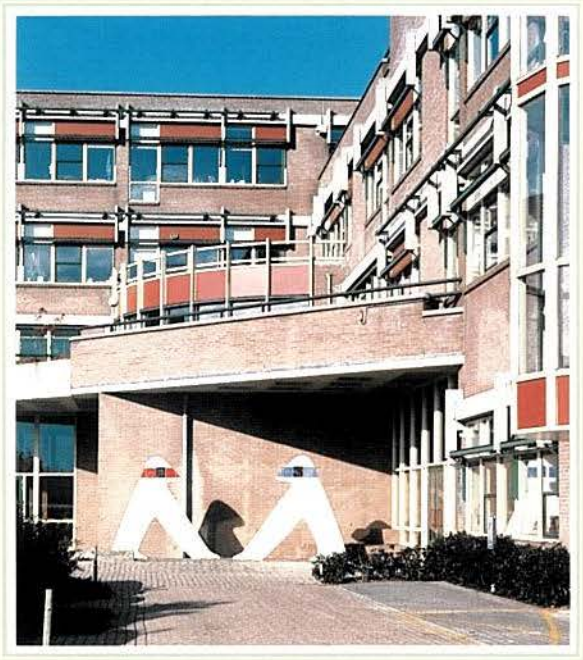
CWI

Policy Document 1988-1993



Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science
Amsterdam the Netherlands

Policy Document 1988-1993

January 1988

Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science

Kruislaan 413 1098 SJ Amsterdam
P.O.Box 4079 1009 AB Amsterdam the Netherlands

Two figures in the form of the Greek letter **lambda** *watch over the entrance to CWI.*
Sculptures: Jan Snoeck
Photo: Hans Mabelis

The Centrum voor Wiskunde en Informatica (CWI)
is the research institute of the Stichting Mathematisch Centrum.
CWI is mainly sponsored by the
Netherlands Organization for the Advancement of Research NWO

Kruislaan 413, 1098 SJ Amsterdam, The Netherlands
P.O. Box 4079, 1009 AB Amsterdam, The Netherlands
Telephone +31(20) 592 9333

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1. Introduction

Developments in the world of research and Dutch and European government attitudes towards science and technology over the last ten years have had their effect on the Stichting Mathematisch Centrum (SMC) and its institute, the Centrum voor Wiskunde en Informatica (CWI). During this period, government scientific policy has stressed national and international coordination of research and development, and the reinforcement of their significance to the community. This has both encouraged concentration of research in 'centres d'excellence', and strengthened contacts between industry and academic research sectors.

Cooperation at the national level and reinforcement of mathematics' contribution to the community have been among CWI priorities from the very start and, in the last few years, these aims have been pursued with new impetus. Specific Dutch and European governmental policy aimed at stimulation of computer science has also had a major influence on CWI. The institute was given the opportunity to strengthen its research in this field significantly. This occurred via participation in the ESPRIT programme, via a grant of extra funds under the Dutch Information Technology Promotion Plan (INSP), in order to expand 'into a leading centre in the field of computer science research', and via involvement in some other Dutch strategic research programmes. This led to a number of close working relationships with partners in the industrial and academic research sectors.

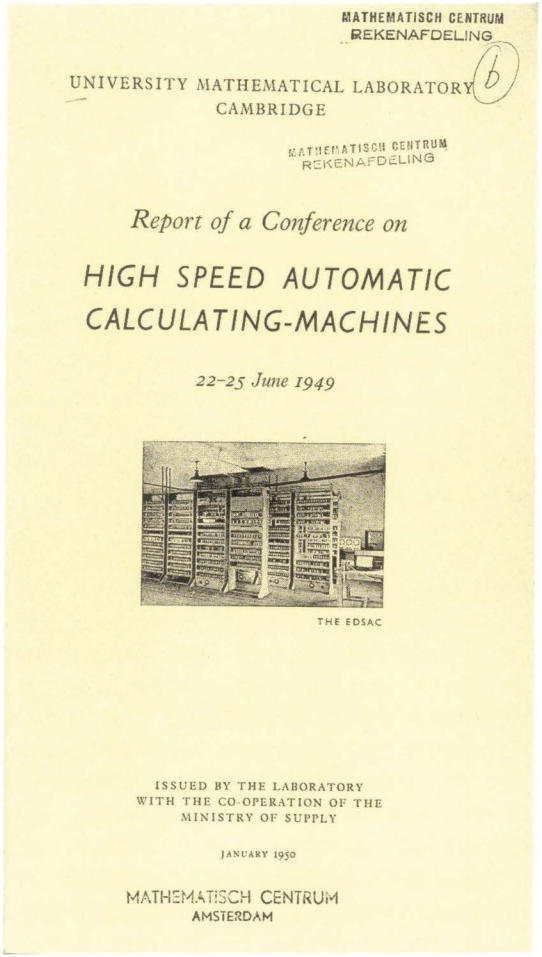
There are several, often interconnected, reasons for presenting a more detailed formulation of general CWI policy at this moment. Firstly, the major stimulation of computer science research has slowed down the development of mathematical research at CWI; and serious consideration of the balanced development of CWI research as a whole — mathematics and computer science alike — is in order. Secondly, the extra Dfl. 2 million granted annually over a five year period, over and above the regular grant, as part of the INSP programme ceases in 1988: hence, a policy is required which offers a permanent basis for this reinforcement of CWI research into computer science. Finally, there is the increasing emphasis on strategic research and joint research with industry: this demands the formulation of a policy guaranteeing a meaningful balance between the purely scientific and the strategic and — by extension — the nature of CWI as an institute for fundamental research.

This document, which will form the basis of policy up to 1993, follows on from the CWI Computer Science Research Development Plan and the ideas formulated at the May 1985 Workshop involving representatives of industry, government and the academic world.

Sections of this policy document — in particular the scientific priorities given in chapters 4 and 5 — have been covered in more detail in reports and supplements. This more detailed information is available on request.

2. CWI: centre for mathematics and computer science

When the *Stichting Mathematisch Centrum* was founded in 1946, it was given the task of the 'systematic pursuit of pure and applied mathematics in the widest sense, and using the fruits of mathematical research for the benefit of the community'.
The research institute Mathematical Centre in Amsterdam, set up by the foundation at the same time, has never lost sight of either aim. The Centre's potential role as initiator has always been in the forefront when deciding on research themes. The first Dutch computer was designed and built at the Centre which later pioneered design of programming languages.
The recognition in the Netherlands of mathematical statistics as a discipline in its own right was largely due to activities stemming from the same source. A more recent example of innovative research is the study of parallel processes.
These are not the only way in which statutory aims have been realized. A significant corps of expertise has been 'cultivated', many senior researchers in mathematics and computer science having previously worked for longer or shorter periods at the Centre. The Centre has shared knowledge via colloquia, courses, books, etc. Nationwide support and coordination has been provided for Dutch research,


MATHEMATISCH CENTRUM
REKENAFDELING

UNIVERSITY MATHEMATICAL LABORATORY
CAMBRIDGE

MATHEMATISCH CENTRUM
REKENAFDELING

Report of a Conference on

HIGH SPEED AUTOMATIC CALCULATING-MACHINES

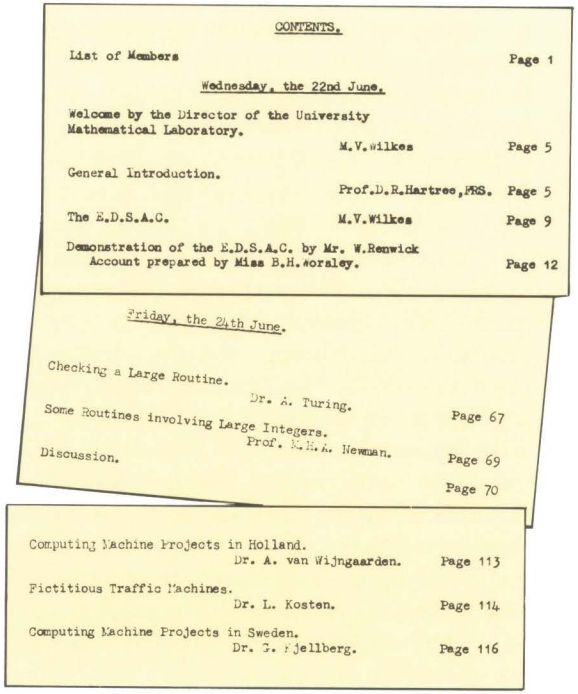
22-25 June 1949

THE EDSAC

ISSUED BY THE LABORATORY
WITH THE CO-OPERATION OF THE
MINISTRY OF SUPPLY

JANUARY 1950

MATHEMATISCH CENTRUM
AMSTERDAM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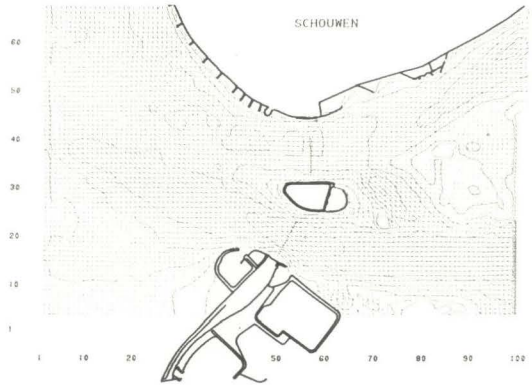
Almost at the very outset, Mathematical Centre (MC) staff became interested in new American and British developments in the electronic computer field. A study trip by A. Van Wijngaarden (Director MC 1961-1980) brought the centre in contact with a number of computer pioneers like Turing and Wilkes in Cambridge, where one of the very first computers, EDSAC, was designed.

specific examples being services for the National Working Parties, the provision of an extensive library service and the contribution to setting up and running of international computer networks.

It has always been a basic principle that an activity should be transferred (to another organization or institute) as soon as it develops to a stage beyond which it no longer fits in with the Centre's function as institute for fundamental research. Good practical examples were the setting up of two operations: N.V. Electrologica in 1956 and the Academic Computing Centre Amsterdam (SARA) in 1971. The first came after pioneering work on computer construction had attracted outside interest in constructing more computers, and SARA filled a gap which occurred when the demand for computational services by the two Amsterdam Universities quantitatively and qualitatively outgrew that which the Centre was meant to provide. Certain items of fundamental research were also transferred at a point when they were clearly more suitable for one or an other university's research programme, e.g. in the areas of Markov-programming and Discrete Mathematics.

Involvement in the Delta sea defense plan was an object lesson in mathematics' making a practical contribution to the world at large. The Centre's work concerned a North Sea model and its numerical calculation. The problem of statistical estimation of extreme water levels for fixing the safe height of the



CWI was involved in research for the Delta project from the 1950's onwards. The photo shows construction of the Eastern Scheldt flood barrier. In the 1980's CWI carried out calculations on flow patterns in the adjacent sea area. Photo: Ministry of Public Works, Delta Service.

sea dikes is still under consideration. Work on the Delta Plan was also an excellent example of multi-disciplinary research (statistics, numerical and applied mathematics, and operations research). Throughout its existence the Centre has acted in a consultancy capacity for government bodies, industry and other organizations. Recent years have brought an increase in the number of joint projects with industry on a national and European level. At home, such projects involve the Foundation for Technical Sciences (STW) and SPIN, and at the European level ESPRIT. The strategic aspect of these projects — the medium-term interests of the community — play an important role.

Computer science evolved into an independent discipline in the 1970s. In The Netherlands this newly won status was formally recognized by inclusion in the university curriculum in 1981 and the recognition in 1983 of the Netherlands Foundation for Computer Science Research (SION) as an independent grouping of ZWO working parties for computer science research. (As from the 1st of February 1988 ZWO has changed its name into NWO: the Netherlands Organization for

the Advancement of Research.) SION's main goal is the promotion of fundamental computer science research. It goes without saying that there is a close working relationship with the SMC. SION has a say in the development of CWI's computer science research via a permanent consultative committee.

It made good sense to reflect this new relationship in the Centre's name and on the 1st of September 1983 it was changed to the current title: *Centrum voor Wiskunde en Informatica* (CWI), reflecting both the growth in computer science (*Informatica*) research and the importance of its integration with mathematics (*Wiskunde*).

A considerable number of national and international programmes for the promotion of computer science was launched in the 1980s. These provide the framework for CWI involvement in joint projects with universities, industry and government agencies. An important programme for CWI is the Dutch Information Technology Promotion Plan (INSP), sponsored and financed by the Ministries of Education & Science, Economic Affairs and Agriculture & Fisheries. The INSP provided CWI with the potential to grow into a 'leading centre for fundamental and application-oriented research into computer science'. The SMC was asked to prepare a development plan showing just how this would be achieved. The plan was completed in 1984.

A two-day workshop organized in 1985 drew representatives from universities, major technical institutes, industry and government. Main topic was CWI's role as 'centre d'excellence' in connection with extra grants from the Dutch government's computer science stimulation scheme.

The role of CWI as a '*centre d'excellence*' in Dutch computer science research was the subject of a workshop in May 1985 attended by some fifty representatives of universities, major technical institutions, industry and government. With a special eye to application-oriented research it was suggested

that CWI would benefit from intensified feed-back from industry — possibly via a joint advisory committee. It was also concluded that visiting committees could prove valuable tools in evaluating research.
July 1985 brought a further evolution of the development plan — in part based on discussions during the workshop. It was stated that fundamental pure-scientific research should remain CWI's primary aim. This would give CWI the basic knowledge for involvement in fundamental, application-oriented and strategic research. In general, CWI would be able to bring such research to the demonstration project or prototype stage, actual product development being a matter for industry. The aims of CWI: fundamental research, knowledge transfer and acting as central coordinating point in The Netherlands, were further elaborated and evaluated.
These aims and other policy factors produced four main research themes in CWI's development plan: (I) Algorithmics, (II) Software, (III) Distributed and interactive systems, (IV) Pattern recognition and artificial intelligence.
As part of the INSP programme CWI received a grant of Dfl. 2 million annually, for five years (1984-1988). These extra funds were used to reinforce or set up three of the above themes (I, III and IV), theme II being reinforced via involvement in the ESPRIT programme. The grant was also used to upgrade computer infrastructure. Even so, the estimate for the activities proposed in the development plan was Dfl. 18 million. Limiting of the INSP grant to Dfl. 10 million required adjustments to the programme as described in the development plan.

So much for background: now, in 1988, it is time to examine just how far CWI has lived up to the founding aims of 1946 and how far it has succeeded in realizing the aims of the 1984 Computer Science Development Plan.
Some examples of CWI initiatory activities in fundamental research have already been given. Similarly, it has been shown that CWI has made its contribution in terms of producing a corps of expertise: around 70 professors in mathematics or computer science spent time at CWI prior to appointment. In the period 1984-87 alone, twelve members of the CWI staff were appointed to professorships, six in mathematics and six in computer science.
Knowledge transfer occurs both via the traditional channels (publication and presentation of papers on research findings, organization of courses, etc.) and increasingly via joint projects with other leading technical institutes, government and industry — at home and internationally. Moreover, in recent years, action has been taken to strengthen the process of knowledge transfer. Measures include reinforced project management (including legal expertise), regular presentation of findings to a wider, non-specialist public and support through organization of courses and conferences.
Even the 'C' for Centre in the institute's initials has widened to encompass broader horizons — as can be borne out by four examples. The quality and quantity of the specialist literature collection has made the CWI library a national resource in its field; the library plays a central, supporting role in Dutch research. Since 1982, CWI has been an essential element in EUNET (the European UNIX^{TM} network) providing the gateway between Europe and North America for EUNET/USENET. The CWI has organized highly successful national colloquia on a number of its main research themes (vector programming, image analysis), bringing together Dutch researchers from the relevant sectors. And, in autumn 1986, 'Frontiers in Information Technology' (FIT) was set up under CWI auspices. FIT is an international umbrella organization for the promotion of knowledge transfer (via conferences and seminars) in new sectors of information technology. One of the first initiatives supported by FIT was the organization of an international conference 'Frontiers in Computing', held in Amsterdam in December 1987.

This section can be rounded off with a short overview of CWI finances in recent years. Diagram 1 shows the proportion of total operating costs for the years 1981-1986 covered by the ZWO grant. It is clear that an increasing proportion of finance comes from sources other than ZWO.
Although the INSP grant accounts for a proportion of these funds during 1985 and 1986,

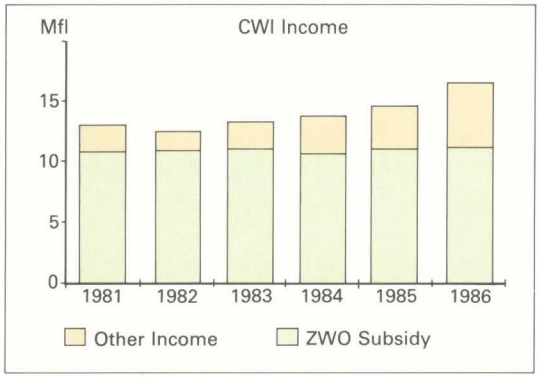


Diagram 1

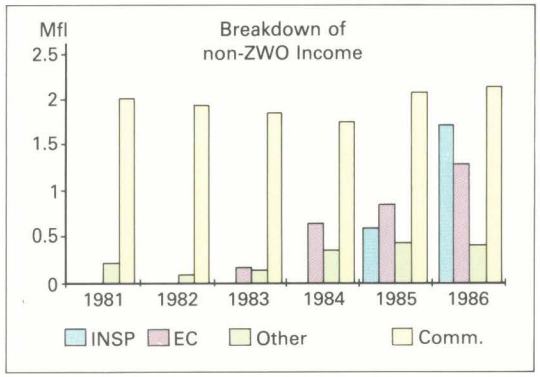


Diagram 2

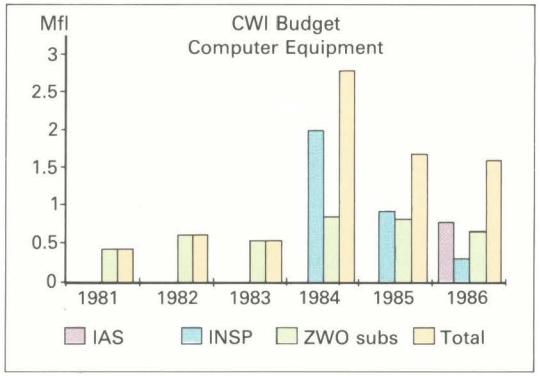


Diagram 3

the further breakdown of income in Diagram 2 shows that other forms of research subsidy and commission fees account for a growing contribution. This source of growing income is particularly related to research into application-oriented computer science. In 1987 this upward trend continued, due to involvement in new EEC projects, SPIN projects and innovative research programmes subsidized by the Dutch government. Finally, Diagram 3 summarizes sources of finance for equipment purchase; as is shown, the ZWO share has fallen from 100% to just under half. However, almost all the remaining amounts concern temporary enterprise grants.

3. Central Policy

This chapter will provide an outline of general CWI policy principles, the next chapters will go into more detail. The basis of these principles is contained in the founding statute of the SMC: the systematic pursuit of pure and applied mathematics in the broadest sense. At the same time it has to be borne in mind that computer science as a discipline did not exist in 1946 but evolved — in part — from mathematics.

The CWI Computer Science Development Plan and elaborations thereof point to three essential elements in executing the plan:

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

Research

It would be superfluous to stress the increasing interest in and applications of computer science; nor is there any doubt about the continual growth of international research in the field. CWI strategy aims to make its computer science research programme part of this process, and thus — together with the universities — keeping The Netherlands in a leading position in the field. To do this requires constant innovation, expansion and depth in research.

The importance of mathematics for science as a whole is quite clear. Virtually every scientific and technical discipline now employs mathematical techniques. This in turn has meant an increasing international priority, for instance in the United States where the NSF mathematics budget has been increased. France and West Germany are also devoting extra attention to reinforcing mathematical research — with particular reference to industrial applications. Here in The Netherlands, government and industrial awareness was illustrated in a statement by the Director General for Science Policy at the European Symposium on Mathematics in Industry (ESMI) in October 1985, and by speakers from both sectors at the CWI Symposium 'Science in Industry' (June 1986). CWI policy centres on involvement in certain strategic sectors of international mathematical research (selected in conjunction with and tuned to computer science research). This demands constant reflection on mathematical research to exploit the potential expertise and set up new research groups — or adjust existing ones.

Active, international level, pure scientific research is a prerequisite for the continued existence of CWI. Research of this nature requires a certain degree of freedom in subject selection as well as guaranteed continuity and appropriate scale ratios in relation to other activities. The results of the pure scientific research provide the basis from which initiatives can be undertaken for strategic and application-oriented fundamental research — preferably undertaken jointly with major technical institutes, The Netherlands Organization for Applied Research (TNO) and industry. Such joint research is often (partly) financed by European and Dutch government or industrial strategic research programmes. Lastly, CWI will be able to accept a limited number of commissions for applied research or development projects which tie in with existing expertise.

In achieving this CWI policy aims at balance between the most important activity: pure scientific research; an essential ancillary activity: strategic/application-oriented research; and a derived ancillary activity: applied research and development. CWI's

During the last few years, CWI (co-)organized some symposia where the significance of fundamental mathematical research to industry was emphasized. Speakers included Mr E. Van Spiegel (right), Director General for Science Policy of the Dutch Education and Science Ministry, and Mr H.J. Van der Molen (left), Director of the Netherlands Organization for the Advancement of Pure Research ZWO (now NWO).

strength in certain research sectors will be significant in the future selection of both pure scientific and other fundamental research.
Moreover, CWI aims at exploiting fully the synergetic effect of mathematical and computer science research under a single roof. Interdepartmental cooperation and research in disciplinary boundary zones are priorities.
Finally, finding and keeping first rate personnel is critical to high quality research. CWI strategy for attracting researchers from home and abroad includes provision of the right working environment and a good computer infrastructure.
International evaluation committees have been set up to oversee research quality. Specialist committees also advise departmental heads on research policy. Lastly a science committee and the SION board advise CWI on strategic budgeting and the scientific programme. Hence, the Dutch scientific community has ample means of supervising CWI's scientific research.
The wider importance of mathematical and computer science research has been referred to several times. CWI aims to increase community involvement (e.g. of government and industry) in the advisory process which leads to policy formation, particularly as regards strategic research and external relations.

Knowledge transfer and expert training
Knowledge transfer and expert training are important aims in their own right, but realizable only on the basis of research: the knowledge concerned is the fruit of CWI fundamental research and expertise is chiefly created by inclusion of young talent in CWI research groups.
Alongside the traditional methods like publication and presentation of papers, priority goes to joint research with industry, CWI's main contribution being fundamental knowledge — a direct and efficient means of knowledge transfer. Joint projects with industry can also provide the finance needed to expand research capacity; at the same time there is the stimulation which comes from confrontation with practical problems.
Alongside organization of courses, seminars and workshops, CWI is also involved in postgraduate training. Many of these activities are developed in conjunction with the post-

academic training organization PAO, universities or industry. CWI also supervises several university and technical college trainees. The contacts built up between CWI personnel, those attending courses, and opposite numbers in higher education provide an excellent basis for future joint activities.

CWI as meeting point

CWI acts as national meeting point for Dutch and international researchers. It takes and supports national research initiatives; where viable and expedient it provides facilities for Dutch research: the library is a good example. Policy aims at strengthening this central function. CWI promotes frameworks for international cooperation and personnel exchange and, whenever feasible, CWI support sections are deployed nationally and internationally. The general aim is to intensify contacts with institutes abroad. Particular attention is given to GMD in West Germany and INRIA in France. Like CWI, these two institutes conduct research into both mathematics and computer science.

CWI and NWO

SMC operates within the Netherlands Organization for the Advancement of Research NWO (previously ZWO). This relationship is essential for the efficient realization of policy aims. A major share of the fundamental research which forms the bedrock on which other CWI activities rest will continue to depend on NWO finance. CWI endeavours to supplement this and cover the cost of strategic, application-oriented and applied research with various other subsidies via commissions, courses, licences, etc. The ratio of the NWO subsidy to other income has undergone considerable change in the last five years (see Chapter 2, Diagrams 1, 2 and 3). CWI considers this a positive development.

Non-NWO income has ceased to be an addendum to the budget and now provides an important contribution to total funds available. The longer term aim is to ensure the continuity in this income with a target of around 50% of the current NWO subsidy. Achieving this will require a degree of freedom vis-à-vis investment in development work and organizational frameworks — or support for the commercial exploitation of research findings.

Hence, CWI is working towards a financial relationship with NWO which both guarantees continuity of the fundamental research programme and offers room — financially and as regards decision making — for investment in activities related to the commercial exploitation of research findings. Generally speaking, such investment will not produce short term yield, moreover, there will be risks involved. The fundamental research programme must to a large extent be independent of success or reverse of commercial exploitation.

CWI and the academic world

CWI fulfills its task as a research centre in the midst of the academic world. This is made possible by the good relations enjoyed with all the universities; improving those relationships even further is a priority. The academic world is involved in the running of the Foundation and its institute via the board of trustees, and CWI stimulates involvement of the academic world in the drafting and execution of the scientific programme. In relation to the academic world CWI feels it should act as a binding agent. It carries this role through the organization of colloquia, seminars and conferences, the invitation of researchers from abroad, coordination via consultation in various organizations, provision of management facilities such as a library, a printing unit and an electronic network, and so on. News of scientific activities is spread far and wide. CWI research is initiated after consultation with those university researchers involved via advisory boards or as scientific advisors. Trainee researchers at CWI are most likely to be guided by senior university lecturers. Lastly, CWI research projects can be transferred if necessary — as when a project leader accepts a university post.

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In 1988, a team from the Department of Numerical Mathematics established a world record in factorizing large composite numbers. The factorization was performed on the Japanese NEC SX-2 supercomputer of the Dutch National Aerospace Laboratory in the Netherlands, and took about 95 hours of CPU-time.

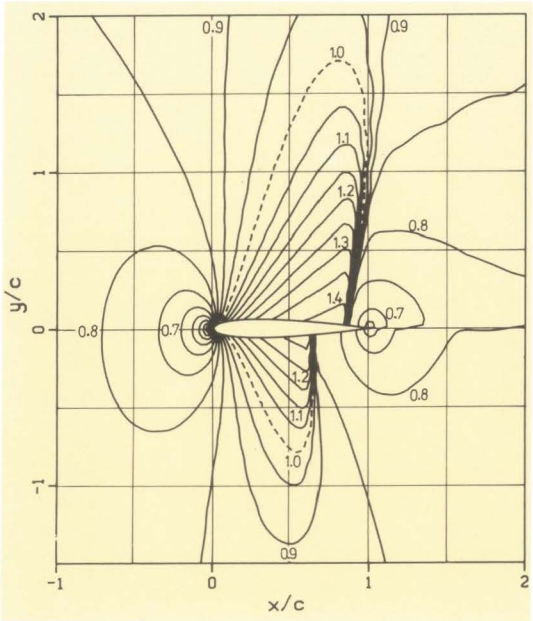
Products of large prime numbers are used to code and decode confidential messages. As it is almost impossible to reconstruct the prime factors from such a product, the encryption is considered very safe. 'Safe' numbers need to be considerably higher than the CWI record.

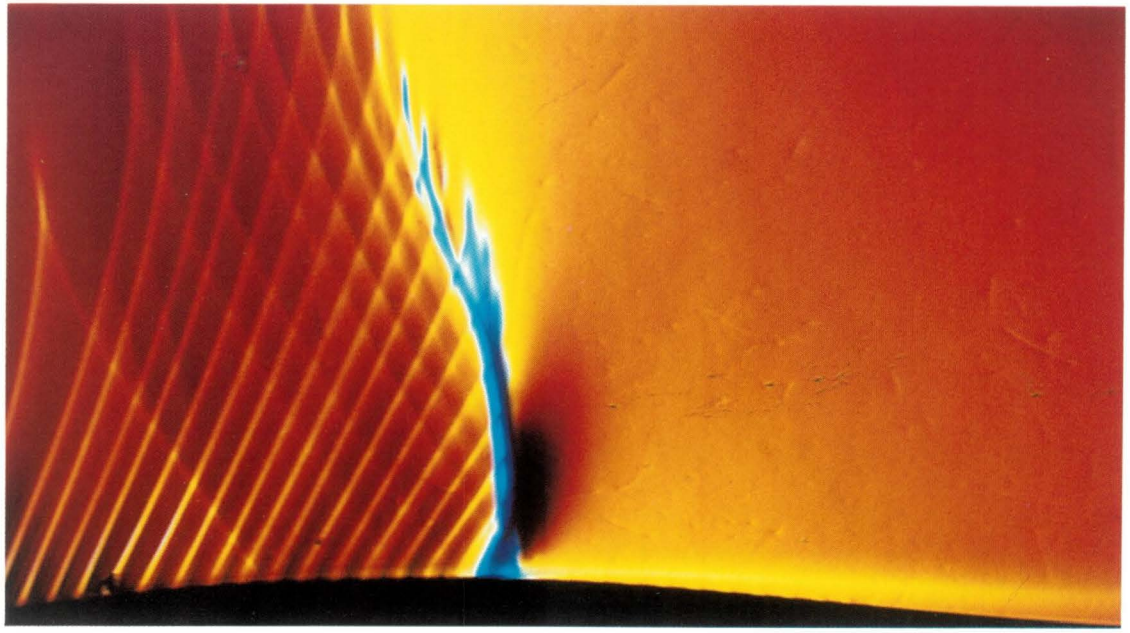
4. Priorities in Mathematical Research

A number of considerations must be made in selecting a CWI research subject. Mathematics may have ancient roots but the discipline is undergoing dynamic change. One sees the arrival of new mathematical techniques and applications in previously unthought of areas. CWI is bound to involve itself in these developments and to carry out quality research in priority areas. This presupposes the compilation and maintenance of expertise in the required techniques. Falling behind in mastering the skills demanded by the mathematical instrumentarium can mean significant quality loss in current and future research activities. Potential for application is among the deciding factors in selection of research themes. The increase in quantity and diversity of such potential has in turn prompted a call to expand relevant activities.
Ongoing research also has an influence on priority selection. New research does not generally materialize out of the fresh air: there is usually a close link with work in progress and, at a given moment, new applications or extraordinary results can suggest a new direction.
The priorities given in this chapter have to be seen in the light of these considerations. At the same time account has to be taken of practical considerations of personnel policy. Indeed starting a new field of research by redeployment of existing activities and staff can be cheaper and more effective than setting up a new study group from scratch. Partial redeployment is less than ideal but sometimes has to be chosen in preference to a far more costly fresh start.

The development of fundamental **Numerical research** remains closely linked to progress in the hardware sector. In line with expectations, the direction of CWI research includes *Numerical methods for vector processing and parallel processing.* This orientation goes back to 1985, when CWI organized a national colloquium in cooperation with the University of Amsterdam and the Technical University of Delft.
An important area of applying numerical techniques is the solution of systems of coupled partial differential equations as these occur in various forms as models of natural phenomena. Alongside continuation of classic applications of which CWI already has considerable experience (e.g. computational fluid dynamics), research will be directed at new and potentially promising areas. Work has already started for the electronics industry on the solution of models crucial for semiconductors. Work has been going on for some time on adaptive grid techniques in which the grid adapts to the local situation — and considerable fundamental research remains to be done in the future. The *Multi-grid techniques for boundary value problems* project will be continued; it is significant for a number of areas including a variety of technical applications. The same goes for *Development of numerical software in the programming language Ada* which is partly financed by the European Commission. The CWI study of *Computer assisted number theory* will also be continued. It has scored several major successes over the years in return for minimal manpower input. The project has also added to experience with software for vector and parallel processors.

The Netherlands has won a leading place in **Mathematical statistics.** The explosive growth in power and means of computation has added a new dimension. On one hand many interesting and hitherto impracticable models are now within reach of statistical analysis: on the other, the potential of computer inspired statistical analysis methods gives impetus to new theoretical research (e.g. Efron's bootstrap method). This potential is already employed in two ongoing CWI projects — *Semi-parametric statistics* and *Applied*





CWI has developed efficient methods for solving so-called Euler equations, applications for which include calculation of air flow around aircraft wings. Also shown, in addition to the result of a computer calculation (performed on SARA's CYBER 205), is the 'Schlieren' picture of a transonic flow around an aircraft wing in a wind tunnel. The flow velocity in the striped area to the left of the shock wave front is greater than that of sound.
Photo: Delft University of Technology, Department of Aerospace Engineering.

statistics; and it is to be studied in depth in a new project — *Computational statistics* — which will slot between research results in mathematical statistics and the practice of statistical consultation.
In many sectors where data are already available in the form of digitized images, e.g. seismic and satellite observations, biology and medicine, there is demand for statistical models and methods to expose the structures behind the images. CWI has responded by starting a new project, *Processing and reconstruction of images.* This concerns a wide variety of applications, and the use of a broad spectrum of mathematical disciplines. For instance, analysis, algebra, topology, numerical mathematics, statistics and system theory, as well as computer science are involved. In this project several CWI groups work together. One of the ingredients for this research is *Stochastic geometry,* and CWI intends to be an active contributor.
The new or recently started research will be matched by continued fundamental research into *Semiparametric statistics,* partly in support of other departmental projects. Over the last years this subject has received considerable boosts from a wide area of application

including biometry and econometry. The current project *Applied statistics* is in fact a collection of larger (usually externally financed) applications, including those in cooperation with or commissioned by the Department of Public Works, which do not readily fit in with other projects. Activities such as these match up well with the aims of CWI. The *Stochastic processes* project, which emphasizes the study of processes in space *and* time, will continue as it is. Sections of this project provide a significant basis for image analysis.

Operations research and **system theory** are areas of major practical economic significance; in recent years, CWI research in *Combinatorial optimization problems* has concentrated on parallel and interactive methods.

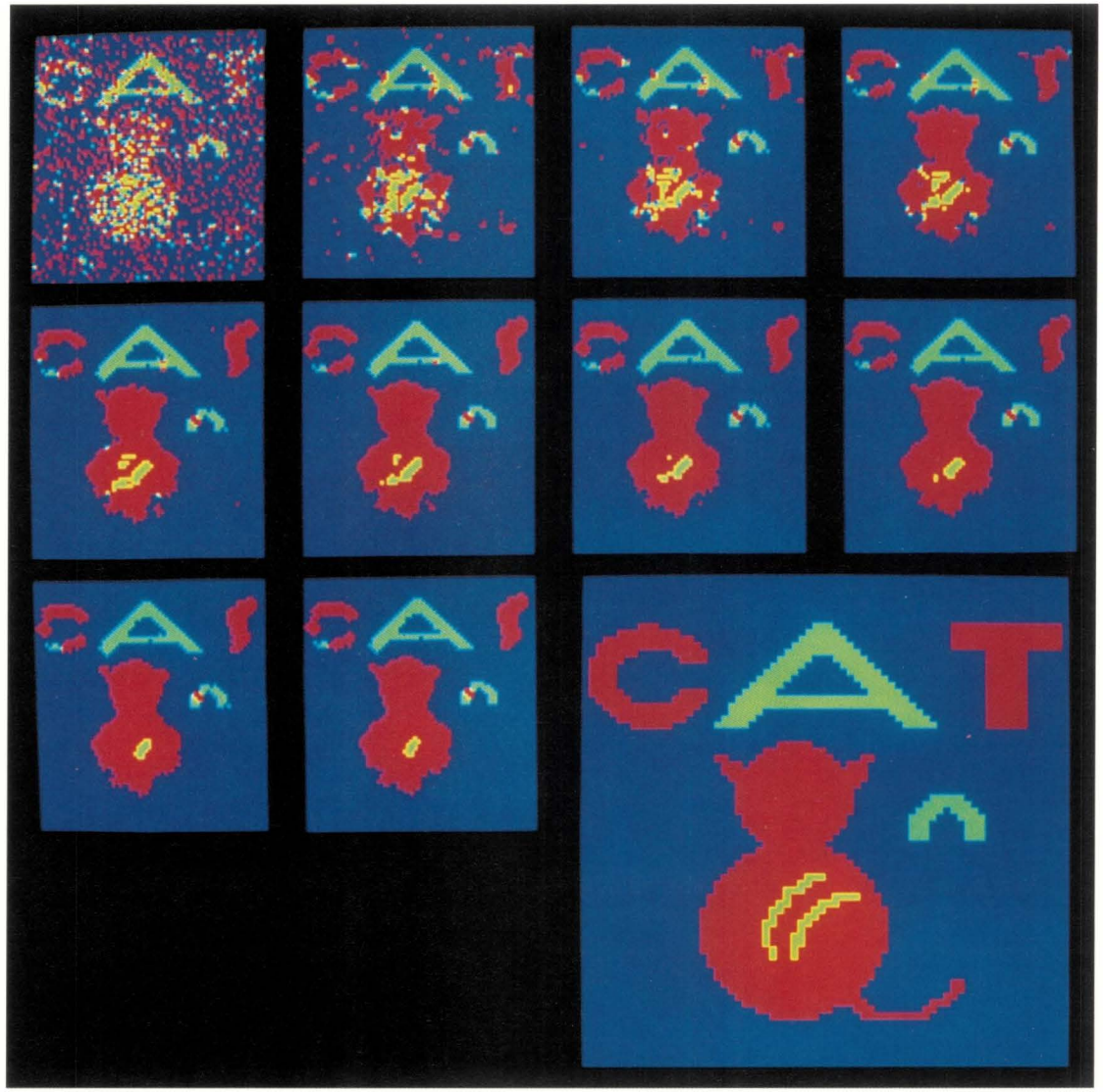
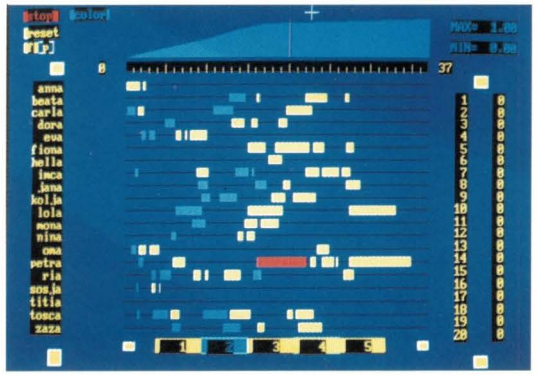


Image analysis and processing forms an important area of CWI research. Restoration of interference deformed images is a frequently reoccuring problem. The example shows the image of a cat (larger illustration) exposed to interference which was subsequently removed using a given mathematical technique (series of smaller illustrations). With this technique of 'Iterated Conditional Modes', invented by J. Besag (1986), the complete image to be restored is modeled by a (stochastic) Markov field. Note that real characteristics can be taken for interference in the course of such a process, and hence lost (the cat does not get his tail back).

Consideration is being given whether or not to adjust this research in the direction of geometrical and randomized methods. These methods are relevant for models, proof methods, algorithms, as well as for construction and decomposition methods, and are currently the subject of international attention. Researchers involved in the CWI project *Analysis and control of information flows in networks* have been analyzing computer communication network performance for some years. The Netherlands has an outstanding name in the field of queueing theory. Its application to modern communication systems is full of potential for an institute like CWI, not only for the many interesting fundamental problems but also because of the significant economic interests involved. Further research within this project concerns analysis of mathematical queueing models and the general theory of communication networks. CWI will also continue work in the area of *System and control theory* — the importance of which to the world at large is growing in line with increasing demand for automatic control and data processing as occurs in the control of robots, traffic and computers, processing of speech and prediction of air- and water-pollution.

The expertise CWI can now offer in areas such as numerical problems results from determined study of fundamentals in the past. As previously noted, there is a number of important areas where CWI has the required research potential, but is in danger of missing the international development connection. In the future, CWI will need to master the mathematical instrumentarium of various fields. This is particularly so in **Analysis**. An example is research into dynamic systems (often with the aid of computer experiments) where the potential of *Non-linear functional analysis* is explored. It is important that the ongoing project *Non-linear analysis and biomathematics* is expanded in this direction. At the same time there may be no lessening in existing attention paid to biomathematics and population dynamics in particular — given their importance to epidemiology. Another important area is *Global analysis* which is particularly aimed at the study of invariants in connection with integrable systems: several such systems, which are highly relevant to a whole range of situations in physics, were recently shown to be integrable. For a number of problems in physics and biology there are considerable hopes for geometrical, and in particular topological methods. The ongoing research in the area of *Mathematical physics* ties in with this, as is the case with research in analysis on semisimple Lie groups and symmetric spaces. Several subdisciplines as stability theory, ergodic theory, strange attractors and bifurcation received already attention. Moreover the project *Processing and reconstruction of images,* which is also thought of under the heading of statistics, is supported from analysis. Existing CWI expertise on these analysis subjects



As part of a joint project with the Fibre Institute of the Netherlands Organization for Applied Research (TNO), supported by the National Computer Science Facility, CWI developed a decision support system for production planning in the sewing department of a clothing factory. The interactive system allows the planner to allocate work, taking account of factors including due dates, availability of seamstresses and equipment, and the seamstresses' skills.

Queueing problems occur in a wide variety of situations, in computer systems as well as road traffic: solutions can be of major economic importance. A Dutch magazine strikingly characterized the queueing theory (used in seeking mathematical solutions to such problems) as the 'mathematics of irritation'. CWI studies various aspects of queueing theory including performance of computer systems.
Photo: AeroCamera — Bart Hofmeester BV, Rotterdam.

offers the basis for expansion. The ability to give advice in the fields of physical and biological research is important. CWI will therefore try to retain the expertise acquired in the project *Asymptotics.*

Research into **Algebra** can be significantly encouraged by systematic attention to *Symbolic computation and formula manipulation.* CWI considers it necessary to start up research, not only because of the help it will give to other projects but because comparatively little of such algebraic research is being done in The Netherlands. With additional financial support, CWI has formed a *Cryptography* group. The group builds partly on the basis of previously acquired expertise in discrete mathematics, and analyzes and constructs protocols and algorithms for the protection of distributed systems. CWI aims to continue and expand this activity which is attracting notice at home and abroad.

Increased attention to strategic research has led to a reconsideration of the organizational structure of the mathematical research. It is important to have strategic and applied research built on pure scientific research as far as possible in one department. Naturally this is no hard and fast rule. Not all pure scientific research projects will invariably be followed up by applied research and there will always be projects like the ongoing *Processing and reconstruction of images* which overlap departmental lines, indeed CWI pol-

Modern aspects of symmetry (e.g. in connection with the theories of elementary particles) are another area covered by CWI. Centuries ago the mathematicians of ancient Arabia already studied symmetry. Here, the last page of Sultan Barquq Mosque Koran (late 14th century) displays intricate symmetrical patterns.
Source: l'Art Arabe Vol.III, A. Morel & Cie, Libraries-editeurs, Paris 1877 (reprinted by Reidel, Dordrecht/Khayat Book & Publ. Cy., Beirut).

icy encourages just that. The policy aims described will mean reconsideration of current departmental groupings and titles 'Pure Mathematics' and 'Applied Mathematics'.

Insofar as the arguments above call for a general strengthening of mathematical research, they are not confined to CWI. The importance of mathematics for a wide range of scientific and technical research prompts and justifies a significant boost for mathematics in the Netherlands. Strategic considerations carry some weight in CWI's selection of priorities. Moreover, historically CWI has always concentrated on fundamental research in the more application-oriented mathematical subdisciplines. At CWI, the practice of what is sometimes called 'pure mathematics' is closely linked with the support of the other mathematical research.

There have been calls from the Dutch mathematics community for extra reinforcement of research into the 'pure' variety of the discipline. As is clear from this document, CWI supports such calls. Even so, the policy line sketched here does not actually envisage a direct reinforcement. The increase in funds required for a reasonably balanced, specialized, pure mathematics research programme would be considerably higher than for the policy choices presented here. However, should funds be available, SMC is certainly prepared to play a role in the organization of extra, national, reinforcement of pure mathematics.

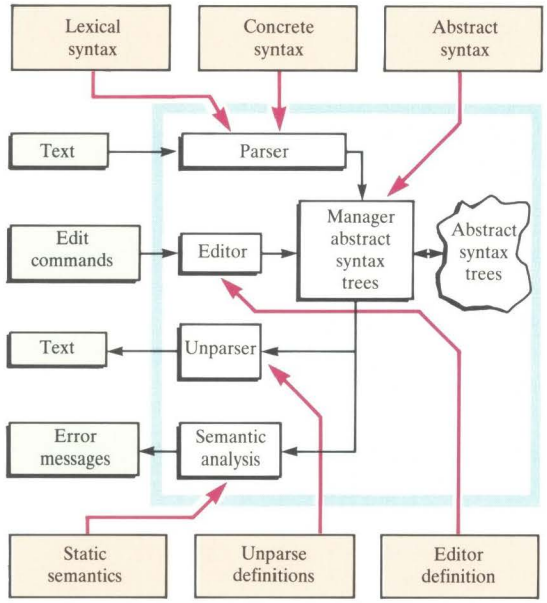
5. Priorities in Computer Science Research

There is at this time a major difference in the selection of priorities for computer science and mathematical research at CWI. The detailed 'Computer Science Development Plan' produced in 1984/85 covered the period up to 1989 — i.e. until the end of the INSP grant. The priorities contained in this document are closely connected with the then proposed areas of concentration. Perhaps more so than for mathematics, computer science research priorities are designed to maintain sufficient pure scientific research.

Financial pressure on the total CWI budget and various funding possibilities for strategic, application-oriented and even applied research meant a certain jostling of the balance between the pure scientific and strategic elements — and this was especially so for computer science. Restoring the balance is a priority. The expected strategic importance of research and availability of expertise to carry it out are also significant factors in the choice of priorities.

Some CWI priorities are based on ongoing research in good cooperation with the Dutch research community. Other priorities concern new proposals. For these projects also closer relations will be sought with research carried out elsewhere in the Netherlands.

A major priority comes from a wide area in which CWI has built up a considerable reputation and expertise; it is best described as **Theory of programming.** CWI will continue the work of past years in two sub-areas. The first is *Concurrency*: distributed data processing has brought about great interest in parallelism in programming languages. The second is *Software engineering:* this involves two projects, *Formal specification methods* and *Extendible programming environments,* directed at the formal description of intended function and operation of software or hardware systems. Much of this work is now carried out via participation in major ESPRIT projects. This is an important research field for CWI and one in which the freedom has to be created for pure scientific research without the obligations involved in major strategic projects. In this connection CWI is endeavouring to set up a project on *Term rewriting systems.* These systems form a paradigm for calculation procedures. They are in principle suited to the natural implementation of parallel computations. The aim is also to give added support for mathematical logic based research into software technology. The option of doing so by starting research within a mathematical department — preferably as a



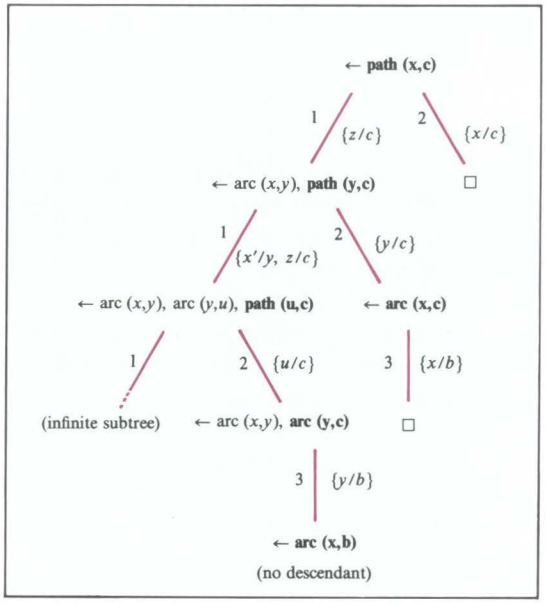
Starting from the formal definition of a programming language, a programming environment can be generated especially intended for this language. The diagram shows how parts of the formal specification result in components of the generated environment. CWI-research in this field is carried out in the framework of ESPRIT-project 348 GIPE (Generation of Interactive Programming Environments).

joint effort with a university research group — will be examined.

The second main theme in computer science concerns **Artificial intelligence.** National and international research is thriving, but has made a slower start at CWI than envisaged in the Development Plan. It is directed to the application of methods of knowledge representation and automatic reasoning in *Expert systems*. The SPIN project PRISMA (Parallel Inference and Storage Machine) involves joint research with Philips into parallelism in expert systems. Research has also started into *Logical aspects of artificial intelligence.* This mainly concerns the logical foundation for expert systems (logical programming and deductive databases).

Another area where CWI will also continue to be active is **Algorithmics** — the design and implementation of algorithms and the study of their complexity and accuracy. CWI will at the very least maintain the strong position achieved by its mathematical departments in research in a number of sub-areas such as numerical algorithms, combinatorial optimization, number theory and encryption systems. Algorithmics is at the very heart of computer science and the synergy of mathematics and computer science is seen to its best advantage in algorithmics — excellent reasons for the subject remaining a CWI priority.

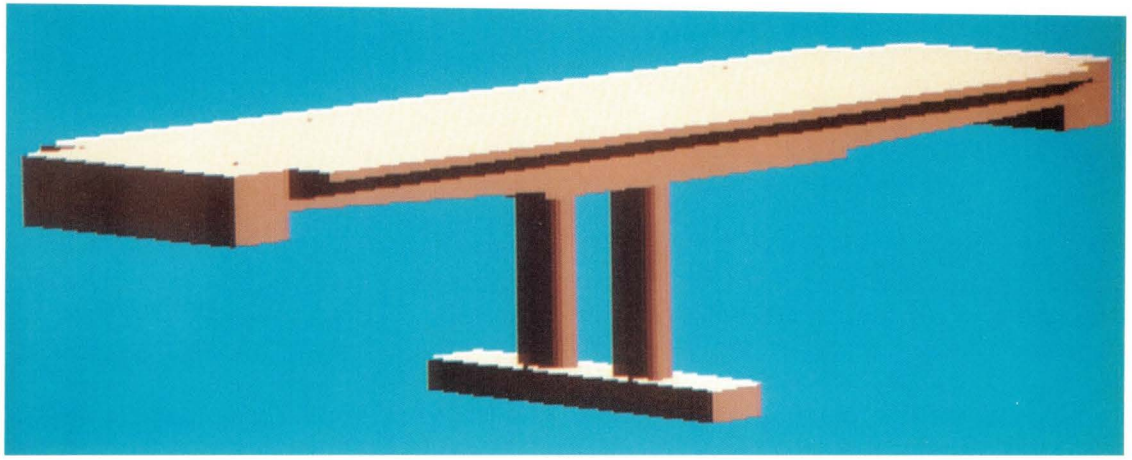
A fourth priority is research into **Architecture,**



An important problem in artificial intelligence is efficient searching in large search spaces. The diagram shows a typical search space of an expert system written in a logical programming language. A square represents a node in which a solution has been found. An incorrect search strategy can enter the infinite sub-tree, left, and thus not produce a solution. Apart from trying a different search strategy, the set-up of another search space can, on occasion, solve the problem.

an increasingly important theme given ever more complex computer systems and networks. Alongside continuation of existing research into *Distributed operating systems* (Amoeba) and *Distributed adaptive information systems* CWI is interested in starting pure scientific research into theory forming for *Processor architectures* and into systematic methods for *Open architectures.* The latter are relevant for the development of standards and integrated working environments. Existing expertise in program environments achieved in the development of the ABC language, will be exploited in the area of *Integrated user environments.* This research primarily concerns theory forming and development of methodology.

CWI has carried out fundamental computer science research, with good application potential, in the field of **Interactive systems** for some years. Recently there has been strong development as is illustrated by the establishment of an international standard, GKS (Graphical Kernel System); CWI played an important role in this. In the future, CWI attention to computer graphics will be directed at man-machine interaction via images of 3-D objects *(Interactive 3-D computer graphics).* In addition to fundamental research attention will be focused on the design of large graphical *Method bases*: information systems in which databases and software libraries are integrated. Long-running research into *User interfaces* (which convert abstract information from computer systems into usable form — word, image,



CWI's IIICAD-project studies integration of artificial intelligence and Computer Aided Design techniques into an intelligent design system. One aspect is the description of design objects. In a closely related project at TNO-IBBC product modeling is used to this end. This technique enables the build-up of an integrated product description. The picture shows a visual representation of a flyover based on information contained in a TNO product model for flyovers.
(Courtesy P. Kuiper and J.J. van Wijk, TNO-IBBC)

sound) will now concentrate on the almost unknown territory of image interpretation.
The purpose of a *Dialogue cell* specification language is to record the behaviour of a system during interaction. An experimental implementation already exists and once development of the language is complete, the system will be extended with advanced facilities such as automatic error recovery and dynamic scheduling. Extension to machine-machine communication (including robotics) is also foreseen. Other research in this sphere concerns the *Ergonomics of computer systems,* where the aim is generation of an integrated user-driven environment; there are links here with research in the field of architectures.
As the name implies IIICAD *(Intelligent Integrated Interactive Computer Aided Design),* is a project involving aspects of both artificial intelligence and interactive systems. CWI's aim is to put down a theoretical basis for such CAD systems and to implement a pilot system for future CAD systems based on *Knowledge engineering.*

The CWI organizational structure is, in principle, flexible. The aim is the greatest possible linkage between strategic and application-oriented research and the pure scientific research on which it is founded.
The recent restructuring of computer science research resulted in three departments: Software Technology, Algorithmics & Architecture, and Interactive Systems. The new divisional structure is working well but, given the fast-changing situation, constant monitoring will be the rule.

6. Knowledge Transfer

Effective transfer of research results is an essential activity for an institute like CWI. It involves both communication with colleagues in international research and transfer of expertise present and developed at CWI to a wide range of potential users.

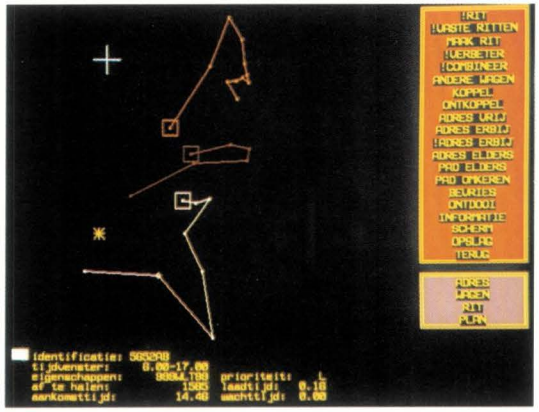
For the communication with colleagues the usual channels apply, e.g. publication in scientific journals, books and reports — presentation of papers at conferences, symposia and workshops — evaluation of articles and research proposals — working visits and invitation of visitors. CWI takes care of printing and publishes books and reports using in-house facilities. The CWI library gives researchers broad access to scientific literature. CWI promotes the organization of scientific conferences. The Frontiers in Information Technology organization (FIT) was set up under CWI auspices in November 1986 to provide a framework for the organization of conferences and symposia on promising sections of information technology. CWI provides regular reports on the many scientific publications, papers, visits, etc. Building up a corps of expertise is also an element of knowledge transfer: many young researchers have been trained and have written their dissertations at CWI.

Knowledge transfer to potential users has grown in importance over the years. Methods and means are many and depend on the group in question — and on finance. User courses in CWI specialities spring immediately to mind, and a variety are given within the framework of post-academic training (PAO). CWI is also involved in postgraduate university training in computer science and mathematics; for instance, CWI contributes to the 'Academy for Computer Science' (which is to be set up by the Universities of Amsterdam and Utrecht for postgraduate professional training). CWI attempts to set up and present courses and seminars in cooperation with industry.

Joint research projects with industry are an especially attractive means of knowledge transfer, and one which strongly stimulates CWI's own activities. In the case of STW projects, industry is involved as potential user and has a place on the user's committee. Other joint projects come under ESPRIT, SPIN or other government enterprise schemes. Others again are set up with major financial support from industry. Lastly, there are projects involving researchers detached by their companies to carry out work at CWI (a particularly effective way of knowledge transfer and one which has been insufficiently exploited). In 1986 joint research accounted for 19% of total income. CWI policy is directed at increasing that share as far as possible.

Research, expert training and knowledge transfer team-up most satisfactorily in the creation of CWI industrial fellowships. This involves a company financing a research place, in a jointly selected area of fundamental research, for a number of years. Fellowships contribute to CWI research and the fellows are supervised by CWI project leaders: at the end of the contract the researcher and the knowledge he has gained, are available to potential employers. Shell created two such fellowships in 1986, and it is expected that other companies will follow suit.

It is CWI policy that suitable research findings, e.g. such software packages as GKS-C and CAR (Computer Aided Routing), achieve their commercial potential. Whenever possible CWI cooperates with established concerns prepared to develop, market and sell the software under licence in return for relinquished royalty rights on income. When this is not feasible, consideration is given to participation in new companies, set up with support of CWI, to market the fruits of research.



CAR (Computer Aided Routing) is an interactive software package which has been developed at CWI as a tool to support physical distribution management. CAR enables the user to construct economical vehicle routes and schedules in a simple way.

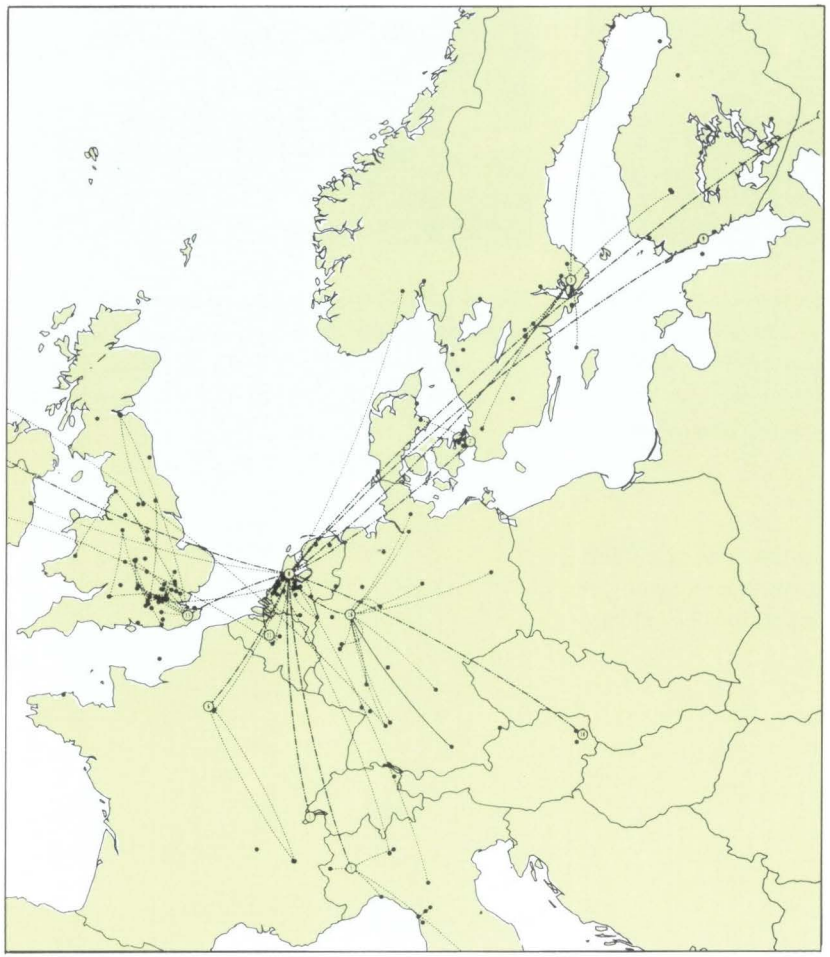
This can mean both consultancy in the fields of mathematics and/or computer science, or the development and marketing of software products.

During the design and development of CAR the cooperation and feedback from the Dutch road transportation company Van Gend & Loos (at the same time the first user) was indispensable.

7. The Role of Supporting Sectors

The basic role of these sections is the support of researchers in their primary tasks: research, knowledge transfer and expert training. In plain terms this means overall management of the institute, maintenance of the library and information service, science information (public relations), project management, infrastructural and technical support, building management, personnel affairs, financial administration, etc. Considerable effort has gone into organizing this support in recent years. Expansion of the institute, governmental demands on research management and, above all, the shift in research funding due to the significant increase from sources outside NWO, have led to restructuring and reinforcement of the non-scientific sectors.

The Computer Systems and Telematics section (CST) bears certain similarities to the scientific departments. CST is responsible for installation and maintenance of the computer infrastructure needed for the research programme. Facilities are also provided at the international level — as for EUNET. CWI sees these activities as integral to its centre function. CWI expertise is already deployed in national and international development and standardization activities. Involvement in strengthening or starting up application-oriented CST research and development pro-



CWI manages the EUNET / USENET gateway between the USA and Europe. These two major networks provide researchers with the means for fast exchange of long-distance information. The map shows European USENET news connections (September 1986).

jects is part of the general aim of employing CWI expertise to the full. These activities and the enormous growth in the use of computers and networks make the reinforcement of the CST section a necessity.

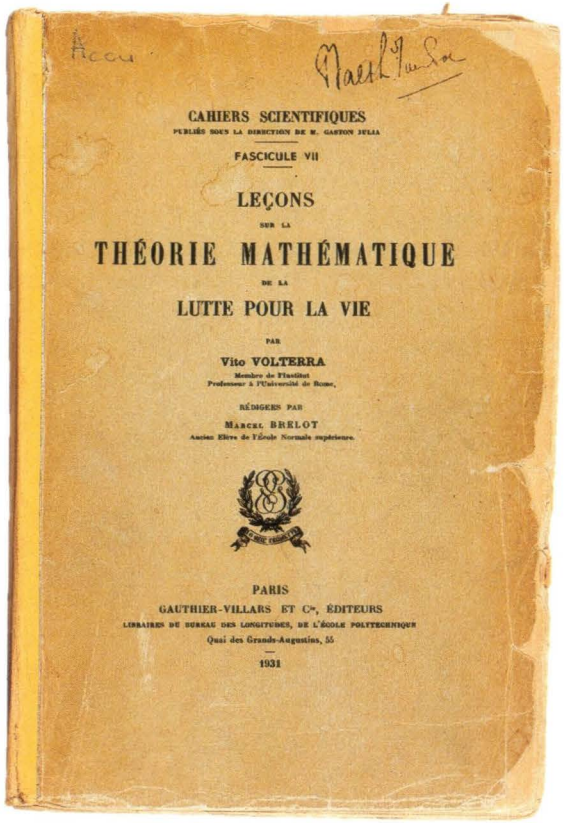
Over the years, work on support via the Library and Information Service has resulted in an extensive and excellent collection of books, journals and research reports. In line with criteria set for the collection, the service has in fact become a national service. Balance has always been the priority when adding to the library collection — as has an eye to CWI research activities. Cooperation with other (international) libraries and use of the potential offered by modern electronic networks and computer technology are among plans for future refinement and expansion. Work has been done to make catalogues on-line available. This facility can be offered to third parties (via SURF-net) which may contribute considerably to the mathematics and computer science research in the Netherlands.

The specific task of the Research Management and Presentation section includes: science information; contacts with industry; legal advice on contracts; conference, congress and course organization; and development of instruments for project management. Alongside purely support functions this section is active in direct promotion of CWI in its centre role. Particularly important are the organization and supervision of NWO-sponsored mathematical projects at the universities, and similarly for computer science projects via the NWO foundation SION (the SION office is based at CWI). Secretarial and organizational facilities are also available to outside societies and organizations on a cost-covering basis. A CWI speciality is support in the organization of conferences and courses which involve its own researchers.

With its 30,000 books and 45,000 research reports the CWI library plays a national role. The collection also includes such historically significant works as 'Leçons sur la théorie mathématique de la lutte pour la vie' by V. Volterra (1931), one of the fathers of biomathematics. The current CWI research programme demonstrates that the subject is as relevant as ever.

An expanding and increasingly more complex organization has led to strengthening of the Social-Economic Affairs section. This boost is aimed at better coordination, improved efficiency and at several personnel and financial tasks relating to reinforcement of the CWI centre-role. Policy is aimed at improved efficiency in financial and personnel administration and providing management with the means and information required.

Where necessary, researchers are supported by (system) programmers from the Technical Support section (STO). A high degree of experience and expertise is necessary for the efficient handling of changing and diverse tasks in the scientific departments. This group of programmers also provides software for


CAHIERS SCIENTIFIQUES
PUBLIÉS SOUS LA DIRECTION DE M. GASTON JULIA

FASCICULE VII

LEÇONS
SUR LA
THÉORIE MATHÉMATIQUE
DE LA
LUTTE POUR LA VIE

PAR
Vito VOLTERRA
Membre de l'Institut
Professeur à l'Université de Rome,

RÉDIGÉES PAR
MARCEL BRELOT
Ancien Élève de l'École Normale supérieure.

PARIS
GAUTHIER-VILLARS ET Cie, ÉDITEURS
LIBRAIRES DU BUREAU DES LONGITUDES, DE L'ÉCOLE POLYTECHNIQUE
Quai des Grands-Augustins, 55

1931

word processing and for office and library automation at CWI. Future reinforcement of the CWI computer infrastructure will demand a similar expansion in user support. The Publication Service (printing and word processing) also operates on behalf of CWI researchers as part of STO. The service takes care of scientific publications such as CWI Monographs and Tracts, the Report Series and many other publications as well as work for third parties connected with CWI. General expansion at CWI has considerably increased the workload.

CWI Monographs

nr.	*Title*	*Authors/editors*
1	Mathematics and Computer Science Proceedings of the CWI Symposium, November 1983	J.W. de Bakker, M. Hazewinkel and J.K. Lenstra, editors (1986)
2	Stability of Runge-Kutta Methods for Stiff Nonlinear Differential Equations	K. Dekker and J.G. Verwer (1984)
3	The Numerical Solution of Volterra Equations	H. Brunner and P.J. van der Houwen (1986)
4	Mathematics and Computer Science II Fundamental Contributions in the Netherlands since 1945	M. Hazewinkel, J.K. Lenstra and L.G.L.T. Meertens, editors (1986)
5	One-Parameter Semigroups	Ph. Clément, H.J.A.M. Heijmans, S. Angenent, C.J. van Duijn and B. de Pagter (1987)
6	Program Correctness over Abstract Data Types with Error State Semantics	J.V. Tucker and J.I. Zucker (1988)

CWI publications cover a considerable range including the CWI-Newsletter, -Monographs, -Tracts, -Syllabi and -Reports. Monographs are produced in cooperation with North-Holland Publishers.

8. Infrastructure

Computer infrastructure

Recent years have seen spectacular developments in the use of computers and the relevant research infrastructure for both computer science and mathematics. CWI has been very much part of this process. Computer science — in so far as it is not practised in a pure form — covers design, specification and construction of systems (software, architecture, languages, networks, codes, equipment, etc.). The step of actual construction is still almost a necessity for judgement of a system on its merits. This makes an advanced infrastructure in the field of computer facilities essential. Use of computers is also increasingly important in mathematical research. Research into systems for formula manipulation, simulation of dynamical systems, cryptography, image analysis, parallel algorithms and computational statistics all demand sufficient computer capacity and good graphic workstations. It is important that the 'capacity' in question should not be assessed against purely numerical data such as total Mips, but against the total quality of the environment provided. In general a production oriented environment, as provided by a computing centre, provides less than ideal computer support for research. There are exceptions, as in large scale numerical calculations on supercomputers, but the nature of use in research usually requires fast interaction and presence of facilities like window managers, and several experimental systems, e.g. compilers for special languages, and good network facilities.

According to the Snowbird report (1981): 'The department that wants its research to be at the frontier of Computer Science will require an investment of about $ 55K to $ 75K per researcher'. A write-off period for this might be about four years. A later report by US statisticians ('Computers in Statistical Research', a report by a workshop chaired by W.F. Eddy, *Statistical Science* Vol. I, Nr. 4, 419-453, 1986) added that for statisticians 'a crude but useful summary figure is that $ 10,000 per researcher per year on a continual basis will provide a department substantial computational resources with adequate operating support'. Although cost of equipment has fallen considerably since 1981, that fall has been matched by increased capacity requirement. Moreover, the same or similar equipment is, as a rule, substantially more expensive in Europe than in the United States. The notion that high level computer science and mathematical research requires major investment in equipment and network facilities is also confirmed by the situation at prominent US and British institutes of computer science, where available computer capacity per researcher is at present already generally many times that at CWI.

In calculating the structurally necessary investment in computer infrastructure, it is obvious that the average amount per research post in both mathematics and computer science, and per (system) programmer post, must be based on the conclusions above. More modest investment per post is also required for word processing, database and financial/administrative applications in the support sector (management and administration, library, word processing and printing unit).

CWI has presented a separate Policy Plan Computer Equipment 1988-1993. In this plan, priorities are discussed and estimated costs are presented. Here we will not further elaborate on this.

Accommodation

CWI moved into its present fine accommodation in 1980. The building was generously designed to house 175 people, a level expected to be reached in the course of the

In 1980 the Mathematical Centre moved to its present location, the Scientific Centre Watergraafsmeer in the outskirts of Amsterdam. Housing, spacious at the time, already has become inadequate, due to much stronger growth of staffing than could be foreseen.
Photo: KLM Aerocarto

decade. Since then, unforeseen developments have led to a far greater expansion in personnel. In period 1980 to 1987, the number of personnel rose by 33%, i.e. 20% over and above the intended 175. The policy presented in this document will increase the need for more space: in the first place because of the desired increase in own research personnel, but also because adequate operation of CWI's centre-function requires accomodation for scientific advisors, experts from abroad and visitors. Moreover, university and higher technical school trainees will also have to be housed. And, efforts towards cooperation with industry and other organizations mean that staff detached to CWI need somewhere to work. Sheer lack of space is a serious stumbling block for policy aims at present.

Finally, CWI believes that it should be able to play an active role in general developments in the research field. Lack of space, on the spot or nearby, may not be allowed to hamper the establishment of research nuclei which should, as a matter of course, operate close to CWI.

Given these problems, CWI is doing everything possible to enlarge its accomodation as soon as possible. CWI makes its case in a 'Programme of Requirements' which was submitted to NWO in 1986.

Investment in the current accommodation will be needed alongside expansion. Significant expansion of the local network is required due to fast development in the area of equipment use. This will require major construction work.

9. Summary and Conclusions

This document provides an outline of CWI policy up to and including 1993. The principles of this policy can be found in the statutory aims of the Foundation: the promotion of the systematic pursuit of pure and applied mathematics. As must be clear from the Centre's scientific activities, the founders also had computer science in mind. The fact that it is omitted from the statutes must surely be because at the time it was not considered a separate discipline.

As far as CWI is concerned, statutory aims are achieved in three ways: carrying out excellent *research, knowledge transfer and expert training* and acting as an international *meeting point.* Chapter 3 goes into some detail on the first three essential aspects. Of these, the first is by far the most important; the second and third may be independent as aims, but their realization is only possible in conjunction with research. At the end of the day knowledge transferred comes from research and experts are trained by including young researchers in the research groups.

Pure scientific research is CWI's most important activity. Strategic and application-oriented research is an essential ancillary activity and applied research and development work is a derived activity. Quality comes first in CWI research and potential inherent to the synergy of mathematics and computer science is exploited to the full.

This balance between pure scientific research and strategic and application-oriented research — endorsed by the 1985 workshop on the position of CWI — requires financing largely by NWO. CWI believes additional funds are necessary from other sources. The aim is to build up this additional income to an amount about 30% of the total budget. With this in mind, the preferred financial relationship with NWO would both guarantee continuity of fundamental research and permit a measure of freedom — financially and in decision making — to invest in activities directed at commercial exploitation of research results.

Its chosen policy involves CWI in important ongoing scientific developments in mathematics. This requires the setting up of new research sectors and, on occasion, the restructuring of existing ones. Sectors and projects which are priorities on grounds of policy and continuity in the scientific programme, are listed in Chapter 4; a separate document goes into more detail on their importance. CWI believes the proposed programme provides for the maintenance of quality in mathematical research as well as an expertise basis sufficient for involvement in joint research.

The proposed mathematical research programme can be partially realized by restructuring existing research. However, gradual growth is needed to set up new research groups, etc. In terms of the 1988 budget, it is estimated that 10 extra posts will have to be created to deal with suggested priorities up to and including 1993. Restructuring will take time. Hence an early start to new research will require relatively fast growth in the beginning of the five year period. Capacity released as a result of restructuring can be used for further renewal in the second half of the period.

In the area of computer science research, participation in various joint projects has displaced the centre of balance between pure scientific and strategic/application-oriented research. Priorities given in Chapter 5 are partly aimed at restoring balance. Most important new projects involve pure scientific research. Computer research is expanding strongly around the world. CWI is confident that the programme put forward in this document will maintain, and even strengthen, the position it has achieved. The priorities given here tie in with international developments

and in-house expertise. In this connection it is essential that the shortfall which will occur when the INSP Dfl. 2 million annual grant stops in 1988, is made up by an equivalent structural increase in the NWO subsidy. In addition, an estimated 10 extra research posts will be needed to deal with the dual priorities of restoring balance and achieving modest growth in line with major development in the field.

CWI promotes knowledge transfer and trains experts. Alongside the classic tools of publication and lecture, CWI gives priority to joint research with industry. Support is also given to organization of courses, conferences, workshops and postgraduate training. CWI supervises university and higher technical school trainees and is active in receiving visitors from abroad. These activities require funding to cover administrative and organizational support, travel and accomodation expenses, and the provision of a good infrastructure for guests. Similarly, manning levels in support sections have to keep pace with those in scientific departments.

By international standards, the CWI computer infrastructure is insufficient. International comparison and expert advice suggest a considerable increase of investments. To this end CWI has presented a separate Policy Plan Computer Equipment 1988-1993, in which the required infrastructure and its costs are indicated.

CWI moved into first rate accomodation in 1980. However, the estimated eventual ceiling of 175 personnel has been overtaken by events. Unforeseen developments since 1980 have boosted numbers considerably, so that in 1987 there are 20% more than planned for. The present policy proposals will lead to increased demand for extra space. This concerns CWI's own people, visitors, trainees and seconded personnel. Clearly, it is of the greatest importance that the Centre is given the means to extend its present excellent — but overcrowded — accomodation.