Stichting Mathematisch Centrum

Scientific Programme 1990

Long-Range Plan 1991-1995

Part 1

Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science

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Preface

The Centre for Mathematics and Computer Science (CWI) is the research institute of the Stichting Mathematisch Centrum, which was founded on February 11th, 1946. The task of the institute is the systematic pursuit of the mathematical sciences and computer science for the benefit of the national and international community. Three essential elements in executing this task are:

* Carrying out excellent research, primarily involving fundamental research (both pure scientific and strategic/application oriented).
* Knowledge transfer and expert training targeting the academic research sector, industry and government agencies.
* Positioning CWI as national and international meeting point for researchers.

The present document details the research plans of the six scientific departments and of the department for Computer Systems and Telematics for the years 1990-1995.

In the period 1984-1988, CWI obtained additional support as part of the Dutch government's Information Technology Stimulation Programme (INSP), in order to develop further as a centre of excellence, in particular with regard to computer science. During those years, CWI also achieved a healthy participation in European R&D programmes such as ESPRIT.

Since 1989, the Dutch research organisation NWO, has provided only a part of the INSP funding, which CWI has been accustomed to receive. At the same time, the income from participation in European research programmes also went down. As a consequence, the research plans for 1989 could not be fully realised. In 1990 and following years, a further reduction of research activities seems inevitable.

The Research Plan for 1990-1995 reflects these difficulties. In all departments several important research projects, which were anounced in the CWI Policy Document 1988-1993 and in previous Research Plans, either could not be started or were insufficiently staffed. In the present Plan, each department has indicated three vacancies (projected research positions; usually replacements for departing staff in temporary appointments) which should be given top priority. It seems unlikely that these priorities will all be realised; in addition, all further requests for research positions are especially in jeopardy.

The tight financial situation has had its effects on all scientific departments. Some examples are:

- *Department of Analysis, Algebra and Geometry (AM).* The number of projects reduced to five. All projects are understaffed; the lack of manpower is especially tangible in analysis (AM 2 and AM 3) and in algebra and symbolic computation (AM 1).
- *Department of Operations Research, Statistics, and System Theory (BS).* The long tradition of consultation and contract work in operations research is in danger because departing researchers in BS 1 could not be replaced. The mathematical statistics group (BS 4, BS 5 and BS 6) is severely undersize.
- *Department of Numerical Mathematics (NW).* The project NW 3, where the research on numerical application of vector and parallel computer architectures is focussed, has no junior researchers and is also otherwise understaffed.
- *Software Technology (AP).* The research in this department is dangerously dependent on external funding. The fundamental research, which is of outstanding quality and essential for future development, is under severe threat.
- *Department of Algorithmics and Architecture (AA).* All projects are undersize. The essential and highly applicable research on distributed systems (projects AA 2 and AA 4) is particularly under pressure. The researchers in these groups are involved in several externally funded projects; at the same time, they are expected to contribute much to the proposed new research project 'Multimedia'.
- *Department of Interactive Systems (IS).* This whole department threatens to become critically undersize. Apart from the research group on intelligent CAD systems - which is funded completely by NFI - all projects are unacceptably understaffed. This endangers the potential for contract research, in which IS has always been very active. In addition, the success of the proposed new research project 'Multimedia' depends strongly on the input from this department.
- *Department of Computer Systems and Telematics (CST).* The expansion of the department from an operating system and networking support group to a research-oriented component of CWI's computer science departments requires an essential extension of the staff in both CST 1 and CST 2.

Contents

Department of

Analysis, Algebra and Geometry

GENERAL REMARKS

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 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 various more specific projects 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. That is also a good way to have expertise available in many specialization areas without having specific projects in all those areas. Moreover, extra attention to interaction fields is in line with global tendencies of the development of mathematics as a whole at the present time. Two examples of these tendencies 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 project AM 2. 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 MAPLE, 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.

This idea has been around since January 1985 but lack of manpower has so far prevented its realization. Such a laboratory should not be just a local CWI activity but should be a part of larger integrated SMC activities in nonlinear systems dynamics also involving neighbouring sciences as suggested in 'NWO naar '95: route en horizon, Part 2, section IV 1.8, page 67'. Some preliminary discussion material concerning this is contained in a recent note by Pasmanter, Sanders, Verhulst, Hazewinkel (May 1989).

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 more 'symbolic computational' (computer algebra) aspects of the 'program library related' aims described above find a measure of realization in the computer algebra part of project AM 1 (research aspects) and the activities of the CAN (Computer Algebra Nederland) centre of expertise (linked to and housed in the department) (implementation and maintenance aspects).

These two 'computational' interests of the department AM agree with a general preliminary recommendation of the most recent evaluation committee (Oct. 1989, no report available yet) to the effect that given its structure and facilities the CWI might do well to concentrate on all aspects of 'computational science' (taken in a wide sense).

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.

DIVISION INTO PROJECTS
At the moment research in the department AM is divided into a number of projects labelled AM 1 - AM 5, and Miscellaneous. Here, basically, under Miscellaneous are grouped together those activities which involve ≤ 1fte (often much less) and which do not fit well into one of the other five 'larger' projects AM 1 - AM 5. Activities under 'Miscellaneous' range from well-defined well-focussed specific smaller project activities such as (aspects of) classical analysis and (computational) number theory and a project on the history of mathematization to various bits of incidental research often arising from the 'knowledge-pool' activities of the department.

The division into projects is different from that of previous years. The main changes are that 'algebraic mathematical physics', 'dynamical systems' and 'analysis on simple Lie groups' have been grouped together - 'algebraic mathematical physics' and 'analysis on simple Lie groups ...' in particular were anyway evolving towards each other - and that the remaining two 'smaller' activities have been moved to Miscellaneous.

THE 'BELEIDSNOTA 1988-1993' AND PRIORITIES. CAUSES FOR ALARM
In January 1988 the CWI published a document (in two parts) describing a number of intended research area priorities. Those involving the department AM immediately were labeled 'Global analysis', 'Nonlinear functional analysis', 'Asymptotics', 'Image reconstruction and processing', 'Symbolic computation', and (joint with NM) 'Computer-aided number theory'.

Comparing this with the current plans for 1990 one notes that the two small planned projects in this list 'Asymptotics' and (the AM part of) 'Computer-aided number theory' receive more or less the attention planned. 'Symbolic computation' gets some attention within the framework of AM 1 but only at something like a half order of magnitude less than should be the case. 'Image reconstruction and processing' has some weight to it (AM 5 and BS 6) but certainly could do with reinforcement. Finally, though aspects of 'Global analysis' and 'Nonlinear functional analysis' can be found in AM 2 and AM 3 it cannot be said that much progress has been made in realizing these project aims.

There is, clearly, a severe lack of manpower. This reflects itself in the assignment of the 'priority vacancies' which are, in that order, assigned to the computer algebra/symbolic computation part of AM 1, to AM 2 (Analysis and mathematical physics) and to AM 3 (Nonlinear analysis and Biomathematics).

Even when all these 'priority vacancies' would be honoured, the department would still be in a position where the talents and expertise of its more senior members would be in a sense insufficiently used. Thus, then, there would still be no junior researcher to profit from the insights and expertise of A.M. Cohen and A.E. Brouwer in the discrete mathematical structures part of AM 1 and project AM 2 with four senior researchers (S.N.M. Ruijsenaars, J. de Vries, T.H. Koornwinder, M. Hazewinkel) would still have had one junior researcher.

This, and what has gone before, motivates the four 'requested vacancies': one for computer algebra, one for discrete mathematical structures, one for integrable systems and/or quantum groups and one for image processing and reconstruction.

There are various 'outside funding sources' besides the regular NWO source with which this document is primarly concerned. These 'outside funding sources' tend to stress at present the applied and saleable product sides of research and development rather than the more fundamental aspects. This makes it more difficult for a department like AM to compete for such funding. Even so attempts are made. In particular the department participates in a seven laboratory SCIENCE proposal on wavelets analysis and applications which, as far as this department is concerned, is focussed on the use of wavelets for image reconstruction and processing. A decision is expected in December 1989. Further possibilities are being explored: for Computer algebra both SCIENCE and STW; for Image Reconstruction and Processing STW and for Mathematical Biology also STW.

Department of
Analysis, Algebra and Geometry

LIST OF PROJECTS

AM 1   Algebra, discrete mathematical structures and computer algebra
AM 2   Analysis and mathematical physics
AM 3   Nonlinear analysis and Biomathematics
AM 4   Asymptotics
AM 5   Image processing and reconstruction
AM Misc. Miscellaneous

		AM1	AM2	AM3	AM4	AM5	MISC	working time in fte	budget time	de-tached	guests	remarks
appointed												
Hazewinkel	head dept.		*				*	1.00	1.00			
Cohen	proj.leader	*						1.00	1.00			
Brouwer	researcher	*						0.10	0.10			
Ruitenburg	researcher	*						1.00	0.79			
Koornwinder	proj.leader		*					1.00	1.00			
Vries, de	proj.leader		*					1.00	1.00			
Ruijsenaars	researcher		*					1.00		1.00		
Dijkhuizen	jr.researcher		*					1.00	1.00			
Temme	proj.leader				*			1.00	1.00			
Olde Daalhuis	jr.researcher				*			1.00	1.00			
Diekmann	proj.leader			*				0.60	0.60			
Metz	advisor			*				-	p.m.			
Heesterbeek	jr.researcher			*				1.00	1.00			
Neerven, van	jr.researcher			*				1.00	1.00			
Greiner	guest research			*				1.00			0.67	
Inaba	guest research			*				1.00			0.56	
Heijmans	researcher			*		*		1.00	1.00			
Roerdink	proj.leader					*		1.00	1.00			
Groen	advisor					*		-	p.m.			
Zwaan	jr.researcher					*		1.00	1.00			
Alberts	researcher						*	1.00	0.24			
Dijkhuis	researcher						*	1.00	1.00			
Lune, v.d.	researcher						*	0.75	0.75			
total appointed								19.45	15.48	1.00	1.23	
priority 1	researcher	*						1.00	0.50			
priority 2	jr. researcher		*					1.00	0.50			
priority 3	jr. researcher			*				1.00	0.50			
advisor	advisor	*										
visitor	guest research				*						0.17	
visitor	guest.research		*								0.09	
request 1	jr. researcher	*						1.00	p.m.			
request 2	jr. researcher				*			1.00	p.m.			
request 3	jr. researcher	*						1.00	p.m.			
request 4	jr. researcher		*					1.00	p.m.			

PROJECT AM 1

TITLE: Algebra, discrete mathematical structures and computer algebra

TITEL: Algebra, discrete wiskunde en computeralgebra

ABSTRACT
The project concerns the relation between graphs/geometries on the one hand and group theory on the other hand. The main interest lies in graphs and groups of Lie type. These studies have led to the development of algorithms and, later software packages, thus focussing in on computer algebra.

SAMENVATTING
Dit project omvat onderzoek naar de relaties tussen grafen en meetkunde aan de ene kant en de groepentheorie aan de andere kant. Het merendeel der interesse gaat uit naar grafen en meetkunden van Lie-type. Deze onderzoekingen hebben geleid tot de ontwikkeling van algoritmen en 'software packages': vandaar ontwikkelingen in de richting van computer algebra en symbolisch rekenen.

PROJECT MEMBERS
Dr. A.M. Cohen (project leader)   vacancy (advisor)
Prof.dr. A.E. Brouwer (researcher)   requested vacancy (junior researcher)
Dr. G.C.M. Ruitenburg (researcher) requested vacancy (junior researcher)
priority vacancy (researcher)

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), J.A. Sanders (Free University of Amsterdam), Prof. M.W. Liebeck (Imperial College), Prof. J. Saxl (University of Cambridge), Dr. A.A. Ivanov (Institute of System Studies, Moscow)

START OF PROJECT: 1981

END OF PROJECT: not yet determined

CLASSIFICATION CODES

NWO-classification   : P110, P120, P150
1980 Math. Subj. Class. : 05-XX, 06-XX, 20-XX, 51Exx, 52-XX, 68Q40

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

1. *Finite Subgroups of Lie Groups.* Starting date: 1983. Dynkin classified maximal semisimple closed Lie subgroups. He restricted his attention to Lie subgroups of strictly positive dimension. A closed Lie subgroup of dimension 0 is a finite group. The problem of classifying all finite subgroups of a classical (simple) Lie group comes down to the search for all finite groups with a representation of a certain degree leaving invariant a quadratic, symplectic or unitary form, and so can be viewed as part of the standard representation theory for finite groups. For each of the groups of exceptional Lie type, the question of determining all finite subgroups that are maximal closed subgroups has been studied, and some of its aspects, such as the construction of examples related to an observation of Kostant's still receive some attention.

2. *Geometries and Groups.* Starting date: 1982. The structure of point/line geometries associated with parabolic subgroups (Schubert varieties) has been the subject of intensive study. In collaboration with Cooperstein major axiomatic characterizations have been given. This knowledge is being used in several combinatorial and finite-group theoretic studies, such as the determination of all parabolic permutation representations of Chevalley groups that are distance-transitive, also for geometric details on Tits systems in groups of Lie type (for example: hyperplanes of polar spaces). The effort of obtaining more geometric insight is now directed to the determination of orbit structures of certain modules on which groups of exceptional Lie type act. These studies often have a known solution in the case of a complex field, but provide a somewhat more complicated picture in the case of finite fields, where the combinatorial importance is usually greatest.

Apart from this, current activities involve characterizations of geometries by local properties that lead to global symmetry, and the writing of a book (jointly with F. Buekenhout) on diagram geometry.

3. *Graphs and Groups.* Starting date: 1981. A highly transitive action of a group G on a graph is the distance-transitive one, in which, for every distance realized in the graph, the set of all pairs of points at that distance consists of a single G-orbit. This action, as well as the related combinatorial concept 'distance regularity' has been extensively studied, and is the main subject of research of J.T.M. van Bon, whose most recent result is a decisive theorem for the complete classification of the affine distance-transitive case; also work of Cohen, Liebeck, Saxl, on the case of groups of exceptional Lie type is in progress.

4. *Software Development.* Starting date: 1988. The computer algebra group at CWI has developed the software package LiE for interactively computing with Lie groups. There are programs to compute a reduced expression of a Weyl group element written as a product of simple reflections, to compute the degrees, dominant weights and multiplicities of highest weight modules of reductive Lie groups, to compute the tensor product decomposition of two

such representations, symmetrized tensor powers of a single representation, to compute the trace and type of centralizer of a semi-simple element of a reductive Lie group, etc.

Currently, the following extensions are being considered: Young tableaux, faster algorithms for specific cases, more arithmetic capabilities, finite characteristic, finite fields, real Lie groups, more 'learning' facilities.

5. *Computer Algebra*. Starting date: 1989. A first exploration in this field has taken place, Cohen and Ruitenburg have written lecture notes on the subject. Presently, the attention is directed towards the theory behind LiE (see the above), and the study of Knuth-Bendix/Gröbner bases algorithms for various problems related to the fields in 2 and 3 (and even 1) listed above.

PLANS FOR THE FUTURE
More-and-more the projects 1, 2 and 3 will be considered from a computer-algebraic point of view. Specifically, we have the following in mind for the near future:
a. Computer algebraic construction of combinatorial objects of group theoretic and/or geometric importance.
b. Synthetic-geometric study of non-parabolic Lie group geometries.
c. Help complete the classification of distance-transitive graphs.
d. Extending/restructuring the existing package LiE.
e1. Further study of Lie group theoretic algorithms, partly covering the theoretic background for software as described in 3, partly directed towards connections of old classical invariant-theoretic problems with modern approaches such as Knuth-Bendix completion and Gröbner basis algorithms.
e2. Pilot study towards the development of a knowledge-based system for specific branches of mathematics (e.g. association schemes, algebraic groups, finite geometries), in which there is sufficient expertise at CWI. Once the goal has been achieved, the framework of the package could be used for other specific branches of mathematics, preferably supplied under the guidance of an expert visiting CWI for a period of at least half a year.

There are a large number of potential uses for symbolic computation packages. Potential uses include the following topics within the research interests of various members of the department: Theory of covariants (A.M. Cohen), Bernstein polynomials (G.C.M. Ruitenburg), Finite subgroups of Lie type (A.M. Cohen), Universal noncommutative formal groups (M. Hazewinkel), Stabilization of twin helicopter configurations (M. Hazewinkel), Nonlinear filtering algorithms for and simulation of stochastic dynamical systems (M. Hazewinkel), 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). Some of these are being, or will be, explored.

PROJECT AM 2

TITLE: Analysis and mathematical physics

TITEL: Analyse en mathematische fysica

ABSTRACT

This project involves (aspects of) harmonic analysis on homogeneous spaces, special functions, quantum groups, q-special functions, integrable dynamical systems, and topological dynamics and some of the manifold interrelations between these topics. There are a number of subprojects. These are described below.

SAMENVATTING

Dit project heeft te maken met de harmonische analyse op homogene ruimten, gewone en q-speciale functies, quantumgroepen, integreerbare dynamische systemen en topologische dynamica en enkele van de vele relaties tussen deze begrippen. Er is een aantal deelprojecten die hieronder apart beschreven worden.

SUBPROJECT AM 2.1

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 (psuedo-) Riemannian symmetric spaces, the study of special functions and the group theoretical interpretation of these functions. In particular extensions of the correspondence representations - special functions to the setting of quantum groups will be considered.

SAMENVATTING
Doel van dit project is de harmonische analyse op (pseudo-) Riemannse symmetrische ruimten, de bestudering van speciale functies, en de groepentheoretische interpretatie van deze functies. In het bijzonder zal de uitbreiding van de interrelatie tussen representatietheorie en speciale functies tot de context van quantumgroepen worden bestudeerd.

SUBPROJECT MEMBERS
Dr. T.H. Koornwinder (project leader)
Drs. M. Dijkhuizen (junior researcher)
requested senior visitor (1 month) (guest researcher)

EXTERNAL CONTACTS
Prof.dr. G. van Dijk, Drs. H.T. Koelink and Dr. E.M. Opdam (Leiden), Drs. R.J. Beerends (applied for NWO post-doc position), Dr. G.J. Heckman (Nijmegen), classical analysis group Delft University of Technology, Prof.dr. E.G.F. Thomas (Groningen), Prof.dr. J. Korevaar (University of Amsterdam), Dr. W. van Assche (Leuven, Belgium), Prof. R. Askey (Madison, Wisconsin, USA), Prof. I.G. Macdonald (London, UK), Dr. K. Mimachi and Dr. M. Noumi (Japan), harmonic analysis group Tunis (Tunesia)

START OF SUBPROJECT: 1972

END OF SUBPROJECT: not yet determined

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

In the near future, Project AM 2 will remain concentrated on the topic of q-deformed structures. Such structures 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 Weyl group, the quantum group deformations of semisimple Lie groups and the q-hypergeometric function deformations of the usual hypergeometric functions. In addition, there are interrelations between these q-deformations.

In particular the research will encompass the following aspects:

- *Quantum groups.* It has been well established now that many q-hypergeometric polynomials orthogonal with respect to discrete weights naturally live on quantum groups, in particular on $SU_q(2)$, see recent work by Vaksman a.o., by Noumi, Mimachi a.o., and by Koornwinder and Koelink. Recently, Koornwinder showed that Askey-Wilson polynomials (being orthogonal with respect to an absolutely continuous measure) can also be interpreted on $SU_q(2)$. Koelink (a Ph.D. student of Koornwinder) has almost completed work on the classification of the irreducible *-respresentations of the Hopf *-algebra corresponding to $U_q(n)$. New developments will be treated in a seminar at the CWI. The research will be continued for quantum group analogues of more general compact, and also noncompact semisimple Lie groups. Both the structure and representation theory of quantum groups and the interpretations of special functions will be studied. For this last topic we hope to make contact with the next item:

- *Special functions associated with root systems.* In a remarkable series of papers Heckman and Opdam have developed a theory of Jacobi polynomials and hypergeometric functions associated with arbitrary root systems. Next Macdonald developed a theory of q-Jacobi polynomials associated with root systems. There are still many open problems, both regarding explicit formulas and harmonic analysis, on which we intend to work.

- *q-Hypergeometric functions* are of course also studied independent of quantum groups or root systems. This theory is expanding very fast, cf. Askey, Ismail, Gasper, Rahman, etc.. In cooperation with the classical analysis group of the Delft University of Technology recent developments will be covered in a seminar and we will add our own research results.

- *Infinite-dimensional Lie algebras and groups.* Research in this area, connected with special functions, will remain an option for the future. However, the quantum groups seminar will also pay attention to developments in this area, joint with subprojects AM 2.2 and AM 2.3 (M. Hazewinkel and S.N.M. Ruijsenaars).

SUBPROJECT AM 2.2

TITLE: Lie algebras, Hopf algebras and integrable dynamical systems

TITEL: Lie-algebras, Hopf-algebras en integreerbare dynamische systemen

ABSTRACT
The project, concerns investigation of algebraic, algebraic-geometric, combina-
torial, and representation theoretic aspects of completely integrable Hamil-
tonian systems (both classical, and quantum) and of the exactly-solvable
models from lattice statistical mechanics. There are relations with strings (via
Kac-Moody and Virasoro algebras), conformal field theory and knot polyno-
mials and monstrous moonshine.
    There is particular interest in the relations between the various known
approaches to complete integrability (AKSRS, dressing, inverse spectral
transform, vertex operators, ...).

SAMENVATTING
Dit project omvat onderzoekingen betreffende de algebraïsche, algebraïsch-
meetkundige, combinatorische en representatie-theoretische aspecten van vol-
ledig integreerbare Hamiltoniaanse dynamische systemen (zowel klassiek al
quantum) en dezelfde aspecten van de zogenaamde exact-oplosbare modellen
uit de rooster-statistische mechanica. Er zijn relaties met 'strings' (via Kac-
Moody en Virasoro en W-algebras), conforme veldentheorie en knopenpolyno-
men en 'monstrous moonshine'.
    Er is speciaal interesse in de relaties tussen de diverse verschillende metho-
den om integreerbare systemen te verkrijgen (AKSRS, 'dressing', inverse spec-
trale transformatie, vertex operatoren, ...).

SUBPROJECT MEMBERS
Prof.dr. M. Hazewinkel (project leader)
priority vacancy (junior researcher) (joint with AM 2.3)
requested vacancy (junior researcher) (joint with AM 2.3)

EXTERNAL CONTACTS
Prof.dr. H. Capel (Theoretical Physics, University of Amsterdam), Prof.dr. R.
Martini (University of Twente), Dr. Th.J. Smit (University of California at
Berkeley), Drs. H.-J. Imbens (Mathematical Institute, University of Utrecht),
Prof.dr. B. de Wit (Theoretical Physics, University of Utrecht), Prof. A.M.
Vinogradov (MGU, Moscow), Prof. F. Bais and Prof. H. Capel (ITF, Univer-
sity of Amsterdam), group of Prof. L. Faddeev (LOMI, Leningrad)

START OF SUBPROJECT: 1982

END OF SUBPROJECT: not yet determined

CLASSIFICATION CODES

NWO-classification   : P120, P130, P140, P150, P190, P210
1980 Math. Subj. Class. : 14K25, 22E65, 82A67, 81E13, 58F07, 16A24, 17B65

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

The field of research, as outlined above is a very large one. So far, attention has been paid to only a few aspects:

(i)   The relation between τ-functions and the Riemann-Hilbert approach. To elucidate: many solutions to soliton equations can be written in terms of τ-functions (a generalization of theta functions), e.g. in the form $\partial^2[\ln\tau(x,t)]/\partial x^2$. An at first sight totally different method of obtaining solutions is the so-called dressing method, for which a family of Riemann-Hilbert boundary value problems is solved. These are intimate relations, however, and aspects of those have been studied.

(ii) The question of whether there exist systematic ways of going from discrete (difference) integrable systems to continuous ones. There is evidence that the discrete systems are more fundamental. No substantial results have been obtained so far.

(iii) Many, but as far as is known, not all integrable systems come from Lie algebras via the so-called AKSRS scheme. One class for which this was still open is the Calogero-Moser class. It turns out that these are obtainable via a generalization of the AKSRS scheme.

(iv) The relation (if any) between the existence of a 'covering linearization' and complete integrability. Such covering linearizations exist e.g. for the KdV only (in a formal sense, so far), for the KP (which turns out to be an infinite dimensional Riccati equation) and the Toda systems (W. Symes).

Future research possibilties include: investigations in the role of Kac-Moody algebra (and associated combinatorial identities) in the hard hexagon model, the structure of the KP equation as an infinite dimensional Riccati equation, the relations between integrability and the existence of a fractional linear covering linearization, the 'dressing specialization problem', the construction and investigation of 'universal' Hopf algebras, uniqueness theorems for Hopf algebras, development of a systematic theory of deformations of Hopf algebras, and the theory of q-special functions associated to quantum groups (= part of subproject AM 2.1). After these fairly global indications let us indicate three specific problems which, given the manpower to do so, we would like to attack.

(a)   Sato's infinite Grassmannian which 'is' the solution space of the KP (this relates to my result that the KP is in fact an infinite Riccati equation) is also (more or less) the classifying space BU of algebraic topology. Now $H^*(BU)$ is (in a natural way) the underlying ring of the functor of the big Witt vectors. And in turn Witt coordinates, according to some recent work of Ueno c.s., are the 'natural' coordinates for certain questions concerning bosonization, and they also make vertex operators look nicer. There clearly is something to be understood behind this series of coincidences. There may also be a link with the fact that the space of Fredholm operators is classifying for topological K-theory.

(b)   The hard-hexagon model and n-spin generalizations of it 'belong to' the Kac-Moody algebra $\hat{A}_1$. To calculate something like magnetization densities on sublattices Baxter could make good use of the Rogers-Ramanujan identities (and in fact he was so led to conjecture a new one). Now one

of the nicest (to my mind) proofs of the RR identities (and also the long-est) is based on a detailed analysis of a few of the simpler representations of $\hat{A}_1$. There should be some deeper reason behind all this. Moreover Miwa and Jimbo discovered a remarkable correspondence between branching coefficients of representations of $\hat{A}_1$ and the so-called LHP (Local Height Probabilities), a sort of local magnetization quantity. The correspondence is there, but it is completely ununderstood where it comes from.

(c) Many integrable systems 'belong' to Lie algebras (or Kac-Moody algebras). Three ways in which this works are the AKSRS construction, the Drinfel'd-Sokolov construction and the dressing method (assuming that the dressing symmetry survives specialization to the specific system under consideration). There are relations between these approaches. Still the ways in which a system 'belongs to' a Lie algebra seems to us to fall into two dual groups exemplified by the KdV and the NLS. Both belong to $\hat{A}_1$. But for the NLS $\hat{A}_1$ is like a symmetry algebra while for the KdV it seems to be nothing of the kind but rather a dual sort of thing. There is also a (related?) duality between Toda chains and the KdV's, which runs roughly as follows. Let $u(t,\tau,x)$ satisfy an mKdV (in t and x). Suppose $u(0,\tau,x)$ satisfies the corresponding Toda (in τ and x), then for every t, $u(t,\tau,x)$ is a Toda solution. This result is due to Drinfel'd-Sokolov. The opposite result is also true (S.M. Verduyn Lunel, who also briefly worked at CWI on this project; unpublished). This smacks of a kind of duality, probably related to that considered by R. Howe, which we would like to understand.

SUBPROJECT AM 2.3

TITLE: Relativistic and quantum integrable systems

TITEL: Relativistische en quantum integreerbare systemen

ABSTRACT
This research focusses on the existence of relativistic and quantum versions of various (classical) integrable dynamical systems and the explicit diagonalization of (the corresponding) commuting families of Hamiltonians.

SAMENVATTING
Dit project onderzoekt het bestaan van relativistische en quantum versies van diverse (klassieke) integreerbare dynamische systemen en behandelt de explicíete diagonalisatie van de bijbehorende families van Hamiltonianen.

SUBPROJECT MEMBERS
Dr. S.N.M. Ruijsenaars (researcher)
priority vacancy (junior researcher) (joint with AM 2.2)
requested vacancy (junior researcher) (joint with AM 2.2)

EXTERNAL CONTACTS
Prof. E.M. de Jager (MI, University of Amsterdam), Prof. F.A. Bais (ITF, University of Amsterdam), Prof. A. Carey (Australia)

START OF SUBPROJECT: 1986

END OF SUBPROJECT: 1991

CLASSIFICATION CODES

NWO-classification   : P150, P190, P210
1980 Math. Subj. Class. : 58F07, 81F99, 81E13, 81D07, 81M05, 81E25, 82A67

PROBLEM FORMULATION, SCIENTIFIC SIGNIFCANCE AND RESEARCH PLANS

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 focussed 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.

SUBPROJECT AM 2.4

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 (b.v. stochastische (partiële) differentiaalvergelijkingen en hun toepassingen).

SUBPROJECT MEMBER
Dr. J. de Vries (project leader)

EXTERNAL CONTACTS
Prof. M.S. Keane, Prof. J.M. Aarts and Dr. S.J. van Strien (Delft University of Technology), Prof. J. Auslander (University of Maryland), Prof. S. Glassner (University of Tel Aviv)

START OF SUBPROJECT: 1976

END OF SUBPROJECT: 1991

CLASSIFICATION CODES

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

PROBLEM FORMULATION, SCIENTIFIC SIGNIFICANCE AND RESEARCH PLANS

This project is a continuation of earlier research in categorical topology and topological transformation groups. It started in 1977 and the work concerns abstract topological dynamics, that is, the study of topological transformation groups (with acting group not necessarily R or Z) with respect to topological problems that can be traced back to the qualitative theory of differential equations (so not differentiable dynamics, no ergodic theory, though there are connections). In this generality, the theory was founded in [GH], worked out e.g. in [El 1]; a recent book is [Au]. One of the central problems is the study of the structure of compact minimal orbit closures (i.e. orbit closures of almost periodic points in compact transformation groups) and their classification. In this generality the problem is far from solved: only for some special classes it is possible to say something. Moreover, it turned out to be convenient to study certain types of morphisms between compact minimal transformation groups rather than the transformation groups themselves. A famous result with many applications (within topological dynamics), and a paradigm for much subsequent research, is Furstenberg's theorem for distal compact minimal transformation groups (1963); these can be obtained as inverse limits of a system of so-called isometrical extensions (a type of morphisms such that on their fibers the group acts like a group of isometries).

The literature on this topic is scattered in the journals and, usually, quite badly written (mimicking the style of the few leading experts?); only for the specialists. The current work in this project consists of writing a book which can serve both as an introduction and a standard reference work for this field: 'Elements of topological dynamics'.

After completion of the book *Elements of Topological Dynamics* and publication of new results that could find no place in the book the project will be terminated (say, summer 1991). Thereafter J. de Vries plans to do research that is more related with the research in the other subprojects of AM 2. The idea is to use his expertise on the 'abstract' theory of dynamical systems in the context of integrable systems. A first thing is to investigate how integrability can be expressed in terms of an action of some (possibly non-commutative) group. There is interesting work of Ch.-M. Marle that could provide a good starting point in this direction. A second circle of problems would be connected with ergodicity (which is, in some sense, opposed to integrability).

A central question here is to what extent an ergodic (deterministically stochastic) or integrable part of a dynamical system can be isolated. Can a general dynamical system be seen as being composed in a suitable sense from integrable resp. ergodic parts. If not how can such systems be characterized?

Related literature

[Au]   J. AUSLANDER (1988). *Minimal Flows and their Extensions,* North-Holland, Amsterdam.

[El 1] R. ELLIS (1969). *Lectures in Topological dynamics,* Benjamin, New York.

[El 2] R. ELLIS (1987). Topological Dynamics and ergodic theory. *Ergod Th. & Dynam. Sys. 7, 25-47.*

[EN]   R. ELLIS, M. NERURKAR (1988). Enveloping semigroups in ergodic theory and a proof of Moore's ergodicity theorem. J.C. ALEXANDER (ed.). *Dynamical Systems, LNM 1342,* Springer-Verlag, Berlin.

[GH]   W.H. GOTTSCHALK, G.A. HEDLUND (1955). *Topological Dynamics,* Amer. Math. Soc., Providence (RI).

PROJECT AM 3

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 modelbouw-methodologie, in het bijzonder voor de dynamica van gestructureerde populaties.

PROJECT MEMBERS
Prof.dr. O. Diekmann (project leader)
Prof.dr. J.A.J. Metz (advisor)
Dr.ir. H.J.A.M. Heijmans (researcher)
Drs.ir. J.A.P. Heesterbeek (junior researcher)
Drs. J.M.A.M. van Neerven (junior researcher)
Dr. G. Greiner (guest reseacher)
H. Inaba B.Sc. (guest reseacher)
priority vacancy (junior researcher)

EXTERNAL CONTACTS
Drs. F. van den Bosch, Drs. S.A.H. Geritz and Ir. V.A.A. Jansen (University of Leiden), Drs. A.M. de Roos (University of Calgary, Canada and University of Strathclyde, Glasgow, Schotland), Prof.dr. Ph. Clément (Delft University of Technology), Dr. A. Grabosch, Dr. M. Kretzschmar (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 of Amsterdam), Prof. R.M. Nisbet (University of Strathclyde, Glasgow, Scotland), Prof.dr. M.W. Sabelis (University of Amsterdam), Dr. H.R. Thieme (Univeristy of Arizona, Tempe, USA), Dr. S.M. Verduyn Lunel (Free University of Amsterdam and Georgia Institute of Technology, USA), Prof.dr. H-O. Walther (Ludwig Maximilians Universität, München, FRG)

START OF PROJECT: 1975

END OF PROJECT: not yet determined

CLASSIFICATION CODES

NWO-classification   : P130, B110
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 1990

1. *Infectious diseases*

The notes of the 1989 colloquium on 'The Spread of Infectious Diseases in Structured Populations' will be extended and polished by the authors (O. Diekmann, J.A.P. Heesterbeek, M. Kretzschmar and J.A.J. Metz), in order to realize publication in book form. Various open problems which were pointed out during the colloquium will be studied by J.A.P. Heesterbeek. In particular he intends to model and analyze the immune response to malaria. H. Inaba will continue his study of age-structured epidemic models.

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 plan is that he will spend the first semester of the academic year 90/91 at the Eberhard-Karls-Universität in Tübingen. The cooperation with Ph. Clément, M. Gyllenberg and H.R. Thieme will be continued.

3. *Banach space structure theory and semigroups of operators*

Research will be done on general geometric aspects of (adjoint) semigroup theory. There seems to be an intimate interrelationship between the existence, structure, and regularity of semigroups and the geometric properties of the underlying Banach space. There are a few classical results in this direction, such as Phillip's theorem on adjoint semigroups in reflexive spaces, and the regularity theorems on measurable- and weakly continuous semigroups. Recently, Lotz proved that certain Banach spaces do not admit any (non-trivial) semigroups. It will be investigated whether modern Banach space structure theory and the theory of (adjoint) semigroups can be interwoven to develop new methods of proof and to derive new results in both fields.

Secondly, it is the aim to develop a semigroup duality theory very much along the lines of the classical duality theory of Banach spaces. The motivation for this derives from the observation that certain theorems on adjoint semigroups can be viewed as generalizations of classical results on duality. In particular, this should lead to a more detailed theory of $\odot$-reflexivity.

Research in these directions has already been started and the results so far look very promising.

4. *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.

5. *Functional differential equations*

H-O. Walther, S.M. Verduyn Lunel, S.A. van Gils 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 to send the manuscript to a publisher in the summer of 1990.

6. *Necessary and sufficient conditions for 'linear chain trickery' in structured population model*

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.

7. *Prey-predator patch problems*

This concerns joint work with M.W. Sabelis, M. van Baalen (University of Amsterdam) and V.A.A. Jansen (University of Leiden) 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).

8. *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.

9. *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 1990

Not all of the above plans can be realized in one year and part of the work will be carried out in 1991 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). We consider the possibility of organizing a colloquium on evolutionary genetics in the context of structured population models in 1991 or later. To realize such plans it is necessary that the number of (experienced) people working in the project grows rather than wanes. In this respect one should note that it is conceivable (in fact rather likely) that Heijmans will stop working on population problems in order to spend all his time and energy on mathematical morphology (project AM 5).

The possibility of stimulating the work on epidemic models by appointing a post-doc (for instance Dr. M. Kretzschmar) for one or two years, starting in say, September 1990, should be considered.

PROJECT AM 4

TITLE: Asymptotics

TITEL: Asymptotiek

ABSTRACT
This project includes research on asymptotic expansions of integrals and differential equations, and solving problems on analysis and asymptotics (with numerical aspects) from physics, biology, and statistics.

SAMENVATTING
Er wordt onderzoek verricht aan asymptotische ontwikkelingen van integralen en differentiaalvergelijkingen. Voorts wordt gewerkt aan problemen op het gebied van de analyse en asymptotiek (met numerieke aspecten) uit de fysica, biologie en statistiek.

PROJECT MEMBERS
Dr. N.M. Temme (project leader)
Drs. A.B. Olde Daalhuis (junior researcher)

EXTERNAL CONTACTS
Prof. F.W.J. Olver (Maryland, USA)
Prof. R. Wong (Winnipeg, Canada)
Prof. K. Soni (Knoxville, USA)
Drs. C.G. van der Laan (University of Groningen)

START OF PROJECT: 1975

END OF PROJECT: not yet determined

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

Asymptotic expansions of integrals

For many physical 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 scientists, both from inside and from 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.

Literature
[1]   F.W.J. OLVER (1974). *Asymptotics and Special Functions,* Academic Press, New York.
[2]   F.W.J. OLVER (1975). Unsolved problems in the asymptotic evaluation of

special functions. R.A. ASKEY (ed.). *Theory and Application of Special Functions,* Academic Press, New York, 99-142.

[3] W. GAUTSCHI (1975). Computational methods of special functions. R.A. ASKEY (ed.). *Theory and Application of Special Functions,* Academic Press, New York, 1-98.

[4] R. WONG (1980). Error bounds for asymptotic expansions of integrals. *SIAM Review 22,* 401-435.

[5] N.M. TEMME (1986). Uniform asymptotic expansions of integrals. J.W. DE BAKKER (et.al., eds.). *Mathematics and Computer Science,* CWI Monograph 1, North-Holland, Amsterdam, 335-351.

[6] C.G. VAN DER LAAN, N.M. TEMME (1984). *Calculation of Special Functions,* CWI Tract 10, Centre for Mathematics and Computer Science, Amsterdam.

[7] N.M. TEMME (1988). *Uniform Asymptotic Expansions of a Class of Integrals in Terms of Modified Bessel Functions, with Application to Confluent Hypergeometric Functions,* CWI Report AM-R8806, Centre for Mathematics and Computer Science, Amsterdam, to appear in SIAM J. Math. Analysis.

WORKING PLAN 1990 AND LATER

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. A new topic of research is the construction of new asymptotic forms of certain classical orthogonal polynomials. The interesting point is that the approximants are again orthogonal polynomials. This approach is based on differential equations, and the first formal results are now under investigation for the construction of error bounds.

2. A textbook on special functions with emphasis on asymptotics and numerical aspects will be finished in August 1990. Also, a monograph on uniform expansion is in preparation. Several earlier papers are rewritten for this project. New topics will be included. A deadline of this work cannot be given.

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. A second volume of the book [6] is still planned.

PROJECT AM 5

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. J.B.T.M. Roerdink (project leader)
Dr.ir. H.J.A.M. Heijmans (researcher)
Drs. M. Zwaan (junior researcher)
Prof.dr.ir. F.C.A. Groen (advisor)
requested vacancy (junior researcher)
requested visitor (2 months) (guest researcher)
programmer (1 fte, to be supplied by STO)

EXTERNAL CONTACTS
This is a joint project with Image analysis (project BS 6, project leader: A.J. Baddeley) of the Department of Operations Research, Statistics, and System Theory, Dr.ir. F.A. Kuijpers and Ir. M. Fuderer (Philips Medical Systems, Best), Dr.ir. J.H. van Schuppen (CWI), Prof.dr. W. Vervaat (Catholic University of Nijmegen), Prof.dr.ir. D.E. Boekee and Dr. J. Biemond (Delft University of Technology), Dr. A. Toet (IZF-TNO, Soesterberg), Dr. C. Ronse (Philips Research Laboratory Brussels), Prof. P. Maragos (Division of Applied Sciences, Harvard University, Cambridge (MA), USA), Prof. J. Serra and Dr. L. Vincent (Ecole Nationale Supérieure des Mines de Paris, France)

START OF PROJECT: 1985

END OF PROJECT: not yet determined

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. 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.

a. Reconstruction

By reconstruction we mean what is commonly called tomography, or the reconstruction of images from projections. 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. 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. In this case the projections are Fourier transforms of the object at successive times.

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. The basic idea of mathematical morphology is to examine the geometrical structure of an image by linking patterns of a certain size and shape (called structuring elements) at various locations in the image. This amounts to nonlinear transformations which are pre-eminently suited for the analysis of the geometrical structure of an image. The ultimate goal is to perform global quantitative measurements on images by the successive application of several morphological transformations. In practice one is confronted with noise and other uncertainties, so that probabilistic and statistical ingredients (random sets, random fields) are being incorporated in the theory.

In contrast with classical (linear) image processing tools which are of an analytic nature, mathematical morphology relies heavily on algebraic methods. The underlying object space (e.g., binary images, grey-level images, functions on graphs) forms a complete lattice, and the operators of interest are those which refer to the order-structure of the space. This observation has recently stimulated researchers to extend mathematical morphology to the general setting of complete lattices. An important application of the abstract framework forms the processing and analysis of images which can be represented by graphs. Vincent (Ecole Nationale Supérieure des Mines de Paris) has made a thorough study of a somewhat special class of morphological operators on graphs. By exploiting the neighbourhood relations between the vertices of a graph one can in principle build a large collection of morphological transformations on a graph which have a straightforward geometrical interpretation (e.g., dilations, erosions, closings, openings, skeletons, etc.).

The most elementary images correspond to geometrical objects. These objects may be described by their primitive components and their spatial layout together with their local and global topological properties of invariance with respect to a class of transformations. Mathematical morphology defines the structure of an object by the set of relationships existing between its constituent parts. Thus, mathematical morphology appears well suited for the construction of a hierarchical graph representation.

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 example, D. and S. Geman (Brown University, USA), J. Besag (Durham, UK), P. Switzer (Stanford University, USA) and others have devised 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. In very recent work the approach has been applied to segmentation problems (line detection) using Markov line processes, and to inverse (tomography) reconstruction problems.

At CWI the general interest centers around the following topics:

- 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.
- The interplay between mathematical morphology and statistical modelling.
- 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 $\mathbb{R}^3$.
- Stereology, the mathematics of making inference from sampled 2-D sections to a 3-D object.

Literature

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WORKING PLAN 1990

Within this project the following topics will be studied:

1. *Dynamic cardiac imaging by magnetic resonance (NMR).* 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. In particular one is interested in the effect of blurring and motion artefacts caused by irregular heartbeats (arrythmia), leading to nonuniform sampling problems. Both the mathematical theory and numerical algorithms will be developed, with the aim to be applied to reconstructing images frome real NMR-data.

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. A systematic study of convergence and continuity properties of morphological operators (in cooperation with J. Serra, Ecole Nationale Supérieure des Mines de Paris)

   c. A study of the probabilistic aspects of the theory (in cooperation with the Department of Operations Research, Statistics, and System Theory).

   d. The initiation of a thorough investigation of mathematical morphology on graphs (in cooperation with A. Toet, IZF-TNO, Soesterberg, and L. Vincent, Ecole Nationale Supérieure des Mines de Paris).

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.

WORKING PLAN AFTER 1990

All subprojects mentioned above are continued after 1990. The scope of these projects may be widened and new projects added, e.g.

1. Continuation of study of algebraic, topological and probabilistic aspects of mathematical morphology.

2. The construction of a concise hierarchical graph representation of (multimodal) images that encode the geometrical and topological aspects of objects in a scene using morphological operators.

3. Investigate the role of mathematical morphology in computer vision problems, in cooperation with the Department of Computer Systems, University of Amsterdam.

4. Explore the theory of 2-D and 3-D wavelet transforms in general, and the applicability to the cardiac imaging problem, as well as seismic inverse scattering problems, in particular.

PROJECT AM MISC.

TITLE: Miscellaneous smaller projects

TITEL: Allerlei kleinere projecten

ABSTRACT
Under this heading a number of smaller projects are grouped together. These range from carefully planned systematic ones of small size to various bits of ad hoc research such as may for instance have been stimulated by the knowledge-pool activities of the department.

SAMENVATTING
Onder dit hoofdje zijn een aantal kleinere activiteiten gerangschikt. Deze variëren van zorgvuldig geplande systematisch onderzoek van kleinere omvang tot diverse stukjes ad hoc research zoals dat bijvoorbeeld kan ontstaan vanuit de 'knowledge-pool' activiteiten van de afdeling.

DESCRIPTIONS
Besides the well focussed smaller projects AM Misc. 1 and AM Misc. 2 described in some more detail below, there are such still smaller research activities as 'The use of Lie algebraic ideas in nonlinear filtering problems' (M. Hazewinkel), 'The systematic use of symbolic manipulation systems like MAPLE and MACSYMA' (B. Dijkhuis, as a result of consulting requests by T. Horn and A.W. Kleijn (both FOM)), 'Questions in 'classical' quantum mechanics and concerning physical diffusion processes' (B. Dijkhuis in contact with R. Pasmanter (Rijkswaterstaat)), 'Universal formal groups (noncommutative) and Hopf algebras' (M. Hazewinkel).

SUBPROJECT AM MISC. 1

TITLE: Classical analysis and number theory

TITLE: Klassieke analyse en getallentheorie

ABSTRACT
This project concerns the study of problems of a (numerical/analytical) number-theoretic nature.

SAMENVATTING
In dit project worden problemen van (numeriek/analytisch) getaltheoretische aard bestudeerd.

SUBPROJECT MEMBER
Dr. J. van de Lune Ph.D. (researcher)

CONTACTS
Dr.ir. H.J.J. te Riele (CWI, Dept. of Numerical Mathematics, project NW 4), Prof.dr. P. Mullender (Doorwerth), Dr. A.M. Odlyzko (Bell Labs, USA), Dr. E. Wattel (Free University of Amsterdam)

START OF SUBPROJECT: 1972/73

END OF SUBPROJECT: not yet determined

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:

1. 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.M. Odlyzko);
    -   various aspects of the conformal mapping, by the zeta-function, of the complex plane to the right of the critical line.
2. The writing of a book on number theory (in cooperation with P. Mullender).
3. Numerical work on the 'error-exponent' in Gauss' lattice point problem and Dirichlet's divisor problem (with H.J.J. te Riele and E. Wattel).
4. The average value of the maximal exponent in the standard prime factorization of a natural number.

SUBPROJECT AM MISC. 2

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 de 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.

SUBPROJECT MEMBERS
Prof.dr. M. Hazewinkel (p.m.)
Drs. G. Alberts (researcher)

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

START OF SUBPROJECT: 1988

END OF SUBPROJECT: 1990

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; its results 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 monograph 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.

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Department of

Operations Research, Statistics, and System Theory

The research in the Department of Operations Research, Statistics, and System Theory (BS) is organized in the following six projects:

BS 1 Combinatorial Optimization and Algorithmics
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

In September 1988, BS has grown out of a merge between the Departments of Statistics and of Operations Research and System Theory. The new department covers a broad range of interconnected mathematical areas. In the selection of projects the department uses the following criteria:
1. The major subject areas of the field should be covered: deterministic and stochastic operations research, deterministic and stochastic system theory, stochastic processes and statistics;
2. Research should be aimed at studying fundamental problems and techniques, while keeping an open eye for the potential practical use of the models and methods under investigation;
3. Each project should be a front-runner in The Netherlands, and should link up with international developments.
The choice of subprojects is further guided by the wish to build bridges between mathematics and computer science, on the one hand, and between the departmental projects, on the other hand.
The relation between mathematics and computer science is in particular apparent in several subprojects in BS 1 (design and analysis of algorithms, VLSI-layout, parallel computations, interactive planning methods) and BS 2

(performance analysis of computer systems), but is also emphasized in other subprojects (e.g., control of discrete-event systems, statistical analysis of software reliability).

The central research themes, which link several of the activities in the projects, are

(i) probabilistic modeling and

(ii) control and optimization.

To give a more concrete insight into the interaction between different (sub)projects, we list some topics of common interest: analysis of algorithms (BS 1.1, BS 2.3); geometric methods (BS 1.4, BS 6.1); parallel computations (BS 1.5, BS 2.3); discrete-event systems and control of queues (BS 2.2, BS 3.4, BS 3.5); stochastic networks (BS 2.2, BS 4.1); reliability (BS 2.4, BS 5.4); traffic models (BS 2, BS 3, BS 4); statistical aspects of stochastic processes (BS 5.1, BS 6.1).

Bottlenecks and priorities

The present financial situation of CWI is already having its effect on some projects of BS, and is threatening to affect others. Let us briefly discuss the state-of-affairs of each project, before listing our priorities for acquiring new personnel.

The project leader and two senior researchers of BS 1 have left in 1989; they have been replaced by a new project leader and one senior researcher. As a consequence, the emphasis has shifted towards fundamental mathematical research in polyhedral combinatorics, VLSI design and computational geometry. These subjects are of considerable strategical interest in an institute where research in mathematics and computer science is combined under one roof. Moreover, CWI research in these topics is internationally considered to be of the highest level. However, another consequence of the above-mentioned changes in personnel is that the consultancy in Operations Research has been drastically reduced. BS 1 has a long and strong tradition of performing high-level consultancy, which not only has been financially profitable but also has often had scientifically interesting spin-offs. Inevitably the question will soon be raised whether CWI is willing and able to make an investment in order to preserve consultancy in Operations Research.

In each of the projects BS 2 and BS 3 two Ph.D. students, all four supported by INSP or STW, have recently successfully completed their thesis or are about to do so. Their research concerns the fields of mathematical computer performance and stochastic system theory. CWI now occupies a very strong position in these fields; it would be truly regrettable if this position were not maintained by attracting new junior researchers.

For a department like BS it is essential to have a strong project on stochastic processes. The size of the stochastics project BS 4 has been maintained at an absolute minimum in recent years. This is not in line with international developments as stochastics, along with statistics, is the most rapidly growing field in mathematics. Statistics has always occupied a prominent place in CWI. In the last few years the departure of a number of statisticians could

only be compensated by attracting several advisors and visitors. As a result the statistics project BS 5, albeit very dynamic and diversified, is lacking sufficient critical mass of senior researchers. Furthermore, the project Computational Statistics, that was mentioned in the Policy Document 1988-1993 as a new project that should link mathematical statistics and statistical consultation, has not yet started.

Image Analysis, another new project mentioned in the Policy Document, did get off the ground. It concerns the statistical analysis of images, and is carried out in close cooperation with the project Image Processing and Reconstruction of the Department of Analysis, Algebra and Geometry. Extension of the Image Analysis group with a Ph.D. student is mandatory to let this important project gain momentum.

The above considerations have led the department to assign the highest priorities (ex aequo) to the appointment of a senior researcher in statistics and of two junior researchers in two recently launched key projects, Computational Geometry (BS 1.4, with Schrijver) and Image Analysis (BS 6.1, with Baddeley). In the personnel table we also mention six additional requests for junior researchers, mainly in areas where a Ph.D. thesis is about to be completed. They concern two junior researchers in the Performance Analysis of Computer/Communication Systems (BS 2.2, BS 2.3, with Boxma and Van den Berg), and junior researchers in the Control of Discrete-Event Systems (BS 3.4, with Van Schuppen), in Stochastic Processes (BS 4.1, with Berbee), in Bootstrap Methods (BS 5.2, with Helmers) and in Computational Statistics (BS 5.7, with Dzhaparidze).

Department of
Operations Research, Statistics, and System Theory

LIST OF PROJECTS

BS 1 Combinatorial optimization and algorithmics
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

		BS1	BS2	BS3	BS4	BS5	BS6	working time in fte	budget time	de-tached	guests	remarks
appointed												
Boxma	head dept.		*					1.00	1.00	-0.20		
Schrijver	proj. leader	*						1.00	1.00	-0.20		
Gerards	researcher	*						1.00	1.00			
Hoogeveen	researcher	*						1.00	1.00			
Lageweg	researcher	*						1.00	1.00			
Lenstra	researcher	*						0.20				
Velde, v.d.	researcher	*						1.00		0.75 (NFI)		
Oosterhout	jr.researcher	*						1.00	1.00			
Veltman	jr.researcher	*						1.00	1.00			
Cohen	advisor		*					-	p.m.			
Berg, J. v.d.	researcher		*		*			1.00	1.00			
Berg, J.L. v.d.	researcher		*					1.00	0.08			
Duijn Schouten	researcher		*					0.20		0.2 (KUB)		
Groenendijk	researcher		*					1.00	0.08			
Wartenhorst	jr.researcher		*					1.00	1.00			
Schuppen, van	proj.leader			*				1.00	1.00			
Kuijper	researcher			*				1.00	1.00			
Schumacher	researcher			*				1.00	1.00	-0.20		
Waal, de	researcher			*				1.00		0.08 (STW)		
Gombani	guest research			*				1.00			0.67	
Berbee	proj.leader				*			1.00	1.00			
Gandolfi	guest research				*			1.00			0.17	
Dzhaparidze	proj.leader					*		1.00	1.00			
Helmers	proj.leader					*		1.00	1.00			
Haan, de	advisor					*		-	p.m.			
Dekkers	researcher					*		1.00	1.00			
Bakker	jr.researcher					*		1.00				0.33 (TEG)
van Pul	jr.researcher					*		1.00		1.00 (STW)		
v.d. Geer	guest research					*		0.20		0.2 (RUU)		
Shiryaev	guest research					*		1.00			0.17	
v.d. Vaart	guest research					*		0.20		0.2 (VU)	0.13	
Baddeley	proj.leader						*	1.00	1.00			
Gill	advisor					*	*	-	p.m.			
Moyeed	researcher						*	1.00	1.00			
van Lieshout	jr.researcher						*	1.00	0.08			
total appointed								28.80	18.24	1.23	1.14	0.33
priority 1	jr.researcher	*						1.00	0.50			
priority 2	jr.researcher					*		1.00	0.50			
priority 3	researcher				*			1.00	0.50			
request 1	jr.researcher		*					1.00	p.m.			
request 2	jr.researcher		*					1.00	p.m.			
request 3	jr.researcher			*				1.00	p.m.			
request 4	jr.researcher				*			1.00	p.m.			
request 5	jr.researcher					*		1.00	p.m.			
request 6	jr.researcher					*		1.00	p.m.			

PROJECT BS 1

TITLE: Combinatorial optimization and algorithmics

TITEL: Combinatorische optimalisering en algoritmiek

ABSTRACT
Combinatorial optimization and algorithmics is the mathematical investigation of problems and algorithms involving the arrangement, grouping, ordering or selection of discrete objects.

BS 1.1 Design and analysis of algorithms;
BS 1.2 Polyhedral methods;
BS 1.3 Multicommodity flows and VLSI-layout;
BS 1.4 Computational geometry;
BS 1.5 Parallel computations;
BS 1.6 Multi-criteria machine scheduling problems;
BS 1.7 Interactive planning methods;
BS 1.8 Model and algorithm representation and manipulation.

SAMENVATTING
Combinatorische optimalisering en algoritmiek houdt zich bezig met de wiskundige bestudering van problemen en algoritmen betreffende het selecteren en ordenen van discrete objecten.

BS 1.1 Ontwerp en analyse van algoritmen;
BS 1.2 Polyhedrale methoden;
BS 1.3 Multi-commoditeitsstromen en VLSI-ontwerp;
BS 1.4 Computationele meetkunde;
BS 1.5 Parallelle berekeningen;
BS 1.6 Machinevolgordeproblemen met meervoudige criteria;
BS 1.7 Interactieve planningsmethoden;
BS 1.8 Representatie en manipulatie van modellen en algoritmen.

PROJECT MEMBERS

Prof.dr. A. Schrijver (project leader)   Drs. S.L. van de Velde (researcher)
Dr.ir. A.M.H. Gerards (researcher)   Drs. H. Oosterhout (junior researcher)
Drs. J.A. Hoogeveen (researcher)   Drs. B. Veltman (junior researcher)
Drs. B.J.B.M. Lageweg (researcher)   priority vacancy (junior researcher)
Prof.dr. J.K. Lenstra (researcher)

EXTERNAL CONTACTS
E.G. Coffman, Jr. (Murray Hill, NJ, USA), W. Cook, C.L. Monma, P.D. Seymour, V.K. Wei (Morristown, NJ, USA), A. Frank (Budapest), J. Fonlupt, A. Sebö (Grenoble), M. Grötschel (Augsburg, FRG), C.V. Jones (Philadelphia,

PA, USA), G.A.P. Kindervater, A.H.G. Rinnooy Kan, H.W.J.M. Trienekens (Rotterdam), E.L. Lawler (Berkeley, CA, USA), R. Kannan (Pittsburgh, PA, USA), W.R. Pulleyblank, B. Reed (Waterloo, Ontario, Canada), W.H. Cunningham (Ottawa, Canada), K.M. van Hee (Eindhoven), L. Lovász (Budapest and Princeton, NJ, USA), D.B. Shmoys, É. Tardos, M.J. Todd (Ithaca, NY, USA), M. Desrochers (Montréal, Canada), L. Stougie (Amsterdam), K. Truemper (Dallas, TX, USA)

START OF PROJECT: 1973

END OF PROJECT: not yet determined

CLASSIFICATION CODES

NWO-classification   : P160, T170, T120
NABS-code   : N024, N059, N069, N089
1980 Math. Subj. Class. : 05Cxx, 90Bxx, 68Rxx

PROJECT DESCRIPTION

Field of study. - Combinatorial optimization and algorithmics concerns the mathematical investigation of problems in which a configuration of certain discrete objects satisfying given constraints has to be found, and of algorithms for such problems. Problems of this type occur in many practical decision situations (such as time table design, distribution planning, production control, facility location) and in computer science (VLSI-layout, robotics, pattern recognition). Due to the relevance of these problems in management environments and their central role in both graph theory and complexity theory, the field intersects operations research, discrete mathematics, and computer science. Results from other parts of mathematics (geometry, number theory, probability theory) and computer science (computational geometry, computer architecture and engineering) are of increasing significance.

Research themes. - Traditional research themes in combinatorial optimization and algorithmics are the following:
1. the complexity analysis of combinatorial problems, with solvability in polynomial time and NP-completeness as key notions;
2. the design and analysis of algorithms, including polyhedral (i.e. linear programming-based), enumerative and approximative algorithms;
3. ths study and solution of novel and advanced practical management problems, including the development of interactive systems (decision support systems).

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.

SUBPROJECT BS 1.1

TITLE: Design and analysis of algorithms

SUBPROJECT MEMBERS
Drs. B.J.B.M. Lageweg (researcher)
Prof.dr. J.K. Lenstra (researcher)

START OF SUBPROJECT: 1973

END OF SUBPROJECT: not yet determined

FIELD OF STUDY
This subject 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.

SUBPROJECT BS 1.2

TITLE: Polyhedral methods

SUBPROJECT MEMBERS
Prof.dr. A. Schrijver (project leader)
Dr.ir. A.M.H. Gerards (researcher)

START OF SUBPROJECT: 1983

END OF SUBPROJECT: not yet determined

FIELD OF STUDY
This concerns the design of polynomial-time algorithms and good characterizations for combinatorial optimization problems with the help of methods from geometry and linear programming. Especially the derivation of decomposition methods and the application of cutting plane techniques for large-scale combinatorial optimization methods are investigated. Research will be done in cooperation with M. Grötschel, L. Lovász, P.D. Seymour and K. Truemper. Moreover, the activities include completion of the book *Polyhedral Combinatorics* (Wiley).

SUBPROJECT BS 1.3

TITLE: Multicommodity flows and VLSI-layout

SUBPROJECT MEMBER
Prof.dr. A. Schrijver (project leader)

START OF SUBPROJECT: 1989

END OF SUBPROJECT: not yet determined

FIELD OF STUDY
Research will be done to graph theoretical and topological methods for the problems of finding multicommodity flows and of determining wire-routing for a VLSI-circuit (chip). The topological methods are based, inter alia, on the theory of surfaces and on homotopy theory. With respect to graph theory, the subject relates to the Graph Minor project of N. Robertson (Columbus, OH, USA) and P.D. Seymour (Bell Communications Research, NJ, USA). The subject forms a link between polyhedral combinatorics and computational geometry.

RESEARCH ACTIVITIES
1. Development of more efficient algorithms for the design of VLSI-circuits.
2. Clarification of the relationship to graph minors.
3. Completion of the book *The Disjoint Paths Problem* (Springer-Verlag).

SUBPROJECT BS 1.4

TITLE: Computational geometry

SUBPROJECT MEMBERS
Prof.dr. A. Schrijver (project leader)
priority vacancy (junior researcher)

START OF SUBPROJECT: 1989

END OF SUBPROJECT: not yet determined

FIELD OF STUDY
This will be a new focus of research, because of its importance for computer science (like computer graphics, robotics, pattern recognition, VLSI-layout), and because of its connections to other research subjects (polyhedral methods, computational complexity). It is expected that research in computational geometry has as a spin-off an increase of expertise in low-order polynomial-time complexity and in the advanced implementation techniques of R.E. Tarjan and his coworkers.

SUBPROJECT BS 1.5

TITLE: Parallel computations

SUBPROJECT MEMBERS
Prof.dr. J.K. Lenstra (researcher)
Drs. B. Veltman (junior researcher)

START OF SUBPROJECT: 1982

END OF SUBPROJECT: not yet determined

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 1.6

TITLE: Multi-criteria machine scheduling problems

SUBPROJECT MEMBERS
Drs. J.A. Hoogeveen (researcher)
Prof.dr. J.K. Lenstra (researcher)
Drs. S.L. van de Velde (researcher)

START OF SUBPROJECT: 1985

END OF SUBPROJECT: not yet determined

FIELD OF STUDY
This subproject concerns the investigations 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 types 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 1.7

TITLE: Interactive planning methods

SUBPROJECT MEMBERS
Drs. B.J.B.M. Lageweg (researcher)
Prof.dr. J.K. Lenstra (researcher)
Drs. S.L. van de Velde (researcher)

START OF SUBPROJECT: 1983

END OF SUBPROJECT: not yet determined

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 1.8

TITLE: Model and algorithm representation and manipulation

SUBPROJECT MEMBERS
Prof.dr. J.K. Lenstra (researcher)
Drs. H. Oosterhout (junior researcher)

START OF SUBPROJECT: 1988

END OF SUBPROJECT: not yet determined

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, Philadelphia) and Dr. M. Desrochers (Montréal).

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

Prof.dr.ir. O.J. Boxma (project leader)
Prof.dr.ir. J.W. Cohen (advisor)
Dr. J. van den Berg (researcher)
Drs. J.L. van den Berg (researcher)
Prof.dr. F.A. van der Duyn Schouten (researcher)
Drs. W.P. Groenendijk (researcher)
Drs. P. Wartenhorst (junior researcher)
requested vacancy (junior researcher)
requested vacancy (junior researcher)

EXTERNAL CONTACTS

Dr. J.P.C. Blanc, Drs. S.G. Vanneste, Drs. J.A. Weststrate (Catholic University of Brabant), Dr. G.A.P. Kindervater, Drs. M. van Vliet (Erasmus University of Rotterdam), Prof.dr. H.C. Tijms (Free University of Amsterdam), Dr. F. Baccelli, Dr. G. Fayolle, Dr. Ph. Nain, Dr. Ph. Robert (INRIA, France), Dr. B. Meister (IBM Zürich Research Laboratory, Switzerland), Prof.dr.ir. W.M.C. van den Heuvel (Eindhoven University of Technology), Dr. H. Levy (Tel-Aviv University), Dr. Y.T. Wang (AT&T Bell Laboratories, Holmdel, USA)

START OF PROJECT: 1981

END OF PROJECT: not yet determined

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.

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

SUBPROJECT MEMBERS
Prof.dr.ir. O.J. Boxma (project leader)
Prof.dr.ir. J.W. Cohen (advisor)
Dr. J. van den Berg (researcher)

START OF SUBPROJECT: 1981

END OF SUBPROJECT: not yet determined

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. Formulation and solution of boundary value problems in the analysis of two-dimensional random walks and queueing models.
2. Analysis of time-dependent behaviour of queueing systems.
3. Modeling and analysis of congestion phenomena in the implementation of branch-and-bound algorithms on parallel computers.
4. Capacity allocation optimization problems in queueing networks.

LONG-TERM PLANS
Emphasis on the activities 1 and 4; focusing of the last activity on multiproduct flexible manufacturing systems and on optimal ordering of queues.

SUBPROJECT BS 2.2

TITLE: Performance analysis of communication systems

SUBPROJECT MEMBERS
Prof.dr.ir. O.J. Boxma (project leader)
Prof.dr.ir. J.W. Cohen (advisor)
Dr. J. van den Berg (researcher)
requested vacancy (junior researcher)

START OF SUBPROJECT: 1983

END OF SUBPROJECT: not yet determined

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)).

LONG-TERM PLANS
1. Continuation of 1 above. 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).
2. A study of the performance of ISDN.
3. A study concerning the applicability of techniques from statistical mechanics for understanding the behaviour of large communication networks.

SUBPROJECT BS 2.3

TITLE: Performance analysis of computer systems

SUBPROJECT MEMBERS
Prof.dr.ir. O.J. Boxma (project leader)   Drs. J.L. van den Berg (researcher)
Prof.dr.ir. J.W. Cohen (advisor)   Drs. W.P. Groenendijk (researcher)
Dr. J. van den Berg (researcher)   requested vacancy (junior researcher)

START OF SUBPROJECT: 1985

END OF SUBPROJECT: not yet determined

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 com-
puter 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 are overlap-
ping more and more.

CURRENT RESEARCH ACTIVITIES
1. Mathematical analysis of queueing systems with feedback mechanisms as
    occurring, among other things, in computer systems with time-sharing. A
    Ph.D. thesis is being completed.
2. Mathematical analysis of various token-ring protocols in local area net-
    works and comparison of the performance of these protocols. Also related
    protocols in distributed systems are being studied. A Ph.D. thesis is being
    completed.
3. Expansion and distribution (among other things, via a newsletter) of
    CWI's available expertise on computer packages for the numerical
    analysis and simulation of congestion phenomena in networks of queues.
4. The probabilistic analysis of algorithms and of scheduling problems.

LONG-TERM PLANS
1. Continuation of 2 above, with an emphasis on optimization problems in
    polling models.
2. Increase of research on the performance of parallel/distributed systems.
3. Analysis of queueing networks in which tasks have a dual role, as being
    both servers of requests and customers in making requests of other tasks.

Such duality phenomena occur, e.g., in the modeling of distributed computer programs using rendez-vous for intertask communication, and of the handling of containers at harbour terminals.

4. Broadening of the scope of 4 above, to cover the probabilistic analysis of deterministic and randomized algorithms, and to study fragmentation problems. This might lead to the formulation of a new subproject.

Subproject BS 2.4

Title: Reliability and availability of networks

Subproject members
Prof.dr. F.A. van der Duyn Schouten (project leader)
Prof.dr.ir. J.W. Cohen (advisor)
Prof.dr.ir. O.J. Boxma (researcher)
Drs. P. Wartenhorst (junior researcher)

Start of subproject: 1987

End of subproject: not yet determined

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
1. 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.
2. Multi-repair facility problem.
3. Dynamic control of repair facilities and its impact on availability criteria.

Long-term plans
Emphasis on activities 1 and 2, leading to computationally tractable algorithms for analyzing multi-component systems. 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)   Ir. P.R. de Waal (researcher)
Prof.dr. M. Hazewinkel (Dept. AM)   Dr. A. Gombani (guest researcher)
Drs. M. Kuijper (resesarcher)   requested vacancy (junior researcher)
Prof.dr. J.M. Schumacher (researcher)

EXTERNAL CONTACTS
Prof.dr.ir. H. Kwakernaak, Dr. H. Nijmeijer and Dr. A.J. van der Schaft (University of Twente), Prof.dr.ir. J.C. Willems and 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

END OF PROJECT: not yet determined

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 Foundation for the Technical Sciences (STW) funds subproject BS 3.5 (2).

SUBPROJECT BS 3.1

TITLE: Deterministic system theory

SUBPROJECT MEMBERS
Prof.dr. M. Hazewinkel (Dept. AM)
Prof.dr. J.M. Schumacher (researcher)

START OF SUBPROJECT: 1984

END OF SUBPROJECT: not yet determined

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, University of Groningen).
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).

SUBPROJECT BS 3.2

TITLE: Stochastic system theory

SUBPROJECT MEMBERS
Dr.ir. J.H. van Schuppen (project leader)
Prof.dr. J.M. Schumacher (researcher)
Dr. A. Gombani (guest researcher)

START OF SUBPROJECT: 1978

END OF SUBPROJECT: not yet determined

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.
5. Representation problems in econometrics. Study of the relation between cointegrated, error-correction, and errors-in-variables models (J.M. Schumacher).
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

SUBPROJECT MEMBERS
Prof.dr. J.M. Schumacher (researcher)
Drs. M. Kuijper (researcher)

START OF SUBPROJECT: 1988

END OF SUBPROJECT: not yet determined

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
-    integer invariants in terms of subspaces of the state space for descriptor systems,
-    application to system inversion and model matching.
Disturbance decoupling by singular controllers.

SUBPROJECT BS 3.4

TITLE: Control of discrete-event systems

SUBPROJECT MEMBERS
Dr.ir. J.H. van Schuppen (project leader)
requested vacancy (junior researcher)

START OF SUBPROJECT: not yet determined

END OF SUBPROJECT: not yet determined

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

SUBPROJECT MEMBERS
Dr.ir. J.H. van Schuppen (project leader)
Ir. P.R. de Waal (researcher)

START OF SUBPROJECT: 1984

END OF SUBPROJECT: not yet determined

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 Foundation for the Technical Sciences (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.   Completion of a Ph.D. thesis.

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. There is one subproject:
BS 4.1   Stationary processes and their applications in physics.

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. Er is één deelproject:
BS 4.1   Stationaire processen en hun toepassingen in de fysica.

PROJECT MEMBERS
Dr. H.C.P. Berbee (project leader)
Dr. J. van den Berg (researcher)
Dr. A. Gandolfi (guest researcher)
requested vacancy (junior researcher)

EXTERNAL CONTACTS

Prof.dr. M.S. Keane and cooperators (Delft University of Technology)
Prof.dr. G.R. Grimmett (Bristol)
Dr. C. Bezuidenhout (Madison)
Dr. S. Kalikow

START OF PROJECT: 1981

END OF PROJECT: not yet determined

CLASSIFICATION CODES

NWO-classification   : P160
1980 Math. Subj. Class. : 60G10, 60G44, 60G55, 60G60, 60K30,
                          62M10, 62M99, 90B20, 60J99, 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 stu-
died. 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 con-
cerns 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 dual-
ity plays a role. Its role can probably be improved considerably. In this con-
nection also percolation models are studied. These are the simplest non-trivial
lattice models which involve critical phenomena, and appear to be very useful
to describe and understand similar phenomena in more complicated systems.

The problems in the research area have relationships with other fields: the
formation of traffic jams is closely associated with phase-transition; time evolu-
tion of particle systems is related to the evolution of cellular automata in com-
puter science, and in mathematical biology to growth or spread of epidemics;
percolation is related to conductivity in random electrical networks, porosity
and ferromagnetism. The models also play an important role in image analysis.

SUBPROJECT MEMBERS
Dr. H.C.P. Berbee (project leader)
Dr. J. van den Berg (researcher)
Dr. A. Gandolfi (guest researcher)
requested vacancy (junior researcher)

START OF SUBPROJECT: 1981

END OF SUBPROJECT: not yet determined

WORKING PLAN 1990

The research for functionals on a Markov chain will aim at limit theory for the likelihood and also at discontinuity. Another important problem investigated by Berbee is the description of 'quantised heat' models.

J. van den Berg joined the project in December 1988. The emphasis of his research is on percolation, in particular the behaviour at and near the critical point. A. Gandolfi is expected to visit us for a period of two months in 1990. He will mainly work on percolation and on the Ising model of ferromagnetism. Also probabilistic aspects of image analysis (BS 6.1) will be investigated. Cooperation takes place with F. den Hollander (Delft) on several of these topics.

WORKING PLAN AFTER 1990

Continuation of the investigation, possibly with new subjects.

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 Statistical inference using extreme order statistics;
BS 5.4 Statistical analysis of debugging and error-counting models in software reliability;
BS 5.5 Nonparametric estimation of the survival function in the presence of bivariate censoring;
BS 5.6 Statistical consultation and cooperation;
BS 5.7 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. De deelprojecten zijn:

BS 5.1 Semiparametrische schattingstheorie;
BS 5.2 Bootstrap methoden;
BS 5.3 Statistiek gebaseerd op extreme waarden;
BS 5.4 Statistische analyse van de betrouwbaarheid van programmatuur;
BS 5.5 Verdelingsvrij schatten van overlevingscurven bij gecensureerde bivariate waarnemingen;
BS 5.6 Statistische consultatie en samenwerking;
BS 5.7 Rekenintensieve statistiek.

PROJECT MEMBERS

Dr. K.O. Dzhaparidze (project leader)
Dr. R. Helmers (project leader)
Prof.dr. R.D. Gill (advisor)
Prof.dr. L. de Haan (advisor)
Drs. A.L.M. Dekkers (researcher)
Dr. S.A. van de Geer (guest researcher)
Prof. A.M. Shiryaev (guest researcher)
Dr. A.W. van der Vaart (guest researcher)
Drs. D. Bakker (junior researcher)
Drs. M.C.J. van Pul (junior researcher)
R. van der Horst (programmer)
Drs. B. Lisser (programmer)
priority vacancy (researcher)
requested vacancy (junior researcher)
requested vacancy (junior researcher)

EXTERNAL CONTACTS
Prof. P. Janssen (Diepenbeek, Belgium), 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)

START OF PROJECT: 1988

END OF PROJECT: not yet determined

CLASSIFICATION CODES

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

PROJECT DESCRIPTION

Project BS 5 combines theoretical and applied research in *semiparametric statistics*. The previous subprojects on the statistical analysis of stochastic processes and the statistical analysis of partially specified models are integrated in subproject BS 5.1 'Semiparametric estimation theory'. Subproject BS 5.4 is a new STW project on the statistical analysis of debugging and error-counting models in software reliability. Another new subproject is BS 5.5. Here the aim is to compare various estimators of the bivariate survival function in the presence of random censoring. The other subprojects BS 5.2, BS 5.3, BS 5.6 and BS 5.7 cover the remaining on-going research and consultation in project BS 5.

The selection of a new senior researcher for the project semiparametric statistics and of two junior researchers for BS 5.7 (with Dzapharidze) and BS 5.2 (with Helmers) should have very high priority.

SUBPROJECT BS 5.1

TITLE: Semiparametric estimation theory

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

Special attention will go to the most important particular case in which an experiment is generated by i.i.d. observations from a probability measure P. This measure itself is regarded as an unknown abstract parameter in a certain parameter space $\mathcal{P}$. The asymptotic behaviour of the estimator P_n for P, defined for a sample of size n as the maximum likelihood estimator (MLE), can be described in terms of the 'richness' of a parameter space $\mathcal{P}$ characterized by its *entropy*. We study, in particular, the convergence rate as $n \to \infty$ of the usual Hellinger distance $h(P_n, P)$ between P_n and P, based on ideas and techniques of the empirical process theory as developed in recent years in CWI by S.A. van de Geer (part time visitor). We will try to present the results in a form close to the regression theory in S.A. VAN DE GEER (1988), allowing extensions to certain non- i.i.d. situations.

In this connection, we study a general sequence of parametric families of experiments defined on a filtered probability space as, e.g., in DZHAPARIDZE and VALKEILA (1989), where the traditional way is followed (cf. IBRAGIMOV and HAS'MINSKII (1981)) of analyzing the convergence rate for the MLE of a parameter in a finite dimensional parametric space $\mathcal{P}$. With Valkeila (Helsinki) we will continue investigating more refined properties of the MLE, such as its asymptotic efficiency. As a first step, we will apply preliminary results by J. JACOD to establish conditions for LAN, expressed in so-called 'predictable' terms - in terms of the Hellinger processes associated to a parametric family of probability measures on a filtered space.

The results can, in general, be extended to the partial likelihood theory: the solutions here will be sought in terms of the so-called partial Hellinger processes (see, e.g., JACOD (1989)). As an important example, we deal with the special counting process model of Cox's regression for censored survival data.

Finally, with Chitashvili (Tbilisi) we study parameter estimation problems in partially observable stochastic models described by a system of stochastic equations with certain unobservable components: a typical example is presented by the Markov representation of an ARMA process as an only observable component of a vector-valued Markov process.

The research fits in the national NWO project 'Statistics for large parameter spaces', and collaboration will take place with statisticians at various universities, especially Utrecht, Delft and Amsterdam (Free University).

SUBPROJECT MEMBERS
Dr. K.O. Dzhaparidze (project leader)
Dr. S.A. van de Geer (guest researcher)
Prof. A.M. Shiryaev (guest researcher)
Dr. A.W. van der Vaart (guest researcher)

START OF SUBPROJECT: 1988

END OF SUBPROJECT: not yet determined

WORKING PLAN 1990

We apply first the entropy approach to i.i.d. observation models indexed by an abstract parameter space $\mathscr{P}$, in order to specify the link between the entropy of $\mathscr{P}$ and the rate of convergence of MLE. Then we investigate possible extensions to certain sequences of parametric families of experiments defined on a filtered probability space.

We also develop the conventional LAN theory for such sequences, indexed first by a finite dimensional parametric space, and then by an abstract parameter space as in IBRAGIMOV and HAS'MINSKII (1989). This will lead to certain statistical inference about parameters involved. We will try to develop along a similar line the partial likelihood theory, with applications to Cox's regression model. We intend here to collaborate with Prof.dr. R.D. Gill (advisor) and Dr. A.W. van der Vaart (part time visitor).

Together with P.J.C. Spreij (Free University of Amsterdam), we will study partially specified models from a different standpoint: it will be assumed that observations represent a sample path of a semimartingale with an unknown parameter involved in the compensator, and the best 'linear and regular' estimator for this parameter will be constructed. The particular case of the nonlinear regression scheme in discrete time will be further investigated, in order to improve estimating by using a priori information about marginal distributions of innovations.

In order to study parameter estimation problems for partially observable models, with R. Chitashvili (Tbilisi) we investigate basic regularity properties (such as LAN) of underlying processes, which are not a priori given by their minimal representation. Here we will need a filtration theory technique, namely Aldous' extended weak convergence theory as applied to the corresponding likelihood density processes.

WORKING PLAN AFTER 1990

Based on the experience gained in studying semiparametric estimation problems in its i.i.d. setting and classical parametric estimation problems in a general setting, we intend to develop a unified theory for general sequences of parametric families of experiments defined on filtered probability spaces. We will try to integrate in this theory problems concerning partially specified or partially observable models.

References
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3. I.A. IBRAGIMOV, R.Z. HAS'MINSKII (1981). *Statistical Estimation,* Springer, N.Y.
4. I.A. IBRAGIMOV, R.Z. HAS'MINSKII (1989). Asymptotically normal families of distributions and efficient estimation. Preprint, submitted to *Ann. Statist.*
5. J. JACOD (1989). Partial likelihood processes and asymptotic normality. *Stochastic Proc. Appl. Vol. 26,* 47-71.

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 5.6 (Statistical consultation and cooperation).

SUBPROJECT MEMBERS
Dr. R. Helmers (project leader)
requested vacancy (junior researcher)
R. van der Horst (programmer)

START OF SUBPROJECT: 1984

END OF SUBPROJECT: not yet determined

WORKING PLAN 1990
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 BHATTACHARYA and QUMSIYEH (1989) 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). Extending the bootsstrap result of [6] to the case of generalized L-statistics based on trimmed weight functions will require a different methodology based on bootstrapping empirical and quantile processes of U-statistic structure. In this connection also U-quantiles are of much interest. A well-known example of a U-quantile is the Hodges-Lehmann estimator of location.

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

A natural extension of [5] would be to study the bootstrap approximations for Studentized U-statistics in a more refined way, by taking not only $n^{-1/2}$ but also n^{-1} terms in the expansions into account. Here we aim at extending recent results of P. HALL (1988) to the U-statistic case. The statistical relevance of this would be the possibility to compare various Edgeworth and bootstrap based confidence intervals not only w.r.t. the error in the confidence level, but also by comparing the lengths of these intervals.

WORKING PLAN AFTER 1990
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 threshold 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 threshold. 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 right 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 the extreme value distribution, classical extreme value theory makes use of only the largest observations in certain time intervals (e.g. yearly maxima). Other methods, like the Pickands estimator, use the m-upper order statistics of the sample. These methods put in general less restrictions on the distribution of the observations than e.g. in SMITH (1987).

DEKKERS & DE HAAN (1989) 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, EINMAHL & DE HAAN (1989). 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.

SUBPROJECT MEMBERS
Dr. R. Helmers (project leader)
Prof.dr. L. de Haan (advisor)
Drs. A.L.M. Dekkers (researcher)

START OF SUBPROJECT: 1986

END OF SUBPROJECT: 1991

WORKING PLAN 1990
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 1990
The project will lead to a Ph.D. degree in 1991.

References
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9. A.L.M. DEKKERS, J.H.J. EINMAHL & L. DE HAAN (1989). A moment estimator for the index of an extreme-value distribution. *Ann. Statist.* to appear.

SUBPROJECT BS 5.4

TITLE: Statistical analysis of debugging and error-counting models in software reliability

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

Statistical models have been introduced to monitor the debugging process and to give quantitative information about the reliability of a software system. So far, however, their use has met with a number of difficulties, in particular due to a lack of methods for testing the goodness-of-fit of the models and due to numerical difficulties in the actual fitting of the models. The purpose of the project is to remove these difficulties by developing statistical estimation and testing procedures for common software reliability models and circumscribing the conditions under which the models and methods may be used. As well as deriving theoretical results on the validity of certain methods we will actually develop a computer package for the statistical analysis of debugging data.

SUBPROJECT MEMBERS
Dr. K.O. Dzhaparidze (project leader)
Prof.dr. R.D. Gill (advisor)
Drs. M.C.J. van Pul (junior researcher)

START OF SUBPROJECT: 1989

END OF SUBPROJECT: 1993
(STW project)

WORKING PLAN 1990
The first proposals for specific software reliability models, and for statistical methods for the analysis of data thought to occur according to such a model, were made by JELINSKI & MORANDA (1972), MUSA (1975), GOEL & OKUMOTO (1980) and LITTLEWOOD (1980). In all cases statistical analysis was to be carried out using the method of maximum likelihood. So far there has been no way of judging whether or not the proposed statistical analysis methods are appropriate. We believe we can solve this problem. We conclude with a brief technical summary of the various components of the research:

1. Development of a general large sample theory for MLE's in software reliability models with intensity functions of a special type, using the martingale and counting process techniques of AALEN (1978) and BORGAN (1984).
2. Investigation of the behaviour of the MLE when the model fails; in particular when the intensity is increasing instead of decreasing. Investigation of the use of nonexistence of the MLE as an indicator of lack of fit of the model.
3. Goodness-of-fit testing using the innovations approach of KHAMALADZE (1982).
4. Investigation of statistical methods when observation of the counting

process $n(t)$ is terminated at a stopping time T (i.e. a random variable).
5. Validation of methods with real and simulated data.

WORKING PLAN AFTER 1990

Though the working plan after 1990 cannot be foreseen completely by now, we mention next to continuation of the research components stated above, the following:

(6) Development of (workstation) software package for analysis of various software reliability models as a collection of S macros; parallel development also as PC-system (PC-ISP).

(7) Investigation of nonparametric variants of the model, see Ross (1985) and of other fields of application, e.g. epidemiology, linguistics, ecology, numismatics, etc.

This project will lead to a Ph.D. degree in 1993.

EXTERNAL CONTACTS

G. Moek (NLR), J. de Groot (Philips NatLab), J. Meinardi (ITI-TNO), S. Heisterkamp (RIVM), A. Verbeek (Gammasoft), a.o.

References

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SUBPROJECT BS 5.5

TITLE: Nonparametric estimation of the survival function in the presence of bivariate censoring

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

In recent years the problem of estimating the survival function in the presence of bivariate censoring has been studied by a number of researchers. Several estimators have been proposed. In the first place we mention an estimation procedure suggested by CAMPBELL and FÖLDES ([1]). Their estimator is a product of two univariate Kaplan-Meier estimators corresponding to a marginal and a conditional univariate survival function. However, the resulting bivariate survival function estimator need not be a survival function. Also the estimator is not symmetric (in the two marginals) and has the unpleasant property of being path dependent.

Recently D.M. DABROWSKA ([2], [3]) proposed and studied a different estimator of the bivariate survival function which is of product integral type. This estimator arises by considering cumulative hazard functions corresponding to double and single failures. This estimator need not be a survival function, but it is symmetric and path independent.

P.J. Bickel (Berkeley), R.D. Gill (Utrecht), and J.A. Wellner (Seattle) proposed an estimation procedure which is based on finding a solution of a Volterra integral equation for the bivariate survival function. Also efficient estimators based on one-step Newton-Raphson iteration, using one of the estimators discussed above as a starting value, are of much interest.

The aim of this subproject is to compare the various proposed estimation procedures, both analytically and by means of simulation studies.

SUBPROJECT MEMBERS
Prof.dr. R.D. Gill (advisor)
Drs. D. Bakker (junior researcher)

START OF SUBPROJECT: 1988

END OF SUBPROJECT: 1990

WORKING PLAN 1990
Study of the estimators proposed by Dabrowska and by Bickel-Gill-Wellner, both analytically and by means of simulation studies. In particular the variances of the various estimators of the bivariate survival function (at a given point) will be compared. As both estimators are known to be inefficient in general, also work will be carried out which will hopefully lead to the construction of efficient estimators. One possibility would be to use a (carefully defined) nonparametric maximum likelihood estimator. However, it appears that this estimator is very difficult to compute in practice. In any case the search for efficient estimators of the bivariate survival function in the presence of random censoring deserves attention. Our study will be completed in the summer of 1990.

WORKING PLAN AFTER 1990
This subproject will be completed in 1990.

References
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SUBPROJECT BS 5.6

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 accesible 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.

SUBPROJECT MEMBERS
Dr. K.O. Dzhaparidze (project leader)
Dr. R. Helmers (project leader)
Prof.dr. R.D. Gill (advisor)
Prof.dr. L. de Haan (advisor)
Drs. D. Bakker (junior researcher)
Drs. A.L.M. Dekkers (researcher)
Drs. M.C.J. van Pul (junior researcher)
R. van der Horst (programmer)
Drs. B. Lisser (programmer)

START OF SUBPROJECT: 1986

END OF SUBPROJECT: not yet determined

WORKING PLAN 1990
An extensive statistical consultation project with the aim to determine the heights of safe sea-dikes along the Dutch coast is currently being carried out in cooperation with the Ministry of Public Works (RWS) and the Royal Dutch Meteorological Institute (KNMI). This work began in 1984 and will most likely be completed in 1990. Recent results were reported in [1]. The new estimators for the index of an extreme value distribution, which were developed in BS 5.3, have been successfully applied to the real data sets supplied by RWS, (see [2] for an overview of the asymptotic theory of these estimators). The project will be completed with the publication of a final report (joint with RWS and KNMI). Hopefully the cooperation of CWI with RWS and KNMI will be continued. Some ideas concerning the contents of a new (follow-up) project are currently being developed.

WORKING PLAN AFTER 1990
Not to be foreseen.

References
1. A.L.M. DEKKERS, H. DAAN, D. DILLINGH, L. DE HAAN, R. HELMERS, J.W. VAN DER MADE, J. VAN MALDE, J.G. DE RONDE (1989). *Frequentielijnen kust,* Tussentijds verslag 2, rapport GWI 89.001, RWS, Dienst Getijdewateren.
2. L. DE HAAN (1989). Statistics of extreme values. *CWI Quarterly, Vol. 2, no. 2.* 101-115.

SUBPROJECT BS 5.7

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 5.1 (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) and PAARDEKOOPER et. al. (1989). 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.

SUBPROJECT MEMBERS
Dr. K.O. Dzhaparidze (project leader)
requested vacancy (junior researcher)
R. van der Horst (programmer)

START OF SUBPROJECT: 1990

END OF SUBPROJECT: not yet determined

WORKING PLAN 1990
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 1990
Studying the effects of increasing parameter-dimensionality in view of possible extensions to statistical schemes involving abstract parameters.

References
1. S. BEINICKE & K.O. DZHAPARIDZE (1982). On parameter estimation by the Davidon-Fletcher-Powell method. *Theory Probab. Appl. 27*, 396-402.
2. K.O. DZHAPARIDZE (1983). On iterative procedures of asymptotic inference. *Statistica Neerlandica 37*, 181-189.
3. M.H.C. PAARDEKOOPER, H.B.A. STEENS and G. VAN DER HOEK (1989). A note on properties of iterative procedures of asymptotic inference. To appear in *Statistica Neerlandica.*

PROJECT BS 6

TITLE: Image analysis

TITEL: Beeldanalyse

This project is concerned with mathematical and statistical aspects of the analysis of digital images and related spatial data. The aims of the project are to apply probabilistic models and statistical techniques to obtain new algorithms and assess the performance of existing ones. There is one subproject:
BS 6.1   Statistical aspects of image analysis.

SAMENVATTING
Dit project betreft wiskundige en statistische aspecten van de analyse van digitale beelden en gerelateerde ruimtelijke data.

De doelstelling van het project is probabilistische modellen en statistische methodieken toe te passen ten einde nieuwe algoritmen te verkrijgen en de prestatie van bestaande algoritmen te evalueren.

Er is één deelproject:
BS 6.1   Statistische aspecten van de analyse van beelden.

PROJECT MEMBERS
Dr. A.J. Baddeley (project leader)
Prof.dr. R.D. Gill (advisor)
Dr. R.A. Moyeed (researcher)
M. van Lieshout (junior researcher)
R. van der Horst (programmer)
Drs. B. Lisser (programmer)
priority vacancy (junior researcher)

COOPERATION
PROJECT GROUP AM 8
Drs. L. Barendregt (ITI-TNO)
Dr. N.I. Fisher (CSIRO Australia)
Prof.dr.ir. F. Groen (University of Amsterdam and Free University)
Dr. J. Moller (University of Aarhus, Denmark)

START OF PROJECT: 1988

END OF PROJECT: not yet determined

CLASSIFICATION CODES

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

SUBPROJECT BS 6.1

TITLE: Statistical aspects of image analysis

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 numerical decision-making process and can be profitably treated by mathematical and statistical methods. This subproject aims to assess and develop new image analysis algorithms, numerical measures of algorithm performance, and techniques for analysing image data in scientific experiments.

In the related field of image reconstruction, new methods based on Markov random field models have been introduced by statisticians with great success. An important role in these algorithms is played by computer simulations of image data sets for the purposes of Monte Carlo estimation and inference. The present project will attempt to develop similar methods for image analysis problems. This entails developing new Markov probability models for various spatial processes, and studying Monte Carlo inference methods in simpler settings such as the statistical analysis of point patterns or line patterns.

There is close cooperation with members of project AM 8 (Image reconstruction) as well as the seismic imaging project BS 3.5.

SUBPROJECT MEMBERS

Dr. A.J. Baddeley (project leader)
Prof.dr. R.D. Gill (advisor)
Dr. R.A. Moyeed (researcher)
M. van Lieshout (junior researcher)
R. van der Horst (programmer)
Drs. B. Lisser (programmer)
priority vacancy (junior researcher)

START OF PROJECT: 1988

END OF SUBPROJECT: not yet determined

WORKING PLAN 1990

(1) *Markov models.* Theoretical study of Markov spatial models of various types (Baddeley-Moller marked point models, Arak polygonal models, etc) and associated birth-and-death processes needed for simulation.

(2) *Monte Carlo inference.* Numerical study of Monte Carlo methods of parameter estimation and hypothesis testing for Markov spatial processes. Initially this will be developed only for point and line patterns.

(3) *Applied spatial statistics.* Analysis of point pattern and line pattern data from a variety of sources including cell location data (Hubrecht

Laboratory), geological fault maps (CSIRO Australia) and ant nest locations (University of London).

(4) *Stochastic algorithms for feature extraction.* Theoretical and practical development of new algorithms for reducing grey-tone images to linear outlines or other graphical representations.

(5) *Software development.* Extension and development of specialised software required for research above. Integration of this software into the general statistical computing environment ('S' package).

WORKING PLAN AFTER 1991

Extension of plan for 1990 in the following directions:

(1) *Stochastic models for mathematical morphology.* In collaboration with project AM 8, research will be undertaken into stochastic models for pixel images, with a view to characterising the image operators of mathematical morphology as optimal filters.

(2) *Bootstrap methods.* Extension of Monte Carlo approach discussed above to the development of bootstrap methods for spatial processes, with the aim of providing inferential devices such as confidence intervals.

(3) *Images in experimental design.* The possibility will be explored of incorporating image data, particularly data from mathematical morphology, in a multivariate analysis of variance.

CLASSIFICATION CODES

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

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, it is impossible to obtain the explicit solution of these problems, numerical approximations are a main tool to get insight in the quantitative behaviour of the solutions. The numerical mathematics department mainly 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 '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, nowadays, 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 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. The last few years have shown a shift from

fundamental to utilization directed research. In particular, in the externally financed shallow water and Boussinesq projects carried out by the group NW 1, hardly no fundamental research is possible due to lack of personnel. As a consequence, interesting mathematical problems cannot be attacked. It is the intention of the department to restore the balance as soon as circumstances do allow.

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 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 installation of the Alliant FX 4 parallel processor computer provides a stimulus for the practical investigation of parallel numerical algorithms. Encouraging results were already obtained for parallel differential equations solvers and many more interesting problems are waiting for solution in this new field of research. Developments in this area are fast and a lot of effort is needed to carry out the investigations adequately. Unfortunately, due to lack of personnel at this moment, it is not possible to reserve sufficient manpower, and, at the same time, to carry out the contract research at the present level.

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 third group NW 3 '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 large 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. In fact, it is here that the department most urgently needs a researcher in order to take part in the international developments. In particular, factorization methods and their performance on vector and parallel computers receive world-wide attention in the past few years, and CWI has contributed considerably to this area. Recently, Pollard designed a new factorization method for numbers of a special form (the so-called Number Field Sieve) and

A.K. Lenstra and others (H.W. Lenstra Jr. and C. Pomerance) have indicated how this method can be generalized for the factorization of arbitrary numbers. Theoretically, this method should be faster than any known method. This area of research is important and challenging and offers a rich source for new results. But again, due to lack of personnel at this moment, the department cannot attack these problems without sacrificing its other equally important and often externally financed projects.

Department of
Numerical mathematics

LIST OF PROJECTS

NW 1 Discretization of evolution problems
NW 2 Steady boundary-value problems
NW 3 Numerical software

		NW1	NW2	NW3	working time in fte	budget time	de-tached	guests	remarks
appointed									
Houwen, v.d	head dept.	*			1.00	1.00			
Verwer	proj.leader	*			1.00	1.00			
Goede, de	researcher	*		*	1.00	1.00			
Hundsdorfer	researcher	*			1.00	1.00			
Sommeijer	researcher	*		*	1.00	1.00			
Blom	sc.programm.	*			0.53	0.53			
Mooiman	jr.researcher	*			1.00		1.00 (STW)		
Trompert	jr.researcher	*			1.00	1.00			
Zegeling	jr.researcher	*			1.00		1.00 (STW)		
Hemker	proj.leader		*		0.90	0.90			
Wesseling	advisor		*		-	p.m.			
Koren	researcher		*		1.00	1.00			
Zeeuw, de	sc.programm.		*		1.00	1.00			
Maarel, v.d.	jr.researcher		*		0.90	0.90			
Molenaar	jr.researcher		*		1.00	1.00			
Nooyen, van	jr.researcher		*		1.00	1.00			
Kok	proj.leader			*	1.00	1.00			
Riele, te	proj.leader			*	1.00	1.00			
Vorst, v.d.	advisor			*	-	p.m.			
Lioen	sc.programm.			*	1.00	1.00			
Louter-Nool	sc.programm.			*	0.60	0.60			
Winter	sc.programm.			*	1.00	1.00			
total appointed					18.93	16.93	2.00		
priority 1	jr.researcher			*	1.00	0.50			
priority 2	jr.researcher	*			1.00	0.50			
priority 3	jr.researcher	*			1.00	0.50			

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: Method of Lines book;
NW 1.3: Adaptive grid methods (STW);
NW 1.4: Static regridding methods;
NW 1.5: 3D Shallow water equations (RWS);
NW 1.6: Smoothing and filtering techniques;
NW 1.7: Boussinesq model (STW);
NW 1.8: Parallel ODE solvers.

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: Methode der Lijnen boek;
NW 1.3: Adaptieve roostermethoden (STW);
NW 1.4: Static-regridding methoden;
NW 1.5: 3D Ondiep-watervergelijkingen (RWS);
NW 1.6: Smoothing- and filtertechnieken;
NW 1.7: Boussinesq-model (STW);
NW 1.8: Parallelle ODE solvers.

PROJECT MEMBERS
Prof.dr. P.J. van der Houwen (project leader NW 1.5-1.8)
Dr. J.G. Verwer (project leader NW 1.1-1.4)
Dr. W.H. Hundsdorfer (researcher)
Ir. J. Mooiman (researcher)
Drs. B.P. Sommeijer (researcher)
Drs. J.G. Blom (scientific programmer)
Drs. E.D. de Goede (junior researcher)
Ir. R. Trompert (junior researcher)
Drs. P.A. Zegeling (junior researcher)
priority vacancy (junior researcher)
priority vacancy (junior researcher)

EXTERNAL CONTACTS
Prof.dr. A. Bellen (University of Triest)
Dr. K. Burrage (University of Liverpool)
Dr. R.M. Furzeland (Shell Research Amsterdam)
Ir. G.J.A. Loman (Hydronamic BV)
Prof.dr. J. Ll. Morris (University of Dundee)
Prof.dr. J.M. Sanz-Serna (University of Valladolid)
Prof.dr. M.N. Spijker (University of Leiden)
Prof.dr. G. Stelling (Delft Hydraulics)
Dr. Th. van Stijn (Ministry of Public Works)
Dr. K. Strehmel (University Halle, DDR)
Dr.ir. E.J.M. Veling (National Institute for Public Health and Environmental
  Hygiene)
Dr. G.K. Verboom ((Delft Hydraulics)
Dr. T.M.M. Verheggen (Shell Research Amsterdam)
Prof.dr.ir. P. Wesseling (Delft University of Technology, advisor)
Dr.ir. F.W. Wubs (University of Groningen)

START OF PROJECT
Project NW 1 is a continuation of the department's research on numerical
methods for stiff ordinary differential equations. During recent years the
interest is gradually shifting towards partial differential equations.

END OF SUBPROJECTS

NW 1.1: No expiration date planned
NW 1.2: 1993
NW 1.3: 1992
NW 1.4: 1992
NW 1.5: 1992
NW 1.6: 1992
NW 1.7: 1990
NW 1.8: No expiration date planned

CLASSIFICATION CODES

NWO-classification   : P170
NABS-code   : N10, N023
1980 Math. Subj. Class.   : 65 LXX, 65 MXX, 76 B15
1982 CR Classification Scheme : G1.8

PPROBLEM 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 1990 attention will be paid to the following four main subjects: convergence and stability analysis, adaptive and moving grid methods, difference schemes for hyperbolic problems, and parallel algorithms. 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 models. In these projects, funded by the Ministry of Public Works (RWS) and the Foundation for the Technical Sciences (STW), there is a close cooperation with engineers and numerical analysts of the Ministry of Public Works (RWS), Delft Hydraulics (WL) and Hydronamic BV. The 3D shallow water equations project has a strong software component and is partly a subproject of the Software group NW 3.

Finally, in recent years the use of vector computers has obtained a firm footing in numerical mathematics. Anticipating on a similar development for parallel (vector) computers, our research on the fourth subject of parallel algorithms will be intensified. Currently, parallel Runge-Kutta methods are under investigation. The development of codes on the Alliant computer will be a joint activity of the Software group NW 3 and the Evolution Problems group NW 1.

WORKING PLAN 1990

NW 1.1 Stability and convergence. Research of project NW 1.1 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 1990 is to give particular attention to stability and convergence questions for methods for partial differential equations based on operator splitting. In previous years, we have investigated several methods based on dimension splitting. Among others, the phenomenon of order reduction was studied along the lines of the *B*-convergence theory for Runge-Kutta methods. It is expected that for operator splitting methods, a similar analysis is possible. Operator splitting is frequently applied by practitioners dealing with large-scale computational problems.

NW 1.2 Method of Lines book. 'Method of Lines book' is a new project, to be started early 1990. Jointly with Prof.dr. J.M. Sanz-Serna from the University of Valladolid in Spain, a book will be written dealing with numerical algorithms for time-dependent PDE problems. This project is related to NW 1.1 in the sense that much work carried out in the past, will be treated in this book. The material presented will emphasize the interplay between numerical methods for stiff ODEs and evolution problems in PDEs. In the coming three to four years, the work on this book will get a somewhat higher priority than the pure research projects planned under NW 1.1.

NW 1.3 Adaptive grid methods (STW project). Adaptive and moving 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). In 1990 the emphasis will lie on methods and techniques for problems in two space dimensions. 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 1.4 Static regridding methods (related to STW project NW 1.3). This project is new (start in spring of 1989) and replaces the project Lagrangian methods (NW 1.5 of Scientific Programme 1989). It is partly meant as background research for the STW project. Research will concentrate on problems in two space dimensions. Unlike Lagrangian methods, a static regridding method does not move nodal points in a continuous way, but it moves points only at discrete time levels. This leads to a completely different numerical problem setting. While Lagrangian methods work well in one space dimension, they are believed to be less attractive for 2D problems. Static regridding methods, where the nodal movement is decoupled from the PDE discretization, are simpler to use in 2D. In 1990 the research will concentrate on the development of a sort of domain decomposition method where in a recursive manner the PDE is integrated over locally uniform, refined grids. The level of refinement will be determined by error indicators and the entire solution process should be automized. Application is planned to reaction-diffusion, convection-diffusion, and to purely hyperbolic problems.

NW 1.5 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 numerical mathematics department of CWI was asked to develop a computational efficient model on vector computers and possibly parallel computers.

In 1990 we shall concentrate on the water flow in a rectangular box taking into account nonlinear terms. Using finite difference space discretization and employing so-called sigma transformations, the partially implicit time integrator developed in 1989 will be compared with the fully implicit integrator developed by RWS and Delft University of Technology. This research started in March 1988 and is carried out in consultation with Dr. Th. van Stijn (RWS) and other researchers of RWS and WL.

NW 1.6 Smoothing and filtering techniques. This project provides fundamental background research for the RWS project NW 1.5. 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. For 1989 we planned the development of a general framework for smoothing techniques in methods for hyperbolic differential

equations (see Scientific Programme 1989). This research plan was dropped because of lack of manpower and also in order to initiate research on parallel algorithms for ODEs. We hope to realize this plan in 1990.

NW 1.7 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 by Wubs in the STW project: 'Evaluation and stabilization of 2D shallow water solvers' which was carried out by the department 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 started medio 1988 and is carried out in close cooperation with Dr.ir. G.K. Verboom (Delft Hydraulics) and Ir. G.J.A. Loman (Hydronamic BV). In 1989 a definite choice of the Boussinesq terms was made and the numerical analysis of a fourth-order accurate numerical discretization was taken up. These investigations wil be continued in 1990.

NW 1.8 Parallel ODE solvers. This project started September 1988 when the installation of the Alliant FX4 at CWI became definite. Our first investigations were concerned with parallel explicit Runge-Kutta methods for ODEs. In 1989 this research was extended to diagonally implicit Runge-Kutta methods and linear multistep methods. A framework of block Runge-Kutta methods was developed which describes a large variety of parallel methods, including those already proposed in the literature, in a unifying way. The subject of parallel ODE (and PDE) solvers receives more and more attention from the numerical analysts and offers a rich source of new research topics that are both of mathematical and practical interest. It is expected that several Ph.D. theses can be prepared in this field in the coming years. It would be desirable to extend the group NW 1 by one or two junior researchers as soon as possible in order to work on the various new open problems in designing efficient parallel ODE and PDE methods.

WORKING PLAN 1991-1995
(1) NW 1.1 will be continued, but at a lower priority than in the past due to the new project NW 1.2.
(2) NW 1.3, 1.4 are planned to last until 1991/1992. These projects will have a high priority.
(3) Likewise, the RWS project NW 1.5 will last until 1992, so that also research on the 3D shallow water equations and the supporting project NW 1.6 will get a high priority.
(4) The STW project NW 1.7 will last until 1990 and has the same priority as the RWS project.
(5) As far as research on parallel algorithms (NW 1.8) 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 1.8 the attention it needs.

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 het efficiënt numeriek oplossen van stationaire problemen. In het bijzonder de studie van multigrid en 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
Prof.dr. P.W. Hemker (project leader)
Prof.dr.ir. P. Wesseling (advisor)
Dr.ir. B. Koren (researcher)
Drs. P.M. de Zeeuw (scientific programmer)
Ir. H.T.M. van der Maarel (junior researcher)
Drs. J. Molenaar (junior researcher)
Drs. R.R.P. van Nooyen (junior researcher)

EXTERNAL CONTACTS
Dr. W. Boerstoel (Dutch Aerospace Lab., Amsterdam)
Ir. N. Voogt (Fokker, Amsterdam)
Ir. W.J. Bannink (Delft University of Technology)
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 (Tech. Univ. 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)
Prof. M. Napolitano (University of Bari, Italy)
Prof. Ch. Hirsch (Free University, Bruxelles, Belgium)
Prof. H. Deconinck (Von Karman Institute for Fluid Dynamics, Rhode St. Genese, Belgium)

START OF PROJECT
Project NW 2 concentrates on applications of multigrid methods since 1979, applications in fluid dynamics since 1983, applications in semiconductor problems since 1987.

END OF SUBPROJECTS
1. The contribution to the HERMES R&D project NW 2.5 will end in 1990.
2. The present phase of the semiconductor modelling (Innovative Research Programs) part will end 1992.

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 discretizations 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 Dutch Aerospace Lab. (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 discretization, for which a special expertise has been built up at the CWI in the last decades.

WORKING PLAN 1990

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 (BRITE). 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. In this subproject cooperation is started with the Von Karman Institute for Fluid Dynamics, Belgium, the Free University, Bruxelles, and the University of Bari in the framework of a BRITE project (EEC) concerning the development of adaptive algorithms for solving the 2D Navier-Stokes equations.

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 2.3 and 2.5).

NW 2.5 Efficient techniques for the solution of the Euler and the 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 $Re = \infty$). 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.

Until January 1990, when an international workshop on the solution of hypersonic problems will be held at INRIA, Sophia-Antipolis, we will emphasize high Mach flows and continue 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). Later we will adapt the direction of the research according to the findings during this workshop, with a bias towards realization of nested local grid-refinements in the existing Euler-Navier-Stokes multigrid code.

NW 2.6 Reliable and efficient methods for semiconductor device simulation equations (Innovative Research Programs). 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 CFT Automation/CPS group, Philips, 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 1991-1995
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 both for the Navier-Stokes and for the semiconductor device equations.
4. Development of a two-dimensional multigrid method for semiconductor device simulation. The aim is to construct an adaptive method in which part of the mesh generation for the discretization is done automatically.

PROJECT NW 3

TITLE: Numerical software

TITEL: Numerieke programmatuur

ABSTRACT
There are four subprojects.

NW 3.1   *Development of numerical software in the programming language Ada.*

NW 3.2   *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 NEC SX-2, CRAY X/MP, Alliant FX/4, transputer systems).

NW 3.3   *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 can play a vital role.

NW 3.4   *Chebyshev reference software.* Provision of algorithms for the assessment of geometric form from coordinate data gathered by a coordinate measurement system.

SAMENVATTING
Het project bestaat uit vier subprojecten.

NW 3.1   *Ontwikkeling van numerieke programmatuur in de programmeertaal Ada*

NW 3.2   *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 NEC SX-2, CRAY X/MP, Alliant FX/4, transputersystemen).

NW 3.3   *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.

NW 3.4   *Chebyshev reference software.* Ontwikkelen van methoden voor het vaststellen van de wiskundige vorm van voorwerpen aan de hand van door apparatuur geleverde coördinaten van het oppervlak.

PROJECT MEMBERS
Drs. J. Kok (project leader NW 3.1, NW 3.4)
Dr.ir. H.J.J. te Riele (project leader NW 3.2, NW 3.3)
Prof.dr. H.A. van der Vorst (advisor)
Drs. E.D. de Goede (researcher)

Drs. B.P. Sommeijer (researcher)
Drs. W.M. Lioen (scientific programmer)
Drs. M. Louter-Nool (scientific programmer)
D.T. Winter (scientific programmer)
priority vacancy (junior researcher)

EXTERNAL CONTACTS

NW 3.1: Dr. K.W. Dritz (Argonne National Laboratory, Argonne, USA),
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NW 3.2: Prof. A. Bellen (University Triest, Italy), Prof.dr. Th.J. Dekker
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NW 3.3: Prof.dr. W. Borho (Gesamthochschule Wuppertal, FRG), Prof.dr.
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NW 3.4: Dr. M.G. Cox (National Physical Laboratory, Teddington, UK)

START OF PROJECT

NW 3.1: 1981
NW 3.2: 1984
NW 3.3: 1976
NW 3.4: 1990

END OF SUBPROJECTS

NW 3.1 No expiration date planned.
NW 3.2 Depends on plans and needs in NW 1 and NW 2.
NW 3.3 No expiration date planned.
NW 3.4 1992 (December).

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 3.1

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. CWI has joined in this activity in particular in an early investigation of the usefulness of Ada for making numerical software, by investigating the possibility of constructing a numerical Ada library with as a result a pilot library, and by designing standard modules of mathematical facilities as extensions of the standard Ada library in cooperation with the ISO section for the Ada programming language.

Of particular interest for ongoing research in numerical mathematics are Ada's high-level features for programming parallel execution. These enable to exploit the possibilities of novel architectures like CWI's multi-processor Alliant on a conveniently abstract level.

WORKING PLAN 1990

Within the framework of the international working group 'Ada-Europe Numerics Working Group' in cooperation with the American working group 'ACM-SIGAda NUM WG', and by representing the Working Group in the standardization body ISO-IEC/JTC1/SC22/WG9, the following activities are carried out:

(1) The language Ada does not define standard 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. Both already available and new proposals for extension of the language Ada with standard mathematical facilities will be further developed and advanced to the ISO body.

(2) We will investigate the design, and efficient and reliable implementation in Ada of parallel algorithms from several areas of numerical mathematics. The extent of portability across different architectures will be investigated and portable implementations will be made for exploiting the possibilities for parallel execution of specific hardware architectures.

WORKING PLAN 1991-1995
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.
5. J. KOK (1987). *Proposal for standard mathematical packages in Ada,* CWI Report NM-R8718, Centre for Mathematics and Computer Science, Amsterdam.

SUBPROJECT NW 3.2

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 parallelized algorithms. Many
algorithms need to be revised if they are to run efficiently on vector and paral-
lel 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 increasing
    emphasis on the possibility to reconfigure the architecture according to the
    amount of parallelism 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 parallelizing software, have a
significant lead over those who have no access to such a system. Fortunately,
CWI obtained its own parallel computer by the end of 1988. This is an Alli-
ant FX/4 shared memory system with four vector processors. It 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 1990
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 parallelize, 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 alge-
    bra software libraries. Purpose of this research is to investigate the extent
    to which these routines can be automatically vectorized and parallelized
    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. *Solution of large linear systems of equations.* Although computer memories have grown considerably in the past ten years, there is still a growing need of efficient numerical software for the solution of large linear systems of equations, where the matrix of coefficients does not fit into the central memory. Algorithms will be studied and designed for this class of problems which maximize the number of operations on data which are in central memory, and minimize the amount of necessary transport of data between central and background memory.

4. *Parallel algorithms for differential equations.* Depending on the availability of parallel computers at CWI, parallel algorithms for 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. Problems of current interest are block Runge-Kutta methods for solving ODEs and the development of an efficient computational model for the solution of the three-dimensional shallow water equations in a variety of practical situations (see the more detailed description in NW 1.6 and NW 1.8).

WORKING PLAN 1991-1995
Depending on plans and needs in NW 1 and NW 2, and on available financial means and parallel computer systems.

SUBPROJECT NW 3.3

TITLE: Computational number theory

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

Number-theoretic problems are 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 cryptographic 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 1990

Note: Important future research in factorization methods is described in 1. below. However, for the execution of this research, this project urgently needs a new scientific researcher.

1. Study of factorization methods for very large numbers on vector and parallel computers (CYBER 205, NEC SX-2, SEQUENT, Alliant FX/4, transputers) and application to the problem of the (non) existence of odd perfect numbers and of unitary perfect numbers.
    Recently, Pollard has found a new factorization method for numbers of a special form and A.K. Lenstra and others (H.W. Lenstra, Jr. and C. Pomerance) have indicated possibilities to extend Pollard's method to general numbers. These ideas are still very provisional, and much work is left to be done. Moreover, this new method is probably faster (at least in theory) than all known methods, but actual implementations, on vector and parallel systems, should reveal its practical meaning.
2. Study of zeros of functions related to the zeros of the Riemann zeta-function. These functions involve moments of the Riemann zeta-function itself.
3. Study and estimation of the so-called De Bruijn-Newman constant which plays an important role in the theory of the Riemann zeta-function, and whose precise value has implications for the Riemann hypothesis.
4. Continue the research and organisational work connected with the central

role of the CWI in the field of amicable numbers ('Centre for Amicable Pairs').

5. Try to extend computations concerning the so-called 'abc-conjecture' (Oesterlé-Masser, Stewart-Tijdeman, De Weger) by means of the Lattice Basis Reduction algorithm).

6. Try to develop iterative methods for the fast approximation of numbers of the form $(a^n + b^n)^{1/n}$, where n is an integer $\geqslant 3$, which should converge faster than Newton's method. This may have implications for the truth of Fermat's Last Theorem.

WORKING PLAN 1991-1995
Continuation of the 1990 plan.

SUBPROJECT NW 3.4

TITLE: Chebyshev reference software

PROBLEM DEFINITION AND SCIENTIFIC RELEVANCE

As part of automated manufacturing processes, coordinate measuring systems (CMSs) are used to acquire and analyze coordinates on the surface of a workpiece. Both the processes of data acquisition and data analysis are under computer control. This project is concerned with the data analysis techniques in cases where the workpiece is to be assessed for departure from fundamental geometric form. The forms considered will be line and circle in a specified plane, and line, circle, plane, sphere, cylinder and cone in 3-space. These forms are basic to metrology; other more complicated shapes are often compositions of these basic forms.

The technical problem is to devise the appropriate mathematics for Chebyshev and one-sided assessment of geometric form. It relates to the measurement of manufactured components for quality assurance and tolerancing purposes. The results will be of benefit to manufacturing industry, particularly mechanical engineering.

The results of this project are algorithms and software that can be used in practice or for comparison/validation of subsequent commercial products. This will particularly benefit those companies not large enough to support the personnel required to produce such software or to benchmark bought-in software.

WORKING PLAN 1990-1992

This is a so-called BCR project, partly funded by the EC's Community's Bureau of References. This project will be carried out in collaboration with NPL (Teddington) and PGB (Brunswijk, FRG), in the period January 1990-December 1992.

The project will provide algorithms for the assessment of geometric form from coordinate data gathered by a coordinate measurement system (CMS). The forms considered will be: line and circle in a specified plane and line, circle, plane, sphere, cylinder and cone in 3-space.

The assessment criterion will be Chebyshev (minimum zone, minimax) in all cases. Additionally, maximum inscribed and minimum circumscribed features will be included where these are meaningful (viz. circle in the plane, sphere and cylinder).

The algorithms will be presented in a high-level language which will enable straightforward encoding in the various languages used in different CMSs.

The documentation will also contain English language and mathematical descriptions of the algorithms, together with discussion of the uniqueness of solutions and the applicability of the algorithms.

The results of the present proposal would be algorithms that could be used in practice or for comparison/validation of subsequent commercial products.

The project can be broadly divided into four main constituent parts. The first stage of the work will consist of a careful examination of the available

literature on the Chebyshev and one-sided methods of assessment. Promising approaches will be adapted to the problem in hand and new approaches sought and developed.

For each of the 14 geometric elements of concern an appropriate algorithm will be devised and implemented in a high-level mathematical computer language. The algorithms will be tested on a variety of data sets. The tests will include those based on the use of synthesized data similar to that employed in BCR Project MTR 075. The final stage will be the preparation of documentation on the algorithms. In addition two interim progress reports and a final report describing the work as a whole will be prepared.

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. A substantial part of the work of the department is supported through the following external contracts:

- ESPRIT II (main programme)
    1. Generation of Interactive Programming Environments (GIPE) II
    2. ATMOSPHERE (technology integration project)
- ESPRIT Basic Research
    1. Integration: Integrating the Foundations of Functional, Logic, and Object-Oriented Programming
    2. Concur: Theories of Concurrency, Unification, and Extension
    3. Semagraph: Semantics and Pragmatics of Generalised Graph Rewriting
- RACE
    SPECS: Specification and Programming Environments for Communication Software
- NFI
    REX: Research and Education in Concurrent Systems
- SPIN
    PRISMA: Parallel Inference and Storage Machine Architecture.

In addition, support is given through NWO's Priority Programme for Informatics. Altogether, about two thirds of the department's staff is funded through the above sources.

In projects AP 1 through AP 4 (listed on the next page), the work will not undergo major changes as to its direction and manpower. Project AP 5 depends critically on the funding through the SPIN/PRISMA project. Since, moreover, two members of the project (will) have left before the end of 1989, it

could unfortunately be necessary to end AP 5 at the moment the PRISMA funding is terminated. Project AP 6, on the other hand, will be extended with work in the area of natural language processing, primarily motivated on the basis of the importance of enhancing human-computer interfaces.

Especially the projects AP 1, AP 2, and AP 4 are for the greater part externally financed. In these research projects the pure fundamental part is insufficiently present. To stop this dangerous development the department gives therefore the highest priority to the utmost necessary extension of each of these three projects.

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

		AP1	AP2	AP3	AP4	AP5	AP6	working time in fte	budget time	de-tached	guests	remarks
appointed												
Bakker, de	head dept.	*						0.80	0.80			
Jacquet	researcher	*						1.00	0.75			
Kok	researcher	*						0.20				0.2 (RUU)
Rutten	researcher	*						1.00	1.00			
Warmerdam	jr.researcher	*								1.00 (NFI)		
Horita	guest research	*						1.00			0.63	
Baeten	proj.leader		*					1.00	1.00			
Bergstra	advisor		*					-	pm			
Bergstra	researcher		*					0.20				0.2 (RUU)
Vaandrager	researcher		*					1.00	0.50			
Weijland	researcher		*					1.00	1.00			
Groote	jr.researcher		*					1.00	1.00			
Ponse	jr.researcher		*					1.00	1.00			
Klint	proj.leader			*				0.60	0.60			
Heering	researcher			*				1.00	1.00			
Hendriks	researcher			*				1.00	1.00			
Rekers	researcher			*				1.00	0.83			
Meulen, v.d.	jr.researcher			*				1.00	1.00			
Klop	proj.leader				*			0.70	0.70			
Vries, de	researcher				*			1.00	0.75			
Middeldorp	jr.researcher				*			0.80				0.67 (VU)
Eliens	researcher					*		1.00	0.67			
Kossen	jr.researcher					*		1.00	0.75			
Spee	jr.researcher					*		1.00	0.75			
Apt	proj.leader						*	1.00	0.67			
Bezem	researcher						*	0.80	0.33			
Emde Boas, van	researcher						*	0.20				0.2 (UvA)
Eyck, van	researcher						*	1.00	1.00			
Walinska de Hackbeil	researcher						*	1.00	0.24			
Bol	jr.researcher						*	1.00	1.00			
Kunen	guest research						*	1.00			0.25	
Total appointed								25.30	18.34	1.00	0.88	1.27
Contr. obligations												
SPI	jr.researcher			*				1.00		(PPI)		
Integration		*						1.00	0.25			
Specs			*					1.00	0.50			
Specs			*					0.50	0.50			
NFI			*							1.00		
GIPE				*				1.00	0.17			
Integration					*			1.00	0.33			
Semagraph					*			1.00	0.25			
Integration						*	*	0.80	0.47			
priority 1	jr.researcher				*			1.00	0.50			
priority 2	jr.researcher		*					1.00	0.50			
priority 3	jr.researcher	*						1.00	0.50			
request 1	jr.researcher				*			1.00	p.m.			
request 2	jr.researcher					*		1.00	p.m.			
request 3	jr.researcher	*						1.00	p.m.			

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 foundational topics related to semantic modelling.

SAMENVATTING
Onderzoek van semantische aspecten van parallelle verwerking volgens diverse programmeerstijlen (imperatief, logisch, object-georiënteerd, applicatief e.d.); voorts grondslagenvraagstukken betreffende semantische modelvorming.

PROJECT MEMBERS
Prof.dr. J.W. de Bakker (project leader)
Dr. J.M. Jacquet (researcher)
Dr. J.N. Kok (researcher)
Dr. J.J.M.M. Rutten (researcher)
Ir. E. Horita (guest researcher)
J. Warmerdam (junior researcher)
priority vacancy (junior researcher)
requested vacancy (junior researcher)

EXTERNAL CONTACTS
REX partners (University of Leiden, Eindhoven University of Technology)
ESPRIT BRA partners, in particular Philips Research Laboratories Eindhoven and University of Pisa
Free University of Amsterdam (Prof.dr. J.-J.Ch. Meyer)
University of Utrecht (Dr. J.N. Kok)
Erasmus University of Rotterdam (Dr. A. de Bruin)

START OF PROJECT: 1984

END OF PROJECT: to be determined

CLASSIFICATION 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 focusses 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, in particular to investigate semantics issues in the integration of logic- and object-oriented languages. 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 (Nationale Faciliteit Informatica), between the Eindhoven University of Technology (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. 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 performs an ESPRIT Basic Research Action. 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 Philips Research Laboratories Eindhoven.

WORKING PLAN 1990
- Designing and comparing semantic models for parallel logic programming languages such as Concurrent Prolog, Parlog, Guarded Horn Clauses or Conclog, with special reference to the relationship between declarative and flow-of-control models.
- Semantic issues concerning the object-oriented language POOL, in particular aiming at extending the previously obtained equivalence results between denotational and operational models to a form of a full abstractness result.
- Domain theoretic foundations for concurrency, using techniques from category theory and (metric) topology; one of the aims is the development of a general method to understand full abstraction.
- The construction and comparison of domains for bisimulation, such as the previously developed metric process domains and Aczel's universe of non-wellfounded sets.
- (In the context of the BRA Integration) Study of the semantic foundations of the integration of logic and object-oriented programming.
- (In the context of the REX project) Organization of a workshop on the foundations of object-oriented programming.
- (Completion of work performed in ESPRIT project 415) Completion of the Ph.D. thesis of F.S. de Boer (former AP member) on Proof Theory for POOL.

WORKING PLAN AFTER 1990
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)
Drs. F.W. Vaandrager (researcher)
Dr. W.P. Weijland (researcher)
Drs. J.F. Groote (junior researcher)
Drs. A. Ponse (junior researcher)
priority vacancy (junior researcher)

EXTERNAL CONTACTS
ESPRIT-partners
RACE-partners
University of Amsterdam (Programming Research Group)
University of Utrecht (Applied Logic Group)
Philips Research Laboratories Eindhoven
PTT Research - dr. Neher Laboratory Leidschendam

START OF PROJECT: 1982

END OF PROJECT: to be determined

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

DESCRIPTION OF THE PROJECT
There is cooperation with the group AP 4 concerning concurrency theory, and
with group AP 3 concerning specification languages.
All research in the project takes place in external contracts.

1. We participate in the RACE project 1046: SPECS (Specification and Pro-
gramming Environment for Communication Software). This project ends in
December 1992. CWI is subcontractor to PTT Research - dr. Neher Lab.
Other partners in this project are GSI-TECSI, CNET, STET-CSELT, IBM
France, NSC, TFL, INESC, GEC, PKI, EB and Alcatel NV. The CWI share
was increased in 1989, since it was felt that CWI gives an essential contribu-
tion to the theoretical foundations of the project.

SPECS 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. The
specifications of telecommunication software in different specification
languages ('tower languages') can be combined using a single underlying
mathematical representation language (MR), which itself forms the basis for
tool development. As of the beginning of 1990, MR version 2 should be opera-
tional.

2. We participate in the ESPRIT II Technology Integration project 2565:
ATMOSPHERE. This project ends in February 1994. CWI is associated
partner of Philips Research Laboratories Eindhoven. Other main partners are
Siemens, Bull, SGFL, ESF, GEC-Marconi and Nixdorf.

ATMOSPHERE aims to develop standardized facilities in support of system
engineering activities. System engineering comprises three stages: requirement
analysis, design engineering, and transformation into implementable designs.
CWI will concentrate on the verification of SDL programs in the ACP frame-
work, and the study of modularization in languages, in the framework of
Module Algebra.

3. We participate in the ESPRIT II Basic Research Action 3006: CONCUR
(Theories of concurrency: unification and extension). This project ends in
August 1991. Partners in this project are INRIA, SICS (Swedish Institute for
Computer Science), and the Universities of Edinburgh, Oxford, Sussex and
Amsterdam. CWI is coordinating partner, and will host a conference in
August 1990.

CONCUR investigates algebraic theories of concurrency, notably CCS, CSP
and ACP. We want to develop accepted standards, that facilitate cooperation,
compatibility and exchange of results, and aim to develop a common tool set
that will provide a strong basis for software development in the area of
verification of concurrent systems.

4. There is a proposed NFI project TRANSFER, ending in July 1993. Partners
are the University of Amsterdam, the Free University of Amsterdam, and the

University of Utrecht. CWI is coordinator.

TRANSFER investigates formal software specification languages in relation with algebraic concurrency theory. The CWI share is concerned with further development of the concurrency theory ACP, in the area of 'True concurrency' (non-interleaving semantics), comparative concurrency semantics, and real-time aspects.

Since all research in AP 2 takes place in external contracts, the research has increasingly become application oriented, and research that has a longer maturing period cannot be undertaken. Thus, we had to discontinue promising research on protocol verification using trace specifications. This is the reason we propose to appoint an *internally funded* junior researcher in AP 2.

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 course 'Formal Specification', which will be offered in the beginning of 1990. In the spring of 1990, an advanced course at the University of Amsterdam will be taught by a member of AP 2 (for the fourth time).

WORKING PLAN 1990

We will work on the RACE project SPECS, the ESPRIT projects ATMO-SPHERE and CONCUR, and (if accepted) the NFI project TRANSFER.

More specifically, the research in 1990 will concentrate on process algebra and algebraic specifications. Some topics that will be relevant:
- verification of algorithms with the help of process algebra;
- design of (the abstract syntax of) specification languages that can specify abstract data types and concurrently operating processes;
- investigating the relationship between abstract syntax, horizontal syntax and vertical syntax of specification languages;
- investigating 'True concurrency' in process algebra;
- investigation of modularization constructs in specification languages;
- installing and evaluating software development tools;
- completion of one or two Ph.D. theses.

WORKING PLAN AFTER 1990

Continuation of the research.

PROJECT AP 3

TITLE: Extensible programming environments

TITEL: Uitbreidbare programmeeromgevingen

ABSTRACT
Algebraic specification of programming environments, incremental develop-ment of language definitions, implementation of algebraic specifications.

SAMENVATTING
Algebraïsche specificatie van programmeeromgevingen, incrementele ontwikke-ling van taaldefinities, implementatie van algebraïsche specificaties.

PROJECT MEMBERS
Prof.dr. P. Klint (project leader)
J. Heering (researcher)
Drs. P.R.H. Hendriks (researcher)
Drs. J. Rekers (researcher)
Drs. E.A. van der Meulen (junior researcher)
junior researcher (NWO Priority Program Informatics)

EXTERNAL CONTACTS
BSO, INRIA, SEMA (Partners in ESPRIT project GIPE)
ADV/ORGA, BULL, GIPSY, INRIA, PLANET, PTL, SEMA (Partners in ESPRIT II project GIPE II)
Programming Research Group, University of Amsterdam
Software Engineering Research Centre (Utrecht)

START OF PROJECT: 1982

END OF PROJECT: to be determined

CLASSIFICATION CODES

NWO-classification	: P120, P170, 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 language 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. These two formalisms have been combined into the single formalism ASF+SDF that allows the specification of all syntactic and semantic aspects of (programming) languages.

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 carried out as part of ESPRIT project 348 (GIPE-Generation of Interactive Programming Environments) started in November 1984 and was completed by November 1989. ESPRIT project 2177 (GIPE II) started January 1989 and will continue until January 1994. In addition to this, a proposal for a project on 'Incremental Program Generators' has been accepted by NWO's Priority Program in Informatics.

Cooperation exists with INRIA (G. Kahn, Sophia-Antipolis and B. Lang, Rocquencourt), the Dutch softwarehouse BSO, the telematics laboratory of the Dutch PTT (PTL), the French softwarehouses GIPSI and SEMA, and the German softwarehouse ADV/ORGA. 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 1990
- Generation of integrated syntax-directed editors and typecheckers on the basis of ASF + SDF definitions.
- Generation of a meta-environment for editing ASF + SDF specifications.
- Optimization of the code generation process for algebraic specifications by extended analysis of language definitions.
- Continuation of the research on deriving *incremental* implementations from given, non-incremental, language definitions.
- Automatic generation of debuggers.

WORKING PLAN AFTER 1990
- Continuation of the work on incrementality.
- 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) and application domains (e.g., proof editing, program transformations).
- Automatic generation of various tools (e.g., dataflow analysis, version management).
- Application of partial evaluation techniques for the automatic generation of compilers.

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
Prof.dr. J.W. Klop (project leader)
Dr. F.-J. de Vries (researcher)
Drs. A. Middeldorp (junior researcher)
priority vacancy (junior researcher)
requested vacancy (junior researcher)

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

START OF PROJECT: JANUARY 1989

END OF PROJECT: to be determined

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

DESCRIPTION OF THE PROJECT

The objective of AP 4 is to perform foundational research in the field of (primarily but not exclusively) term rewriting systems. This extends to theoretical applications in the field of process algebra (in cooperation with AP 2), as well as in logic programming (in cooperation with AP 6). Most of the work in the project takes place in external contracts.

Scientific relevance

The primary theme of AP 4, term rewriting systems, and the secondary theme, process algebra, are not unrelated. Investigations in both subjects strictly adhere to the algebraic-axiomatic methodology. Just as TRSs are nothing else then 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, however.)

We now discuss in more detail the scientific relevance of the theme TRSs.

(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 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 Integration, see below.)

Specific research subjects
- Modular properties of TRSs. In cooperation with Prof.dr. H.P. Barendregt (Catholic University of 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. Continuation of this work will be attempted by Middeldorp in collaboration with Toyama.
- At various places in process algebra a term rewriting analysis can be (and has proved to be) fruitful, using techniques such as critical pair completion, induction-less induction, methods for termination proofs. As yet, a comprehensive analysis has not been made. This work fits into the project CONCUR.
- In the framework of BRA project Integration: an investigation of the relationships between critical pair completion, narrowing, and conditional rewriting. Also, a survey will be made comparing various resolution and unification techniques in equational logic programming (paramodulation etc.).
- 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 project SemaGraph, see below. Possibly category-theoretic aspects of graph rewriting will be studied.

External contracts
We participate in the following ESPRIT Basic Research Action projects:
(i) Integration: *Integrating the Foundations of Functional, Logic and Object-Oriented Programming.* Partners: CWI, CAIMENS (France), Imperial College (UK), UNINOVA (Portugal), Univ. of Pisa, Philips Research Labs. (For more data about this project, see AP 1, AP 6.).
(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. Duration: two years. (For more precise description of this project, see AP 2.).
(iii) SemaGraph: (ESPRIT BRA 3074): *Semantics and Pragmatics of Generalised Graph Rewriting.* Partners: Univ. of East Anglia, CWI, ICL (Manchester), Imperial College (London), Catholic Univ. of Nijmegen, LIENS (Paris). CWI participation: 1fte over 2.5 years. Starting date: July 1, 1989.

WORKING PLAN 1990
(i) Outside BRA contracts:
- Completing a monograph on term rewriting systems, with Dr. R.C. de Vrijer (Free University of Amsterdam).
- (Possibly, depending on available personel:) Investigation of type theories (polymorphic lambda calculus, Theory of Constructions of Huet and Coquand, Automath, Martin-Löf etc.).

-    Continuation of educational activities such as tutorials, PAO courses (on elementary logic, foundations of logic programming, term rewriting, process algebra).

We remark that the junior researcher, replacing AP 4's former member Drs. Van Glabbeek, is necessary to ensure the continuity of work in this project which does not take place under an ESPRIT contract.

(ii) In the framework of BRA contracts:

-    Investigation of term rewriting vs. graph rewriting (SemaGraph).
-    Investigation of methods to combine term rewriting and logic programming (Integration).
-    Scientific coordination of first year project CONCUR, including organization of a large conference in August 1990 at CWI.

WORKING PLAN AFTER 1990

Continuation of the research.

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 (researcher)
Drs. L. Kossen (junior researcher)
Drs. J.W. Spee (junior researcher)

EXTERNAL CONTACTS
Philips Research Laboratories Eindhoven
University of Twente
University of Amsterdam

START OF PROJECT: 1985/1986

END OF PROJECT: 1990

CLASSIFICATION CODES

NWO-classification   : P170, S260
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 (AI) 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 100-node coarse-grained data and knowledge-based multiprocessor machine, called POOMA. 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 expert systems research in the PRISMA project is carried out along the lines of small experiments in which various approaches to parallelism are being investigated for their viability. The development and the study of the distributed behaviour of prototype systems in the parallel object-oriented programming language POOL-X by means of a machine simulator and on the POOMA machine, is an essential part of the research. The application of parallelism in expert systems is investigated from two different perspectives. One study by L. Kossen focusses on the application of many-sorted logic as a knowledge-representation formalism in expert systems. The advantage of many-sorted logic when compared to the usually applied production rule and frame formalisms, is its clear declarative semantics. Moreover, there are sound and complete inference methods available for use in a logic-based expert system. However, these inference techiques are computationally much more expensive than similar techniques in production systems, which explains the interest in applying parallelism. In the PRISMA project several resolution-like inference techniques are being investigated for their suitability to exploiting coarse-grain parallelism. A second study by J.W. Spee investigates the potentials of parallel search in a causal qualitative expert system for fault finding in the IC production process, called EQUIP, which has been developed by Philips Research

Laboratories Eindhoven. An additional subject of study is the use of optimization strategies to prune the search space in such an expert system.

In addition to the above-mentioned activities in PRISMA, a parallel object-oriented PROLOG-like system has been developed by A. Eliëns in the language POOL-X. The prototype system offers language facilities for process creation, and communication by rendez-vous. It incorporates a new mechanism for distributed backtracking. The envisaged future work, which will take place outside the PRISMA project, concerns the study of the semantic basis of several mechanisms in the language. Dependent on the manpower available, the suitability of object-oriented logic programming for building expert systems, will also be a subject of study.

For the research concerning the logic-based expert system and logic programming, 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 on expert systems to the development of languages for knowledge representation lies.

The research on models for the representation and manipulation of uncertain and incomplete information in expert systems which has been carried out the last two years in collaboration with Prof.dr. R.D. Gill of the Mathematical Institute at the University of Utrecht has been fruitful. A mathematically sound model for plausible reasoning has been proposed by L.C. van der Gaag, former member of AP 5, departing from incompletely specified probability measures in causal graphs. It is conceivable that a successful application of the model in an expert system will lead to a breakthrough in the field. Unfortunately, lack of manpower makes continuation of this research in the project group unrealistic.

WORKING PLAN 1990
- Study of parallelism in resolution-like inference methods in the context of PRISMA.
- Study of optimization strategies in parallel search in the context of PRISMA.
- Implementation of POOL-X prototype expert systems within the context of PRISMA and study of their performance. Experiments on the POOMA multiprocessor machine.
- Study of the semantic basis of the integration of object-oriented and logic programming.

WORKING PLAN AFTER 1990: not applicable

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, non-monotonic reasoning and natural language processing.

SAMENVATTING
Onderzoek betreffende logisch programmeren, deductieve databases en kennisbanken, 'theorem proving', niet-monotoon redeneren en natuurlijke taalverwerking.

PROJECT MEMBERS
Prof.dr. K.R. Apt (project leader)
Dr. M. Bezem (researcher)
Dr. P. van Emde Boas (researcher)
Dr. J. van Eijck (researcher)
Dr. H. Walinska de Hackbeil (researcher)
Drs. R.N. Bol (junior researcher)
Prof. K. Kunen (guest researcher)
requested vacancy (junior researcher)

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

START OF PROJECT: 1987

END OF PROJECT: to be determined

CLASSIFICATION CODES

NWO-classification	: P110, P175, T120
NABS-code	: N076
1980 Math. Subj. Class. (1985)	: 68P15, 68Q40, 68Q50, 68T15, 68T30
1987 CR Class. Scheme	: F.3.2, F.4.1, F.4.2, H.2, I.2

DESCRIPTION OF THE PROJECT

The aim of this project is to investigate the logical foundations of Artificial Intelligence by using the methods of mathematical logic. More specifically, our research concentrates on 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 systems. In our recent research in this area we have investigated several aspects of logic programming, in particular its semantics, recursion theoretic aspects, the problem of termination, loop checking mechanisms aimed at blocking infinite computations, relation with non-monotonic reasoning. See also items 2. and 3. below.

2. Integrating logic and functional programming

The research carried out under this title is part of a larger research effort, namely the ESPRIT Basic Research Action 'Integration', which aims at integrating the foundations of logic, functional and object-oriented programming. Functional programming has its mathematical foundations in the fields of lambda calculus and term rewriting, and logic programming is rooted in predicate logic and automated theorem proving. Both styles of programming are commonly used in Artificial Intelligence. These programming styles heavily rely on mathematical logic and the idea of declarative programming, which states that the meaning of a program is the meaning of the collection of formulas or expressions of which it consists. The integration of these two programming paradigms is a challenging research issue. A natural approach to combining logic and functional programming is to consider the union of a set H of Horn clauses and a set E of equations as a program. Thereafter three lines of research will be pursued. The first line is concerned with so-called E-unification, a strengthening of the usual notion of unification where equality is not simply syntactical identity but is axiomatized by the theory E. The second line consists of amalgamating the operational semantics of logic and functional programming by means of a computation process in which each resolution step is followed by a reduction of the terms appearing as arguments of predicates. The third line of research studies a combination of resolution with a technique called narrowing used to simplify the terms.

3. Non-monotonic reasoning and logic programming

Non-monotonic reasoning naturally arises when dealing with incomplete and evolving information over a dynamically changing environment. It is modelled by a number of non-standard proof systems and methods including McCarthy's circumscription method, default theory, autoepistemic logic, 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 shall focus on a special class of logic programs which we call *acyclic* programs. Acyclic programs form a powerful subclass of Przymusinski's locally stratified programs and can be characterized as logic programs with negation and well-founded recursion. This latter condition has a beneficial effect on the termination behaviour of an acyclic program, but it also has a number of interesting semantical consequences.

4. Natural language processing

Knowledge as used in knowledge-based 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. Two important topics of research in this area are the treatment of quantification in natural language and the description of temporal relations. We intend to systematically describe the use of generalized quantifiers in the semantics of natural language. Important issues here are the compositional description of complex noun phrase constructions and the treatment of comparative constructions in terms of generalized quantifier theory. As for the other topic, in order to achieve an account of the way in which natural language describes temporal relations, one first has to develop a theory of the logic of time as applied to the dynamics of situations. We intend to work on such a theory, with the specific aim of clarifying the two key notions in a linguistic account of tense, those of 'events' and 'states'.

WORKING PLAN 1990

We plan to study the following aspects of the above-mentioned subjects:
- Semantics of various forms of integration of logic programming and functional programming and its relation with proof theory.
- Relation between various theories of non-monotonic reasoning and the theory of logic programming.
- Use of loop checking mechanisms for logic programs admitting function symbols and negation.
- Use of generalized quantifier theory in the compositional description of the semantics of noun phrases and comparative constructions.
- Study of logics with generalized quantifiers for the description of situations characterized by incomplete information.
- Study of logics of time and events and their application to dynamic situations.

WORKING PLAN AFTER 1990

Continuation of the research initiated in 1990.

Department of

Algorithmics and Architecture

Each of the ongoing projects in the AA department combines excellence in research with research topics that are of extreme relevance for today's Computing Science. In times in which a reduction in personnel is unavoidable, a general and abstract consideration is that the discontinuation of one complete project may be preferable to a cut 'across the board'. However, it is not possible to single out an AA project whose termination could be justified on scientific grounds. Instead, most of the projects will have to cope in 1990 with the situation in which the strength is less than optimal. This, by itself, has not been an easy decision. For several projects with a development component (e.g. AA 2, AA 4 and AA 6) the nature of the work requires a certain 'critical size' for the staffing of the project. For other projects whose orientation is currently confined to pure research aspects, the size may be less critical, but these projects are already of very modest size.

An important aspect is also, of course, as it is for other departments, that obligations stemming from EC and other contract research simply must be fulfilled. The unfortunate, but - at least for the immediate future - unavoidable, consequence is that the balance between the fundamental, innovative, aspects of the research, and the more development-oriented side of it, threatens to be further disturbed.

Originally, the intention was to start a few new AA research projects in the early nineties, among which two small-scale projects for fundamental research into design methodologies concerning, respectively, the design of processor architectures, and the design of open system architectures. Although the urgency and relevance is in no way less than when originally conceived, and both topics have a connection with existing AA and other CWI research, there is little hope now that this research can be taken up in the foreseeable future.

On at least two accounts, we will make a concerted effort to start new

research that does not (within CWI) form part of an existing project, subject to success in acquiring support in the form of outside funding. One project, the Beehive project, will combine expertise from the projects AA 2 and AA 4. The new CWI Multimedia project, will, as foreseen, span the departments of AA, IS and CST. In both cases, extensive use can be made of existing expertise, and to some extent existing software prototypes, and it is expected that the joint research will be fruitful as well for the other research of the participating projects. For a description of the envisaged research, we refer to the project description of AA 2.

In a quick round over the projects, which cannot do justice to the issues involved, we have the following.

Projects AA 1 and AA 5 are both small-scale projects, mainly concerning theoretical aspects, although with important practical overtones. The number of accepted papers from project AA 1 to the leading international conferences in its field, like STOC and FOCS - generally considered as more prestigious even than publication in the leading journals - is a strong indication of the excellence of the work in this group. A new approach to program construction originated and under development in AA 5 is internationally attracting increasing attention.

Projects AA 2 and AA 4 both concern state-of-the-art approaches to system construction in the important field of distributed computing, one of the main topics in CWI's computing-science research. Both have a strong development component, and are heavily involved in cooperative and contract research.

A considerable involvement in cooperative and contract research can be found as well in project AA 6. The group has, moreover, established an excellent track record in developing new protocols for provably secure communication, based on the notion of untraceability, and thereby pushing cryptography ahead to new areas of application. In the largely communication-based information technology of tomorrow, secure communication will be one of the key issues.

Project AA 3 combines a component of pure innovative research, the new Views project, with contract research in the development-oriented EUROMATH project.

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

		AA1	AA2	AA3	AA4	AA5	AA6	multi media	working time in fte	budget time	de-tached	guests	remarks
appointed													
Meertens	head dept.			*		*			0.70	0.70			
Vitanyi	proj.leader	*							0.80	0.80			
Kranakis	researcher	*							1.00	1.00			
Tromp	jr.researcher	*							1.00	1.00			
Mullender	proj.leader		*				*		1.00	1.00			
Rossum, van	researcher		*						1.00	1.00			
Jansen	sc.programm.		*						1.00	1.00			
Pemberton	proj.leader		*		*				1.00	1.00			
Barfield	researcher		*						1.00	1.00			
Dijk, F. van	sc.programm.		*						1.00	1.00			
Krijnen	sc.programm.		*						1.00	1.00			
Boeve	jr.researcher		*						1.00				0.16 TEG
Kersten	proj.leader			*					0.80	0.80			
Berg,C.A.v.d	researcher			*					1.00	1.00			
Siebes	researcher			*					1.00	1.00			
Verbrugge	jr.researcher			*					1.00	0.75			
Voort, v.d.	jr.researcher			*					0.80	0.80			
Fokkinga	researcher				*				1.00				0.90
Jeuring	jr.researcher				*				1.00				1.00(NFI)
Chaum	proj.leader					*			0.20	0.20			
Coster	researcher					*			1.00				0.16(NFI)
Bos	jr.researcher					*			1.00	1.00			
Heijst, van	jr.researcher					*			1.00	1.00			
total appointed									21.30	17.05			2.32
contr.obligations													
Zee,v.d. OSF	sc.programm.		*										
Bosch,P. OSF	jr.researcher		*										
priority 1	jr.researcher			*					1.00	0.50			
priority 2	jr.researcher		*						1.00	0.50			
priority 3	jr.researcher						*		1.00	0.50			
request 1	jr.researcher				*				0.50	p.m.			
request 2	jr.researcher		*						1.00	p.m.			
request 3	jr.researcher			*					1.00	p.m.			
visitor	guest research	*				*							

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 (researcher)
J.T. Tromp (junior researcher)
NN (guest researcher)

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 University of Waterloo (M. Li), Technion (A. Israeli), Northeastern University (L. Longpré), the Bell Labs (K. Oikonomou), University of Rochester (J. Seiferas).

START OF PROJECT: 1980
(ongoing project)

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 on 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, in particular persistent object storage, 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, met name opslag van langlevende objecten, 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) A.J. Jansen (scientific programmer)
Drs. G. van Rossum (researcher)   S. van der Zee (scientific programmer)
P. Bosch (junior researcher)   priority vacancy (junior researcher)

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 of Amsterdam (VU).

A collaborative SION project has started where CWI (AA 2 and AA 4), the Free University of Amsterdam, the University of Twente and the University of Amsterdam work on distributed systems and applications (complex object server, robotics).

Several European research institutes have expressed a desire to collaborate with the Amoeba group and to use Amoeba as the operating system basis for their research (Universities of Cambridge, Newcastle, Lancaster, Tromsø, Grenoble and Bologna, Queen Mary College, and INRIA). We expect that some real collaboration with a subset of these institutes will start in 1990.

The Open Software Foundation is funding a project of CWI and VU (the Culture Project) to prepare an Amoeba distribution by mid-1990 with 2 man years each at CWI and VU.

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

START OF PROJECT: 1984

END OF PROJECT: not yet determined

CLASSIFICATION CODES

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 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 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 less than 1.4 ms; user-process-to-user-process bandwidth is 6 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 a 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, MIPS R-2000 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, Ajax, 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

The Beehive Project
The Amoeba group (AA 2) and Daisy group (AA 4) are collaborating in the start of a project on efficient and reliable data storage through the design and implementation of a reliable, fast, extensible *object server* as a replacement of the file servers that are ubiquitous today.

Reliable means that the object server will continue to operate correctly in the face of processor, media, and network crashes and that the consistency of the stored data under correct usage is guaranteed.

Fast means that the object server delivers data quicker that local secondary storage media.

Extensible means that the object server can be extended with more servers and storage media to storage capacities of the order of terabytes while it continues to work efficiently.

Amoeba will serve as the distributed operating system basis for the project. The design and implementation of Beehive will profit from the experiences of Amoeba and those of the AA 4 PRISMA and TROPICS projects.

Beehive will initially be tested in two applications; first as a replacement of the current file systems in distributed systems in a research environment, second as a server for high-performance *on-line transaction processing*.

Proposals for the funding of this project have been or will be submitted to the SION Speciaal Programma Informatica (SPI), the Stichting Technische Wetenschappen (STW) and to the Nationale Faciliteit Informatica (NFI).

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 develoment 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 Project, 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 AA, IS and CST departments of CWI are planning a large multimedia research project (Kersten, Mullender, Ten Hagen, and Bulterman; possibly Meertens, Pemberton, Baddeley (BS)). The aim of the CWI Multimedia project is to design and build a distributed multimedia system that can span a large geographical area. The system should use state-of-the-future graphic capabilities (HDTV quality), high-speed communication and database-storage facilities.

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:

Multimedia networks

High-speed (i.e., $\sim$ 1 Gbps) network technology, protocols and interfaces. Gateway design for minimum delay. Interfaces to public networks. Synchronization of multiple, parallel networks.

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.

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).

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.

Multimedia user interface

Designing an interface to come to grips with multimedia streams. Collaboration with the Views project seems a logical step.

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.

Graphics capabilities

To achieve state-of-the-future graphics, new graphics interfaces need to be designed and built, capable of high-resolution display (e.g., 16 planes of $2K \times 2K$ pixels of 24 bits), and real-time processing of the data on the display at a rate of 25 frames per second.

Distributed Computing over Wide-Area Networks

In collaboration with other European research institutes, CWI plans to start a project 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. CWI plans to 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 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 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, one researcher and three programmers (two of which work in the OSF project).

In the Beehive project, 3 new staff are needed over and above the current staff of AA 2 and AA 4.

At this stage, it is not clear what form the multimedia project will take. For the Amoeba group, we will need at least one or two extra people.

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 consistent, and obvious to use, tools. The project consists of three subprojects:

AA 3.1 The ABC Project;
AA 3.2 Human-Computer Interfaces (Views);
AA 3.3 EUROMATH.

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, constant en duidelijk te gebruiken hulpmiddelen. Het project bestaat uit drie subprojecten:

AA 3.1 Het ABC-project;
AA 3.2 Mens-Computer Interfaces (Views);
AA 3.3 EUROMATH.

PROJECT MEMBERS
S. Pemberton (project leader)
Dr. L.G. Barfield M.Sc. (researcher)
Prof. L.G.L.T. Meertens (researcher)
Ir. E.D.G. Boeve (junior researcher)
Drs. F. van Dijk (scientific programmer)
Drs. T.J.G. Krijnen (scientific programmer)
requested vacancy (junior researcher)

EXTERNAL CONTACTS
Within CWI there is collaboration with researchers from projects AA 2 (S.J. Mullender and G. van Rossum), AA 4 (M.L. Kersten), and CST 2 (D.C.A. Bulterman). The Views subproject includes collaboration with the University of Utrecht (Prof. S.D. Swierstra) and the University of Groningen (Prof. R.C. Backhouse). An NFI project proposal 'Systematic Design of User Interfaces' has been submitted in collaboration with the Delft University of Technology, the Catholic University of Brabant, the Free University of Amsterdam, and the University of Twente. The Euromath subproject is CODEST funded, and includes collaboration with a number of European research centres amongst

whom INRIA (Paris), Fachsinformationszentrum Karlsruhe (FRG), the University of Paderborn (FRG), and the University of Bath (UK).

START OF SUBPROJECT AA 3.1: 1985
START OF SUBPROJECT AA 3.2: 1985
START OF SUBPROJECT AA 3.3: 1988

END OF SUBPROJECTS: not yet determined

CLASSIFICATION CODES

NWO-classification   : P175, T120
1985 CR Classification Scheme : H.1.2, K.8, D.2.6, D.3, I.3.6, D.2, D.2.2, D.2.3,
                                D.2.7, D.3.2, H.2.3, H.3.3, I.1.7

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 1990
1. Maintenance of the ABC implementation.
2. Integration of the implementation into Views (see AA 3.2).

WORKING PLAN AFTER 1990
Continuation of the maintenance.

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. Views therefore is an open-architecture user-interface system, stronger than WYSIWYG, where the user model is editing (potentially dynamic) documents for all actions. The internal consistency of the system is kept valid through updating 'invariants' which go temporarily out-of-date through the user editing a document.

Working plan 1990
Design and implementation of major sub-systems under Views.

Working plan after 1990
Continuation of the research.

Project description

Subproject AA 3.3: EUROMATH
EUROMATH is an ambitious project to link mathematicians in (currently) 19 European countries via a communications network, allowing them to access remote databases, edit and format mathematical articles, and communicate via conferencing systems and electronic mail. The aim is to provide a system with a single user-interface to allow the mathematicians to access and control these functions.

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 data-bases. 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.

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.

An initial implementation of the project is based on the existing functionality of a series of interconnected Unix hosts. This implementation was produced at CWI during the first phase of the system, and provides first versions of the text-editing, mailing, and conferencing parts of the system.

Working plan 1990
The next stages of the implementation will be divided amongst the collaborating partners. It is foreseen that the CWI will be responsible for the system environment parts, working on the kernel of the system, and the central system functionality.

WORKING PLAN AFTER 1990
Continuation of the research and implementation.

PROJECT AA 4

TITLE: Distributed adaptive information systems

TITEL: Gespreide adaptieve informatiesystemen

ABSTRACT
Research on data models 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 datamodellering, 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 applicaties en het realiseren van software prototypes op een hierop toegesneden (virtuele) machine-architectuur.

PROJECT MEMBERS

Dr. M.L. Kersten (project leader)
Drs. C.A. van den Berg (researcher)
Drs. A.P.J.M. Siebes (researcher)
Drs. N.Th. Verbrugge (junior researcher)
Drs. M.H. van der Voort (junior researcher)
NN priority vacancy (junior researcher)
NN requested vacancy (junior researcher)

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 a high-performance parallel system for the office. 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

END OF PROJECT

PRISMA   : 1990
TROPICS : 1993
NFI   : 1993

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 different, yet complementary perspectives. They are described in more detail below.

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 better supports modelling of complex objects with their semantics.

The short-term goal is to alleviate this problem by our extending 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 University of Technology. 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, wrote a functional design of the PRISMA database software, and implemented the system.

The short-term objective is 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. 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 an 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.

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 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.

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 2 and AA 3.

The Beehive Project

The Beehive is a collaborative project that will be carried out in collaboration with the Amoeba group, AA 2. Its description can be found there.

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 four extra persons, including a post-doc, are needed (two persons funded by the CWI, one through NFI and one through TROPICS).

EQUIPMENT
The distributed adaptive information systems project currently uses the computer infrastructure of the CWI. In the near future we will 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 and TROPICS will require hardware for multimedia applications.

WORKING PLAN
See the project description.

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 specialized 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 en van formalismen om algoritmen te beschrijven, alsmede het ontwikkelen van gespecialiseerde theorieën voor bepaalde gegevenstypen of probleemklassen.

PROJECT MEMBERS
Prof. L.G.L.T. Meertens (project leader)
Drs. M.M. Fokkinga (researcher)
S. Pemberton (researcher)
Drs. J.T. Jeuring (junior researcher)
requested vacancy (junior researcher)

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

START OF PROJECT: 1977

END OF PROJECT: To be determined. The STOP project runs until the end of 1992.

CLASSIFICATION CODES

NWO-classification   : P175
1985 CR Classification Scheme : D.1.2, D.2.1, D.3.1, D.3.3, F.3.1, F.3.3, 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.

Cooperation. 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 of 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.

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. 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. By using initiality of the algebra, and therefore the unique extension property of homomorphisms, induction proofs to show the equivalence of programs can be replaced by calculation and equational reasoning.

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 been examined in depth. Some theory is known for infinite structures, which correspond to a final rather than an initial algebra, but for graphs little or no theory is yet available. The results that have been obtained display a certain commonality, and - mainly due to the efforts of the group at Groningen - an 'embracing' theory of data types is beginning to emerge, which can be elegantly phrased in a categorical setting.

Among the construction methods that have emerged 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. Here the following general method can be applied. 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.

Next to the development of theory, work will be done on the design of tools for mechanical assistance in creating program developments. This is done in the context of the STOP project.

WORKING PLAN
See the project description.

PROJECT AA 6

TITLE: Cryptology

TITEL: Cryptografie

ABSTRACT

All aspects of cryptology and information security are covered. Particular emphasis is given to the construction and analysis of cryptographic algorithms and protocols, practical implementations, and related complexity-theoretic investigations.

SAMENVATTING

Aan alle aspecten van cryptologie en databeveiliging wordt aandacht geschonken, maar speciaal aan de constructie en analyse van cryptografische algoritmen en protocollen, praktische implementatie, en verwante complexi-teitstheoretische onderzoeken.

PROJECT MEMBERS
Dr. D. Chaum (project leader)   Ir. E.J.L.J. van Heijst (junior researcher)
Dr. M.J. Coster (researcher)   A.G. Steenbeek (programmer)
Ir. J.N.E. Bos (junior researcher) NN (guest researcher)

EXTERNAL CONTACTS
Some of the crypto group's contacts are as follows: within CWI: P.M.B. Vitányi & E. Kranakis (AA 1), S.J. Mullender (AA 4), A.E. Brouwer (AM 1), A.G. Steenbeek (AP 1), and H.J.J. te Riele (NW 4.3); within the Netherlands: H.C.A. van Tilborg (Eindhoven University of Technology), G. Roelofsen (PTT Neher Labs), C. Jansen (Philips USFA), and J.-H. Evertse (University of Leiden); within Europe: P. Camion (INRIA), I. Damgård (Aarhus University), W. Fumy (Siemens), S. Herda (GMD), O. Staffelbach (Gretag), and J. Van-dewalle (Catholic University Leuven); and elsewhere: G. Brassard (University Montreal), A. Fiat (Tel-Aviv University), R. Impegliazzo (University Toronto), M. Naor (IBM Almeden), A. Shamir (Technion)

START OF PROJECT: 1980

END OF PROJECT: not yet determined

CLASSIFICATION CODES

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

PROJECT DESCRIPTION

Security is widely realized to be essential in many applications of information technology, and desirable to some extent in almost all such applications. Cryptography has proven to be a major - if not the only - means to achieve such security in many cases. With VLSI, information technology just now reaching performance levels that allow the new public-key cryptographic systems developed over the last decade to be applied. Protocols based on such techniques offer a wide range of possibilities beyond simple confidentiality of data. Examples include digital replacements for handwritten signatures or spoken agreements, numbers that can be securely yet untraceably spent like cash, and techniques allowing a person to maintain the single database of all their personal credentials while convincing others of the truthfulness of answers to queries made to this database. In essence, we are standing on the threshold of a new era of information technology, where the only enforceable rules are based on cryptography.

The crypto group has established CWI as one of the leading research centres within the field. This has been achieved in part due to international activities such as courses, conferences, and cooperative research projects. But the most significant component is research results. The major themes of the group's current research can be divided as follows:

Cryptographic protocols based on the notions of untraceability and limited pseudonymity: Development of new protocols; devising new cryptographic algorithms upon which to base such protocols; and investigating application possibilities while developing a general model. This fruitful area is expected to continue to be investigated vigorously. We hope to maintain our leadership in this area that we pioneered, though publications are now coming from groups in California, Israel, Japan, Denmark, and West Germany.

Theoretical investigation of cryptographic protocols: Continuing leading-edge work in the theoretical possibilities of multiparty cryptograhic protocols; developing a theoretical basis for these; and developing other potentially useful protocols with formal proofs of security. Not only have the results of our group been keeping pace with the others working in the area, but our latest is the strongest known for the general case [1].

Conventional cryptographic techniques: Design of algorithms, evaluation (including cryptanalysis) of algorithms, and continuation of more theoretical work. This work has been quite successful to date. The two major conventional cryptographic algorithms, DES and FEAL, have suffered the most serious attacks in the literature at the hands of the crypto group: 7 rounds of DES and FEAL 4 were broken [2 & 3].

PLANS FOR FUTURE RESEARCH

Cooperation on number theory and information theory. The potential role in cryptography of these two more established disciplines is evidenced by some important papers in the literature, but we believe their mathematical techniques are applicable to a much wider range of problems in cryptography. Under a proposed new NFI project for cooperation between Eindhoven, Leiden, and CWI, there would be an exchange of junior researchers and visitors, in combination with regular contacts in the area of cryptography. Emphasis in the project is expected to be on training, but there will be a significant research component. This activity is expected to substantially broaden the scope of CWI's research program.

Fundamental complexity-theoretic investigations. Perhaps the deepest question in cryptography, and arguably one of the most interesting in complexity theory, relates to the existence of provably computationally intractable problems. One new approach to addressing this question was developed at CWI [5], and it seems potentially fruitful and at least worth exploring. Another approach, which will be considered cooperatively with P.M.B. Vitányi (AA 1), is the application of Kolmagorov/Chaitin complexity. More generally, complexity-theoretic perspectives continue to be an important theme in cryptographic research, and the crypto group expects to be involved collaboratively in this area.

Distributed computer systems security. The original proposal for encrypted capabilities, a combined addressing and access control mechanism for computer operating systems, was made by a member of our group [4], and it has remained essentially unimproved until now. We plan to re-open this investigation in light of the last ten years of progress towards distributed operating systems, combined with the new cryptographic techniques and hardware that now make their implementation practical. As an example of the new situation, consider that Sun workstations have DSP chips available which can perform tens of RSA encryptions per second. Related problems are workstation security, authentication server protocols, and the use of encryption to protect the contents of databases. Cooperation on this theme with S.J. Mullender and his group (AA 4) is already planned.

New kinds of signatures and their interaction. The possibility of digital signatures was proposed in 1976. Shortly afterwards actual schemes were discovered, and VLSI is just now making them practical - by either dedicated chips now on the market or sufficiently fast DSP chips. A number of variations and extensions on the digital signature concept have been proposed in the literature: blind signatures, one-show blind signatures, and undeniable signatures (in fact these proposals originated from members of the crypto group). They are essentially as practical as RSA. A fertile area for new research remains open, however. It addresses questions like: How can these new types of signatures be combined? Can their implementations be improved in terms of

performance? What problems can their security be shown equivalent to? Can further new and useful types be devised? ⸱

Evaluation of integrity primitives. Integrity, sometimes used synonymously with authentication, can be thought of as embracing all aspects of information security apart from confidentiality. Because of the RIPE project, CWI will be taking a leading role in evaluating integrity algorithms and protocols that are submitted responsive to the RIPE calls. Already more than a dozen primitives, expected from the first call, are to be evaluated during 1990. The second call will be made at the end of 1990 and evaluation of its submissions will extend into mid 1992. It is expected that further rounds of calls will be made perhaps under new funding and at increasing intervals.

WORKING PLAN
See the project description.

References
1. D. CHAUM. *The spymasters double agent problem: Computations unconditionally secure against minorities and cryptographically secure against majorities,* Proceedings of Crypto '89, Springer, to appear.
2. D. CHAUM, J.-H. EVERTSE. *Cryptanalysis of DES with a reduced number of rounds,* Proceedings of Crypto '85, Springer.
3. B. DEN BOER. *Cryptanalysis of FEAL,* Proceedings of Eurocrypt '88, Springer.
4. D. CHAUM, R.S. FABRY. *Implementing capability based addressing using encryption,* U.C. Berkeley Memorandum UCB/ERL M78/46.
5. D. CHAUM, R. IMPAGLIAZZO. *Super-one-way functions and their implications,* to appear.

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.

If financial means will be limited further next year, all projects will suffer from anaemia. Amputations, though painful, may heal the department as a whole. The limb that may be considered for this kind of autocanibalism, is the 'User controlled system' project, because this choice minimizes the immediate effect on other projects. On the long run, however, lack of knowledge on the methodology of the design of user interfaces, and on the design of interfaces for large and complex systems, will turn out to be a serious handicap in the application of the results of other projects, and in raising external funds.

If the IS 1 project is not fully manned, the BONSAI project may fail or may not be on schedule. This will have consequences for the applicability of the results of the STW project on special hardware. A third victim of cutting downs is the multimedia project. It will not take off.

For multi-media it is now the right time to start a major project. Further

delay would force us to leave this important topic to others (outside the Netherlands). Currently CWI is in the position to combine results of trail-blazing research in graphics, interaction, distributed systems and the major expertise in UNIX and data bases into this new project. The results of the various research projects are directly relevant for multi-media. Hence, there is an ideal starting point.

Department of
Interactive Systems

LIST OF PROJECTS

IS 1 Computer graphics
IS 2 User interfaces
IS 3 Dialogue environments
IS 4 Intelligent CAD systems

		IS1	IS2	IS3	IS4	multi media	working time in fte	budget time	de-tached	guests	remarks
appointed											
Hagen,ten	head.dept		*	*	*	*	1.00	1.00			
Kuyk	proj.leader	*				*	1.00	1.00			
Blake	researcher	*					1.00		1.00(STW)		
Herman	researcher	*				*	1.00	0.75			
Guravage	sc.programm.	*					1.00		1.00(STW)		
Blom	proj.leader		*				1.00	1.00			
Ruiter,de	proj.leader		*			*	1.00	1.00			
Vegt,van der	jr.researcher		*				0.80	0.80			
Eshuis	proj.leader			*		*	1.00	1.00			
Schouten	researcher			*			1.00	0.45			
Liere,van	sc.programm.			*		*	1.00	0.92			
Spilling	jr.researcher			*			1.00	1.00			
Arbab	proj.leader				*		1.00		1.00 (NFI)		
Rogier	researcher				*		1.00		0.75(TNO)		
Veerkamp	researcher				*		1.00	0.75			
Klarenbosch	jr.researcher				*		1.00		1.00(NFI)		
Otten	jr.researcher				*		1.00	1.00			
PietersKwiers	jr.researcher				*		1.00		1.00(NFI)		
total appointed							17.80	10.67	5.75		
NN	researcher	*					1.00		1.00 (STW)		
priority 1	researcher			*			1.00	0.50			
priority 2	jr.researcher	*					1.00	0.50			
priority 3	researcher	*					1.00	0.50			
request 1	jr.researcher		*				1.00	p.m.			
request 2	jr.researcher			*			1.00	p.m.			
request 3	jr.researcher					*	1.00	p.m.			

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, again 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

Drs. A.A.M. Kuijk (project leader)
Dr. E. Blake (researcher)
I. Herman M.Sc. (researcher)
M. Guravage M.Sc. (scientific programmer)
Dr. M. Bakker (programmer)
F.J. Burger (programmer)
B.P. Rouwhorst (programmer)
NN (researcher)
priority vacancy (researcher)
priority vacancy (junior researcher)

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 and objects-oriented graphics in close cooperation with EUROGRAPHICS.

START OF PROJECT: 1980

END OF PROJECT: 1994

CLASSIFICATION CODES

NWO-classification	: P175, T120
1980 Math. Subj. Class.	: 68K31, 68K32
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 multilateral functionality to 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 needed 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 achieved 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 1990

In 1990 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.

The STW project 'A new architecture for rastergraphics on the basis of VLSI' (in cooperation with the University of Twente) will be focussed on embedding of the custom designed chips obtained so far in general purpose hardware to result in a working prototype. This will involve hardware as well as software aspects. The working prototype will be used for simulation of the complete architecture. This activity will also give insight in to what extend custom designed integration hardware is desirable.

A configurable parallel system will be built on which the incremental algorithms under development will be studied in further detail. Based on results of this study a decision will be made on which (parts) of these algorithms are candidates for implementation on special purpose hardware.

A new graphics system, called BONSAI, is being developed which is a prototype for future graphics systems which allow for: - standardizable programmer interfaces on the basics of object-oriented programming; - configurable graphics pipelines to accommodate specific graphics hardware (2D and 3D) to exploit parallelism and to support introduction of domain specific graphics primitives and rendering functions; - full support for interaction techniques including windowing. This system is not only of importance for the standard work, it will also provide the software basis for the transfer to industry of the VLSI project results. A new line of research will be opened to investigate the

widening domain of overlap between graphics and image processing. Several external cooperation will take place in this new line both commercial and academic. For this domain the above-mentioned hardware and software systems will provide a suitable experimental basis. The first attempt will be to develop a family of hybrid primitives which allow for interactive use of graphics and image processing techniques.

WORKING PLAN AFTER 1990

The STW project will continue to develop the set of RGF-primitives and design and implement incremental picture change algorithms. This especially aimed at fast and high-level interaction support. The relation between real-time behaviour and minimal image quality desired during the interaction process will be analyzed for the new generation of hardware developed. Results of this will be used to implement a new generation of automatically optimized interaction techniques.

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
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 hand, put increasing demands on the mappings between the user language and the abstract system concepts. Future information systems using speech, natural languages and pictures (e.g. sketches), put their own specific demands on the user interface.

This project focusses on systems using graphical information. The user interface for these systems must support the construction, manipulation and interpretation of pictures. For the construction and manipulation of pictures by users a picture editor will be developed, while for the interpretation of pictures by the computer the construction process and associated semantic information will be used.

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. De toekomstige informatiesystemen waarin spraak, natuurlijke talen en beeldelementen (b.v. schetsen) voorkomen, stellen hun eigen specifieke eisen aan de user interface.

Dit project richt zich op systemen die vooral gebruik maken van grafische informatie. De gebruikersinterface voor dergelijke systemen moet het construeren, manipuleren en interpreteren van beeldelementen ondersteunen. Voor het construeren en manipuleren van beeldelementen door gebrukers wordt een picture editor ontwikkeld, terwijl voor het interpreteren van beeldelementen door de computer gebruik wordt gemaakt van constructieproces en de geassocieerde semantische informatie.

PROJECT MEMBERS

Drs. C.L. Blom (project leader)   Drs. J. van der Vegt (junior researcher)
Drs. M.M. de Ruiter (project leader) requested vacancy (junior researcher)
Drs. P.J.W. ten Hagen

EXTERNAL CONTACTS
National: Catholic University of Nijmegen (Dept. of Experimental Psychology) University of Amsterdam (Dept. of Psychonomics).
International: GMD Bonn.

S<small>TART OF PROJECT</small>: 1984

E<small>ND OF PROJECT</small>: 1993

C<small>LASSIFICATION CODES</small>

NWO-classification   : P175, T120
1980 Math. Subj. Class.   : 68D54, 68K32
1982 CR Classification Scheme : I.3.6, D.4.7

PROBLEM AREA AND SCIENTIFIC RELEVANCE

A user interface is the collection of means through which a user can access an information system. It can have many different realizations. Examples are: a control panel, a command language and a drawing tablet. A user interface contains all necessary functions to map between abstract system information and concrete representation, 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. Future information systems using speech, natural languages and pictures (e.g. sketches) put their own specific demands on the user interface. Focussing on systems with graphical information, one can easily see that the creation and manipulation of pictures need other support than the treatment of text. Due to the non-sequential nature of pictures the relations between components of the picture will depend on the interpretation of the picture. This interpretation is often very obvious to a user, except for illusions, but the unique interpretation of a picture by a computer requires methods to represent the structure of the picture. Therefore, a syntax for pictures will be defined in order to describe the components as well as the hierarchical structure. Both the components and structure of a picture 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 construction and manipulation of pictures by users. One of the basic problems is that the user will not easily guess the components and the structure of the picture. Furthermore, 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 the connection to the workstation resource manager (e.g. window management), and the dynamically installation of the appropriate picture-syntax parser and semantic interpreter. The implementations will use logic- and object-oriented programming.

WORKING PLAN 1990
Picture editing:
The syntax for pictures will be used for analyzing various methods for automatic structuring. These methods can be applied in various mixtures according to the known or observed usage of the pictures by users and

applications. For the experimental editor an additional mode will be further 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 1990.

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 1990 the feedback mechanisms will be further 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 1990 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 environments

TITEL: Dialoogomgevingen

SUBPROJECT IS 3.1

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) Drs. D. Soede (programmer)
Drs. H.J. Schouten (researcher)   requested vacancy (junior researcher)
R. van Liere (scientific programmer)

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 SUBPROJECT: 1983

END OF SUBPROJECT: 1992

CLASSIFICATION CODES

NWO-classification   : P175, T120
1980 Math. Subj. Class.   : 68K36, 68D43
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. The production of such systems puts high demands on the dialogue programming methods, to achieve results such as: fine control over real time behaviour, tolerance towards syntactic rigour, etc..

From Dialogue Cells to Transaction Cells
The existing method for Dialogue Programming developed in the previous years on the basis of DICE (DIalogue CElls), will be generalized towards the cooperation of an arbitrary number of processes, including those that interface to a human user.

The generalized system will be called TRANCE (TRANsaction CElls). It will differ from DICE for a number of important aspects. First of all there is an object-oriented view of the processes involved. They are characterized by the methods they supply for reading, writing, activation (connection) and deactivation (disconnection). Every write of a process has a corresponding read of another process. This couple is called a transaction. This allows us to generalize the read grammar of DICE into a read/write- or transaction-grammar of TRANCE. Hence the grammar describes meaningful configurations of transactions between processes. An independent rule based on the activations describes the possible transactions between active processes.

The system automatically guards the consistency and completeness of the meaningful transactions with respect to the possible ones. This also provides for synchronization.

The specification language of TRANCE constitutes a fully language independent method. In contrast DICE could only run with a *C* environment.
The TRANCE environment contains a new type of graphics system, called the 3D-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. This system is the successor of the radical system used in DICE.

WORKING PLAN 1990
The TRANCE 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 TRANCE, an extension of software design methods à la IDEF will be developed in collaboration with software industry and major

research institutions. H.J. Schouten will complete his Ph.D. thesis on the design of DICE and the rôle of the graphics system in it.

The TRANCE project will continue contributing to the ISO-work on graphics standards to produce the next generation of standards (see also under IS 1). The TRANCE system will also be the starting point for the intelligent user interface of the IIICAD system (see IS 4).

WORKING PLAN AFTER 1990

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

SUBPROJECT IS 3.2

TITLE: User controlled systems

TITEL: Gebruikersbesturende systemen

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

Gebruikersbesturende systemen 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 programmatheken 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).

SUBPROJECT MEMBERS

Drs. W. Eshuis (project leader)   Drs. D. Soede (programmer)
Ir. P. Spilling (junior researcher) priority vacancy (researcher)

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 Delft Hydraulics (Ir. K. van Smeden).

START OF SUBPROJECT: 1987

END OF SUBPROJECT: 1990

CLASSIFICATION CODES

NWO-classification	: P175, T120
1980 Math. Subj. Class.	: 68D22, 68D26, 68D43, 68H12, 68H20, 68K36, 68L60
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 data scheme 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 3D-DICE (IS 3), which has been transferred to a distributed processing environment. Facilities for process-to-process communication and for dynamic adaptability are being designed as extensions to the 3D version of the DICE system.

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 1990 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 1990

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.

WORKING PLAN AFTER 1990

Continuation of the development of the software engineering methods for user interfaces.

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 existing and newly acquired knowledge about the design object, about the design process and about their relations. The encoding and treatment of design knowledge is studied in the context of geometric modelling, object-oriented databases, user interfaces and geometric reasoning.

SAMENVATTING
Door gebruik te maken van kunstmatige intelligentie methoden worden CAD-systemen verbeterd, 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. De codering en behandeling van ontwerpkennis wordt bestudeerd aan de hand van problemen betreffende geometrische modellering, object-georiënteerde databases, gebruikersinterfaces en redeneren over geometrie.

PROJECT MEMBERS

Prof. F. Arbab (project leader)   Drs. H.E. Klarenbosch (junior researcher)
Drs. P.J.W. ten Hagen   Ing. D.B.M. Otten (junior researcher)
Ir. J.L.H. Rogier (researcher)   Drs. R.S.S. Pieters Kwiers (junior researcher)
Drs. P.J. Veerkamp (researcher)

EXTERNAL CONTACTS
Delft University of Technology (Prof. 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), University of Edinburgh (Prof. A. Bijl)

START OF PROJECT: 1985

END OF PROJECT: 1992

CLASSIFICATION CODES

NWO-classification : P175, T120
1980 Math. Subj. Class. : 68D22, 68D43, 68K10, 68L60, 68H20
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, may be, 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 activities 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 representation 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 design 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 represen-
tative?, are the solutions adequate?). To this end some carefully selected appli-
cations (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 1990-1995
The activities in the project are centered around three joint studies: the design
theory, the ICAD-language and architecture and the evaluation of experimen-
tal 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 gen-
erated by/for scenarios.

Specific topics to be studied in this context are: (1) the multi-world mechan-
ism, the partitioning strategy for supporting the knowledge base, (2) the user
interface monitor (which can modify interactions based on context informa-
tion, (3) a solid geometric modeller, a visualization medium which produces a
retractable image of the design object, (4) an object-oriented database, used for

the storage of design objects and their components, and (5) a geometric reasoning module for describing and reasoning about geometric knowledge.

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.

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. Dependent on the filling of a number of vacancies, this expansion can start in 1990 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 research topics that are not currently being addressed with other groups at the Institute. In addition to these tasks, 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 plans to initiate two research projects within 1990: one of these expands our activities in the area of protocol support for wide-area networks (principally between existing UNIX-based networks and ISO protocols) and the other is a new project for efficient job-dispatchment and monitoring for use in a multi-server/multi-client computing environment. In both 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. One

additional project that had previously been situated within the department (the EUROMATH project for network-based document retrieval and manipulation) has, for reasons of staffing support, been moved to an existing project group within the department AA.

A list of the department's projects are:

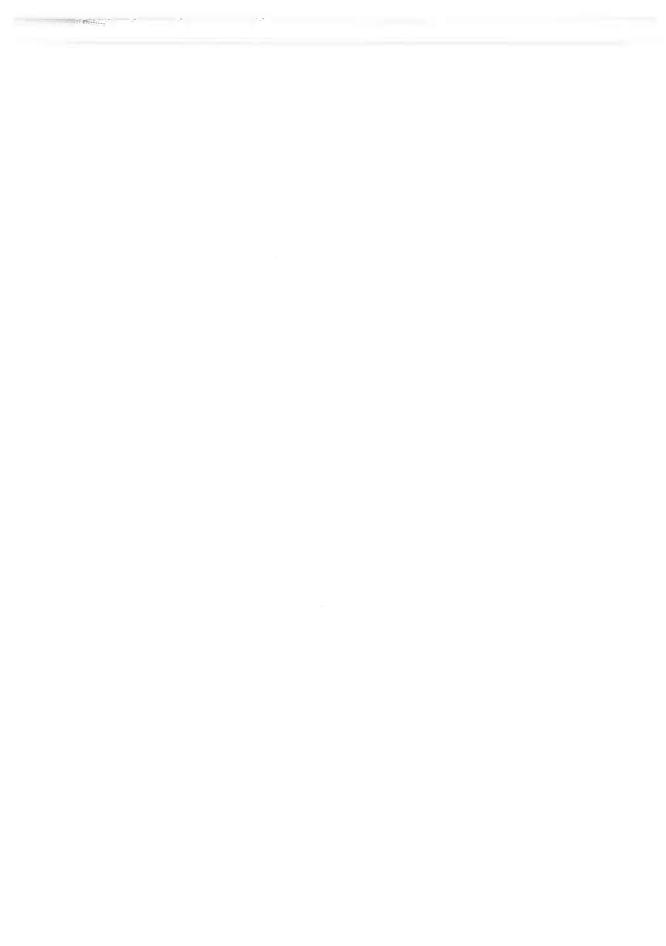CST 1 : Internet/ISO protocol development
CST 2 : Network-based task submission and performance monitoring

Department of
Computer Systems and Telematics

LIST OF PROJECTS

CST 1 : Internet/ISO protocol development
CST 2 : Network-based task submission and performance monitoring

		CSI	CS2	misc.	working time in fte	budget time	de-tached	guests	remarks
appointed									
Bulterman	head dept.		*	*	1.00	1.00			
Beertema	programmer			*	1.00	1.00			
Karrenberg	programmer			*	1.00	1.00			
Kroode, ten	programmer			*	1.00	1.00			
Kuiper	programmer			*	1.00	1.00			
Mullender	programmer			*	1.00	1.00			
Rahmani	programmer			*	1.00	1.00			
Roos Lindgreen	programmer			*	0.50	0.50			
Steen van der	programmer			*	1.00	1.00			
IJsselstein	programmer			*	0.70	0.70			
totally appointed					9.20	9.20			
priority 1	researcher		*		1.00	0.50			
priority 2	researcher	*	*		1.00	0.50			
priority 3	jr.researcher	*			1.00	0.50			

PROJECT CST 1

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
priority vacancy (researcher)
priority vacancy (junior researcher)

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: 1990

END OF PROJECT: not yet determined

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 2

TITLE: CST 2: Network-based task submission 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)
priority vacancy (researcher)
priority vacancy (junior researcher)

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). As this is a new project, we will also investigate other forms of national and international cooperation.

START OF PROJECT: 1990

END OF PROJECT: not yet determined

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.

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

A current prototype 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.