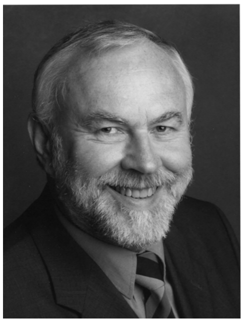

Matheon: Introducing the DFG Research Center “Mathematics for key technologies” in Berlin

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Abstract

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- Keywords and Phrases: mathematics for key technologies, research center, Berlin

In October 2000, the Deutsche Forschungsgemeinschaft (DFG) created a new coordinated program called DFG research centers. This article describes the intentions and the application process of this program briefly. It particularly focusses on the establishment of the DFG Research Center Matheon in Berlin. The Matheon is one of six existing DFG research centers and is the only one operating in mathematics. Its complete name DFG Research Center “Mathematics for key technologies: Modelling, simulation, and optimization of real-world processes” describes the Matheon agenda in broad terms. Matheon is organized along application areas which currently are: life sciences, traffic and communication networks, production, electronic circuits and optical technologies, finance, visualization, and education. The mathematical work done and the special applications addressed will be outlined in the sequel.

Eingegangen: ● ●

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Coordinated research programs

The German Research Foundation (DFG) offers quite a number of support programs, each targeted at different needs. With an allocation of roughly one third of all DFG funds (about 1,300 million Euros), the most important one is still the *Individual Grants Program* (Normalverfahren) where an individual researcher can ask for support for a particular project with a defined thematic focus and project duration.

Once it became apparent that certain research efforts require the cooperation of a larger number of scientists, coordinated research programs were created. These coordinated programs promote cooperation and structural innovation by encouraging national and international collaboration in areas of current relevance and by concentrating scientific potential at a university. Till the end of the 1990s the DFG supported *Research Units* (Forschergruppen, FOR, established in 1962), *Priority Programs* (Schwerpunktprogramme, SPP, established in 1953), *Research Training Groups* (Graduiertenkollegs, GRK, established in 1990), and *Collaborative Research Centers* (Sonderforschungsbereiche, SFB, established in 1968).

Due to the careful and unbiased refereeing processes aiming at excellence and not at uniform distribution of research funds, the existence of DFG supported projects has always been considered significant evidence of high-quality research activities at a university. Among the support programs, the Collaborative Research Centers have (probably) achieved the highest prestige. One can infer this from the fact that university presidents never fail to mention the number of SFBs when trying to indicate the excellence of research at their universities.

The statistics in Table 1, quoted from the DFG Jahresbericht 2004, shows in absolute and relative terms how much mathematics participated in the coordinated DFG programs in the year 2004.

Table 1

	FOR	SPP	GRK	SFB	FZT
Total number	175	134	257	272	5
Total funding (M €)	89.7	152.5	80.2	381.1	25
# Math projects	6	5	19	5	1
Volume math projects	1.2	7.3	5.2	5.6	5.0
% Funding math projects	1.3	4.8	6.5	1.5	20.0

The first line of Table 1 indicates the number of projects supported in each of the five coordinated research programs, the second line the total amount spent in each program in 2004 (in millions of Euros). The third, fourth, and fifth line indicate the number of mathematical projects, their total funding, and the percentage of funding spent by the DFG on mathematics in 2004.

The last column shows the numbers for the DFG research centers to be introduced below. Frank Kiefer, the DFG-Fachreferent for mathematics, pointed out that mathematicians participate considerably in programs accounted under other scientific fields. It is very difficult to estimate the funding obtained by mathematicians via this indirect way.

DFG research centers

At the beginning of this decade a new coordinated research program came into being due to an unexpected new financial source. In August 2000, the German government sold licenses for third generation cell-phone services (UMTS) via an auction. This auction resulted in a spectacular total revenue. The federal government cashed about 50 billion Euros. Part of the auction earnings went to the Bundesministerium für Bildung und Forschung (BMBF) that, in turn, increased its support of the DFG.

The DFG decided to use some of this additional funding to start a new coordinated program: DFG research centers (in German called DFG-Forschungszentren, abbreviated FZT). The aim of the program is described in the first paragraph of the resolution of the DFG Senate of October 26, 2000:

„Ziel des Programms ist es, in deutschen Hochschulen in begrenzter Anzahl international sichtbare und konkurrenzfähige Forschungszentren zu etablieren. Diese Zentren sollen wichtiger Bestandteil der strategischen und thematischen Planung einer Hochschule sein, ihr Profil deutlich schärfen und Prioritäten- bzw. Posterioritätensetzung verlangen. Die Konzentration von Exzellenz, Ressourcen und Kompetenz soll unter anderem durch die Anfinanzierung und Ausstattung von Professuren durch die DFG erreicht werden, deren spätere Übernahme einen wichtigen Beitrag der Grundausstattung darstellt.“

The current description (July 2005) reads:

“Research Centers are an important strategic funding instrument to concentrate scientific research competence in particularly innovative fields and create temporary, internationally visible research priorities at research universities.

DFG Research Centers enable the universities to establish research priorities on the basis of existing structures. The thematic focus must incorporate a high degree of interdisciplinary cooperation. Networking with other research institutions at the university location is encouraged. DFG Research Centers are open for cooperation with partners from industry.

Funding may be provided for up to six professorships as well as associated independent junior research groups working within a DFG Research Center. Following the start-up funding provided by the DFG, the host university commits itself to financing the professorships from its core budget. Appropriate personnel and material resources will also be made available. Funding for each DFG Research Center averages approximately 5m per annum. Research Centers may receive funding for up to a maximum of 12 years.”

The first round of FZT proposals

Although aiming at highest standards, international visibility, and competitiveness, there was, after the announcement of the new program, almost no time left for a deep exploration of possible options. The DFG expected the universities to submit pre-proposals (Konzepte) within eight weeks. And thus, pre-proposal writing had to start immediately. Another quote from the resolution:

„Es wird um Konzepte (ca. 25 Seiten) für die Gründung eines konkreten Zentrums gebeten, dem bereits eine wissenschaftlich exzellente und das Profil der Hochschule prägende Struktur zugrundeliegt, welche mit den durch das Programm der DFG-Forschungszentren angebotenen Möglichkeiten ausgestaltet werden soll. Diese Konzepte, die in einer ersten, nicht thematisch definierten Auswahl-

runde berücksichtigt werden sollen, müssen bis zum 20. Dezember 2000 in der Geschäftsstelle der Deutschen Forschungsgemeinschaft eingetroffen sein. Der Senat wird darüber entscheiden, welchen Initiativen danach eine Antragstellung ermöglicht wird."

By Christmas 2000, almost 90 pre-proposals had reached the DFG. They came from all parts of the country and ranged over all areas of engineering, the sciences, and the humanities.

One of the pre-proposals was written by a group of applied mathematicians working at Freie Universität (FU), Humboldt Universität (HU), or Technische Universität (TU) in Berlin or at one of the two Berlin-based mathematical research institutes, the Weierstrass Institute for Applied Analysis and Stochastics (WIAS) or the Zuse Institute Berlin (ZIB). The pre-proposal was formally submitted to the DFG by the president of TU Berlin on December 19, 2000 and finally resulted in the creation of the DFG Research Center MATHEON that will be described in this article. The main text of our December 2000 pre-proposal started as follows:

„Ohne Mathematik tappt man doch immer im Dunkeln.
schrieb vor über 150 Jahren der Berliner Student Werner von Siemens an seinen Bruder Wilhelm. Schon für Siemens war die Hochtechnologie seiner Zeit ohne Mathematik nicht beherrschbar. Diese Aussage gilt heute umso mehr. Disziplinen verschmelzen miteinander; zusammen mit neuen ökonomischen Konzepten und durch staatliche Deregulierungsmechanismen werden sie zu Motoren der Weltwirtschaft: zu Zukunftstechnologien. Diese äußerst komplexen Systeme bedürfen der Mathematik, der Sprache der Wissenschaft und der Technologie. Aber die neuen Technologien benötigen nicht nur die mathematische Sprache. Ohne die Algorithmen der Mathematik ist ein effizienter, kostengünstiger und ressourcenschonender Einsatz der Technologien nicht möglich.

Angewandte Mathematik ist damit selbst eine Schlüsseltechnologie im globalen Wettbewerb um Ressourcen und Marktanteile; als Querschnitts- und Strukturwissenschaft besitzt sie ein besonders hohes Potential zum effektiven Einsatz. Sie wirkt jedoch im Verborgenen; ihre Beiträge zur Problemlösung sind den Endprodukten in der Regel nicht mehr anzusehen. Aber nur wer sich als fähig erweist, das innovative Potential der Angewandten Mathematik effektiv zur Entwicklung neuer Produkte und moderner gesellschaftlicher Strukturen zu nutzen, wird im Zeitalter der globalen Informationsgesellschaft auf Dauer erfolgreich konkurrieren können. Dies gilt für lokal operierende Firmen und politische Einheiten genauso wie für die Global Players."

These sentences characterize the general view on the role of mathematics and its relations to its application areas that the members of MATHEON share. Mathematics, there is no doubt, is a field of basic research in its own right. But mathematics has also a tremendous potential for other sciences and industrial applications that both sides, mathematicians and the employers of mathematics, have not made sufficient use of. MATHEON is determined to help change this situation and to support scientific and industrial development, in particular in key technologies.

Let us look, slightly more concrete, into a modern production environment. High tech companies may have made an excellent invention and may manufacture an outstanding product. But due to the very fast international information networks and global knowledge transfers they may quickly loose their competitive advantage. Understanding the invention fully, perfecting the product and its production, fabricating and distributing it at minimum cost, estimating the risks involved, avoiding environmental hazards, etc. often require very specific mathematical models and appropriate model simulations. And only mathematical models that have stood the test of simulation runs and critical reviews by experienced practitioners are utilizable for optimization. Many steps in this development process cannot be made without employing adequate mathematics tuned to the particular application. The mathematics necessary is often not available from the "bookshelf" or from software vendors. Meeting theses challenges depends on the development of mathematics in collaboration with the user and requires the design of algorithms and their implementation in a way that the user's needs are supported. MATHEON tries to participate in these processes and to make the important role of mathematics more visible.

This briefly indicated "MATHEON vision" of collaborative development of mathematics and of mathematical software has been made specific in the final application.

Results of the first round of FZT applications

Making reasonable decisions on almost 90 very heterogeneous applications is an imposing task. The DFG decided to invite seven (quite diverse) pre-proposals to present full-fledged applications. Forty two applications (including our pre-proposal) received a positive vote and were put on hold for further consideration. Over 30 pre-proposals were rejected.

Three of the seven selected proposals finally won a research center. These centers were established in 2001:

- FZT 15 "Ocean Margins – Research Topics in Marine Geosciences for the 21st Century" in Bremen
- FZT 47 "Center for Functional Nanostructures" in Karlsruhe
- FZT 82 "Rudolf Virchow Center for Experimental Biomedicine" in Würzburg.

The second round

While handling the seven finalists, the DFG sent out a call for new pre-proposals. This time proposals were invited that focused on two particular (though broad and transdisciplinary) areas. One of the topics selected by the DFG was:

„Modellierung und Simulation in den Natur-, Ingenieur- und Sozialwissenschaften".

The group of applied mathematicians from Berlin decided to try again and to submit a polished and enhanced version of the previous pre-proposal. The deadline was April 25, 2001. The DFG specified criteria for the selection; I quote:

(1) Quality of the research
(2) Extent of cooperative financial support obtained so far (from the DFG and other supporting institutions)
(3) International visibility of the site
(4) Utilizing the possibilities of the program to structure the development of the university and to focus on research areas
(5) Importance for young scientists
(6) Originality of the submitted project compared to other current supported activities.

Fourteen proposals from a wide range of groups covering, e.g., engineering, computer science, biochemistry, and medicine reached the DFG by April 25. Many applications were interdisciplinary, some involved colleagues from mathematics. Our proposal was the only one focusing on mathematics.

To be mentioned in passing: The second topic selected by the DFG was "Neurosciences: from the Molecular Foundations to Cognition". The winner of this competition was the University of Göttingen together with three Göttingen based research institutes, the Max Planck Institute for Biophysical Chemistry, the Max Planck Institute for Experimental Medicine and the German Center for Primate Research. The

- FZT 103 "Molecular Physiology of the Brain" was set up in 2002.

The opening of 2004 asked for applications in the areas "Regenerative therapies" or "Cognitive technical systems". After the initial application phase the DFG decided to drop the second area and give one center to the first. Making a selection from ten applications the DFG decided on September 2, 2005 to establish the DFG Research Center

- "Regenerative Therapy" at the Dresden University of Technology.

The *real* application

On July 17, 2001, we learned that we were among the three finalists and that the deadline for the full application was November 15, 2001. This information arrived within the last week of the Berlin summer semester, and everybody was heading for conferences or vacation, a really bad time to meet each other and to discuss how to proceed.

At the end of August 2001, the preparation of the detailed application started. Within two and a half months about 50 mathematicians in Berlin found a joint vision for their future work, coordinated their research projects, and agreed on many details so that a streamlined application with a clear goal and focus arose. Considering that, in mathematics, it is rather unusual that such a large group works together in such a short time, this was a formidable achievement. Not only did we have to streamline our mathematical thoughts, but five institutions had to be convinced to actively support the project. Many of us had to attend lots of meetings with academic and political representatives and quite a number of committees of all kinds. The result was extremely positive. After brief explanation, unanimous support came from all academic institutions involved.

The Deutsche Forschungsgemeinschaft also expected financial support from the State of Berlin. This was (sort of) granted initially, but the promise never materialized. To fill the financial gap the five academic institutions jointly made a substantial effort to match what the DFG expected from the host state of the research center. All in all, this process showed that the academic institutions in Berlin are able to act, to define priorities, and to move forward in a joint and coordinated effort – despite the almost hopeless financial situation in Berlin.

On November 14, 2001 we were ready and shipped a 412-page application book to DFG via express mail signed by the presidents/directors of FU, HU, TU, WIAS, and ZIB. A really hectic period of time was over.

The final selection

The submission of the application was not the final word. On January 21 and 22, 2002 each of the three finalists (groups from Berlin, Darmstadt, and Heidelberg) had half a day to present the application orally and visually. Eighteen persons, including representatives from all participating institutions and the State of Berlin, travelled to Bonn, gave thirteen short presentations, and passed the detailed interrogation by the international group of reviewers with distinction.

The DFG Hauptausschuss finished the competition on May 8, 2002, and declared our application the winner. The new center took up operation on June 1, 2002 under the name "Mathematics for key technologies: Modelling, simulation, and optimization of real-world processes" with the DFG abbreviation FZT 86 (reflecting the fact that our proposal was the 86th application for a Forschungszentrum reaching the DFG).

As much as we were happy to receive the grant, celebrated in a spontaneous party, we could feel the disappointment of our competitors. They worked as hard as we did but did not gain any financial support. "The winner takes it all" competitions result, unfortunately, in many frustrated participants.

Figure 1: Opening ceremony, TU Audimax

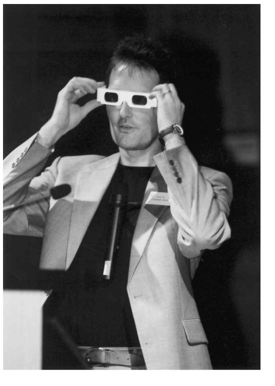

Figure 2: 3-d show

A formal celebration took place on November 11, 2002. The „feierliche Eröffnung" in the TU Audimax was attended by more than 1,000 persons, see Figure 1, listening to words of welcome, an overview of the MATHEON research activities, and seven brief talks by young MATHEON members about their projects. The "3-d show" introduced by Christof Schütte, see Figure 2, was the most spectacular part of the presentation.

Naming the center

The full name mentioned above is a "monster", and it turned out that nobody really used it. Whenever an article about our center was published, the name of our center was altered in an arbitrary way or dropped at all. The abbreviation FZT 86 sounds more like a name for a database or a bookkeeper. So we started looking for a "better" name for our DFG Research Center. We asked center members, colleagues, and many other persons for suggestions and ended up with creations such as CAMB, MathKeyTech, MathKT, Keymathics, or KeyMath Center. Finally, we called Töchter+Söhne, a student run spin-off company of the Universität der Künste in Berlin, for creative input. They came up with the name MATHEON. One can find various interpretations (you can view it as mathe-on, i.e., switching on mathematics, or one can employ the similarity to pantheon), but it is just an artificial name that is apparently new and sounds good.

Before coming to a final naming decision in 2004 we used the name MATHEON at various public occasions. Most people found that this name made them curious (journalists, persons from other sciences). That is what we wanted to achieve. We also consulted Greek colleagues who, for instance, commented: *"It is for sure that* MATHEON *is not a Greek word. However, it sounds perfectly like a Greek word. I could give you two possible explanations, not of the meaning (which is evident) but of the structure of this word: –* MATH *(from mathematics) and* THEON *(means God) → Ma[th]eon. – Adding* EON *(which is a usual extension in Ancient Greek, for instance* PANTHEON = *the ensemble or house of Gods) to* MATH. *You understand that, in fact, the two explanations are strongly linked together. Let me say that* MATHEON *is a very smart name and you should congratulate the person who proposed it!"*

The first year of MATHEON

Starting a center like this just three weeks after its formal creation was decided is not an easy task. The infrastructure had to be set up, the internal organization to be designed, the legal structure to be worked out, responsibilities to be distributed, administration persons to be hired, rooms to be found, openings for 6 new chairs and 7 leaders of junior research groups (Nachwuchsgruppenleiter) to be formulated and advertised, and about 70 new research positions to be filled. Not everything went as smoothly as hoped, but almost everything went much better than feared.

Of course, all individual projects started their research agenda right from the beginning. And after about one year of hard work, the MATHEON began operating as a joint research center with a common vision and not just as a collection of independent individual projects. The goal and promise was that the center should be more than the sum of its parts. And indeed, the added value became soon visible.

True, there were (fortunately very few) colleagues who viewed the MATHEON as a means to get more research money and who made no effort to contribute to the whole operation. The executive board monitored the development closely and in a few cases decided to stop projects because of the unwillingness of project leaders to cooperate – even though good mathematics was produced. Such decisions are unpleasant but seem to be inevitable if one wants to keep a large activity like the MATHEON on track.

Statistics

I will not go into the details of the development of MATHEON, but I want to summarize some of the important facts.

Finances

The annual financial support from the Deutsche Forschungsgemeinschaft is about 5 million Euros. The Berlin institutions provide additional annual support of about 3 million Euros.

Legal Aspects

MATHEON is not a legal entity. It exists via a cooperation agreement between its participating institutions, which are

- FU Berlin (Fachbereich Mathematik und Informatik)
- HU Berlin (Institut für Mathematik and Institut für Informatik)
- TU Berlin (Institut für Mathematik)
- Weierstrass-Institut für Angewandte Analysis und Stochastik (WIAS)
- Konrad-Zuse-Zentrum für Informationstechnik (ZIB).

The TU is the leading university (Sprecherhochschule). All legal and financial actions of a MATHEON member for MATHEON are made via the institution to which the acting MATHEON member belongs. All central operations go through TU. This sounds complicated but has not lead to any difficulties so far.

Organization

Here is a brief overview of the internal organization. There is, of course, some fluctuation. Whenever persons and numbers are mentioned, the state as of July 1, 2005 is reflected.

– MATHEON has

- a *Chair* (Sprecher), Martin Grötschel (TU and ZIB) and a *Deputy Chair*, Volker Mehrmann (TU),
- an *Executive Board* (Vorstand) consisting of 6 professors and 1 junior scientist: Peter Deuflhard (FU, ZIB), Martin Grötschel (TU, ZIB), Peter Imkeller (HU), Volker Kaibel (ZIB), Volker Mehrmann (TU), Christof Schütte (FU), Jürgen Sprekels (HU, WIAS) (The Executive Board "runs" MATHEON and is responsible for all its activities.),
- a *Council* (Rat) consisting of up to 20 members (with at least 3 junior scientists), see `http://www.matheon.de/about_us/organization/list_bodies.asp` (The

Council coordinates and directs the activities within the seven application areas and three mathematical fields of MATHEON and fosters cooperation between these topics.),

- a *General Assembly* (Mitgliederversammlung) that, for instance, elects all the other bodies,
- a *Scientific Advisory Board* (Wissenschaftlicher Beirat) consisting of 10 members meeting once a year, see `http://www.matheon.de/about_us/organization/advisory.asp` (It advises and supports MATHEON in various matters, such as national and international cooperation with other sciences and industry, organizational aspects, and long term perspectives.).

– The central management and administration of MATHEON, `http://www. matheon.de/about_us/organization/management.asp`, is located on the third floor of the mathematics building of TU. This floor, completely made available to MATHEON by TU, also hosts the central rooms (seminar and guest rooms, lounge) and the two TU MATHEON chairs. Otherwise the MATHEON members reside at their institutions, and every researcher hired from MATHEON funds is integrated in the research environment of the project head.

– MATHEON has 200 members, 42 of whom are professors. 94 of the MATHEON members are paid from the DFG MATHEON grant, the others from their home institutions, grants from industry, or other sources.

New chairs

Six new C4-professor positions, two at each of the participating universities, have been created from the DFG funds, and additional professors (on regular and open positions) have been hired by the three universities in areas related to the center. The 6 new MATHEON professors are:

– Carsten Carstensen (HU), chair for "Numerical Solution of Differential Equations" (formerly TU Wien, Austria)
– Andreas Griewank (HU), chair for "Nonlinear Optimization" (formerly TU Dresden)
– John Sullivan (TU), chair for "Mathematical Visualization" (formerly U Illinois at Urbana-Champaign, USA)
– Harry Yserentant (TU), chair for "Numerical Solution of Partial Differential Equations" (formerly U Tübingen)
– Alexander Bockmayr (FU), chair for "Mathematics in Life Sciences" (formerly U Nancy, France)
– The FU chair "Mathematical Geometry Processing" will hopefully be filled within a few weeks.

For each of the six MATHEON C4-positions, a currently filled professor position has been designated to which the MATHEON professor will move as soon as the current position holder retires. At that moment in time a new MATHEON chair can be opened.

MATHEON also created 7 junior research groups (Nachwuchsgruppen), 3 at TU and 2 each at FU and HU. The decision to establish such research groups is just one of many actions of MATHEON to particularly promote young researchers. The leader of a junior research group (Nachwuchsgruppenleiter) is – within the area to which the group has been assigned – free to choose his or her particular research and application activity and to fill the positions that have been granted to the group. The chance to follow one's own research tracks independently very early in an academic career seems to be attractive and to produce particular visibility. That is one of the reasons why there has been quite some fluctuation on these positions – just as MATHEON hoped would be the case.

Vision & Mission

A research center such as MATHEON has to specify a vision that is supposed to guide its future developments. And we have to convince colleagues in other fields that mathematics is an important ingredient in technological progress. What can mathematics offer to those who invent and develop high tech? I have already indicated the MATHEON vision above. Our vision statement in our application was as follows:

"*Key technologies become more complex, innovation cycles get shorter. Flexible mathematical models open new possibilities to master complexity, to react quickly, and to explore new smart options. Such models can only be obtained via abstraction. This line of thought provides our global vision: Innovation needs flexibility, flexibility needs abstraction, the language of abstraction is mathematics. But mathematics is not only a language, it adds value: theoretical insight, efficient algorithms, optimal solutions. Thus, key technologies and mathematics interact in a joint innovation process.*

The mission of the center is to give a strong push to the role of mathematics in this interactive process. The center's research program is application-driven. Its implementation will have a strong impact on the development of mathematics itself and will define a new stage of inter- and transdisciplinary cooperation."

Mathematical Fields

Of course, there is no way to support every high tech subject. And not all mathematical fields potentially useful in these areas are present in Berlin. Building upon the special strengths of mathematics in Berlin, we decided to involve the following fields:

I Optimization and discrete mathematics
II Numerical analysis and scientific computing
III Applied and stochastic analysis.

The mathematical fields have been structured along well-established cooperations between the participating institutions, for example, along already existing DFG-supported Research Units, Priority Programs, and Research Training Groups. The existing seminars, colloquia, etc. in these fields continue, of course. MATHEON successfully fosters the interaction between the fields through special lectures and workshops such as

„Stochastik/Numerik“, „Nichtlineare Optimierung und Diskrete Geometrie“, „Stochastische Aspekte kombinatorischer Netzplanung“, or „Scheduling-Probleme und Hysterese-Operatoren“. Such workshops try to bring together mathematicians from different fields (who usually do not talk to each other) with the aim to make important questions, results, and techniques known to the members of the other group. These workshops are also employed to describe questions from industry one research team tries to solve, where it hopes that another team may be able to provide some mathematical input or fresh ideas.

Application areas

Just as the mathematical fields reflect the Berlin expertise in applied mathematics, the application areas chosen build upon cooperations that have proven to be fruitful in the past. Of course, the goal is to extend the applications considerably and open up further lines of cooperation with industrial and scientific partners. The following key technologies are addressed in the first 4-year period:

A Life sciences
B Traffic and communication networks
C Production
D Electronic circuits and optical technologies
E Finance
F Visualization.

In addition, MATHEON views

G Education
as an important area to which its activities should radiate.

We are, of course, aware of the fact that it would be outrageously arrogant to claim that MATHEON is vital for the scientific progress of huge and important areas such as life sciences or production. These labels simply indicate that MATHEON makes a considerable effort to develop certain mathematical aspects of these areas.

While these application areas seem quite disjoint in real terms, the mathematical approach to major questions in these diverse topics brings out common structures. Analysis, stochastics, and discrete mathematics supply conceptual frameworks in these areas. Numerical mathematics and optimization provide the algorithmic machinery that enables the quantitative solution of a wide range of real-world instances. Even though the existing expertise has been highly successful in quite a few practical applications, more research has to be initiated to cope with many of the challenges of current technology. The DFG Research Center MATHEON “Mathematics for key technologies” is built as an institutional basis to further increase this level of competence. Modelling, simulation, and optimization of real-world processes are highly important aspects of many activities in industry and society, MATHEON views itself as a major effort in this direction.

MATHEON's application areas: an overview

It is beyond the space limit of this survey paper to outline all the research activities in the mathematical fields and projects in the application areas. The interested reader is invited to visit `http://www.matheon.de/research/research.asp` and check the more than 80 projects that have been carried out within MATHEON so far. What follows is a brief characterization of our application areas, a short description of their research activities together with some examples of project titles.

It is occasionally useful to employ the "matrix view" of the MATHEON activities shown in Figure 3. This helps spotting possible synergies and initiating research cooperations between various mathematical fields, application areas, and projects therein.

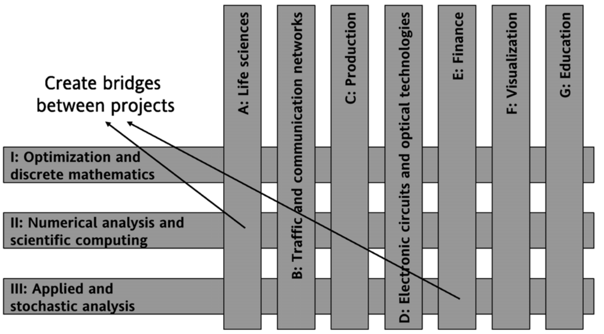

Figure 3: Matrix view

Application Area A: Life sciences

(Scientists in Charge: Alexander Bockmayr, Peter Deuflhard, Hans Jürgen Prömel, Christof Schütte)

Laboratory work or surgery experiments are, of course, outside the expertise of MATHEON. Our center contributes to *computational aspects* of the life sciences. During the first four-year period the focus is on two fields: *computational medicine* and *computational biology*.

The long term vision in computational medicine is the development of mathematical models (and their mathematical analysis) that will make *quantitative individual medicine* possible, i.e., a patient-specific medical treatment on the basis of individual data and physiological models. In computational biology the vision is to understand molecular flexibility and function up to proteomic and systemic networks.

Most projects in Application Area A have to incorporate several, if not all, of the following aspects: *modelling* (in contrast to other fields, in biological or medical applications appropriate mathematical models are not at hand and need to be developed), *efficient simulation* (many of the resulting models couple several levels of description, and reliable and efficient discretization techniques are not available "from scratch", adequate numerical simulation techniques have to be designed), *optimization* (in patient-oriented medical treatment, e.g., the ultimate aim is the design of an optimal strategy or control of the treatment), *data acquisition and/or data analysis* (producing data by experiments is not the key issue, but getting the right data and understanding them), *visualization* (visualizations help analyzing data and computational results and are extremely important for the communication with partners from medicine and biology).

It is MATHEON's vision to incorporate simulation, optimization, and data analysis into virtual laboratories that support interfaces between the different algorithms, help to extract features by means of visualization, and finally make *conceptualization* possible.

Five project titles may indicate the concrete questions that are addressed in Application Area A (the project heads are mentioned in parentheses):

- A1: *Modelling, simulation, and optimal control of thermoregulation in the human vascular system* (Weiser, Deuflhard, Tröltzsch)
- A2: *Modelling and simulation of human motion for osteotomic surgery* (Deuflhard, Kornhuber), see Figure 4
- A4: *Towards a mathematics of biomolecular flexibility: Derivation and fast simulation of reduced models for conformation dynamics* (Deuflhard, Schütte)
- A6: *Stochastic modelling in pharmacokinetics* (Huisinga)
- A8: *Constraint-based modeling in systems biology* (Bockmayr)

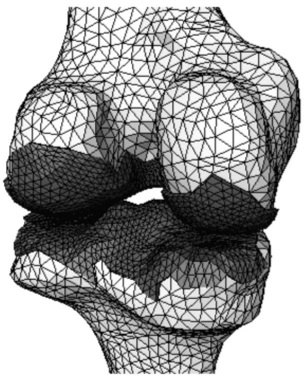

Figure 4: Modelling / simulation of human cartilage

Application Area B: Traffic and communication networks

(Scientists in Charge: Martin Grötschel, Volker Kaibel, Rolf Möhring)

The guiding question for Application Area B is brief: *"What constitutes a good network?"*. We all want to be connected to a good telecommunication network or want to be served by a good public transport network. But what does *good* really mean here? Different "players" (customers, operators, politicians, tax payers) may value different aspects. Can we quantify quality in some way to come up with (somewhat) objective "quality measures" so that optimal networks can be designed?

Our society is becoming more and more "networked". Networks are crucial for the functioning of our daily life. But networks are also expensive to install, maintain, and control. Therefore, adequate network design and utilization is crucial for many activities. Application Area B focusses on traffic and communication networks. The vision is to ultimately develop theory, algorithms, and software for a new, advanced level of network analysis and design that addresses network planning problems as a whole. The "machinery" developed here has, of course, a much wider range of application than just transport and communication.

Linear and integer programming and combinatorial optimization are "key mathematical technologies" for the analysis and optimization of networks. There has been tremendous progress in the recent years in the algorithmic solution techniques so that there is now some hope to address not only single issues (such as vehicle circulation in transport networks or message routing in telecommunication networks) but integrated models that combine various network features. Moreover, the time is ripe to incorporate stochastic and nonlinear aspects to obtain models that more faithfully represent complicated scenarios.

The following project titles represent some of the issues studied in this application area:

- B1: *Strategic planning in public transport* (Borndörfer, Grötschel)
- B3: *Optimization in telecommunication: Integrated planning of multi-level/multi-layer networks* (Wessäly, Grötschel), see Figure 5
- B5: *Line planning and periodic timetabling in railway traffic* (Möhring)
- B6: *Origin destination control in airline revenue management by dynamic stochastic programming* (Römisch)
- B7: *Computation of performance measures of communication networks* (Scheutzow)

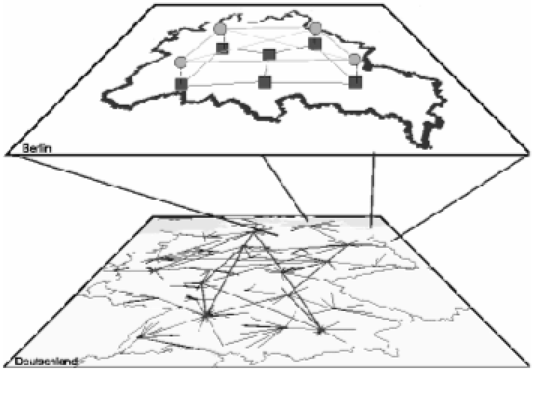

Figure 5: Integrated planning of multi-level / multi-layer networks

Application Area C: Production

(Scientists in Charge: Carsten Carstensen, Jürgen Sprekels, Fredi Tröltzsch)

Condensed to one sentence, the long-term vision of Application Area C is to make a significant step towards the ultimate goal of production control and planning: fully automatic (and optimized) online control of the processes involved. Of course, there is a long way to go before a sound mathematical understanding of the effects of modern production processes is achieved and production innovations can be guided and optimized via mathematical models.

Production is a vast field with many facets. Application Area C focusses in particular on selected *multi-functional materials* and various aspects of *power generation.*

For multi-functional materials, for instance, we study a variety of phenomena that occur on a whole hierarchy of different space and time scales, ranging from microscopic changes of crystal lattice configurations, over the effects of mesoscopic thermo-stresses, to macroscopic hysteresis. Examples include the formation of liquid droplets in GaAs-crystals, martensitic phase transitions in shape memory alloys, the occurrence of spatial patterns in thin magnetic films, and structural phase transitions in the crystal lattices of modern steels. The mathematical tools required for such studies range from stochastics, asymptotic and multiscale analysis, thermodynamic modelling and phase-field theories, to numerics and optimization.

Here are a few example projects:

- C1: *Coupled systems of reaction-diffusion equations and application to the numerical solution of direct methanol fuel cell (DMFC) problems* (Fuhrmann)
- C8: *Shape optimization and control of curved mechanical structures* (Sprekels)
- C9: *Optimal control of sublimation growth of SiC bulk single crystals* (Klein, Sprekels, Tröltzsch), see Figure 6
- C10: *Modelling, asymptotic analysis and numerical simulation of the dynamics of thin film nanostructures on crystal surfaces* (Münch, Wagner)
- C11: *Modeling and optimization of phase transitions in steel* (Tröltzsch, Hömberg)
- C18: *Analysis and numerics of multidimensional models for elastic phase transformations in shape-memory alloys* (Mielke)

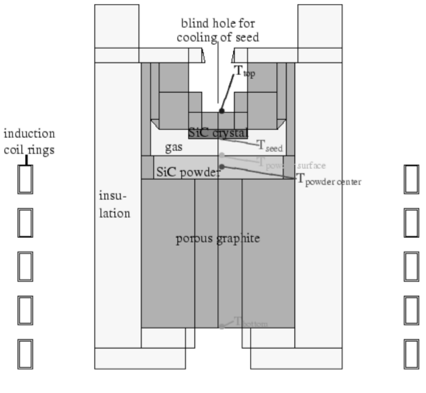

Figure 6: Optimal control of sublimation growth of SiC crystals

Application Area D: Electronic circuits and optical technologies

(Scientists in Charge: Volker Mehrmann, Frank Schmidt, Caren Tischendorf)

By contributing to the development of electronic circuits and opto-electronic devices, MATHEON gets to the core of most current key technologies. The innovation cycles and the life cycles of products get shorter implying that new products have to be developed in ever shorter time periods. This requires increased design automation, new simulation, control, and optimization techniques, as well as new verification tools.

To cope with many of the difficulties coming up in this area (e. g., fast-growing density of components on a chip, parasitic and thermal effects, crosstalk, noise effects due to small signal-to-noise ratio) MATHEON follows a new paradigm: Modelling, analysis, simulation, optimization, and software development are carried out in an integrated way by joining the mathematical fields of MATHEON: applied and stochastic analysis, numerical analysis and scientific computing, optimization and discrete mathematics. This unique way of combining almost all areas of applied mathematics makes MATHEON an ideal partner for research institutions and industry.

Here are a few example projects of this application area:

- D1: *Model reduction for large-scale systems in control and circuit simulation* (Mehrmann)
- D4: *Quantum mechanical and macroscopic models for optoelectronic devices* (Hünlich, Rehberg)
- D7: *Numerical simulation of integrated circuits for future chip generations* (Tischendorf, März)
- D8: *Nonlinear dynamical effects in integrated optoelectronic structures* (Wolfrum, Recke)
- D9: *Design of nano-photonic devices* (Schmidt), see Figure 7

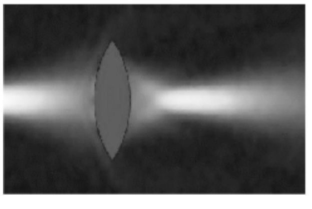

Figure 7: Gaussean beam

Application Area E: Finance

(Scientists in Charge: Anton Bovier, Peter Imkeller, Alexander Schied)

The topic of this application area is the mathematical modelling of risk with a particular emphasis on modelling and understanding financial risk. A slightly longer title could, thus, be *Mathematics of financial risk*.

Mathematics has become a major driving force in finance and insurance. The central problem this industry faces is the management of *risk* in its various forms. Advanced probabilistic and statistical methods are being applied to qualify and quantify financial risk. Mathematics dominates all levels of approach: from the conceptual challenge of *modelling* and measuring risk in terms of stochastic processes, to the challenge of statistical-numerical *simulation* in the *optimization* of investment by minimizing risk.

MATHEON aims at moving towards a new generation of market models, in which a multitude of highly interdependent risk factors (e.g., volatility clusters, long-term memory effects, or external factors such as climate events) become integrated into an adequate model and MATHEON emphasizes the implementation of more sophisticated measures for the financial downside risk. Constructing hedging strategies that are risk-minimal in terms of these risk measures leads, for instance, to new mathematical optimization problems.

Examples of projects in this application area are:

- E1: *Microscopic modelling of complex financial assets* (Bovier)
- E2: *Hedging of external risk factors: Weather and climate* (Deuschel, Imkeller)
- E4: *Beyond value at risk: Quantifying and hedging the downside risk* (Schied, Föllmer)
- E5: *Statistical and numerical methods in modelling of financial derivatives and valuation of risk* (Schoenmakers, Spokoiny)

Application Area F: Visualization

(Scientists in Charge: Konrad Polthier, John M. Sullivan, Günter M. Ziegler)

Visualization is a field that does not have a “natural home”. There are, for instance, engineering, biology, or computer science aspects. The emphasis on *Visualization* as a separate discipline and application area within a mathematical research center is a unique selling point of MATHEON. Visualization techniques open an informative (and attractive) window into mathematical research, scientific simulations, and industrial applications.

Application Area F concentrates on key problems in the fields of geometry processing, medical image processing, and virtual reality. Geometric algorithms are key to many industrial technologies, including computer-aided design, image and geometry processing, computer graphics, numerical simulations and animations involving large-scale data sets. For all these technologies, a deep understanding of the underlying abstract mathematical concepts is essential. Notable has been the effort in recent years by the CAD industry to rethink the foundations of their work and put it on a firmer mathematical footing. Today, progress in the development and use of new mathematical concepts is often what characterizes state-of-the-art applications. Mathematical knowledge then becomes a key resource within industry to stay competitive.

Application Area F operates the PORTAL, a new virtual reality installation at TU Berlin, to do interactive, immersive visualizations of various topics from geometry and other sciences. Needless to say, the PORTAL is in high demand for presentations.

Some of the projects in Application Area F are:

- F1: *Discrete differential geometry* (Bobenko, Pinkall, Polthier, Ziegler)
- F2: *Atlas-based 3d image segmentation* (Deuflhard, Hege)

- F4: *Geometric shape optimization* (Bobenko, Polthier), see Figure 8
- F5: *Mathematics in virtual reality* (Pinkall, Sullivan).

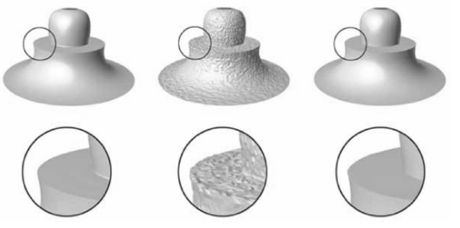

Figure 8: Geometric shape optimization

The MATHEON buddy bear standing in front of the TU mathematics building, see Figure 9, was designed by the MATHEON visualization group. The bear carries the three-dimensional version of the MATHEON logo on one of his paws. The body painting is the image of a conformal mapping of a cylinder surface around which the MATHEON logo has been wrapped several times. The picture in Figure 9 was taken at the inauguration of the MATHEON bear on June 11, 2005.

Figure 9: MATHEON bear

Application Area G: Education

(Scientists in Charge: Ulrich Kortenkamp, Jürg Kramer)

The basic motivation for the scientists of MATHEON to engage themselves in educational activities is the need for more qualified young people in the MINT fields (Mathematik, Informatik, Naturwissenschaften, Technik), in particular in mathematics. To achieve this goal, the basis for a positive attitude towards mathematics has to be built already in school. Furthermore, the unbalanced transitions from school to university, and later on to the working life, have to be smoothened out by integrating these phases more strongly with each other, specifically in mathematical education. As a consequence, the mathematical education for teachers and engineers must become more practice- and problem solving-oriented. The scientists of Application Area G – with the support of many other members of MATHEON – provide various activities in this direction. Based on their application-oriented research and their teaching experience, they develop concepts for teaching in a more application- and problem-driven way. At the same time, through the close cooperation with schools, in particular the four mathematically profiled schools of the Berlin Network, prototypical examples for a smooth transition from school to university have been set up. This, in turn, leads to a fruitful cooperation between teachers, teacher students, and teacher educators at the universities.

Examples of projects in application Area G are:

- G2: *Current mathematics at schools* (Kramer)
- G3: *Teachers at universities* (Kramer)
- G5: *Discrete mathematics for high school education* (Grötschel)
- G6: *Visualization of algorithms* (Kortenkamp)

In addition, the scientists of Matheon help – with the support of the teachers of the Network Schools – bridging the gap between mathematicians and the public at large via Matheon's public relations program. A particularly successful activity is the Urania lecture series directed towards high school students and teachers. Three to four times a year, three mathematical lectures are presented in the Berlin Urania on one morning. The lecture topics are Matheon mathematics and applications and, of course, the presentations are tuned towards high school students.

Matheon has had (most likely) its highest public visibility through its „Mathematischer Adventskalender", see `http://www.mathekalender.de/` and Figure 10. More than 6000 persons participated in the Adventskalender 2004. Over 500 pupils attended the awards ceremony in January 2005. The fact that a report on Matheon in the ZDF „heute journal" opened up with the Adventskalender certainly contributed to its success. Of course, Education is not really an application area. In the next funding period we will merge this area with our public relations activities and call it our *Outreach* program.

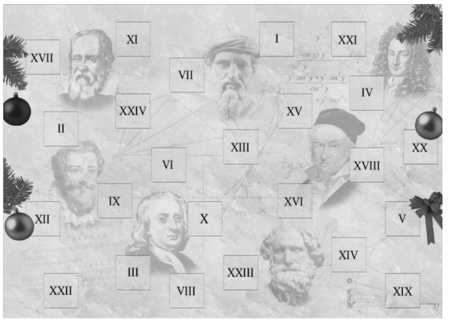

Figure 10: Mathematischer Adventskalender

Links and cross fertilization

What I cannot indicate here, because of lack of space, are the many links that have been established in the meantime. There are links between different application areas; colleagues from different mathematical fields communicate mathematically much more than before the beginning of Matheon; and – due to the close contact with industry – all mathematical fields involved find many more challenges in the real world than they dreamt of before we started the "MATHEON experiment". Mathematics, at our own universities, at related scientific institutions, and in industry has become much more visible. The added value of a large scale endeavor such as MATHEON shows up via this cross fertilization more than anywhere else.

Industry cooperation and scientific networking

MATHEON is not just a mathematical research institution. It aims at cooperation with other sciences, engineering, management science and economics, and in particular, with partners in commerce and industry that are active in the key technologies the center is addressing. MATHEON is open for discussion in its range of expertise and invites proposals for cooperation.

MATHEON is not just waiting for partners. We are actively seeking industry cooperations. The contact management is very individual. There may be merely one general lecture in a company to high ranking representatives or potential partners, a series of presentation to members of the research department of a company, a meeting with "the boss", or direct contacts to persons in the "production line". Such efforts are made on all levels of MATHEON, but of course, the executive board and the leading figures whose names are known in the industrial world play a particular role here.

MATHEON by now has collaborations and joint projects with major firms such as DaimlerChrysler, Volkswagen, Siemens, NEC, Infineon, Deutsche Bank, Deutsche Telekom, Schering, BASF, Bayer, Lufthansa, etc., but there are also medium size and small companies with which MATHEON cooperates.

Former and some new spin-off companies of the participating institutions play a particular role in the distribution of mathematical software that is developed at MATHEON. Mentioning everything that is going on here is also beyond the scope of this article.

MATHEON also seeks international cooperation with mathematical centers that are active in a similar scientific domain. A cooperation agreement with MASCOS in Australia is already working in real practice. We are jointly trying to optimize a container terminal in Sydney. Cooperation agreements with MITACS in Canada and CMM in Chile have just been signed. A similar arrangement with a partner in China is in preparation. The MATHEON concept has influenced the foundation and the vision of several other centers around the world. We have, in fact, been formally asked in several cases to endorse the use of certain parts of our application in the application texts of others. (Some have not asked but just copied from our pages.) We view this a particular success. If you are copied you must be doing something right!

MATHEON and the mathematical community

This article is not the place to "show off". But I would like to mention that MATHEON mathematicians are not only greedily cashing grant money. Many colleagues spend considerable time and energy for the general scientific community. At present, two MATHEON members are members of the Executive Board of DMV and two of the Executive

Board of GAMM, one colleague is president of the Mathematical Programming Society, one a member of the Executive Committee of the International Mathematical Union, and one will become DMV president in 2006. Four members of MATHEON have been elected by the German mathematical community to the DFG mathematics review board (Fachkolleg). Many of us serve in scientific advisory boards, engage in activities for developing countries, electronic information and communication, etc., on national and international levels.

Quite a number of scientific awards have been bestowed upon MATHEON mathematicians, the younger ones received a lot of recognitions for their PhD and Master theses. And of course, MATHEON did not only offer position to others. About twenty offers for professorships reached MATHEON members in the last three years. More than ten colleagues (in particular young scientists) accepted these offers. One project group consisting of four persons, for instance, was almost "wiped out". Three members (young scientists) followed the calls to other universities. We consider such events success and not disaster. MATHEON tends to let certain research and application topics move with the scientists leaving for other universities (so that they have a good chance to create their own research environment) and to take up new challenges and redirect the MATHEON work.

To our regret, not all offers MATHEON made for professor or head of junior research group positions materialized. In these cases the home institutions made counter offers that MATHEON somehow could not match. This typically resulted in a strengthening of the local research group, an upgrade in position or salary and, in particular, in a reassessment of the value certain persons or groups have for the local academic community. In this way MATHEON indirectly influenced the research focus and the structural development of a number of institutions outside of Berlin.

Further information

MATHEON maintains an extensive Web presentation. Since we were not happy with the first version, we recently launched a new home page. Have a look, if you want to learn more about MATHEON and its activities, see `http://www.matheon.de/`. The new Web site is supposed to be completed by November 2005.

The future of MATHEON, excellence clusters

MATHEON has been existing for more than three years. Its members are currently writing their reports on the achievements during this period of time. And we are also writing the reapplication for the second 4-year period. All projects went through a thorough internal screening period. Almost one third of the projects will not be continued and replaced by new ones. No project has a survival guarantee. Even for a running project, whenever a MATHEON financed member leaves, the project head has to reapply for this position.

The full report and the reapplication are due by November 15, 2005, while the onsite evaluation by a DFG nominated group of referees will be at the end of January 2006. We hope that we will be successful.

This summer the German government announced the creation of a new support program: *excellence clusters*. All university presidents in Germany are lining up their "armies", and at the time of writing this article, "tons" of colleagues are writing and rewriting preliminary applications for this new form of financial support. Will MATHEON become one of the new clusters of excellence?

Well, nobody knows in the long run. Not only the DFG will have difficulties to explain the difference between a DFG research center and a cluster of excellence. According to "trusted information sources", for the time being, the DFG research center program and the excellence cluster will run in parallel. The two programs have different financial sources and different time lines, although from their intentions there will not be much of a difference. In fact, whenever the DFG is asked how an excellence cluster should look like, the usual answer is "like MATHEON". We are happy to hear that, of course, though there is some irony here. The DFG research centers were conceived as centers at one university, possibly with support from research institutions in the vicinity. After our application won the competition, the DFG was not sure that the somewhat decentralized center in Berlin was what it wanted. It took the DFG a while before it granted the center to Berlin.

Reading the plans for the 7th Research Framework of the European Union, one can find that one of the main objectives will be the creation of *European centers of excellence*. They are supposed to be established through collaboration between laboratories with the aim to launch European technological initiatives, to stimulate the creativity of basic research, to make Europe more attractive to the best researchers, and to develop a research infrastructure of European interest. Nobody knows at present whether these plans will materialize. If they do, the mathematical community can't ignore such a development. To participate, strong mathematical partners in Germany are needed. In fact, we should start soon looking for German mathematical centers that may be able to play a role in this "game". The experience we had with creating MATHEON may help in this process.

A personal final remark

Not every mathematical colleague, as I learned, was happy that the Berlin group won a DFG Research Center. Leaving aside a few statements indicating jealousy, the critique was that now "big science" is entering mathematics. Shouldn't we rather keep the successful small scale individual approach? And why do we need all this emphasis on applications? Let's, so the suggestion, just develop mathematics as before, whatever comes out will be used some day. I personally believe that these are dangerous misconceptions of the role of mathematics. It is my opinion that mathematics, when overemphasizing its independence as a scientific endeavor, looses much of its vitality. The real world, at any time of our history, has presented a lot of new challenges to mathematics. And the masters of our field took them up. Just remember that Gauss computed the trajectory of the planetoid Ceres (which made him famous worldwide and resulted in the invention of the least squares method). Gauss accepted to carry out the geodesic survey of the state of Hannover (which lead to the normal distribution and to differential geometry) and he made risk calculations and asset management for the *Witwen- und Waisenkasse* of Göttingen University. Fortunately, he did not know that there is one type of mathematics called pure and another called applied. One of our problems in mathematics (in our professional work and in our student education) is that pure and applied are defined not by work and attitude but by subject: numerics and stochastics are applied, number theory and differential geometry are pure, for example. But I do know quite a few number theorists and differential geometers who are much more into real applications than certain colleagues in stochastics. And there are numerical analysts who have not touched real data. For me, doing applied mathematics means interaction with real problems (from business, industry, society, or other sciences), the willingness to dig into details, to cope with unclear specifications and possibly fuzzy data, all this with the aim to help others solve their problems.

Problem solving of this type is, today, best done in larger scientific environments with a mix of people ranging from the "computer wiz" to the totally pure, but where there are overlaps of interest and respect for the work the other person does. It, moreover, needs the readiness to talk to users of mathematics, to learn their language and to try to formulate their questions mathematically. We cannot stay away from modelling issues, we cannot leave simulations to the engineers, we cannot reduce our work to the final step of mathematical analysis. MATHEON tries to create such a work and research environment and to teach its students and junior scientists this approach to mathematical research. MATHEON makes its offsprings fit for an industrial and an academic career. And that is not a contradiction. Remember, Gauss did the high tech mathematics of his time and got his fingers dirty with data. And MATHEON is trying to give this approach to doing mathematics a strong push. It has selected key technological topics of our present day as application areas where there is hope that the interaction with practitioners leads to particular progress in the application, but also in mathematics.

MATHEON is not the only institution doing this, of course. Let me just mention, in Germany, the Institut für Wissenschaftliches Rechnen (IWR) in Heidelberg, the Fraunhofer-Institut für Techno- und Wirtschaftsmathematik (ITWR) in Kaiserslautern, the Max-Planck-Institut für Mathematik in den Naturwissenschaften (MIS), Leipzig, or the Zentrum Mathematik at TU München where the philosophy of mathematical work is related to the MATHEON approach. And there are beginnings of such moves visible worldwide. If the mathematicians in Germany (and the world over) find the right balance between theory and application, experimental mathematics and rigorous approaches, there is every reason to be optimistic about the future of mathematics. The world and not only the scientific world needs good mathematics, and it needs mathematicians ready to get involved.