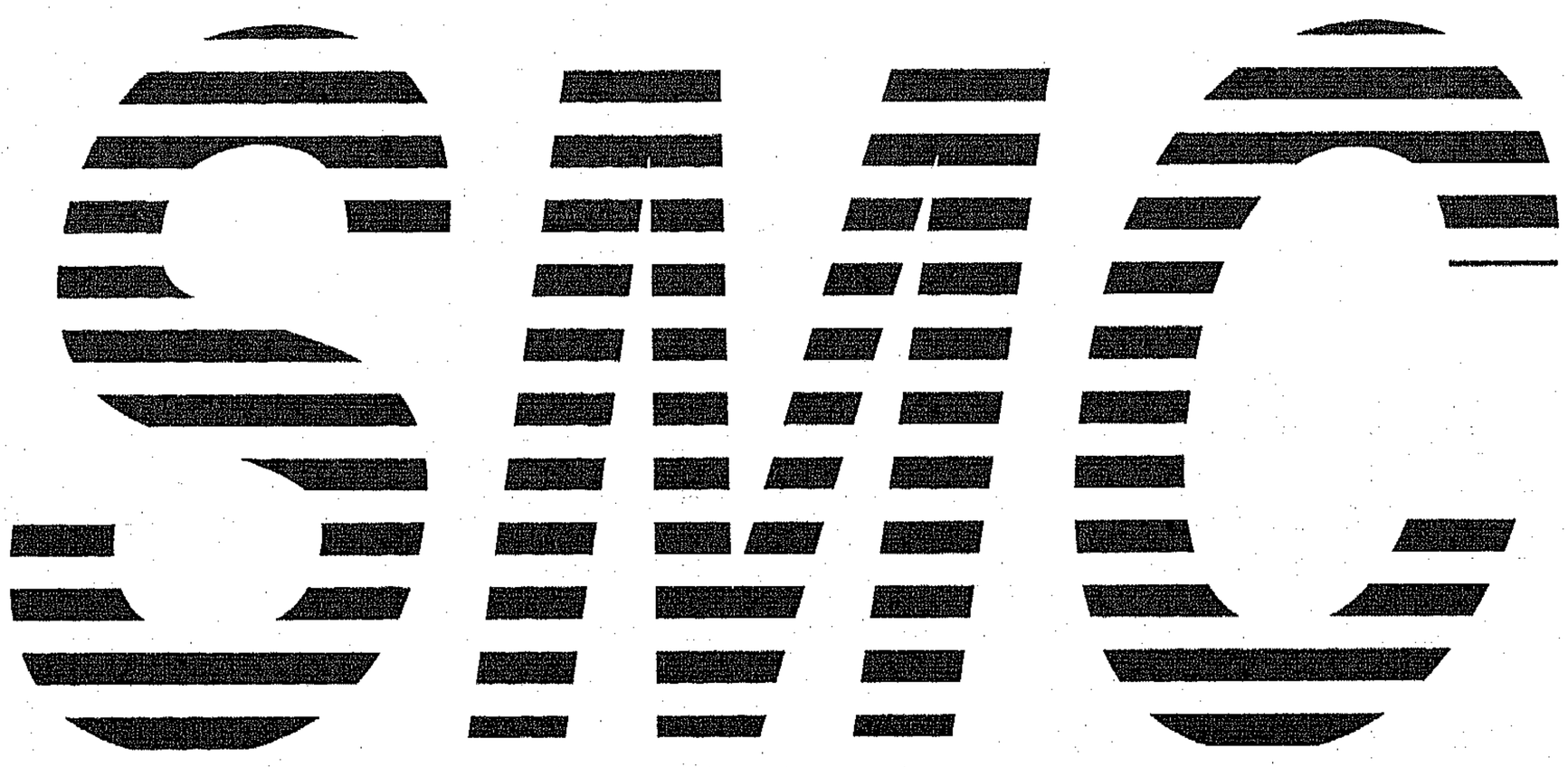
Interim Policy Document 1993-1997
Budget Projection 1993



Stichting Mathematisch Centrum

Interim Policy Document 1993-1997
(Interim Beleidsnota)

Budget Projection 1993
(Ontwerpbegroting)

Stichting Mathematisch Centrum
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Summary

The core task of SMC is to foster fundamental and strategic research at an international level in mathematics and computer science. This is realized by giving support for a number of mathematical research projects at Dutch universities, and by providing research facilities at CWI. This document presents the current and future thrust of SMC policy.

Mathematics and computer science are key scientific disciplines with strong mutual interaction. They affect and are affected by several other areas of research, engineering, and indeed the world at large.

Increasingly, the policy of supporting research projects at the Dutch universities focuses on structuring these activities on a larger scale. Whilst this involves a number of universities it still leaves scope for promising individual researchers with meaningful and original plans.

SMC will also provide back up for programmes initiated by NWO, including Special Years, Special Attention Areas and Person-Directed projects. This in turn will link up with support activities like the priority programme Nonlinear Systems and Dynamical Systems Laboratory.

SMC's promotion of Special Years will be a response to urgent need for wider, nationwide coverage of a number of research topics. New research groups will have to be set up, and existing will also benefit from the initiative.

SMC has also provided physical and moral support for the discussion process aimed at establishment of Graduate Schools. In due course CWI researchers will be participating in these schools, and SMC will strongly encourage new research networks in areas where these are desired.

A new resource will be made available to the Dutch mathematical community in the form of the SMC bureau. This will comprise secretariat, support, management, communication and other selected services. Realization will be through greater involvement of existing SMC support staff in national and international activities.

On the international level, SMC initiatives also gain awareness through ERCIM. CWI is one of the three founding members of this international network of research institutes in mathematics and computer science. Six countries are currently involved. SMC fully intends to continue its pro-active participation.

CWI's aim is to continue performing fundamental research, covering the whole range from the pure through to the application-oriented - but with an emphasis on pure and strategic research. Computational mathematics will be given an even higher priority. There will be ongoing promotion of synergy of mathematics and computer science. Cross-fertilization of these two sciences will be strengthened by fostering interdepartmental and multidisciplinary projects on image analysis, environmental mathematics, computational geometry, and scientific visualization. Additional new areas of research are wavelets, large scale computing, multimedia systems, and advanced information systems.

CWI will continue to acquire research contracts and to participate in national and European research programmes. This policy is aimed at securing a substantial portion of funding outside the NWO budget, and at emphasizing CWI's role in transfer of knowledge to other institutes, business and industry, and the world at large.

1. INTRODUCTION

The SMC Mathematical Centre Foundation (Stichting Mathematisch Centrum) performs a central role on behalf of the Dutch Mathematics community. This comprises support for several research projects in mathematics at Dutch universities and sponsorship of national activities in mathematics.
SMC is also responsible for the CWI National Research Centre for Mathematics and Computer Science (Centrum voor Wiskunde en Informatica). This main activity consists of fundamental and strategic research at an international level in mathematics and computer science.
The SMC is a foundation under the umbrella of NWO, The Netherlands Organization for Scientific Research (Nederlandse Organisatie voor Wetenschappelijk Onderzoek), which is the main source of funding.

Mathematics

July/August 1991 saw the publication of *Moving Beyond Myths*, the final report of the US National Research Council's "MS2000 committee". The section immediately following the preface, is headed *The challenge*, and starts as follows:

> Prosperity in today's global economy depends on scientific and technological strength, which in turn is built on the foundation of mathematics education. It is no wonder, therefore, that mathematics is in the spotlight. As the foundation of science and engineering, mathematics offers a key to our nation's future.

In 1985 the British science journal, New Scientist, commissioned a series of articles on progress in mathematics.The title 'Mathematics counts' was borrowed from the 1982 Cockroft report which had sold an amazing 38,000 copies by 1985 - over and above the many thousands of free copies. And Keith Devlin's 'Mathematics: the new golden age' (Penguin, 1988), is just one of a spate of semi-popular books on new developments in mathematics and computer science.
Clearly, the world of mathematics is anything but static. And at certain levels at least, there is considerable concern about its health and future. The same holds for a mature and highly attractive offspring of mathematics - namely computer science.

The sheer volume of publications demands respect. The STN database at Karlsruhe lists 36,233 articles published in 1974, and a relatively stable level in the subsequent seven years, ending at 51,266 in 1988. For comparison, in 1988 the same collection of databases lists 12,8643 articles on physics and 24,139 on computer science.

Obviously, choices have to be made. It would be quite impossible for The Netherlands, with some 700 mathematicians and around 800 computer scientists, to keep abreast with such a mass of material. Even if this were possible, it would not be enough; active participation is needed: merely keeping pace, and applying existing knowledge - or random discoveries - is a formula for ossification of scientific initiative. This threat has been exacerbated by the current stress on immediate applicability. One way out might have been to identify the growth areas in these databases. But when this exercise was carried out in March 1990, the results were inconclusive: by and large, according to the classification schemes used, there was uniform, approx. 45% output growth in the areas examined.
Even so, the research community knows where things are really moving. Any inquiry would readily identify the list below as growth areas. The items appear in no particular order, and the aim is to offer examples rather than exhaustive coverage. Some of the topics and areas will be dealt with later in this document as research themes, topics for a special year, or special attention areas.

- *Symbolic manipulation, computer algebra*
  The computer is more than a calculator, it is a general purpose symbol processing device. It can be used also to perform symbolic calculations and formula manipulation, provided you really understand the mathematics involved.
- *Logic*
  This topic has a strong interaction with computer science. Computability, complexity, logic of programming, and consistency of programs have given new additional impulses to logic. Automatic proof verification interconnects with computer algebra.
- *Nonlinearity*
  An initial arsenal of techniques has now been developed to make a good solid start on exploring the rich world of nonlinear phenomena. Paradoxically, at first sight, infinite-dimensional linear analysis is also a powerful tool.
- *Interactions between algebra and combinatorics.*
  Both fields interact with many other part of mathematics as well as with computer science, the physical sciences and technology.
- *Stochastics*
  Certainly in its interactions with other mathematical structures, but also as a greatly strengthened tool. New impulses to stochastics and statistics come from topics like image processing, ecological modelling, and chaos.
- *Wavelets*
  Perhaps easiest understood as a local version of Fourier analysis. There is an additional flexibility to wavelets permitting the design of custom made filters for the detection of special phenomena and "signatures". Just as with Fourier analysis, there is an underlying group, so that wavelets also fit into the next, more general theme.
- *Symmetry and groups*
  Possibly Lie groups and associated structures in particular, but also more general ideas of symmetry. Lie groups, and symmetric spaces form one of the more deeply explored parts of mathematics. There is an enormous amount of detailed knowledge, and at the same time there is enough variety and richness of phenomena to test ideas from other parts of nonlinearity. And they turn up everywhere. In 1983 more than 50% of the articles in one leading theoretical physics journal dealt with groups or representations in one way or another.
- *Gauge field theory*
  The three Fields medals awarded in 1990 are eloquent enough.

Several of these topics, for instance Computer algebra, Logic, and Wavelets, have strong interactions and synergetic relations with computer science.

Computer science

The discipline of computer science concerns the research and development of scientific methods and techniques for designing, specifying, constructing and evaluating various kinds of systems, including software, architectures, languages, networks, and databases. Very clearly, the emergence and upsurge of computer science is intimately linked to technological development. There is a major and increasing need to provide systems for increasingly diverse applications. As well as motivating and stimulating computer-science research, this poses threats. The stimulus is evident. The danger comes from the pressure for a short term payoff. This could inhibit the development of theory addressing the fundamental problems and give priority to ad hoc, specific aspects of the issues at hand, thereby retarding maturation of the field and boosting virtual-duplication of research. In plain terms this means inefficient use of scarce human resources in the form of talented researchers.

For computer science in all its diversity, the single most important task is the development of tools which will allow human intellect - with all its limitations - to cope with the complexity of the systems we design and build. And this complexity is unrivalled in any other field of human endeavour. Indeed, these tools are prerequisites for achieving a

generally recognized priority: the efficient construction of reliable and meaningful systems. This concept of a "tool" comprises theories, methods, and systems, all three of which are mutually essential. But the bottom line is, and must remain, the development of theory - theory driven by the problems it seeks to address and giving insights on the principles of the other kinds of tools, i.e. methods and systems.

It is generally recognized that formal methods are indispensable in reducing the inherent complexity. Even so, despite the relative youth of computer science as a discipline, systematic exploration is a very new departure.

Some things have become evident at this very early stage of exploration. Firstly, while applicability of such methods is in principle far wider and more pervasive than might appear at first sight, making them work in practice will be no small task. Secondly - and this came as a pleasant surprise - a considerable body of existing, independently developed mathematics, has turned out to be of direct importance and applicability to the development of theory. Of the mathematical disciplines that have proven important to computer science we mention algebra, logic, category theory and topology. And it is here that we find the prospect and the promise of a fruitful and long-lasting close cooperation between mathematics and computer science.

Not all aspects of computer science can be addressed from a theoretical or abstract point of view. There is a substantial and important experimental aspect. Many systems are designed to function in a larger context, i.e. the real world. And for that reason it is still important to put the theory to the practical test. Moreover, to take distributed systems as an example, it is often so that analytical performance analysis can only be performed with a simplified model. Without actually building the systems, it is impossible to acquire solid data to substantiate the claims made from a theoretical analysis.

With the steady increase in the size of systems which can realistically be built, particularly in the context of burgeoning computing power, the new theme of integration is emerging; and it requires examination in its own right. Integration involves the tools which enable us to meld the various systems into a larger system, easily and harmoniously. Integration provides a significant impulse for both theoretical and experimental research, as in these challenging areas of computer science:

- Integration of functional, logic and object-oriented paradigms
- Scientific database management systems
- High-performance computing systems
- Architectures for interoperable systems
- Visualization of computer manipulated data.

The ad hoc approach to the issues involved is increasingly less satisfactory given the ongoing evolution of the desired scale of integration. Theoretical study is needed to overcome and outgrow this situation. Within the context of distributed and cooperative computing on an ever larger scale, experimentation is necessary because integration factors make very heavy demands on the performance of current equipment - and will make similar demands on future equipment.

2. LAW: NATIONAL ACTIVITIES MATHEMATICS

2.1. Introduction

The SMC acts in a national, central role by stimulating and coordinating several activities in the Dutch mathematical community's LAW network (Landelijke Activiteiten Wiskunde).

The extent of LAW funding has been the cause of increasing concern to SMC over the past several years, a feeling shared by the NWO's Council for the Natural Sciences (GB-E). Part of the SMC mission is to encourage the appointment of around fifteen new doctoral and postdoctoral positions in mathematics, in The Netherlands, every year.

Several years ago NWO started a range of support programmes aimed at stimulating new activities in scientific research. SMC provides back up for these initiatives. Throughout the world important developments in mathematics are happening which - scientific aspects apart - have a wider impact on human endeavour. In 1992 SMC will be using these programmes to introduce new activities in mathematics including special 'years', special attention areas and person-directed group support. This will link up with other support activities like the priority programme Nonlinear Systems and Dynamical Systems Laboratory. Funding of this laboratory could possibly be obtained through the IAS-programme.
LAW will also be participating in other European and international mathematics programmes; indeed, SMC is one of the founding members of the European Research Consortium for Informatics and Mathematics (ERCIM), where it acts as front-end for the Dutch community of researchers in mathematics and computer science.

2.2. Activities

2.2.1. Structure

As The Netherlands Foundation for Mathematics, SMC supports and coordinates the following eight National Working Groups:

- Numerical Mathematics
- Stochastics
- Operations Research and System Theory
- Discrete Mathematics
- Analysis
- Algebra and Geometry
- Logic and the Foundations of Mathematics
- Mathematical Physics (jointly with the FOM Physics Foundation).

In addition, there is the History and Social Function of Mathematics national working group.

2.2.2. Research Projects

Funds allocated to the LAW network are being directed to mathematics research projects at Dutch universities, and SMC is tasked with related selection, supervision and evaluation. Policy is increasingly aimed at structuring the research in larger projects, with involvement of several universities - whilst still leaving scope for promising individual researchers with meaningful and original plans. In response to demand from the universities, recent years have seen a considerable shift of stress, within the LAW budget, to post-doctoral appointments. In view of the volume of interest so far in these postdoctoral positions, this policy will be continued.

2.2.3. Survey of positions

New positions 1991

	doctoral	postdoctoral	total
applications	17	4	21
granted	12	3	15

Total positions 1991

	doctoral	postdoctoral	total
continuations	38	3	41
new positions	12	3	15
total	50	6	56

2.2.4. Special attention areas (Aandachtsgebieden)

In recent years LAW has designated three special attention areas: Mathematical Physics, Lie Groups, and Geometry. Now that the logjam on funding projects appears to be a thing of the past, SMC, backed by its Science Committee, can further realize the concept of special attention areas; this may involve changes in one or more of the areas.

The average scope of the areas amounts to 4-5 doctoral and postdoctoral positions for 4-5 years. Experts from abroad and visitors will also be involved. The aim is to create three of these reinforced special attention areas within two years. Obviously, the SMC Science Committee has an essential role in the choice of a particular area. Basic criteria for designation of a special attention area are as follows:

- in the Dutch context it must be seen as an area of mathematics which is of present or future fundamental or applied importance, or wider social significance,
- or, it must be an area rich in highly promising young talent.

Part of the funding for these 'new-style' special attention areas will have to be found within the existing budget, but sufficient additional LAW funding will also be applied for to allow meaningful implementation of SMC's policy of stimulating research. The first Special attention area will be started in 1992, along the outlines given above. The subject selected, 'Pure mathematical aspects of nonlinear dynamical systems', will be highly complementary to the multidisciplinary and application oriented NWO priority programme Nonlinear Systems.

2.2.5. Special Years

Nationally there is an urgent need for wider annual coverage of several subjects in mathematics. Potential subjects for Special Years are those in which no research is being done in The Netherlands as yet, but whose importance is recognized, or those in which Dutch researchers are already active and which may profit from more intensive and prolonged contacts with invited experts from abroad.

These subjects will receive nationwide special attention through a number of coordinated activities (symposia, seminars, working groups), with a definite stress on course participation from abroad. Prominent foreign researchers will stay in The Netherlands for a month or more, and a group of promising young Dutch mathematicians will be intensively involved in these key themes. The "Logic Year" will be initiated in 1992, and two new Special Years per annum are envisaged starting in 1993.

2.3. NWO Programmes

2.3.1. PIONIER programme

The period 1992/1993 will see a new round of the NWO's PIONIER programme for person-directed group support. The Dutch mathematical community offers several excellent candidates, and SMC has received four highly qualified proposals. After a painstaking and arduous selection process, two proposal were chosen for submission in this PIONIER round. The first of these proposals concerns *Logic, Category Theory and Topology*, a reasonably new research area, introduced to The Netherlands in the 'eighties; the second is *Spatial Information Processing*, a new discipline to be built up by fusing elements of mathematical statistics, image processing, spatial data analysis and computationally intensive mathematical methods.

2.3.2. Priority Programme Nonlinear Systems

NWO has created a multidisciplinary priority programme on Nonlinear Systems, which will run from 1991 till 1998, and will concentrate on the following seven themes:

1. Bifurcations; theory and applications
2. Cell to cell signalling: from experiments to theoretical models
3. Filtration theory
4. Meteorology and oceanography
5. Population dynamics, including epidemiology
6. Process technology
7. Spatial organization of physical systems.

The programme aims to promote the cross-fertilization of research in a broad spectrum of experimental and applied nonlinear systems on the one hand, and the development of the mathematical theory of dynamical systems on the other. SMC will provide support for this programme, and, as mentioned above, the *Pure mathematical aspects of nonlinear dynamical systems* will receive extra back up and encouragement as a new special attention area to be launched in 1992. This extra focus on pure mathematical aspects will complement the highly application oriented priority programme and - quite clearly - there will be mutual reinforcement.

2.3.3. CAN Expertise Centre (Computer Algebra Nederland)

The CAN expertise centre was founded in 1989 with the aid of a grant from NWO/SURF. CAN develops activities for research in computer algebra and its applications. Mainly concerned here are courses, service support and consultancy for the corporate sector and for educational and scientific institutes. Financial support is due to cease at the end of 1991.

In the considered view of SMC computer algebra is an interesting discipline - as evidenced by the growing following in both education and industry. With an eye to establishing closer institutional contacts, valuable initiatives were directed at universities, technical colleges and the industrial sector. The relevant NWO evaluation committee underwrites the CWI conclusion in this area.

Continuation of this expertise centre's activities from 1992 onwards will require a minimum annual funding level of Dfl. 100,000. The SMC is encouraged by the increasing applications for this type of mathematical tool, and by the fact that the applications are mainly by non-mathematicians.
Continuation of CAN activities is of great importance for the LAW National Activities in Mathematics programme; of the total budget of Dfl. 100,000, Dfl. 60,000 is for investments, with the remainder covering working expenses.

2.4. Further developments

2.4.1. Graduate Schools (Onderzoekscholen)

Plans have been under development since 1990 to start structured second-phase research training facilities (graduate programmes) in The Netherlands. The government has taken advice on this from a committee chaired by Professor A.H.G. Rinnooy Kan. In June 1990 SMC took the initiative to establish a common view of the Dutch mathematics community on these Graduate Schools.
In May 1991, a proposal was made for two or three regional Graduate Schools in Mathematics. Where quality or efficiency of their educational tasks required, the Schools could call on existing and future national research networks (aio-netwerken). Where possible, this matrix structure builds on the existing healthy national infrastructure in mathematics. SMC will strongly encourage new research networks in areas where these are desired.

2.4.2. ERCIM

In 1989 the German (GMD), French (INRIA) and Dutch (SMC/CWI) national organizations in informatics and (applied) mathematics took the decision to found the European Research Consortium for Informatics and Mathematics (ERCIM). The United Kingdom (SERC/RAL) joined ERCIM in 1990, followed by Portugal (INESC) and Italy (CNR/IEI) in 1991.
The members of ERCIM are fully aware that purely national planning, financing and implementation is no longer feasible if European research is to match the pace of international competition. The consortium aims to be a platform for European Information Technology and Applied Mathematics research. ERCIM members will explicitly act as a front-end for all their countries' researchers and institutes. ERCIM is also tasked with helping European researchers to forge a common research policy and establish priorities. The consortium develops close and permanent ties between academic research and industry.
Current activities focus on active cooperation between researchers through joint workshops and jointly organized advanced courses. Other activities comprise a fellowship programme for outstanding young European scientists, a newsletter with world-wide circulation and the organization and sponsoring of international conferences.
It is ERCIM policy to welcome other European national research organizations in the field, to its ranks. Among future objectives is for ERCIM to act as the research community's spokesman in representations to the European Commission in Brussels, on all aspects of Information Technology and Applied Mathematics.

It is the intention of SMC to continue its active role and participation in the present and further activities of ERCIM.

2.5. Investment

Projects

Sadly, once again in 1991, it was not possible to meet the first request for an investment grant for SMC's National Projects in Mathematics. A recent stock-taking reconfirmed the increasing need for investment in computing equipment. Mathematics faculties are late-comers in the use of decentralized computing facilities, and frequently their infrastructure in networks and workstations is bad. The pressing need to improve these facilities is exacerbated by the burgeoning role of advanced computing at the frontier of mathematics research, and in experimental (preparatory) studies and visualization of results as in such supporting techniques as symbolic manipulation and computer algebra. An important point to note here is that equipment budgets of Dutch mathematics faculties are often so limited

as to preclude acquisition of what would elsewhere be termed 'smaller equipment'. Requests submitted for project-bound equipment in 1992 mainly concern advanced workstations.

Dynamical Systems Laboratory

There is a general awareness that much of the understanding of systems as in the Nonlinear Systems priority programme, mentioned in Section 2.3.2, is vitally dependent on the combination of abstract theory and computer experiments. A dynamic systems laboratory is a prerequisite here. This in turn would include a network of powerful workstations with high-resolution graphical display, a central parallel computer, and a collection of specialized software which together can create a user-friendly environment for experiments with dynamic systems. SMC may be requested to make arrangements for the funding application for this laboratory. SMC endorses the importance of such a laboratory, and would certainly respond to an eventual request.

The initial costs will be Dfl. 1 million and this amount will be needed in 1993. A further Dfl. 900,000 will be needed for additional workstations, half in 1994 and half in 1995, with an annual amount of Dfl. 250,000 thereafter for replacement and extension.

This dynamic systems laboratory can be created within the infrastructure provided by the CAN Expertise Centre; as well as serving projects in the priority programme, it will be explicitly available for all researchers in the field of Dynamical Systems. As proof of the truly interdisciplinary credentials of this undertaking we cite the overwhelmingly non-mathematical background of most of these projects, which belong to such fields as physics, chemistry and biology.

2.6. Bureau

As already outlined above, during the period covered by this policy document we will be concentrating very hard on optimal use of existing tools for vigorous research activities in a coherent national setting; and where need be we will also look at development of new instruments. A prerequisite for realising these objectives will be meaningful support from a well equipped bureau (SMC parlance for a cluster of secretariat, organizational, support, management and communication services).
The SMC Bureau is tasked with providing staff and secretarial support for the Board of Governors, the Directors, the SMC Science Committee and the National Working Groups. It also provides administration and support services for all national research programmes under the sole or joint auspices of SMC. In addition, the Bureau will in future take on the public distribution of information on advances and developments in the mathematical sciences. This will cover the international research scene, and more particularly the Dutch research angle. The new activity will be carried out in close cooperation with the Dutch Mathematical Society (Wiskundig Genootschap).
The SMC Bureau also offers organizational support for Dutch-based international conferences and symposia in the mathematical sciences.

Obviously, the Bureau will be located at CWI - which is the SMC Foundation's only institutional facility. Operational territory will cover all SMC activities irrespective of whether these come under a national working group/programme, or occur within CWI.

3. CWI: NATIONAL RESEARCH CENTRE FOR MATHEMATICS AND COMPUTER SCIENCE

3.1. Introduction

CWI, the National Research Centre for Mathematics and Computer Science (Centrum voor Wiskunde en Informatica) is the research institute of the SMC Mathematical Centre Foundation (Stichting Mathematisch Centrum). The SMC charter calls for the pursuit of mathematical sciences for the benefit of society as a whole. At the time SMC was founded in 1946, computer science was still in its infancy, but it became an integral part of the institute's scientific activities during the 'fifties. This change was formalized in 1983 by a change of name from Mathematisch Centrum to CWI.

The SMC charter has lost nothing of its relevance over the past 45 years. A recent analysis by the OESO[1]) indicates significant international demand for people with a background in mathematical sciences. This is certainly the case in The Netherlands, according to the recent ESB[2]) forecast.

CWI's management policy needs regular tuning in line with world-wide advances in fundamental research and the evolving needs of society as a whole. This adjustment process is based on four core aims set down in the founding charter:

- to provide a national facility for research in mathematics and computer science;
- to promote the CWI as an international research centre;
- to narrow the gap between fundamental research and R&D in industry;
- to engage in knowledge transfer and expert training.

Below we go into detail on the implementation of these principles and the resulting research and management policy for coming years.

3.2. Central Policy

3.2.1. Research programme

The research programme of the CWI is focused on a limited number of strategic topics in mathematics and computer science. The choice of topics is guided by what are perceived to be exciting and important new developments. Substantial weight is also given to potential for complementing and supplementing research elsewhere in The Netherlands. A balanced and well-focused research programme is safeguarded by involvement of SMC's scientific advisory board, the SION Foundation for Computer Science Research (Stichting Informatica Onderzoek Nederland), and advisory boards in specific areas.

A criterion for selecting research themes at CWI has always been the quality of the research, as apparent through recognition and appreciation by the international research community. With this in mind the internal CWI Science Review Committee (Onderzoekcommissie) and permanent advisory boards of qualified researchers drawn from Dutch universities and industry, are supplemented by ad-hoc international visiting committees of highly qualified, independent external experts tasked with advising departments and directors on research plans, and evaluating progress. Additional advice on the scientific programme and its budget comes from the SMC scientific advisory board and the board of SION.

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1) OESO, *Research Manpower: managing supply and demand,* Paris, 1989.

2) H. Berndsen, A. de Grip and J.T.A. Willems, *Gevraagd: Bèta-onderzoekers (I),* Economisch Statistische Berichten, 26 June 1991, pp. 652-654.

CWI's flexible organizational structure, based on the three-tiers of department, research group, and project, allows control and timely adjustment of the thrust of research. A department is an organizational unit based on common research interests, methodology and objectives. A research group covers a research area in mathematics, computer science, or both, with work organized around projects. In a project, senior, postdoctoral and junior researchers work together on well-identified problems. The duration of a project will often coincide with the PhD track of the junior researcher, the duration of the postdoctoral position, and/or external funding.

The 'eighties brought increased intertwining of mathematics and computer science. CWI's mathematics departments continue to expand their use of computer science products, such as formula manipulation, parallel programming, scientific visualization, and hypertext. Conversely, computer science forms a source of challenging mathematical problems. Likewise, several branches of mathematics, such as logic, algebra, numerical analysis, and combinatorics, are important instruments in the formalization and analysis of computer science problems.

There will be ongoing promotion of this synergy of mathematics and computer science within a single institute. Everything will be done to cross-fertilize the two sciences by fostering interdepartmental projects. A recent development emphasizing the synergy between mathematics and computer science at CWI is the introduction of multidisciplinary, combined research projects on several strategic fields. Good examples of this include the research on *image analysis, environmental mathematics, computational geometry and scientific visualization.*

CWI's aim is to perform fundamental research, covering the whole range from the pure through to the application-oriented - but with an emphasis on pure and strategic research. In pure research the problems addressed and the approach taken come from the internal dynamics of evolving science. In the first instance, results may either be of primary importance to science itself, or provide explanations for the 'laws of nature'. In strategic research there is also an external influence on the problems and the approach taken; often there will be an experimental component or a substantial level of development expenditure. (Experiments are also necessary to validate the models derived in pure fundamental research as they provide the stimulus for new directions).
Looking to the longer term, the results from strategic research may lead to economic or wider social benefits. In many instances cooperation with government and industry evolves as a natural process; CWI will actively seek to structure this interaction.

It is CWI policy to maintain a meaningful balance between pure and strategic research, and to arrive at a good and similar mix of the mathematics and computer science components.

3.2.2. Knowledge transfer and expert training

Knowledge transfer and expert training are intertwined with the research activities. In addition to publications, presentations, and organization of seminars as prime tools of knowledge transfer, special attention also goes to joint projects with industry. The prime CWI role in such projects is as supplier of fundamental knowledge: this is a direct and efficient means of knowledge transfer. Moreover, this sort of cooperative project can provide an important stimulus for CWI-based research, and the scale of accompanying financial support enables CWI to implement the research programme.

The policy set for the coming years is to improve Dutch research-synergy, within a European context, via stronger links with industry. The knowledge transfer activities act both as carrier for the research product of CWI - i.e. our own results - and the knowledge acquired through a world-wide involvement in many aspects of mathematics and computer science.
Given the similarities between CWI research activities and those of Dutch universities it is important to avoid duplication and isolation, hence priority goes to complementary research

topics and topics requiring a larger national critical body. In turn this requires close links with the university-based research groups, and a clear demarcation of work. The process is aided by the fact that many of CWI's senior researchers have part-time assignments at Dutch universities. Also, it is not uncommon for knowledge transfer to receive an extra impetus when projects are taken over by universities, for example if a project leader takes up a new position outside CWI.

3.2.3. Centre role and international relations

CWI fulfils its task of providing an international meeting place for researchers in both mathematics and computer science. The institute stimulates and fosters initiatives for innovative research actions, and contributes to the infrastructure needed by researchers in The Netherlands. A good example of the latter is the CWI library which serves a large group of researchers. As a national and international centre, CWI is involved in the organization of conferences, seminars, and lecture series. Members of staff are also involved in a wide range of advisory boards and institutions at home and abroad.

CWI policy aims to enhance international visibility for the institute. CWI researchers maintain extensive formal and informal international contacts, some of which have been formalized at institutional level. Among bodies with which SMC/CWI has concluded scientific exchange agreements are the Tata Institute for Fundamental Research of Bombay, and the Steklov Institute of Mathematics of Moscow/Leningrad. Letters of intent have also been exchanged with institutes in Tokyo, Prague and Budapest. Over the next several years, CWI will energetically continue this process of forging global links.
Further evidence of the international orientation of SMC/CWI is the active participation in the European Research Consortium for Informatics and Mathematics (ERCIM), already covered in Section 2.4.2.

Maintaining and building on the existing good relations with the Dutch research community is an ongoing priority. As previously outlined, CWI intensively consults with its research liaison bodies on development of the multi-year research programme. In addition, the institute plans to develop an exchange programme for Dutch researchers, and to schedule "Special years" and/or Summer schools on selected topics.

The institute plans to boost the presentation of its research activities to a wider public, and to win even greater awareness in the world of industrial R&D.

3.2.4. Financial management

The SMC is a foundation under the umbrella of the NWO Netherlands Organization for Scientific Research (Nederlandse Organisatie voor Wetenschappelijk Onderzoek). As such, NWO finances the core activity of CWI. Research scope and volume is further increased by the substantial surplus from additional funding realized by contract research, national and European programmes, course-ware, royalties, etc. Although financial management policy aims to continue this situation, optimal use of this income in the present economic environment dictates flexible allocation of human resources, capital expenditure, and organizational structures. The yardstick for all decisions in this area continues to be the potential added-value for fundamental research within CWI.

The core of CWI is formed by tenured senior researchers, aided by postdoctorate and junior researchers with short-term contracts. This set-up will be continued in the coming years with an emphasis on increasing the number of temporary positions. Mobility of the researchers will be fostered through domestic and international activities and research planning.

Closer contacts and cooperation between the business and academic applied research sectors are crucial for the industrial and technological development of the world in which we live. These contacts also help define objectives for strategic and application oriented

research, while contract research provides a welcome source for additional funding (30% of the total budget is seen as the optimal level of contract research income). European Community programmes for fundamental and pre-competitive research, such as ESPRIT and RACE, currently provide ample opportunities for cooperation with industry. However, considerable input by management and senior staff will be needed to maintain an adequate flow of new research contracts.

3.3. Research Priorities

3.3.1. Priorities in Mathematical Research

INTRODUCTION

The range of CWI research in mathematics goes from the theoretical right through to applied mathematics. In theoretical or pure research, the potential for application is a major selection factor for research topics. The applied mathematical research also needs to be of high quality.

In October 1989, a Visiting Committee on Algebra, Analysis, Geometry, Optimization and Numerical Mathematics made two general suggestions on CWI research in mathematics:

- computational and applied mathematics should be given an even higher priority;
- the synergy between mathematics and computer science needs further development.

Over the next several years CWI will continue this policy by selecting research topics which are inspired by several fields of applications, and in which high standards of mathematical discipline are considered to be crucial. The mathematics departments aim to expand the interdisciplinary element in research. Increasingly, selection of research topics also has to be viewed against the background of computer technology.

The aspects and criteria which guide the mathematics departments in selection of research topics are as follows:

- it should involve fundamental mathematics and should have potential applications in technology, the natural sciences, or elsewhere;
- it should be internationally recognized as important and the results should meet international standards;
- computational aspects are emphasized where relevant;
- new research topics should fit into expertise existing in the departments or available to the institute;
- research, including contract research, should lead to publications in leading scientific journals and proceedings of conferences; the scientific quality should also be reflected in delivering PhD mathematicians.

New areas of interest in mathematics for CWI are :

- computational geometry;
- wavelets;
- large scale computing;
- application of scientific visualization (an area of interest for the computer science departments) in computational dynamics and other parts of mathematics.

Interest in these topics evolves naturally from existing research programmes. The new multidisciplinary research programmes are *Environmental mathematics* and *Computational geometry*; these topics will be described separately.
Below we describe the science policy and future plans of the three mathematics departments of CWI, namely:

- Analysis, Algebra and Geometry
- Operations Research, Statistics and System Theory
- Numerical Mathematics.

Analysis, Algebra and geometry

Apart from the dominant policy of performing quality research in selected areas of analysis, algebra, combinatorics or geometry, the department will serve as an advisory and consultative group for other researchers, and as a focal point for national and international contacts. On several points the research and expertise is unique in The Netherlands. Examples include biomathematics (with its thorough mathematical orientation), wavelets, Hopf algebras, quantum groups, and (q-) special functions.

The department believes that algebra and combinatorics, coupled with algorithmics and computation will play an increasingly important role in future mathematics. Not only in the domains just named, but also in analysis, geometry, and control, where 'natural' algebraic structures give guidance for computation and spur further investigation. We expect to contribute to these developments in the directions detailed below.

The fact that research in the group *Algebra, Discrete Mathematics and Computer Algebra* originated in discrete mathematics, continues to influence that research. In the meantime, Lie groups and Lie algebras (and generalizations such as Hopf algebras which embody more general symmetry principles) have become the central objects in the activities of this group. The selection of topics is also inspired by the problems coming from the fast developing field of computer algebra. The general themes are: availability of algorithms for specific problems, the complexity of new and existing algorithms, and implementation for researchers in other areas.

The core research is based on the topics:
- discrete mathematics, geometry and groups;
- Lie algebras, Hopf algebras, and quantum groups;
- special functions and their q-analogues.

The last two of these have applications in theoretical physics and all topics have their computational aspects:
- computational coding theory;
- computational Lie algebra, quantum group and Hopf algebra theory;
- manipulations with q-special functions.

This research group wishes to expand activities in the design and architecture for computer algebra systems, in cooperation with the department of Software Engineering.

At present the research in the group *Modelling and Analysis* concentrates on models of biological phenomena. The general policy of this group is to focus on fundamental research, and on the biological interpretation and motivation. The trend simultaneously goes in the direction of nonlinearity and stochasticity. A major role has been played by evolution semigroups (in a non-classical setting). This has been a main tool which can and will also be employed in the new stochastic direction. The modelling of natural phenomena and the mathematical analysis of dynamic systems can reinforce each other in a substantial way. Concrete applications are e.g. the biological control of pests and the extrapolation to natural conditions of experimental results concerning the effects of toxic chemicals. The mathematical interests are:
- general functional analytic theory of structured population models,
- functional differential equations,
- infinite dimensional dynamical systems, in particular semigroups of operators,
- asymptotics,

with applications in
- structured population models,
- epidemiology,
- evolutionary genetics.

The department *Analysis, algebra and geometry* aims at the development of the following future topics of interest:

- analytical and group theoretical aspects of wavelets; also the algorithmic and computational aspects including the design of special "detector" wavelets and the corresponding bases and processing algorithms;
- the systematic development of 'combinatorial algebra', including the hitherto neglected area of algorithms for the computation of knot and link invariants; the representations of quantum groups and (more generally Hopf and bi-algebras) are central here;
- the incorporation of stochastic components in models for population dynamics and infectious diseases, and the study of nonlinear dynamics in infinite dimensional spaces.

Operations Research, Statistics, and System Theory

The research in this department combines fundamental research with applications. The successful long-term projects on machine scheduling and interactive planning in the research group *Combinatorial Optimization and Algorithmics* will soon be terminated. The emphasis in this group is shifting towards fundamental mathematical research in polyhedral combinatorics, VLSI design and computational geometry. This research constitutes a combination of discrete mathematics, operations research and computer science which is unique in The Netherlands. The wide, international interest in computational geometry is yielding many fundamental new methods, techniques and problems demanding intensive further investigation. There will be reinforced joint effort with a number of computer science groups, within the framework of a Computational Geometry (multidisciplinary) research theme.

Research in *Analysis and Control of Information Flows in Networks* continues to be devoted both to basic queuing models and to the performance analysis of computer and communication networks, with a growing emphasis on distributed computer systems and ISDN communication networks. These application areas are presently suggesting a host of novel and challenging queuing problems. A new theme which is sure to spur growing interest is the integration of queuing and reliability issues in one model. In particular, basic models are being developed for the following question: What is the influence of limited manpower for preventive and corrective maintenance of complex systems on their performance? Finally, more attention will be devoted to the study of general stochastic models which are relevant for performance analysis. Examples are: higher dimensional random walks and related boundary value problems, probabilistic analysis of algorithms (e.g., for computer memory storage) and percolation problems (arising, e.g., in cellular automata models).

The aims of the *System and Control Theory* research group are to formulate and analyze dynamic systems as models for phenomena which evolve in time and space, and to solve control and prediction problems. Future research efforts will be directed at fundamental problems of realization and control. At the core of system theory there are problems of deterministic and stochastic realization and system identification which demand dynamic systems as mathematical models for observed phenomena. Current efforts on realization of linear and nonlinear deterministic systems will be pursued with methods of linear algebra and differential geometry. The internationally recognized efforts in stochastic realization of Gaussian and finite-valued stochastic processes will be continued, with emphasis on new classes of stochastic dynamic systems. Control of distributed computer systems will receive attention in a project funded by NFI and undertaken jointly with the queuing/performance analysis group. Other control problems are likely to arise from contacts with the private sector and government agencies.

The new *Image Analysis* research group is gradually expanding its activities. The main focus is on stochastic models and algorithms for analyzing images and spatial data. There

is minimal overlap with the research of the Dutch university groups involved in image processing; in our approach, image analysis is considered as a statistical parameter estimation problem, and nonlinear, geometric models and methods (stochastic geometry, mathematical morphology) are applied rather than the standard signal processing theory. Obviously, access to fundamental results in mathematical statistics is required here, and this is enabled by CWI's unique combination of expertise in mathematical statistics (stochastic iterative techniques, changepoint methods for images, bootstrap methods for empirical functionals of spatial patterns and for image reconstruction). Although it has been decided to abolish the research group in *Mathematical Statistics and Probability,* expertise in these areas will be preserved to support research in related fields such as image analysis.

The highest priority in this department is to give excellent opportunities for further development of the group in *Combinatorial Optimization and Algorithmics* (currently in a transition phase) and in *Image Analysis* (which is still in its infancy). Novel research developments also have our ongoing attention. However, in the present circumstances, preference in taking up new research topics will go to those which fulfil the dual conditions of being closely related to existing CWI research, *and* receiving insufficient attention from Dutch university groups in mathematics. Among the fields being considered are:

- Stochastic Models for Financing (which is related to Markov decision processes and stochastic control theory) and
- Probabilistic Algorithms (which is related to combinatorial optimization and to performance evaluation).

Furthermore, it has been noted that the partly intertwined areas of *Flexible Manufacturing* and *Automated Distribution* have strong connections with ongoing research in this department - and the department of Interactive Systems. Given the wider practical potential, it would be an exciting challenge to undertake a unified approach to the mathematical aspects of these problems.

NUMERICAL MATHEMATICS

As most mathematical models of problems occurring in the technical and physical sciences cannot be solved by analytical means, mathematicians have to resort to numerical techniques to obtain quantitative solutions. A substantial body of these problems is modeled by differential equations. For this reason, the research of the numerical mathematics department has always concentrated on the numerical solution of ordinary and partial differential equations. Recent years have seen increasing emphasis on solution methods which are attuned to advanced computer architectures; this trend will be ongoing. A major part of the department's research programme is externally funded - or has prospects of external funding.
Among topics with a unique position in The Netherlands, are formulation of the multigrid method as a defect correction process, parallel methods for initial value problem solvers and the adaptive time depending grids.

Priorities for present and future research programmes are as follows:

Parallel methods for initial-value problems:

- Integration of oscillatory problems described by higher-order differential equations;
- Diagonally implicit iteration of Runge-Kutta correctors for solving stiff and non stiff initial-value problems with applications in circuit analysis and control engineering;
- Three-dimensional models for the shallow water equations with applications to sediment transport and pollution;
- Waveform relaxation techniques.

Numerical modelling of evolution problems and environmental applications:

- Locally uniform grid refinement for time-dependent partial differential equations;
- Adaptive techniques for groundwater modelling;
- Moving finite element method for two-dimensional convection-diffusion problems.

Multigrid methods and steady boundary-value problems:

- Defect-correction techniques;
- Singularly perturbed boundary-value problems with applications to non-standard finite element methods and semi-conductor models;
- Adaptive algorithms for the compressible Navier-Stokes equations;
- Multigrid techniques for semi-conductor models.

Large scale computing:

- Computational number theory: robust factorization methods, "gaps" between theoretical practical results in number theoretical problems;
- The Number Field Sieve;
- CRAY-YMP4 software: multigrid methods, multilength integer arithmetic;
- Multimedia software;
- Inverse problems in chemical reaction kinetics

In addition to these research topics, the department intends to develop the following research topics:

- Parallel methods for convection-diffusion problems;
- Research-monograph: 'The method of lines' (stability, order reduction, convergence);
- Matrix-free solution techniques for large systems of equations;
- Numerical analysis of dynamical and Hamiltonian systems;
- Sparse grid techniques: wavelets, multigrid methods, applications to singular perturbation problems;
- Number theoretical problems: constant of De Bruijn-Newman, Conjectures of Graham, of Oesterle-Masser, etc.

To guarantee the perspectives on fundamental research in numerical mathematics it is important to create positions for experienced researchers such as postdocs and long term visitors. However, financial criteria are likely to be a major factor in selection of the research projects, and this in turn demands a close watch on any possible disruption of the equilibrium between fundamental and applied research.

3.3.2. Priorities in Computer Science Research

INTRODUCTION

During the 1960s and 1970s computer science became a recognized field of scientific study. Subsequently, in the 1980s, it has been stimulated through European and governmental instruments, both in the private and the non-profit sector, e.g. INS, RARE, RACE, and ESPRIT. The outcome has brought far-reaching benefits and changes inside and outside the scientific community. A recent analysis by WRR[3)] , The Netherlands Council for Government Scientific Policy indicates that further progress requires a balanced investment in the enabling technologies, both hardware and software, and a preparation of the market for advanced applications.
CWI policy on computer science for the next several years is based on continual effort in the core areas, i.e. computer architectures, software technology, and information systems, with an emphasis towards synergy and multi-disciplinary research actions. This goal calls for both fundamental research activities to improve our understanding of computer science problems via mathematical modelling, and for computer science experimentation to validate the models and obtain the quantitative aspects for further theoretical and systems research.

The synergy between mathematics and system experimentation - the two dimensions of computer science research - will be a decisive factor in the allocation of resources for new research topics. The objectives require a critical body of senior researchers and strong relationships with external research groups, based on:

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3) H.L. Jonkers, F.M. Roschar, *Samenhang in doen en laten*, Wetenschappelijke Raad voor het Regeringsbeleid, 1991, ISBN 90-399-0033-7.

- a focus on a few promising areas of computer science;
- a proper balance in resources between theory and system experimentation;
- a stimulus for cooperative projects, both national and European;
- a search for external funding for potential economic valuable results;
- safeguarding of fundamental research against fluctuations in external funding.

Promising new areas of research are scientific visualization, multimedia systems, advanced information systems, machine learning and computer linguistics. These activities are further illustrated by a short overview of the research programme under way, and being planned, for the three computer science divisions.

Below we describe the science policy and future plans of the four departments of CWI in the field of computer science:

- Software Technology
- Algorithmics and Architectures
- Interactive Systems
- Computer Systems and Telematics

SOFTWARE TECHNOLOGY

The research options of this department are based on the development and application of formal methods, and on the development of tools which support the use of formal methods. The department's research programme can be divided into two main themes: applied logic and semantics, and formal methods in programming. The present and future research programme of the department is as follows:

Applied logic and semantics

Semantics:

- completely abstract semantics for versions of logic and object oriented programming languages;
- the use of not well-founded sets in semantic modelling;
- semantics as a basis for programming methodology;
- capita domain theory;
- true concurrency.

Algebraic and syntactic methods:

- conditional rewriting as connection between functional and logic programming;
- concurrent lambda calculi: common extensions of lambda calculus and a calculus for processes;
- type theories, especially typed lambda calculi.

Logic and language:

- study of aspects of correctness of logic programs;
- aspects of non-monotonic reasoning in connection with circumscription, default theory, autoepistemic theory, various forms of closed world assumptions, and logic programming;
- aspects of natural language semantics which play a part in non-monotonic reasoning;
- relations between logic programming and functional programming in one uniform framework;
- semantic and structural parallels between natural languages and programming languages;
- dynamic and partial semantics for natural language;
- foundations for categorial grammars, and coherence with linear logic.

Formal methods

Concurrency and real time systems:

- further development of real time process algebra;
- verification support by means of software tools;
- probabilistic reasoning on concurrent systems;
- concurrent specification languages.

Extensible programming environments:

- generating complete compilers from formal language definitions;
- formal descriptions of parallel programming languages;
- application of the ASF + SDF meta environment to several areas, such as programming transformations and proof checkers.

In the department's view it is extremely important to start up research on the theoretical computer science aspects of neural networks and, in particular, the mathematical foundation thereof. Moreover, availability of a well-accessible parallel architecture to verify part of the department's theoretical research experimentally, would be highly beneficial (e.g. in verification of implementation methods for parallel languages and specification and verification of parallel algorithms).

ALGORITHMICS AND ARCHITECTURES

The research and expertise in this department covers a broad spectrum of computer science, with a balance of theoretical and experimental research. The activities in the research group *Algorithms and Complexity* cover fundamental studies in complexity theory for non-conventional computer networks and distributed information systems. Advances in these areas are also of interest to the area of *machine learning*, where a sound mathematical basis is needed both to forecast the experimental results and to discriminate the results produced in prototype systems.

The research in the *Cryptology* group balances mathematical theory on encryption with experimental work on future payment systems like the smart card. Emphasis in the near future shifts towards authentication and untraceability. The former gives proof of one's identity by answering numerical questions. The latter aims at improved privacy in public payment systems.

The research group on *Databases* concentrates on database theory and architectures of new generation database systems, such as foreseen in design application areas, office-automation, geographics and astronomy. The size and complexity of a database management system requires a careful choice of small-scale experiments to develop effective techniques and to evaluate (analytically) proposed parallel architectures. Hence, the work in this group is focused on an object-oriented database management system, which will also form the basis towards *interoperable* information systems.

The research on formal specification of algorithms is undertaken in the group *Constructive algorithmics*. Its focus is to develop the mathematical theory enabling the derivation of efficient and correct implementations of algorithms from a high-level description. The issues investigated include unification of specification formalisms and development of specialized theories using experimentation with the formalism in well-identified algorithmic domains.

The sheer complexity of computer systems, networks, and user interfaces forms a continual technology push towards more effective use via better software systems architecture. With this in mind, the department aims at establishing a *Computer Systems Research* group to address the crucial link between the theory of software modelling and experimentation.

INTERACTIVE SYSTEMS

The central theme in the department is interaction between human and computer, between external processes and computer, and the mastering of interaction among computer processes. The trend towards more powerful user interfaces is considered to be a strategic economic factor. Direct access to large information systems as well as access and control over complex computational intensive applications is deemed necessary to support high technology systems and decision making. There are two notable emergent areas of research

which could offer the solid base for powerful man-machine interaction, they are *multimedia* and *scientific visualization.*

Scientific visualization provides the tools to model applications and to interact with a computational intensive process for analysis. Multimedia techniques provide the infrastructure for a virtual world onto complex information systems. Both areas require advances in hardware- and software- architectures to provide the processing capacity for direct interaction. Such architectures are based on the highly parallel hardware and software systems, which form a proper continuation of our work on *Computer graphics.*

The provisions required for parallelism in an interactive setting are experimentally studied in two themes: parallelism in interactive systems and concurrent (groupware) design. The former aims at providing the programming support environment to develop parallel and multimedia applications. This work is performed in an international setting, and could lead to standardization activities.

The research into *Intelligent CAD systems* has uncovered the fundamental problems associated with groupware, i.e. support for interaction between cooperative designers. The technical problems are addressed with the MANIFOLDS programming language construct, which captures the dependencies among parallel processes in a declarative manner. The prototype MANIFOLD environment provides a platform for experimental studies into rule-based control structures. The results foreseen are of direct importance to improvement of CAD systems.

The *Interaction* research group focuses on and around the interpretation of images, based on techniques from artificial intelligence. Further improvements are expected from applying computer linguistics in the domain of geometric feature analysis in 3-D images and the construction of 3-D images from hand drawings.

Computer Systems and Telematics

The CST department has a joint research and support role. The support role consists of developing and maintaining CWI's computing systems and local and wide-area computer networks. The research role is to investigate applied and experimental topics dealing with operating systems and computer networks.

The department has one research group currently engaged in multimedia research. The thrust of this group is to investigate operating systems and systems architecture support for synchronizing independent data multimedia streams in a distributed computing environment. This work consists of investigating operating systems structures (with an emphasis on resource partitioning within a hybrid distributed/conventional operating system), investigating the development of network protocols and device drivers for efficient multimedia data transfer, and investigating the development of application program interfaces (APIs) for supporting generalized models of highly-synchronized multimedia documents.

In addition to the multimedia research group, the department also engages in joint research with other departments within CWI and with external organizations, concerning the integration of new facilities at the operating system or network protocol levels. Examples of current projects are the development of security algorithms in a UNIX environment (in conjunction with the Algorithms and Architectures department) and the development of the Amoeba operating system on a variety of hardware platforms.

3.3.3. Priorities in Multidisciplinary Research

INTRODUCTION

A recent development in the organization of the research at CWI is the introduction of multidisciplinary research projects. These combine research on a given strategic field and involve scientists from several departments. We are confident that this formula will promote fruitful cooperation between existing and new research groups, and that the teaming of several disciplines (e.g. from both mathematics and computer science) could well result in new directions of research. Multidisciplinary research already exists at CWI; a good example is research on mathematical aspects of *image analysis*, which is now concentrated in one mathematics department, BS (prior to 1991 in AM and BS). Future research in image analysis will also be multidisciplinary, for example with regard to numerical analysis and scientific visualization. Another example is *wavelets*, which started in the AM department with support from the numerical department, and which can expect to benefit from other departments' expertise. Below we describe other activities with multidisciplinary potential.

MULTIMEDIA

Multimedia research studies the coordinated use of various information streams within a computing system, and seeks ways to support the capture, transfer, and storage of potentially vast amounts of information across appropriate user, system, and device interfaces. At CWI the field of interest includes aspects of the definition, manipulation, and presentation of multimedia data. The goal is to share results obtained from complementary research activities, which span a wide range of interests from user interface systems to operating system support, from database models to network protocols, and from data models for images to data models for sound.

ENVIRONMENTAL MATHEMATICS

There is a definite boom in environment-related scientific research at universities and governmental and applied research institutes. Support from mathematical modelling, biomathematics, statistics, risk analysis, probability theory, large scale computation and computer science is crucial in this area. The expertise offered by CWI in these fields is available, and will be combined by directing several research groups at environmental problems.

SCIENTIFIC VISUALIZATION

The goal of scientific visualization is to provide additional insights into existing scientific methods through novel presentation techniques. Scientific visualization embraces both image understanding and image synthesis, resulting in methods both for interpreting image data, and for generating images from complex multi-dimensional data sets. Scientific visualization unifies the largely independent but convergent fields of computer graphics, image processing, computer vision, signal processing and user interface studies. The research theme Scientific Visualization is planned to start in 1992.

COMPUTATIONAL GEOMETRY

Computational geometry designs and analyzes algorithms for geometric problems, usually in low-dimensional (two- or three-dimensional) Euclidean spaces. The novelty of the field comes from the current demand to solve geometric problems very fast - not to say instantly - in practice. This is essential e.g. in steering a robot, or implementing computer graphics. Many of the algorithms presently available are too slow for these purposes. One needs algorithms that run at not more than linear time. This extends the field of interest to several research areas in that there are mathematical, operations research, theoretical and practical computer science components.

3.4. Support departments, Computing Facilities

3.4.1 Support departments

As the name implies, these departments provide support for CWI researchers in their primary tasks: research, knowledge transfer and expert training. Among our specialities in this area is provision of support in the organization of national and international conferences, seminars and courses, which involve CWI researchers. Where necessary, researchers are given support - often over longer periods - by programmers or system programmers. A high degree of experience and expertise is necessary for the efficient handling of wide range of support tasks for the scientific groups.

The CWI Library has an extensive and excellent collection of books, journals and research reports, and provides a high level of support both to CWI researchers and, indeed, the entire Dutch mathematics and computer science community. In practice the CWI Library acts as a nationwide service. The journals section, including the current journals collection of the Dutch Mathematical Society (Wiskundig Genootschap), is the country's largest in the field of Mathematics and Computer Science, and is a cornerstone of the library's national function.
An active programme of exchanges brings many Chinese, Russian and other East-European publications into the CWI Library. The extensive collection of research reports was partly obtained through the European Mathematical Council's grey literature project. It is not uncommon for researchers from abroad to make a special stop-over in Amsterdam in order to visit the CWI Library.

The Computer Systems and Telematics department is responsible for the installation and maintenance of the computer infrastructure needed for the research programme. Facilities are also provided at the international level; CWI houses the central node of EUnet, the European UNIX network, and manages one of the major gateways between the USA and Europe. During the past decade CWI has gained an international reputation for its work in stimulating the use of wide-area computer networks throughout The Netherlands and Europe. The report entitled *Computer Networking at CWI: Requirements and Strategies for the Early 1990's,* which was published in December 1990, contains a review of CWI's networking strategies, with the stress on national and international network connections, rather than local area networks. The report discusses how the general networking requirements of CWI - which are representative for many research-level institutions - will be met during the coming five years; it also goes into the current problems arising from European networking support.

CWI firmly intends to continue with all these vital support services.

3.4.2. Computing facilities

CWI has been able to realize an adequate computing infrastructure via the Dutch Education and Science Ministry's IAS programme. In recent years we have made real progress in providing all our researchers, support staff and visitors with facilities to meet their basic computing needs. However, the present CWI infrastructure is still far from being "state-of-the-art".

Very simply, high level research needs a high level of computing facilities to attract and keep high-level personnel. There is direct relationship between the level of facilities and support provided, and the quality of researchers one can attract.
New computer equipment coming on the market every year does more than enables us to work more productively, it also broadens the range of work that can be accomplished. In coming years CWI must be able to keep on modernizing and expanding present facilities to make the most of the potential offered by its researchers and visitors. CWI's equipment acquisition and support policy for the coming period was presented in the report

Computing Facilities Policy Document CWI, 1991-1996, published in June 1990. The pace of technological development now makes it imperative to update this document at the start of 1992. Particularly with an eye to IAS funding, this time scale prevents us from setting the firm annual figure needed from 1994 to 1998; however, at this stage we envisage that the overall funding requirement for this four year period will be between Dfl. 10 and 12 million.

4. BUDGET PROJECTIONS

4.1. National Activities Mathematics (LAW)

1. **WORKING EXPENSES** (in Dfl. x 1,000)

	1993	1994	1995	1996	1997
Projects (excl. areas-for-attn.)	2,220	2,270	2,430	2,680	2,830
Special-attention areas	600	900	1,000	1,000	1,100
Special years	250	250	270	270	300
Visitors	90	90	100	100	110
Expertise Centre CAN	40	40	50	50	60
SMC-bureau	200	250	250	300	300
Other	40	50	50	60	60
Total Expenses	3,440	3,850	4,150	4,460	4,760

2. **INVESTMENTS** (in Dfl. x 1,000)

Projects	420	450	500	550	600
Expertise Centre CAN	60	60	60	60	60
Dynamical Systems Lab	1,000	450	450	250	250
Total Investments	1,480	960	1,010	860	910

4.2. National Research Centre for Mathematics and Computer Science (CWI)

1. **WORKING EXPENSES** (in Dfl. x 1,000)

	1993	1994	1995	1996	1997
Expenses					
Personnel cost	14,600	14,800	15,100	15,300	15,600
Materials and overheads	3,610	3,610	3,710	3,810	4,110
VAT-SARA	220	220	220	0	0
CWI use of SARA	0	0	0	300	300
To Buffer fund	400	230	175	300	185
Total Expenses	18,830	18,860	19,205	19,710	20,195
Personnel					
Average number in full time equivalents	170	172	174	176	179
Income					
NWO grants (excl. SARA)	12,600	13,000	13,400	13,800	14,300
Personnel provision	360	360	360	360	360
Other NWO funds	290	115	60	15	0
SMC-bureau	200	250	250	300	300
Other grants	2,095	2,235	2,235	2,235	2,235
Orders & contract research	1,500	1,800	1,800	1,900	1,900
Miscellaneous	1,100	1,100	1,100	1,100	1,100
NWO-loan	685	0	0	0	0
Total Income	18,830	18,860	19,205	19,710	20,195

Explanatory notes:

1. During the last couple of years personnel numbers have stabilized at the level of 170 full time equivalents. Modest growth is projected from 1993 onwards.
2. Of overall personnel costs, 50% can be attributed to computer science research and 50% to mathematical research. The same ratio applies to materials and overheads costs.
3. The item "CWI use of SARA", to the amount of Dfl. 300,000 per annum has been created to take account of the fact that use of SARA services will be charged directly to CWI from 1996 onwards.
4. Other sources of NWO funds include the STW and SION foundations, and special projects such as Priority programmes.
5. The institutional activities of the SMC are supported by the SMC Bureau. The activity plans as outlined demand intensified support.
6. The item Other grants includes income from national programmes and international cooperation projects such as ESPRIT, BRITE, RACE etc, and income from universities and national networks.
7. The item Orders & contract research includes the income from activities commissioned by third parties and via the liaison-programme.

2. **INVESTMENT** (in Dfl. x 1,000)

	1993	1994	1995	1996	1997
NWO equipment grant	1,400	1,400	1,500	1,500	1,600
NWO building maintenance grant	900	950	950	1,000	1,000
IAS grant	2,200		(Total 10,000 to 12,000)		
Other grants	200	200	200	200	200

Explanatory notes:

1. As previously mentioned in Section 3.4.2, it would be premature to quote a firm figure needed for the overall annual IAS grant from 1994 to 1998; at this stage the requirement envisaged would be in the region of Dfl. 10 to 12 million for the four year period.
2. The NWO grant shown above is exclusively for the use of CWI and does not include funding for SARA.
3. According to the NWO Medium range plan (Meerjarenplan) 1991-1994 the building maintenance level for institutes amounts to approximately 5 % of the working expenses.
4. The inevitable response to any reduction in the IAS grant would be an increased request for funding via our NWO channels.