will be prepared for by two target applications from the area of architecture and product-modelling (for civil-engineering models).

The evaluation will proceed in three stages. The first to evaluate the (initial) theoretical frame, the second to evaluate the experimental IIICAD system architecture and IDDL and the specification language. The third stage will evaluate the quality of the experimental CAD systems built using the IIICAD system.

PROJECT IS 5

TITLE: User controlled systems

TITEL: Gebruikersbesturingssystemen

ABSTRACT
User controlled systems are information systems for which all tasks are command driven. Meta-level commands allow the definition of new tasks. The task oriented architecture requires a high degree of integration among program libraries and databases. In addition this task oriented approach must bring about comprehensible user interfaces for very complex systems, such as CIM systems (Computer Integrated Manufacturing).

SAMENVATTING
Gebruikersbesturingssystemen zijn informatiesystemen waarvoor geldt dat alle uit te voeren taken door commando's gedefinieerd en gestuurd worden.

Een meta-niveau in het systeem maakt het mogelijk on-line nieuwe taken te definiëren. Voor zo'n taak-georiënteerde architectuur moet een hoge graad van integratie tussen programmateken en gegevensbanken bestaan. De taak-georiënteerde aanpak is ook de belichaming van de strategie om te komen tot hanteerbare gebruikersinterfaces voor zeer complexe systemen, zoals CIM-systemen (Computer Integrated Manufacturing).

PROJECT MEMBERS
drs. W. Eshuis (project leader)
drs. P.J.W. ten Hagen
ir. P. Spilling
junior researcher (STW, vacancy)

COOPERATION
Within the scope of SPIN-FLAIR project the group cooperates with the University of Twente (prof.dr.ir. H.J.J. Kals). Further cooperations on the basis of the use of user interface management systems for integrating large applications are with PTL (dr. D. Stok) and with Waterloopkundig Laboratorium (ir. K. van Smeden).

START OF PROJECT: 1987

CLASSIFICATION CODES

NWO-classification	: P175, T120
1980 Math. Subj. Class.	: 69D22, 69D26, 69D43, 69H12, 69H20, 69K36, 69L60
1982 CR Classification Scheme	: D.2.2, D.2.6, D.3.3, H.1.2, H.2.0, I.3.6, J.6

PROBLEM AREA AND SCIENTIFIC RELEVANCE

User Controlled Systems (UCSs in the sequel) embody the information technology needed for design, operation and maintainance of complex systems. According to the concept of UCS, standards are designed for the exchange of data and for external control. These standards are a combination of function schemata and data formats. A UCS enables a user to become an on-line operator of a system; a user can interactively compose programs from process activations and database transactions. A new dimension is added by allowing the building blocks to interact mutually and with the composer, optionally under interactive control of the latter.

Examples of applications of UCSs are: a datascheme for design information together with a collection of pre- and post-processors; the description of an object to be manufactured, and the set of manufacturing processes together with a procedure to select an optimal process. Each example shows aspects of integration, distribution and contemporal multiple users. The view on the system has to change with the nature of the usage or its user. Particularly interactive usage requires a flexible distribution of transactions and decisions between user and system.

In the forthcoming years interactive user controlled systems will be worked on. I.e. both data and processes related to the data can be managed and controlled. One of the goals will be to realize a large consistency and uniformity of all user interfaces figuring in such complex systems. User interface and supervisory components of UCSs will be based upon DICE (IS 3), which is now being transferred to a distributed processing environment. Facilities for 3D-I/O, process-to-process communication and for dynamic adaptability are being designed as extensions to the current DICE system.

WORKING PLAN 1989

User controlled systems are partially developed as the visible and sensible part of systems in the computer aided production engineering traject, namely PART (Planning of Activities, Resources and Technology), a SPIN/FLAIR process planning project together with the University of Twente.

The PART project started 1988; in 1989 tools and techniques will be developed to evaluate user interface requirements to implementable specifications. A first supervisory system will be designed to integrate these interfaces.

WORKING PLAN AFTER 1989

Apart from the continuation of the SPIN/FLAIR project, research will be directed towards developing a combined method for designing information systems and user interfaces, with ergonomic quality. To this merging user interface specific methods in general software engineering techniques is necessary.

Department of Computer Systems and Telematics

The department of Computer Systems and Telematics is in the midst of an expansion from an operating systems and networking support group to a research-oriented component of CWI's computer science departments. This expansion started in 1988 and will continue for a period of three years, at which time we expect the department to have a series of fully-staffed research projects that cover a broad range of areas that are not currently being addressed with other groups at the Institute. In addition to these tasks, several members of the department will continue to be responsible for the support of CWI's central computing facilities and our national and international network connections.

The research goals of the department are to draw on its considerable systems expertise as a means of expanding the capabilities of operating systems in a networked environment. That environment may be multi-disciplined and cover a wide geographic area, it may be directed toward the support of a particular discipline over a wide geographic area, or it may involve the development of systems to serve users in a local area network environment. It covers both user-level applications support as well as operating systems and, where appropriate, hardware-level support for protocols to implement time critical aspects of interconnected computing.

At present, the department supports one research project that studies multinational networked information collection and presentation systems for mathematical texts. In addition, we continue to expand our activities in the area of protocol support for wide-area networks (principally between existing UNIX-based networks and ISO protocols). We also plan to start a new project this year to study protocols for efficient job-dispatchment and monitoring for use in a multi-server/multi-client computing environment. In all cases, our aim is to provide not only a series of prototypes that investigate compelling

systems-related problems, but to also acquire an insight into fundamental systems-related issues in network-based computing.
A list of the department's projects are:

CST 1 : Networked document retrieval and manipulation
CST 2 : Internet/ISO protocol development
CST 3 : Network-based job entry and performance monitoring

Department of
Computer Systems and Telematics

LIST OF PROJECTS

CST 1 : Networked document retrieval and manipulation
CST 2 : Internet/ISO protocol development
CST 3 : Network-based job entry and performance monitoring

	Projects				working			
Name	CS1	CS2	CS3	misc.	hours	regu-	de-	guests
						lar	tached	
appointed								
Bulterman			•		1.00	1.00		
Meertens	•				-	p.m.		
Beertema		•			1.00	1.00		
Pemberton	•				-	p.m.		
Karrenberg	•	•	•		1.00	1.00		
Mullender			•		1.00	1.00		
Draper	•				1.00	1.00		
Carrasquer	•				1.00	0.50		
Kroode, ten				•	1.00	1.00		
Kuiper				•	1.00	1.00		
IJsselstein				•	0.70	0.70		
Rahmani				•	1.00	1.00		
Klaauw, v.d.				•	1.00		1.00	
Orange				•	1.00	1.00		
total appointed						10.20	1.00	0.00
regular priority								
operator 1				•	0.50	0.50		
scient.res.1			•		1.00	0.70		
scient.res.2			•		1.00	0.30		
total priority						1.50	0.00	0.00
total estimated						11.70	1.00	0.00

PROJECT CST 1

TITLE: Networked document retrieval and manipulation

TITEL: Opzoeken en manipuleren van documenten over netwerken

ABSTRACT
The EUROMATH project is aimed at investigating the retrieval and manipulation, with an integrated user interface, of mathematical documents residing in local, national and international databases throughout European countries. The EUROMATH project consists of a number of components, including database access mechanisms (for processing of queries regarding available articles), communication mechanisms (for transferring abstracts and other documents internationally and nationally), text formatting mechanisms (for describing and storing articles), and text processing mechanisms (for producing soft-copy and hard-copy output for individual readers).

SAMENVATTING
Het EUROMATH project onderzoekt het opzoeken en manipuleren, met een geïntegreerde gebruikersinterface, van wiskundige documenten opgeslagen in plaatselijke, nationale of internationale gegevensbanken. Het EUROMATH project bestaat uit een aantal componenten, waaronder mechanismen voor de toegang tot gegevensbanken, voor communicatie, voor formatteren en voor tekstverwerking.

PROJECT MEMBERS
prof. L.G.L.T. Meertens (project leader), AA
D.L. Draper
M. Carrasquer
D.F. Karrenberg
S. Pemberton (AA)

EXTERNAL CONTACTS
EUROMATH is a CODEST project in which the technical partners are NIHE (Dublin), DDC (Lyngby), and CWI, with the cooperation of FIZ (Karlsruhe). Overall project direction is monitored by the European Mathematical Trust (EMT).

START OF PROJECT: 1988

CLASSIFICATION CODES

NWO-classification	: P175, T120
1987 CR Classification Scheme	: D.2.2, D.2.3, D.2.7, D.3.2, H.1.2, H.2.3, H.3.3, I.7

PROJECT DESCRIPTION

The EUROMATH project aims to provide Europe's mathematicians with an integrated interface for the production, manipulation, retrieval, and delivery of structured mathematical documents. The project, which is currently in its first phase, will combine the facilities provided by electronic mail, database management, and electronic publishing systems. CWI has the major design responsibility during this phase to provide an adequate system specification for an eventual implementation during the project's later phases.

The overall structure of the EUROMATH network is to provide support for a series of local user hosts that are connected either directly or indirectly via national access networks (utilizing existing facilities) to one or more national backbone hosts. The backbone hosts are, in turn, connected to an international backbone network that provides sharing possibilities for multi-national databases. Each user of the EUROMATH network will have local facilities available for the formatting and printing of documents on a machine type that is appropriate for that user. These may range from PC-style machines (IBM PC's or Macintoshes), Sun-style workstations, or larger local facilities (with shared printing and typesetting facilities). The national host will act as a local server for documents and document search requests for both national clients and international clients.

PLANS FOR NEW RESEARCH

The EUROMATH project is currently in a definitional phase, where the basic requirements of the system are being defined, a feasibility analysis of the project is being undertaken, and an overall functional specification is being developed. A part of this work includes the surveying of existing facilities for electronic mail and database access, as well as facilities for electronic publishing on a wide range of machines. The functional specification for the system will outline the further research needs in terms of interactive document editing and formatting, and the development of an information retrieval system that can make use of both existing databases and new information specific to the EUROMATH project.

While much of the basis for the EUROMATH project is available in existing (but non-connected) application program bases, the plan is to expand on the functionality of these systems. There are several significant research problems that need to be addressed in the area of interactive structured document editing for mathematical texts, as well as in coordinated network access in a multi-level network hierarchy. There are also several security and integrity issues that need to be considered within the overall structure of the project.

It is expected that an initial implementation of the project will be based on the existing functionality of a series of interconnected UNIX hosts. Work on the initial implementation, using existing text formatting and database facilities, will start already in 1989.

PROJECT CST 2

TITLE: Internet/ISO protocol development

TITEL: Het Internet/ISO protocol ontwikkeling

ABSTRACT
As the desire to communicate electronically among researchers within Europe (and worldwide) increases, it becomes important to expand the reach of individual computer networks. The Internet/ISO protocol development project is aimed at realizing this goal by investigating means of implementing protocols and protocol converters which will allow user-level network traffic to be routed between networks that support varying protocols. In particular, this project is aimed at providing protocol translation facilities between Internet protocols (primarily RFC-822) and ISO protocols (X.400) for message and mail traffic.

SAMENVATTING
Gezien de toenemende wens van onderzoekers binnen Europa (en wereldwijd) om elektronisch te communiceren, wordt het belangrijk om de reikwijdte van individuele computernetwerken uit te breiden. Het Internet/ISO protocol ontwikkelingsproject richt zich op het realiseren van deze wens door mogelijkheden te onderzoeken voor het implementeren van protocollen en protocol converteerders die het mogelijk maken dat netwerkverkeer op gebruikersniveau wordt geleid tussen netwerken die verschillende protocollen ondersteunen. In het bijzonder richt dit project zich op het beschikbaar stellen van vertaal protocol faciliteiten tussen Internet protocollen (voornamelijk RFC-822) en ISO-protocollen (X.400) voor bericht en postverkeer.

PROJECT MEMBERS
D.F. Karrenberg (project leader)
P. Beertema

EXTERNAL CONTACTS
The primary contacts will be at the University College London (S.E. Kille) and at Nottingham University (H.T. Smith). In addition, contact will be maintained with RARE as well as members of other constituent networks (such as EARN, EUnet, and Janet).

START OF PROJECT: 1988

CLASSIFICATION CODES

NWO-classification : P175, T120
1987 CR Classification Scheme : C.2.0, C.2.2, H.4.3

PROJECT DESCRIPTION

The Internet/ISO protocol project is a joint effort between CWI, University College London and Nottinghan University aimed at developing a publicly distributable X.400 implementation in a UNIX environment. This system is particularly targetted at the area of protocol conversion. This will be of importance in establishing full OSI services in conjunction with existing networks such as EARN, EUnet, and Janet.

There is currently a X.400 system development project that is being undertaken by researchers at UCL and Nottingham U., with some participation from other sites. These groups have produced an initial X.400 implementation for a UNIX environment called *PP*. PP has demonstrated X.400 interworking with a number of other systems, and has a basic queue structure which will support all X.400 P1 functionality. The queue structure is designed in a flexible manner to support general reformatting. In particular full RFC 987 reformatting will be supported. During the period of this contract, X.400(88) will be developed, and the system will be able to operate as a relay between X.400(84) and X.400(88). The intention is to provide a flexible X.400 system, which can be developed to provide a very wide range of services.

PLANS FOR NEW RESEARCH

The primary goal of the project is to develop an X.400 implementation that will service the needs of the UNIX (and therefore, the EUnet) community. The produced system will provide the following types of support:

- The 1984 P1 protocol.
- The 1988 P1 protocol (including all new protocol elements and procedures for distributed operation).
- The 1984 P2 protocol.
- The 1988 P2 format (including support for all new heading protocol elements, and flexible use of body parts).

The developed system will include a facility to handle X.400 extended naming and addressing, but will not yet utilize directories. It will provide full mapping between X.400 and RFC 822 based systems, according to RFC 987 and RFC 1026. In addition, it will provide mapping to 1984 and 1988 RTS. The latter will include ACSE and Presentation, and Session Version 2.

The CWI component of the project will be the protocol conversion between existing EUnet protocols and X.400. All of the well-known 1984 profiles will be supported: NBS, BT ONA, Cen/Cenelec, CCITT. Choice of 1988 profile is not clear at this stage, but it would be expected to support any reasonable profile.

In terms of protocol expansion, mailgroup 19 (RFC 987) will be updated to provide support for X.400 (1988), and these extensions will be implemented. It is hoped that this revision will be done in conjunction with RARE, as well as with the UK and US groups who participated in the first specification.

The software developed for this project, will be made available to RARE with no restrictions on usage. It is intended to make available or use the software produced to Universities and Research Groups, as this package is a general purpose X.400 system, as well as a gateway. The package will be publicly distributable in source form.

PROJECT CST 3

TITLE: Network-based job entry and performance monitoring

TITEL: Op netwerk gebaseerde taakverdeling en vermogen meetsysteem

ABSTRACT

The Networked Execution Server (NES) project is aimed at studying the use of a collection of compute server computers in a coordinated manner for remote execution (and parallel execution) of user programs in a workstation-oriented environment. In particular, we are interested in studying three aspects of this problem:

1) Task Allocation and Resource Sharing within a network of compute server, compute client, and monitoring computers;

2) Communications Structures for supporting high-speed communication, possibly including hardware interconnection issues and hardware/software protocol issues;

3) User Interfaces for graphically defining execution streams as collections of user-defined and system-defined components located across the network, and for displaying the status of both the execution stream and the system as a whole in user- and system-defined forms.

Our work is constrained by the desire to use existing communications equipment where practical (i.e., Ethernet), although not necessarily existing network communication protocols.

SAMENVATTING

Het Networked Execution Server (NES)-project is gericht op het bestuderen van het gebruik van een collectie compute server computers op een gecoördineerde wijze voor uitvoering op afstand (en parallelle uitvoering) van gebruikersprogramma's in een omgeving die georiënteerd is op werkstations. We zijn in het bijzonder geïnteresseerd in de bestudering van drie aspecten van dit probleem:

1) Task Allocation en Resource Sharing in een netwerk van compute server, compute client, en monitoring computers;
2) Communicatiestructuren voor de ondersteuning van hoge-snelheid communicatie, mogelijkerwijs hardware verbindingsproblemen en hardware/software protocolproblemen inbegrepen;
3) Gebruikersinterfaces om uitvoerstromen te definiëren als verzamelingen gebruikersgedefinieerde en systeemgedefinieerde componenten in het netwerk, en voor het tonen van de status van zowel de uitvoerstroom als het systeem als geheel in gebruikers- en systeemgedefinieerde vormen.

Ons werk wordt beperkt door de wens gebruik te maken van bestaande communicatiemiddelen indien dit praktisch is (b.v. Ethernet), hoewel niet noodzakelijkerwijs van bestaande netwerk communicatie protocollen.

PROJECT MEMBERS
dr. D.C.A. Bulterman (project leader)
D.F. Karrenberg
E.S. Mullender
junior or scientific researcher (vacancy)

CONTACTS
Within CWI, contacts will be maintained with several groups, namely those involved in distributed systems (S.J. Mullender, project leader) and with the user interface groups of AA (S. Pemberton, project leader). Outside of CWI, contacts include Brown University (dr. T.W. Doeppner) and with Encore Computer Corporation (R. Simpson). As this is a new project, we will also investigate other forms of national and international cooperation.

START OF PROJECT: 1989

CLASSIFICATION CODES

NWO-classification	: P175, T120
1987 CR Classification Scheme	: C.2.1, C.2.2, C.2.3, D.4.4, D.4.8

PROJECT DESCRIPTION

The Networked Execution Server Project (NES) is a new project that is aimed at investigating means of defining and controlling execution streams that will be implemented across a local area network. For our purposes, an execution stream is considered to be one or more threads of control that make up a separate unit of work called a 'job'. Each component will be a self-contained unit that may or may not execute in conjunction with other units. Any of the components of the job may execute on any of the machines across the network. Note that unlike distributed operating systems, we offer no network-wide automatic scheduling services, but will rely on a mechanism for dispatching work based on a user's evaluation of the present state of a number of server computers. The dispatching process accounts for program data as well as program text.

In particular, we are interested in investigating means of:

- defining execution streams that have component parts residing on a set of central server computers which are connected at a 'peer' level, with minimal restrictions on the a-priori assignment of processes to processors (except in the case of physical devices that need to reside at a well-known location in the network);
- defining protocols and communication structures that allow the owner of an execution stream to flexibly pass data from one control computer to another, with support for data rates and error/exception control that will make their use practical;
- defining a user interface environment that provides a layout system for defining execution streams as collections of interconnected set of shared and private components, an execution guidance system that assists in selecting a target set of machines, and a performance monitoring system that allows the user to monitor his or her job (or those of other users) from any workstation in the network.

Preliminary work on NES project was performed at Brown University (Providence, RI, USA). As a part of this effort, a prototype execution server system was developed that addresses the issues listed above. The prototype system consists of two subsystems: NES-LAYOUT and NES-CONTROL.

NES-LAYOUT

LAYOUT allowed a user to define a job by selecting predefined functions from a system library and then indicating their logical interconnection. The LAYOUT function then produced an internal representation that was suitable for subsequent loading when the execution stream was ready to be run.

NES-CONTROL

Once an execution stream had been defined, the CONTROL function was used to activate the stream itself, and to monitor its performance and status on any appropriate display in the network. At activation time, the user could manually control the detailed allocation of stream components,

or he could rely on defaults that were specified at the time the system was created with LAYOUT. The user could also monitor the status of any other stream that was active in the system.

The prototype NES was intended to be a vehicle to understand the significant research problems that exist in developing a full-scale prototype system. It was implemented using Internet (TCP/IP) protocols, an X-windows interface system and an an Ethernet local-area network.

Plans for new research

Our current work will be segmented into three related activities. An overview of each of the activities will be presented here.

Task Allocation and Resource Sharing

The current version of the NES environment uses a rigid, manual system of assigning tasks to individual hosts over the network. While this assignment has been useful for purposes of evaluation, it has demonstrated the need for a more flexible, automatic assignment procedure.

The task allocation process depends on several factors: the level of granularity provided by the execution stream itself, the capabilities of the communications structure, the capabilities of each host in the system, the dynamic loads on each host, and the dynamic network usage levels. To date, we have investigated worst-case overhead situations in which the level of task granularity has been very low (as low as a single cosine function call in C); this has demonstrated a system in which short network packets are created that are processed with the full overhead of the TCP protocol.

Once a protocol structure has been defined, a detailed task allocation process will be developed that will be used to assist placement of applications across hosts in the network. This work will initially be limited to run-time dispatching of various threads of control, using a mixture of system and user insights. The work could include the development of scheduling algorithms to assign processes to processors at compile-time, although the feasibility of this approach in a dynamic environment is open to question. Additional work will investigate means of dynamically balancing the load of an executing experiment, although we feel that this result will probably only be realized in the context of an underlying distributed systems framework (such as that being considered in AA 2, Amoeba).

Communications Protocols

The demonstration NES system has given positive indications of the value of a stream server in a multi-machine environment. It has also shown that the use of communications protocols that are intended for conventional communications cannot be used to support efficient communication within and among various streams of control. It has not shown, however, that the Ethernet network structure is, in-and-of itself, an unsuitable communications medium.

During this phase of our work, we will evaluate the use of various Ethernet-based protocols as an information transfer medium in a NES environment.

Ethernet is practical because of its wide integration into the workstation marketplace, and its wide acceptance on various types of compute servers at CWI. In order to make the use of Ethernet technically (as well as economically) practical, we will evaluate existing communications protocols and, if necessary, define a protocol that is suitable to relatively sustained communications and that can co-exist in both a UNIX and an Amoeba environment.

User Interface Design

The design of an appropriate user interface will consume the initial portion of our research effort. In particular, we will investigate revisions to the current NES system that will make the user interface more universal and more robust. The activities that need to be pursued here include the development of a transportable interface that can be initially be used in a multi-vendor UNIX environment, but that is also transportable to other environments, such as the Amoeba distributed operating system, and the integration of site-specific configuration information into the LAYOUT and CONTROL subsystems.

The development of a user interface for the execution stream environment can be seen as the development of a graphics-based language. The development of the language consists of the specification of the properties of that language (including the definition of components in a multi-threaded job stream), the development of a logical interconnection structure, and the mechanism for integrating user-defined output displays into the monitoring scheme. The implementation of the language consists of defining a specific instance of the specification for a particular operating environment. In this regard, we plan to provide a version of the language that will be able to be used in multiple operating systems environments. The purpose of this approach is to make sure that the language itself is not tied to the facilities of a particular operating system, and that a broad-range of execution computers can be used.